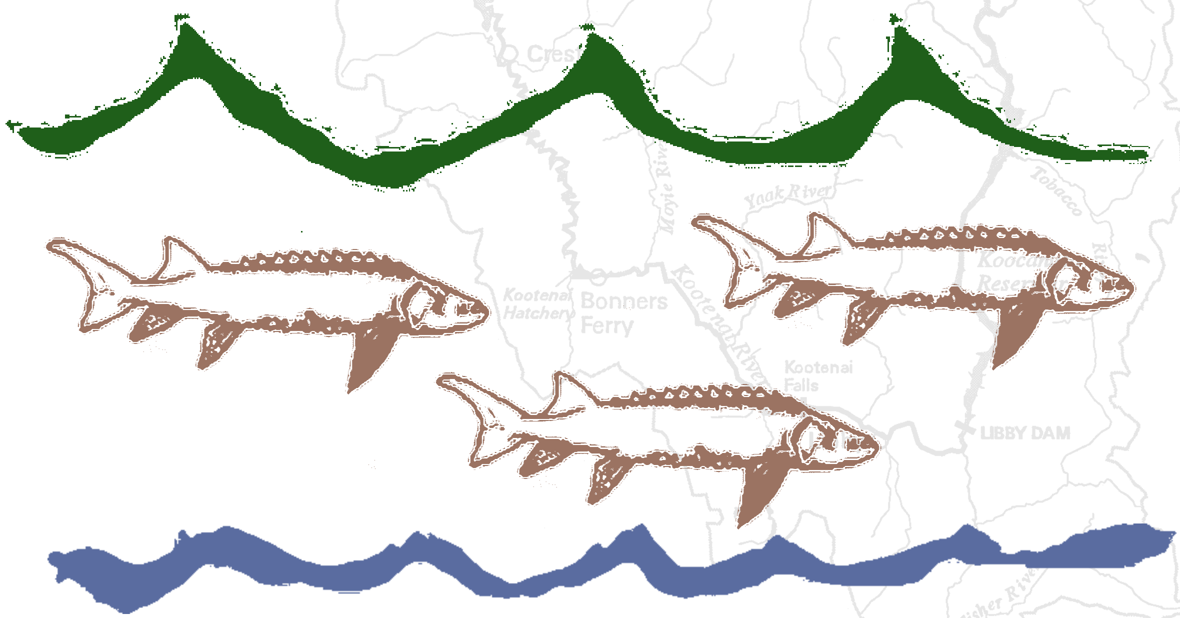
COMPREHENSIVE WATER QUALITY MONITORING PLAN FOR THE

KOOTENAI RIVER BASIN

BRITISH COLUMBIA, MONTANA AND IDAHO

June 2000



COMPREHENSIVE WATER QUALITY MONITORING PLAN FOR THE
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BRITISH COLUMBIA, MONTANA AND IDAHO

Prepared for:

KOOTENAI RIVER NETWORK, Inc.

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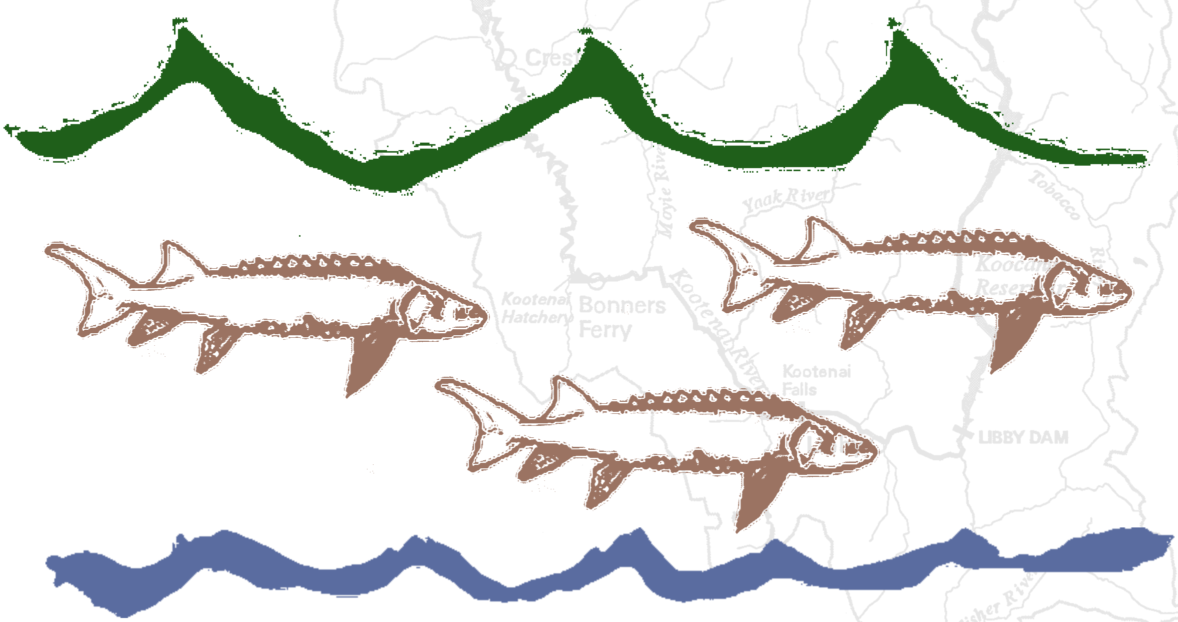

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ACRONYM LIST

ABA	Aquatic Biology Associates, Inc.
AOX	absorbable organic halides
BC	British Columbia
BC MELP	BC Ministry of Environment, Lands and Parks
BC MOF	BC Ministry of Forests
BC MOH	BC Ministry of Health
B-IBI	Benthic Index of Biotic Integrity
BOD	biological oxygen demand
BPA	Bonneville Power Administration
BURP	Beneficial Use Reconnaissance Project
CDOE	Canadian Department of Environment
COD	chemical oxygen demand
CPOM	coarse particulate organic matter
CRM	certified reference material
EMS	Environmental Management System
ESA	Endangered Species Act
ESRI	Environmental Systems Research Institute
FPC	Forest Practices Code
FRBC	Forest Renewal BC
FsRBC	Fisheries Renewal BC
GIS	Geographic Information System
HBI	Hilsenhoff Biotic Index
HUC	Hydrologic Unit Codes
ID	Idaho
IDEQ	Idaho Division of Environmental Quality
IDFG	Idaho Department of Fish and Game
IRI	Idaho River Index
ISO	International Organization for Standardization
IWI	Index of Watershed Indicators
km	Kilometer
KRBTWAG	Kootenai River Bull Trout Watershed Advisory Group
KRN	Kootenai River Network
KTOI	Kootenai Tribe of Idaho
LOD	limit of detection
MBI	Macroinvertebrate Biotic Index
MDEQ	Montana Department of Environmental Quality
MDFG	Montana Department of Fish and Game
MDL	method detection limit
mi	mile
MILS	Mineral Information Location System
MT	Montana
NAQUADAT	Canada's National Water Quality Data File
NASQAN	National Stream Quality Accounting Network
NAWDEX	National Water Data Exchange

ACRONYM LIST

NAWQA	National Water Quality Assessment Program
NGO	Non-Governmental Organization
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NRIS	Natural Resources Information System
NWQSS	National Water Quality Surveillance System
OFR	Open File Report
PAH	polycylic aromatic hydrocarbons
PCB	polychlorinated biphenyls
PFC	Proper Functioning Condition
QA	quality assurance
QC	quality control
SDWIS	Safe Drinking Water Information System
SEAM	System for Environmental Assessment and Management
STD	Standards
STORET	Storage and Retrieval System of EPA
TAC	technical advisory committee
TAT	technical advisory team
TMDL	total maximum daily load
US	United States of America
US BOM	US Bureau of Mines
US EPA	US Environmental Protection Agency
USFS	US Forest Service
USGS	US Geological Survey
VOC	volatile organic compound
WATDOC	Water Resources Document
WATSTORE	National Water Data Storage and Retrival System – USGS
WQB	Water Quality Branch
WQDMS	Water Quality Data Management System
WSC	Water Survey of Canada

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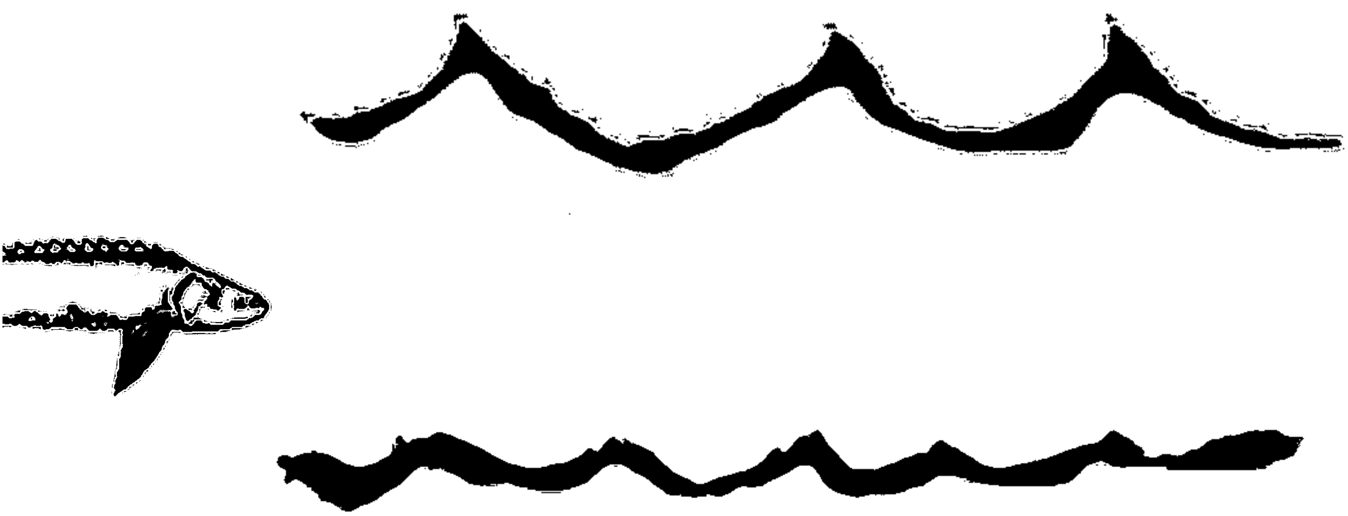
SECTION 1.0
INTRODUCTION



1.0 INTRODUCTION

1.1 Overview

The Kootenai River Basin is an international watershed that originates in British Columbia (BC), Canada. The river flows southeast and enters the United States of America (US) through Koocanusa Reservoir, which has its outlet at Libby Dam in Montana (MT). The river then proceeds northwest through Idaho (ID) and returns to British Columbia, where it flows into Kootenay Lake and eventually joins the Columbia River at Castlegar, BC. A diagram of the Kootenai River Basin is shown in Figure 1-1. The Kootenai River flows approximately 485 mi (781 km) and drains approximately 18,000 mi^2 (46,650 km^2). The involvement of two states, one province, two countries and affected tribal nations in both countries complicates coordination of the investigation and regulatory efforts in the basin.

The Kootenai River Network (KRN) is an alliance of diverse citizens' groups, individuals, business and industry, and tribal and government agencies in Montana, Idaho and British Columbia. The group formed late in 1991 in response to citizens' concerns of threatened or deteriorating water quality and aquatic resources in the Kootenai River Basin. KRN has been successful in bringing together interstate, international and tribal interests of different political jurisdictions to form a watershed-based organization dedicated to solving priority environmental problems and bridging jurisdictional obstacles to achieve watershed management. One of the KRN’s goals is to develop a comprehensive water quality monitoring plan for the entire Kootenai River Basin. This document is intended to fulfill that goal.

Land uses in the Kootenai River Basin have included hydroelectric power generation, mining and mineral processing, logging, lumber and pulp production, recreation, agriculture, urban development and transportation. These activities contribute to sediment and toxin pollution, altered water flows and temperature as well as habitat degradation, which appear to have resulted in lower spawning success for some native fish species. The Kootenai River is home to several sensitive fish species, including the Kootenai River white sturgeon, bull trout, Kootenay Lake strain of kokanee salmon, Westslope cutthroat trout, redband rainbow trout and burbot. In the United States, white sturgeon and bull trout have been listed as endangered species. Burbot in the lower river section is a species of special concern. Genetically pure populations of Westslope cutthroat trout are found in the Canadian part of the basin.

The KRN commissioned a 1994 water quality status report by Ecological Resource Consulting of Helena, MT. This report provided a history of the Kootenai River Basin, discussed basin water quality and environmental issues, and recommended future activities in the basin (Knudson, 1994). The report identified sources of water quality and fisheries habitat degradation in the Kootenai River Basin, including the following:

- Hydroelectric facilities - Loss of aquatic and terrestrial habitat due to flooding, changes in magnitude and timing of flow; restriction of migration; reduced silt

load downstream; alteration of turbidity and nutrients downstream; clear water erosion downstream
- Forestry - erosion due to road building and increased runoff volume and bedload
- Agriculture - herbicide and pesticide contamination
- Mining (hard rock and coal) - heavy metal/process chemicals contamination and biomagnification through the food chain; sedimentation
- Pulp mill operation - organochlorine contamination
- Municipal waste discharge - increased nutrient loading, particularly ammonia
- Highways and railroads - habitat loss and erosion.

Activities not identified by Knudson (1994) but that may potentially affect water quality and aquatic resources, and which are of concern within the basin, include urban development, development of recreational areas (including ski areas), grazing of domestic animals, water withdrawal, diking and channeling. Understanding the effects of these activities is important to protect community water supplies, regulate flooding of developed areas, control changes in water flows and temperature, and continue to provide sustainable aquatic and timber resources.

The 1994 report recommended that the KRN coordinate the water quality monitoring efforts in the Kootenai River Basin (Knudson, 1994). As a result, the KRN obtained funding to begin the process of developing a comprehensive water quality monitoring plan for the Kootenai River Basin upstream of the inlet to Kootenay Lake. The purpose of water quality monitoring will be to develop an accurate and complete picture of water quality throughout the basin. Monitoring information can then be used to guide decisions on activities in the basin

1.2 Monitoring Plan Goals and Objectives

The goal of the comprehensive water quality and aquatic habitat monitoring program is to determine basin-wide water quality and aquatic habitat status and long-term trends. The monitoring information and public education efforts can be used for proactive, scientifically based land and water resource management in the watershed, including the implementation of priority restoration projects.

The objectives of the monitoring plan are varied due to the diversity of the watershed and the comprehensive nature of the KRN membership. The key objectives are as follows:

- Develop sound scientific baseline information so that future regulation and land management strategies affecting water quality are based on scientific fact
- Provide information to determine whether water quality standards are being met in both the tributaries and the mainstem (functional trophic interactions, water chemistry, habitat and fisheries)
- Identify water quality impaired streams and prioritize basin-wide restoration projects
- Monitor the effectiveness of restoration techniques using standardized pre- and post-monitoring plans

- Provide information to support community participation in stream restoration projects, stream monitoring and decision making
- Support enhanced management of native aquatic species in the watershed
- Evaluate the effect of water quantity on stream form and function in flood-prone areas (proper functioning condition).

1.3 Plan/Study Objectives

The plan/study objectives are as follows:

- Identify a range of operating costs and monitoring scenarios and the plan's potential to detect water quality conditions and trends at various confidence levels (i.e., detect an effect of a specified magnitude, if that effect is present)
- Develop recommendations concerning the periodic reevaluation of the monitoring program and its effectiveness in achieving KRN goals and objectives
- Provide early warning of emerging water quality issues.

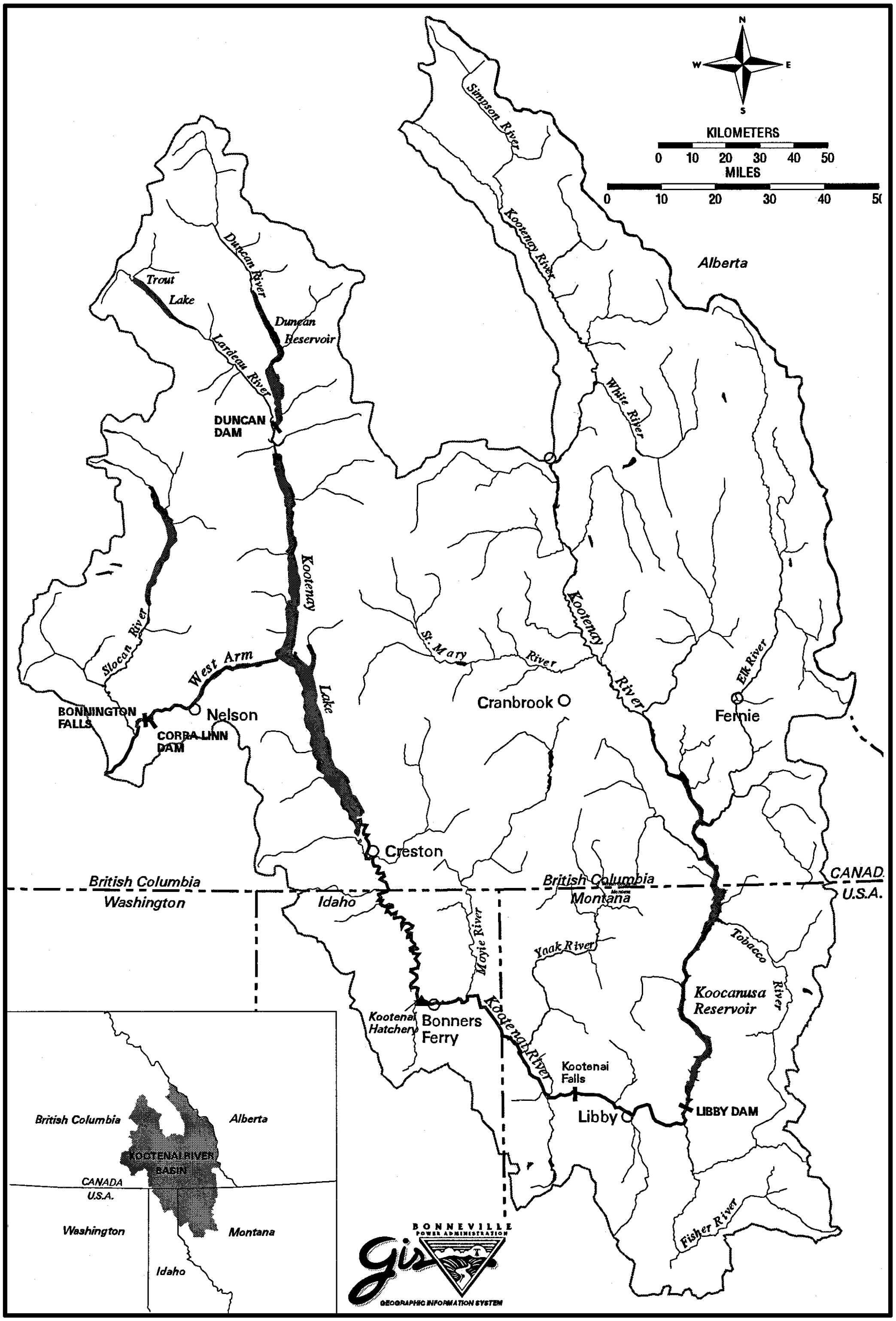
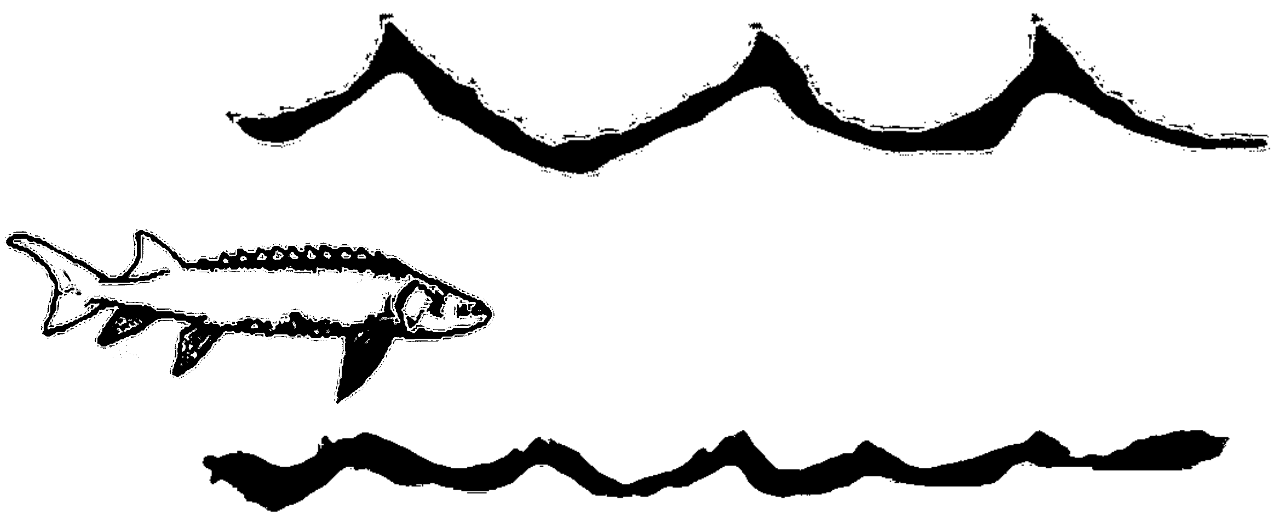


Figure 1-1. Kootenai River Basin Monitoring Plan Project Area (British Columbia, Idaho and Montana)
Source: Bonneville Power Administration

Section 2.0
Kootenai River Basin



2.0 KOOTENAI RIVER BASIN

2.1 Location and Description

The Kootenai River (spelled Kootenay in Canada) primarily is located within the province of British Columbia with smaller portions of the basin within the states of Montana and Idaho (Knudson, 1994). The headwaters of the Kootenai River flow from both national and provincial parks and unprotected areas along the British Columbia-Alberta border in the Northern Rocky Mountains. The Upper Kootenai River drains an area of approximately 2,080 mi^2 (5,387 km^2) and is fed by the Vermillion, Simpson, Cross, Palliser and White Rivers before entering the Rocky Mountain Trench at Canal Flats 70 miles (113 km) south of its origin. The Rocky Mountain Trench between Canal Flats and the Montana-Canadian border is 83 miles (134 km) long and varies in width between 3 to 17 miles (5 to 11 km). This represents a drainage area of 4,280 mi^2 (11,085 km^2). The Kootenai flows south through the Trench where several tributaries, including the St. Mary River, join it north of Cranbrook, BC, the largest population center in the basin. South of Cranbrook, it then enters Koocanusa Reservoir, which was created by damming the Kootenai River 17 miles (27 km) upstream of Libby, MT, to provide flood storage, hydroelectric power production and recreation benefits (Richards, 1997). Koocanusa Reservoir, which has a surface area of approximately 73 mi^2 (189 km^2) and a volume of 5.9 million acre-feet (7.3 billion m^3) at full capacity, was officially impounded on March 21, 1972. The Elk River, Bull River and Gold Creek join the Kootenai River/Koocanusa Reservoir complex north of the Canadian/US border. The total drainage area north of the border (East Kootenay) is approximately 6,360 mi^2 (15,695 km^2) or approximately one-third of the total drainage.

South of the border, the Tobacco River and numerous small tributaries flow into Koocanusa Reservoir. The river then flows west to the town of Libby, MT. The Fisher River joins the Kootenai River upstream of Libby where the Kootenai then turns and flows generally northwest toward Troy, MT. Between Troy and the Montana-Idaho border, the major tributary is the Yaak River. The Moyie River joins the Kootenai from the north between the Montana-Idaho border and Bonners Ferry, ID. At Bonners Ferry, the river turns north into the Purcell Trench and flows through flat agricultural land toward the Idaho-Canada border. North of the border, the river flows past the city of Creston, BC, and into the south arm of Kootenay Lake. Kootenay Lake's west arm is the outlet. From this point, the Kootenai River flows west to Castlegar, BC, where it joins the Columbia River. The Kootenai River is the second largest tributary to the Columbia River in terms of runoff volume and third largest in terms of watershed area (17,600 mi^2) (45,584 km^2) (Knudson, 1994; Richards, 1997). It descends approximately 10,000 ft (3,048 meters (m)) in elevation along its approximately 485-mile (781-km) length.

To simplify discussion and study of the river, it is practical to divide the Kootenai River Basin into different watersheds or sub-basins. The BC Ministry of Environment, Lands and Parks (BC MELP) has divided Canadian portions of the basin into Watershed Groups. For US portions of the basin, this study will use the fourth field watershed delineations completed by the US Geological Survey (USGS). These delineations are called Hydrologic Units and are represented by Hydrologic Unit Codes (HUC). The five USGS HUCs in the US section of the Kootenai River Basin are listed in Table 2-1.

2.2 History of Land Use

2.2.1 Early Uses. American Indians used resources along the Kootenai River and its tributaries until the late 1800s when reservations were established in the US and Canada for the American Indians, the Kutenai (Kootenai), who occupied the basin. The first known geographic exploration of the basin occurred in 1808 and trapping and fur-trading activities began shortly after. Early settlement included the establishment of a trading post near the present site of Libby, MT, in 1809 and a mission on the Tobacco Plains in 1845. A detailed summary of the history of the Kootenai River Basin is provided in a Water Quality Status Report by Knudson (1994).

2.2.2 Aboriginal History. The people of the Kootenai Basin always have called themselves Ktunaxa. They have lived in the basin for thousands of years. The name "Ktunaxa" has been translated in English as "lean and fast," the "way we kept our horses," and "to lick the blood from the spear," a symbolic reference to their marksmanship. The history of the Ktunaxa people that follows is quoted directly from "A Traveller's Guide to Aboriginal BC" (Coull, 1996).

> *Ktunaxa boundaries are irrefutable* (Figure 2-1). *Their seven communities occupy the wide valley trenches of southeastern B.C. and the adjacent American states of Montana and Idaho. The 3,000-metre walls of four parallel ranges--the Rockies and Purcells, the Selkirks and Monashees--rise suddenly from plains and plateaus, creating a mountain enclave that flourished unto itself for thousands upon thousands of years. The Ktunaxa language is a rare "isolate." Like that of the Haida on their remote archipelago, it has no links to any other. The culture that goes with it is steeped in the mists of the continent's most ancient landforms. And their history reaches back to account for the more "recent" developments here, such as the formation of rivers.*
>
> *Some elders say the name Kutunai, given them by their Prairie neighbours, is from their word, kulni, "to travel by water." And they speak of Natmuqcin, a giant who travelled about the land giving places names. In the wide trench between the Rockies and Purcells, he moulded, with his knees, one of this continent's most remarkable features: the two-kilometre portage that separates the Columbia River at its very source from the first freshets of the Kootenay River. From here, these two great rivers, channelled by the ranges, flow in opposite directions: the Columbia to the northern perimeter of the Ktunaxa world, the Kootenay to its southern reaches. Then, both rivers, having travelled the same distance, turn and merge in the heart of Ktunaxa territories.*

They continue to the sea as the Columbia, the fourth-longest river on the continent. The story of Natmuqcin is echoed by archaeologists who have followed an unbroken trail of Ktunaxa presence here that dates back 14,000 years. The trail evaporates--into the last major ice age--about the time glaciers were carving out the river routes.

In the 7,500 years following the ice age, the Ktunaxa were concentrated in the then dry, open forests of the Purcell Mountains. Then, when the climate changed again, the Purcells became a divider. The people on the moister, west side travelled the rivers and lakes in canoes, fishing and pursuing small game. Those on the drier east side hunted bison and large prehistoric animals. Some Ktunaxa people crossed to the far side of the Rockies, hunting for bison, then returning. They thrived as a whole, cooperative civilization, enduring earthquakes, floods, blocked salmon runs, and little ice ages like the one that ended just two centuries ago.

In 1807, the first white fur trader, David Thompson, made his way through the rocky barriers with the help of the Ktunaxa. They even assisted him in setting up the region's first post, Kootenae House, on the west shores of Lake Windermere. But for some, his arrival engendered a deep sense of foreboding. One Ktunaxa prophet travelled ahead of Thompson's party as it continued down the Columbia River to the coast, warning all she met: the end of the world was coming.

Within half a century, smallpox had turned gathering places to ghost towns. Gold seekers, silver, lead, copper, and coal miners blasted their way through the ancient mountain walls. An invisible and arbitrary international boundary in 1846 formed a new wall, dividing north and south. In 1887 Ktunaxa law was challenged at what became Fort Steele by an army of North West Mounted Police. Then the Indian Act imposed its more than 200 laws and regulations on a reserve-bound people. Natmuqcin’s rivers--the Columbia and Kootenay--were dammed, from head to mouth, their power siphoned to smelters and cities.

Still, the Ktunaxa endure. Together with their closest Secwepemc neighbours, the Kinbasket people, they continue to address the land question, knowing its resolution may take generations. They resist the invisible boundary, and strive for the preservation and practice of their culture, language, and identity. They have initiated the Canadian Columbia River Intertribal Fisheries Commission, to restore life--salmon--to their rivers. The prophet promised: the end of the world would be followed by a time of plenty.

Before reserves were set out in 1887, the Ktunaxa people travelled freely, gathering at several settlements each year. Communications were informal but constant and extensive, enhanced, in recent centuries, by the *introduction of horses. Leadership was hereditary--father to son, or adopted son, until 1953, when the federal government imposed its electoral system on First Nations across Canada. Today, the Ktunaxa/Kinbasket Tribal Council represents four Ktunaxa communities in Canada, and the Kinbasket people, the easternmost community of Secwepemc (Shuswap) peoples. The Ktunaxa people north of the 49th parallel are related to and aligned with the Kootenai Tribe of Idaho, based at Bonners Ferry, and the Kootenai of the Confederated Salish Kootenai Tribes of the Flathead Reservation, Pablo, Montana. Each year since 1979 a general assembly of Ktunaxa peoples has been held as a forum for discussing issues common to all.*

The Ktunaxa population within Canada is 1,000 or more; outside, 600. The language spoken here is Ktunaxa: it is not related to any other.

The primary communities of the Ktunaxa people in the Kootenay drainage are outlined below (Coull, 1996).

akaqtahat (Creston): (pop. 4,125/15 Ab)

79 km south of Kootenay Bay, at the lower end of Kootenay Lake in the wide valley at the confluence of the Goat and Kootenay rivers. The Ktunaxa name refers to the sloughs or marshlands where they navigated their unusual "sturgeon-nosed" canoes, hunting and harvesting the wild rice that grew as tall as they were. The wetlands challenged trail-blazers David Thompson and Edgar Dewdney, and land developers such as W.A. Baillie Grohman (see below). In the late 1800s, the Ktunaxa who lived here strongly opposed the draining of their slough and the destruction of their cemetery for orchards and alfalfa fields. They left their village, but their history remains: at higher elevations are rock paintings, obsidian quarries, and tools, often turned up during road or house construction. These indicate that water levels were much higher at one time. The people remained in the area: they are the yaqan nu?kiy of today (see below). Land reclamation projects continued in earnest through the 1930s.

South into Idaho and Montana

From yakan nu?kiy, the Kootenay River snakes south across the B.C./Idaho border. When government officials first came to discuss this boundary with the Ktunaxa people, they interpreted them to mean the land was literally going to be cut in two. It is 50 km via Hwys 1 and 95 to the Kootenai Reservation at Bonners Ferry (pop. 100).

akinkumlasnuqli'it (Tobacco Plains): (Pop. 149/89)

The reserve stretches 12 km from the Canada-U.S. border at Roosville to the community centre at Grasmere. Its Ktunaxa name means "tobacco plains." Tobacco was cultivated in two locations just south of the border, and on this side too. Some accounts give the plant a local origin, like the rivers, in the vicinity of Canal Flats. It was not smoked for pleasure: the Ktunaxa offered it ceremonially to the spirits, so they would take care of the people. Its cultivation and use fell off after European diseases swept through the land. These plains were also a base camp for bison-hunting expeditions and the setting, until the late 1800s, for religious dance ceremonies. Many here today are descendants of Ktunaxa from yakyaqanqat, "way through the mountain," 65 km north, now the coal-mining centre of Fernie. It was the Ktunaxa who in the late 1800s led gold commissioner William Fernie to the Elk Valley coal they had long used to keep their fires burning. Elders speak of the time he persuaded a young woman to divulge the source of the coal she wore as a necklace. He later spurned her and invoked her mother's wrath. She called upon the spirits to deliver a curse upon the valley, and the history of the town of Fernie from then on is a litany of disaster after disaster--an explosion, fires, and a flood. In 1964, Tobacco Plains chiefs Red Eagle and Big Crane held a ceremony to lift the curse.

Tobacco Plains today is a strong community with an eye on the future. In the 1960s, the Ktunaxa's first woman chief was elected here. In 1979, this was the site of the first annual General Assembly of all Ktunaxa people. From Tobacco Plains, Hwy 3 leads north and east along the Elk Valley. Here, somewhere--its location currently guarded--is a bison jump similar to Head-Smashed-In, Alberta's World Heritage Site, where hunters on foot stampeded buffalo over the edge of a cliff. The Elk Valley jump is one of only two known west of the continental divide in Canada. It was last used about 1600, when the little ice age wiped out the bison here. After that, the Ktunaxa, who did survive, made regular journeys through Crowsnest Pass to hunt bison in the warmer "chinook" country.

akisqaqli'it: (pop. 16,245/220 Ab)

*Where **Cranbrook** sits today, at "two little creeks or channels." The 1860s-1880s was a time of great change even for the adaptable, mobile Ktunaxa people--and things changed here as much as anywhere in their territories. In 1863, just north at Wild Horse Creek, the region's biggest gold strike drew 1,500 miners and a small group of settlers around Galbraith's Ferry. A cable-powered vessel eased miners across the Kootenay River just below its confluence with the St. Mary's River.*

About this time, Chief Joseph and his followers, the akamnik, "people of the thick woods" who gathered on Ktunaxa lands south of the 49th parallel, chose "where two ram horns lay" on the east side of Cranbrook's present-day townsite as their winter headquarters. By the 1870s, white settlers were crowding in on "Joseph's Prairie." The akamnik returned to a quieter base at the junction of the St. Mary and Kootenay rivers, the west side of Galbraith's Ferry. In 1874, when Father Fouquet of the Oblates took up permanent residence at St. Eugene's Mission just a few kilometres up St. Mary's River, the akamnik formed its nucleus and later became known as the St. Mary's band. Joseph handed over chieftainship to his adopted son, Isadore.

In 1884, as told by the chief's descendants today, a Ktunaxa man named "Little Isadore" came upon a pair of prospectors who had built a cabin on their land. "They didn't understand white language, they didn't know white law said non-natives could take up land, regardless of the Ktunaxa." The misunderstanding led to violence and two miners died. Meanwhile the Canadian Pacific Railway joined British Columbia to the rest of Canada, cutting into Ktunaxa territories at Golden to the north in 1885, drawing more settlers and speculators into Ktunaxa lands. Among the latter was Colonel Baker, magistrate and member of the provincial legislature—elected by at least 11 of the 22 white people he represented. From Galbraith, a settler and ferry operator, he bought Joseph's Prairie, and despite Chief Isadore's protests, surveying and fencing was underway. Then, two men, including Little Isadore, were arrested and jailed near Galbraith's Ferry for the murder of the miners. Chief Isadore, declaring that "Indians have been found dead, yet no white man was ever put in jail," freed the accused and ordered Baker's surveyor out of his territory. The North West Mounted Police—75 armed men—were called in to enforce the new government's law and order. Chief Isadore returned the prisoners, and although NWMP Inspector Sam Steele ultimately released them for lack of evidence, colonial law prevailed. The NWMP departed; Chief Isadore agreed to leave Joseph's Prairie to the newcomers. By 1887, Ktunaxa reserves were defined as the small spaces where they still live today, marking the biggest change of all--the Ktunaxa no longer travel freely throughout their land.

Fort Steele

In 1887, Sam Steele and his division of North West Mounted Police put up a rectangle of buildings for their winter quarters. There were no palisades, as the fort reconstruction suggests, but this was a bastion of white authority nonetheless. Some of that story is told here. The museum, open July and August, displays the unusual Ktunaxa canoe, made from a single piece of white pine bark set in a frame. Archaeologists speculate that these vessels, in use for at least 5,000 years, served as early ore cars, *transporting heavy materials up and down the rivers. Outstanding Ktunaxa bead and leather work is also featured.*

Ktunaxa Headquarters aqam (St. Mary's): (Pop. 245/203)

The St. Eugene Mission was founded here by the Oblates in 1855; a resident priest arrived in 1874. The "people of the thick woods" who lived here under Chief Joseph became known as outstanding farmers and still operate a 240 hectare cattle ranch and Christmas-tree farm. The elegant St. Eugene Church was built in 1897, and remains a rare example of Ktunaxa benefits from modern-day mining. A Ktunaxa man, Pierre, led Father Coccola and a mining promoter to the galena deposits that became the St. Eugene Mine. Pierre, at the urging of the priest, spent most of his profits on the church, which has hand-painted Italian stained and leaded glass, pinnacles, and buttresses. The mine prospered after they sold out, giving Consolidated Mining and Smelting Canada, "Cominco," its start.

The mission residential school, built in 1912 and closed in 1971, is being converted into a major destination resort and meeting facility, with banquet room, craft shops, golf course, and recreation centre. It will also house a Ktunaxa interpretive centre, a Native Women's' Arts and Crafts Cooperative, and serve as headquarters for the Kootenay Ecomuseum, intended to give the Ktunaxa more stewardship of some of the oldest petroglyphs in the world, alpine game-drive sites, bison jumps, prehistoric mine shafts, and village sites that are being lost, daily, to development.

This new development is at the confluence of Joseph Creek and the St. Mary River—both significant cutthroat trout streams. If done well, this development could highlight the value of the fisheries resource; however, significant stream degradation could occur, particularly from golf course construction and maintenance (i.e., herbicide use, riparian devegetation) if adequate precautions are not taken.

Hoodoos: At the north end of Columbia Lake

The Ktunaxa say an enormous fish wounded by Coyote tried to make its way along the Rocky Mountain Trench, where it finally gave up and died. As its flesh decomposed, the ribs fell apart and half became the hoodoos here; the other half are hoodoos farther south, near St. Mary's. At a campsite, yawulnik, just below the hoodoos, people came to gather tamarack moss, which was roasted and eaten.

Columbia Lake: (Pop. 203/141)

The reserve, well above Columbia Lake, embraces the shores of the Columbia River and Lake Windermere from just north of Fairmont Hot Springs to the town of Windermere. The administration office is just before

Windermere Loop Rd. The Ktunaxa call this area akisdnuk, "two bodies of water," for the two lakes. The Ktunaxa name for Windermere is yaqunaki, mentioned in the story of the giant, Natmuqcin, and also site of a mission village.

Ktunaxa Travels

From Kenpesq't, Hwy 95 follows the Columbia, the river route of the Ktunaxa people, to Secwepemc frontiers. Hwy 93 traces the Kootenay River to its very beginnings in the Rocky Mountains. After the little ice age which caused the disappearance of bison on this side of the Rockies, and then the timely arrival of horses, the Ktunaxa made regular treks through the mountains to Kootenay Plains, west of Red Deer, Alberta, to hunt bison and to trade. The more northern passes were especially vital after the 1800s, with the Blackfoot people blocking the southern routes. These mountains, designated a World Heritage Site, and embraced by a chain of national parks, were held sacred to the Ktunaxa, as all things are. But Sinclair Pass tracing the Kootenay River (now Hwy 93 from Radium Hot Springs) was particularly so. The hot springs at Radium were a place of spiritual cleansing; the canyon beyond, their cathedral. Here too, was a valuable source of iron oxide, pigment for the paints the Ktunaxa applied to horses, tipis, shields, their faces, clothing, and rock walls, and which they traded for bison products up at Kootenay Plains.

Farther along, their trail traces the turquoise Vermilion River--the glacial headwaters of the Kootenay River--to yet another source of the pigment, the Vermilion Paint Pots.

2.2.3 Upper Yaak Basin. Schrenk (1990) provides a broad summary of the Yaak basin, which is reprinted here.

2.2.3.1 Prehistory.

The Yaak River Valley has seen a progression of inhabitants; first known were the Kootenai (Kutenai) Indians who initially visited and used the area for hunting and religious purposes. Knowledge of human presence in the general area goes back at least 8,000 years, when people moved across the landscape as hunters and gatherers. One of the oldest archeological sites on the Kootenai National forest was found along the Yaak River. The early period of occupation (8,000-4,000 years ago) was probably characterized by small family groups moving frequently (up to 80 times per year) to secure their food. These people camped on the high terraces of the nearby Kootenai River. These terraces are thought to have been open areas providing prime big game habitat as well as commanding view of the Kootenai River.

Around 4,000 years ago, a cultural change occurred, which was probably spurred by a climate or vegetation change. The forest canopy closed in on the higher terraces and game animals moved to the lower terraces and valley floors. This, plus an increasing human population, caused hunting territories to diminish. A broader range of the area's resources had to be used by the Kootenai tribe. The people began placing more emphasis on fish and the intentional burning of the forest to increase big game browse, a practice which may go back 2,000 years.

Written history of the Kootenai tribe begins with the trappers' and explorers' journals written in the early 1800s. The Lower Kootenai (that group living in the Yaak area) were more isolated from their neighbors, were more oriented to hunting and fishing, had fewer horses, used the canoe more extensively, had tule covered tipis and organized a more complex political system than the Upper Kootenai (that portion of the tribe further east) (Smith 1984).

The only crop that the Kootenai people grew was a tobacco cultivated on the plains of the Tobacco Valley (around Eureka, MT). This tobacco was mixed with the shrub kinnikinnick and smoked in beautifully carved pipes made from a local pipe stone. The Kootenai knew how to utilize a multitude of plant resources for both medicinal and food resources. One unusual food source was the sweet cambium layer of the ponderosa pine tree. Certain ponderosa were selected in the spring when the sap was flowing. The cambium layer was removed by making an axe mark near the base of the tree and peeling back the bark. This practice left behind a distinctive mark still visible today on surviving trees.

The earliest known occupants of the forest in the Decision Area were prehistoric hunters and gatherers. Because they required large territories for hunting (Binford, 1983), these same groups also utilized lands in Canada. An understanding of these people transcends the international border. While the work of Canadian archaeologists has contributed to this knowledge, the Provincial laws do not adequately protect the resource, resulting in a greater, more rapid loss of site information.

Several factors influenced the settlement of the area after the 1910 fire and the decline of the Sylvanite mining boom. The 1906 Forest Homestead Act, the establishment of the Kootenai National Forest, and the associated lumber industry all contributed to the settlement and development of the valley (Lahren et al., 1983).

The first ranger in the Yaak was Frank Benning, who stationed at the Sylvanite Ranger Station in 1908. The 1910 wildfire shaped the future of the forest rangers who followed, with fire suppression playing a major role in forest management. Lookout towers, standing as sentinels on many *mountain tops, attest to the importance of fire fighting in bygone years. National economic recovery programs like the Civilian Conservation Corps also made their mark on the Yaak Valley. This work force built several ranger station structures that are now held as sites of national historic significance.*

The timber industry played an important role by bringing an influx of settlers into the area. Logging began in the Yaak River area around 1890 to supply railroad ties and lumber. Primitive roads were built soon after, but the primary method of moving logs from the Upper Yaak River area to sawmills in Troy and Idaho was by log drives that continued into the 1940s. Human settlement of the valley increased in the 1920s.

With the primitive road access in place, a few hardy families moved in to set up ranches and rural homesites. On the heels of the earlier loggers, these families cleared river bottom lands for pastures and fields. The local economy was a mix of small-scale ranching, logging, trapping and seasonal employment for the Forest Service. In the winter, many residents ran traplines, and most grew short season vegetables, kept some cattle, and became as self-sufficient as possible (Lahren et al., 1983).

2.2.4 Mining. The Kootenai River area has a long history of mining and mineral exploration.

In 1876, Bill Keeler discovered gold below Yaak Falls (Turner in Friedman, et al. 1983). The Yaak River Valley, though, did not become an important scene for mining in the Kootenai region until after 1890. The Keeler discovery led to the establishment of Snipetown in 1894 near Ferrel Creek. The town shut down a year later when the placer workings diminished. At the same time, further to the north the town of Sylvanite was being established as a result of the Goldflint and Keystone claims on Keystone Mountain in 1895. Sylvanite grew to a population of around 600 (in contrast to around 35 residents today), and was reputed to be the most active mining district in the area. However, the forest fires of 1910 destroyed most of Sylvanite (Lahren et al., 1983). (Schrenk, 1990)

In present times, a mining and ore concentration facility operated by ASARCO near Troy, MT, was in production for almost 20 years. There is speculation that this will reopen, but it currently remains closed. Another closed industrial operation that took place in the basin was the mining and processing of vermiculite by the W.R. Grace Company. The mining took place in Vermiculite Mountain, northeast of Libby, MT, on Rainy Creek. The drainage from the process tailings caused water quality problems in Rainy Creek and the Kootenai River until 1971, when the facility constructed a closed-circuit re-circulation system.

On the Canadian side of the border, the North Star and Sullivan ore deposits were discovered in 1892 near Kimberley, BC. The Kootenai River played a significant role in ore transport from the North Star mine by riverboat from Fort Steele to Jennings, MT. From Jennings, the ore was hauled overland to Great Falls where it was smelted. In 1901 the rail line from Cranbrook to Kimberley was completed and railway cars replaced the riverboats. The North Star mine was operated until 1910 when ore reserves became exhausted (KSCHBC, 1979). The Sullivan mine (currently owned and operated by Cominco, Ltd.) proved to be much more significant and began production of sulphide ores, including lead and zinc sulphide in 1909. It is scheduled for closure in 2001. Atmospheric exposure of the sulphide ores from the Sullivan and other hardrock mines has led to acid leaching of toxic heavy metals from the ores. Wastewater from the mine was discharged into tributaries of the St. Mary River, and ultimately ended up in the Kootenai River. Heavy metal studies of the St. Mary River and some of its tributaries, conducted in the 1960s, revealed high concentrations of lead in the St. Mary watershed and the Kootenai River. In 1979, the Sullivan mine began operation of wastewater treatment facilities to remove heavy metals and raise the pH of the effluent. Since that time, metal concentrations in downstream waters have decreased significantly.

The St. Eugene mine near Moyie, BC, was another significant operation in the Kootenai Basin. It was discovered in the late 1800s and operated near Moyie Lake, and currently is closed. Numerous claims also were operated along Kootenay Lake in the early part of the century. All mining operations in this region (except the Sullivan) are closed with the possible exception of smaller gold placer operations. Mines that were in production included the Estella and Kootenay King mines east of Wasa and the Placid Oil pit mine at the southern end of the Bull River. The Placid Oil mine closed in 1972, the Estella mine closed in the mid 1950s and the Kootenay King mine closed in 1953.

Cominco also operated a phosphate fertilizer plant near Kimberley from 1953 to 1987. Production at the plant resulted in high phosphorus discharges to the St. Mary and, consequently, the Kootenai River. Phosphorus concentrations in the watershed decreased significantly after the plant closed.

Underground coal mining in the Elk Valley dates back to the turn of the previous century. Large-scale surface open-pit coal mining in the Elk River watershed did not begin until the 1960s. Mining activities resulted in high sediment levels in the watershed until the mid-1970s when settling ponds were installed at the larger mine sites. Before construction of the ponds, tributaries to the Elk River were frequently black as a result of the coal dust sediment load. Recent data confirm that high selenium levels in the Elk River are caused by surface coal mining in the region (McDonald and Strosher, 1998).

2.2.5 Road and Railroad Construction. Construction of the Great Northern Railroad was completed in 1893. Several major highways were constructed in the basin in the 1930s. Railroad construction also occurred in the late 1960s when the railroad was redirected. The impacts of road and railroad construction on the basin have not been fully identified. However, road and railroad construction have resulted in the straightening, shortening, narrowing and confining of water channels, which could lead to increased erosion and suspended sediment, and destruction of aquatic habitat.

2.2.6 Forestry and Forestry Products. Much of the northern part of the Kootenai Basin north of the Rocky Mountain Trench is devoted to Kootenay National Park and Mount Assiniboine Provincial Park. In contrast, much of the southern half of the region, including practically all land east of the Kootenai River, is used for timber harvesting. Much of this timber is immature lodgepole pine and is trucked to the Skookumchuck pulp mill and the Canal Flats sawmill. Until 1998, Crestbrook Forest Industries also operated a sawmill at Cranbrook. A majority of the lands in the basin are managed by natural resource agencies including the BC Ministry of Forests (BC MOF) and the US Forest Service (USFS). These agencies manage logging and logging road development on their lands. In addition, private timber companies own, manage and harvest much of the Fisher River and other watersheds.

Little quantitative data are available to completely describe the impacts of logging and logging road development on the water quality of the basin; however, the results of sporadic monitoring events suggest that these activities negatively impact the watershed by increasing sediment load in the streams and rivers. It is known that higher sediment loads can impact fish populations by burying fish eggs and destroying habitat for young fish. Growth of primary producers can be inhibited by reduced light penetration into the water column, which in turn can reduce food resources for secondary producers. Activities in riparian areas can decrease shade cover over streams and rivers and thus increase water temperatures. Road building and culvert placement has served to isolate salmonid populations and increase risk of local extinction.

Facilities for processing forestry products also exist in the Kootenai River Basin. In 1968, Crestbrook Forest Industries began operation of a pulp mill at the confluence of the Kootenai River and Skookumchuck Creek. The activities of the pulp mill resulted in the discharge of toxins, such as chlorophenols and dioxins, to the Kootenai River. The effluent also discolored the river, especially during low flows. In 1981, Crestbrook Forest Industries began discharging effluent to rapid infiltration ponds. Discoloration and toxin concentrations were significantly lower after implementation of the ponds until 1986, when discolored seepage was noted in the Kootenai River near the ponds. In the early 1990s, Crestbrook Forest Industries upgraded their facility and installed wastewater treatment facilities designed to improve effluent quality.

2.2.7 Hydroelectric Facilities. Libby Dam, constructed in 1972, has had a profound impact on the entire Kootenai River Basin. The dam provides the outlet for Koocanusa Reservoir, which spans the Montana-British Columbia border, with 60 percent of the lake in Montana and 40 percent in British Columbia, except at low reservoir levels. Beneficial impacts of the dam include flood regulation, which has resulted in increased cropland downstream of the dam, silt reduction and power generation. Known negative impacts of the dam include decreases in fish habitat, nutrient removal by storage in the reservoir, dampened peak flows resulting in decreased spawning rates, increased downstream temperatures and dissolved gasses, and decreased flushing and dilution of contaminants.

Implementation of the turbine system in 1975 and installation of a selective withdrawal system in 1977 mitigated the dissolved gas and temperature problems. Irregular releases of water through the turbines to optimize power generation have resulted in downstream erosion of dikes near the Idaho-Canadian border, downstream water temperature fluctuations and unpredictable flows. Reductions in native fish populations continue to be a concern upstream and downstream of the dam. Several smaller hydroelectric dams also are located along the tributaries of the Kootenai River, downstream of Libby Dam.

2.2.8 Agriculture. The primary area of agricultural activity is between Bonners Ferry, ID, and Kootenay Lake. The rich soils are used for growing grain and forage, as well as for pasture land while the warmer valley slopes are used extensively for orchards in Creston. There also are areas that are used for the production of hops, which are used to make beer. This area, known as the Kootenai Flats, has been extensively diked in order to drain valley bottom lands for farming. Historically, this area was a maze of lakes, ponds and marshes along both sides of the river. In the early 1880s, W.A. Bailie-Grohman implemented a plan to reclaim lands for farming in the Kootenai Flats area. This two-part plan included diverting flows from the Kootenai River into Columbia Lake through a canal/marsh at present-day Canal Flats. This canal was operated for only 1 year due to protests over high-water levels in the Columbia River canyon north of Columbia Lake. The second part of Baillie-Grohman's plan was to widen the outlet below Kootenay Lake (Grohman Narrows) to lower the water levels in the Kootenai River. This was not accomplished until many years later.

The first efforts to reclaim the lands along the Kootenai River began in 1891 with the construction of a dyke along the Canadian side of the Idaho-British Columbia border to divert Boundary Creek into Idaho. Within 2 years, the reclaimed land was being used to graze cattle in BC. The lands were reflooded by high flows in 1894 and for the next 10 years, diking projects continued in the area in a difficult battle to prevent flooding. Six separate drainage districts eventually were created between the Idaho-British Columbia border and Kootenay Lake.

Both Canada and the US actively pursued diking projects to reclaim land in the Kootenai Flats. The US government engineers began to dyke and drain Idaho lands in 1915. By 1920, Idaho area farmers had also begun reclamation efforts, which culminated in the formation under state law of Drainage District 1 in 1922 and District 13 in 1931. Also in 1931, the Corra Lin dam was built on the outlet of Kootenay Lake and the river channel was widened at Grohman Narrows. In 1933, floods totally submerged six of the Idaho drainage districts. By this time there were 91 miles (146 km) of river levees and cross dykes on tributaries. Idaho farmers blamed the Corra Lin dam for their flooding problems and thus further widening of the river channel below the dam was completed in 1939. The intent was to lower gauge elevations by 2.95 ft (0.9 m) at Nelson, 1.95 ft (0.59 m) at Porthill and 1.10 ft (0.34 m) at Bonners Ferry.

In 1948, a year of exceptionally high springtime water levels and floods caused by mid-winter rain-on-snow events throughout the Kootenai region, the Kootenai River rose more than 25 feet (7.62 m) and nearly all reclaimed lands were flooded. The Libby Dam was completed in 1972 and provided a final major limitation to flooding in the Kootenai Flats area.

> *Before the construction of Libby Dam, the Kootenai River was characterized by a 4-6 km wide floodplain in the furthest downstream 79.5 mi (128 km) of the river. Diking of this stretch of river, from the 1920s to the 1950s, eliminated approximately 50,000 acres (202 km^2) of natural floodplain in Idaho alone. Estimated floodplain loss in British Columbia may be equal or greater.* (Richards, 1997)

Efforts to reclaim lands on the Kootenai River flood plain have never been concerned with the needs of native fish populations. Even programs dealing with wetland conservation have not considered the needs of fish. The isolation of channels, sloughs and lakes from the main river undoubtedly has impacted spawning, rearing and food production. A once diverse and thriving ecosystem essentially has been reduced to a deep and homogeneous canal.

A secondary agricultural area is in the lower Rocky Mountain Trench in the areas around the Bull River, St. Mary River, Fort Steele, the Grasmere Valley and Sand Creek. The farms are moderately sized (250 acres) with hay and cattle production being the main source of income. The majority of the farmers are situated in close proximity to the receiving waters since the land suited for crop production is located in the valley bottoms leading to and including the Kootenai River Valley.

Irrigation has contributed to lower water volumes in several watersheds of the basin and can contribute to erosion, causing higher sediments loads. Extreme variations in discharge volumes of water from Libby Dam have resulted in dike erosion from Bonners Ferry to Kootenay Lake. Crops are grown in the flood plains downstream from Libby Dam. Herbicide and pesticide runoff from croplands can increase toxin concentrations in waterways. Grazing along streambanks can severely damage riparian and aquatic habitat.

2.2.9 Population Centers. Several municipalities including Kimberley, Fernie and Creston in BC; Libby, Troy and Eureka in MT; and Bonners Ferry in ID discharge treated wastewater effluent directly to the Kootenai River and its tributaries. Wastewater effluent discharges can increase suspended solids, nutrients and some toxins in the waterways. In 1977, Cranbrook, BC, the largest population center in the basin, implemented a land application disposal process for its wastewater effluent. In less populated areas, sewage is disposed of through septic systems, which could result in pollutants leaching to waterways.

2.2.10 Wilderness. Portions of the basin remain pristine wilderness, some of which has been set aside as protected, restricted-use areas. These include Kootenay and Mt. Assiniboine National and Provincial Parks in British Columbia and the Cabinet Mountains Wilderness in Montana. Primary use of these areas includes hiking, fishing, hunting, camping and other recreational activities.

2.3 Existing and Historic Monitoring Projects

Several water quality and aquatic habitat studies have been conducted in the Kootenai River Basin. Data and monitoring stations from these projects provide information that may be used in conjunction with or to guide the monitoring activities outlined in this plan.

2.3.1 Legislative/Regulatory Monitoring. Some water quality and aquatic habitat monitoring in the basin is conducted in accordance with legislative or regulatory requirements. In general, these studies are overseen in some aspect by regulatory agencies including the BC MELP; the Idaho Division of Environmental Quality (IDEQ); the Montana Department of Environmental Quality (MDEQ); and the US Environmental Protection Agency (US EPA). Table 2-2 provides a list of agencies responsible for water quality monitoring in the Kootenai River Basin.

Legislative/regulatory monitoring projects in the Kootenai River Basin include the following:

- City of Cranbrook, Discrete Water Quality Monitoring Program and Forest Renewal, BC Continuous Water Quality Monitoring Program and Meteorological Monitoring Program—Joseph Creek and Gold Creek
- BC MELP, Forest Renewal BC (FRBC) and City of Kimberley Upper Mark Creek Remote Continuous Water Quality Monitoring Program and Discrete Water Quality Monitoring Program—Upper Mark Creek
- Cominco Ltd., Lower Mark Creek Water Quality Monitoring Program—Lower Mark Creek
- Crestbrook Forest Industries, Effluent Discharge Monitoring Program—Kootenai River
- Cominco Ltd., Effluent Discharge Monitoring Program, Drainage Water Treatment Plant—St. Mary River
- IDEQ, Beneficial Use Reconnaissance Project—All water segments in Idaho
- City of Libby, MT, Treated Waste Water Effluent Monitoring—Kootenai River
- City of Bonners Ferry, ID, Treated Waste Water Effluent Monitoring—Kootenai River
- Stimson Lumber Company, Treated Waste Water Effluent Monitoring—Kootenai River
- BC MELP, selenium mobilization from surface coal mining in the Elk River Basin, BC—Elk River
- Water survey of Canada hydrometric stations throughout the Kootenai Watershed; some stations have incorporated water quality instrumentation [locations to be confirmed].

2.3.2 Research and Academic Monitoring. Several monitoring projects in the basin are conducted to gather information about conditions of the basin without oversight of a regulatory agency. Many of these studies are conducted in cooperation with academic institutions including the University of Victoria in BC, the University of Idaho and the University of Colorado. Government and tribal agencies, such as the USGS, Kootenai

Tribe of Idaho and BC MOF, conduct some studies. Research and academic monitoring projects in the Kootenai River Basin include the following:

- BC MOF Research Branch (Nelson Region), Sediment Transport and Bedload Study—Gold Creek
- Department of Fish and Wildlife Resources, University of Idaho, Evaluation of Pesticides, PCBs and Metals in Kootenai River White Sturgeon Eggs
- G.O. Kruse and KTOI, Contaminant Analysis of Soil, Water and Invertebrates in the Lower Kootenai River
- City of Cranbrook, Long-Term Temperature Trends in Joseph Creek
- USGS for Army Corps of Engineers, Water Quality in Koocanusa Reservoir and the Kootenai River, downstream of Libby Dam
- Plum Creek Timber Company, Bull Trout and Macroinvertebrate Studies—Fisher River Area
- Idaho Fish and Game, Kootenai River white sturgeon, burbot and salmonid investigations—Kootenai River
- Kootenai Tribe of Idaho, Kootenai River macroinvertebrate investigation
- Kootenai Tribe of Idaho, Water quality monitoring on the mainstem of the Kootenai River from Libby Dam downstream to Porthill, ID, and the lower Kootenai River tributaries.

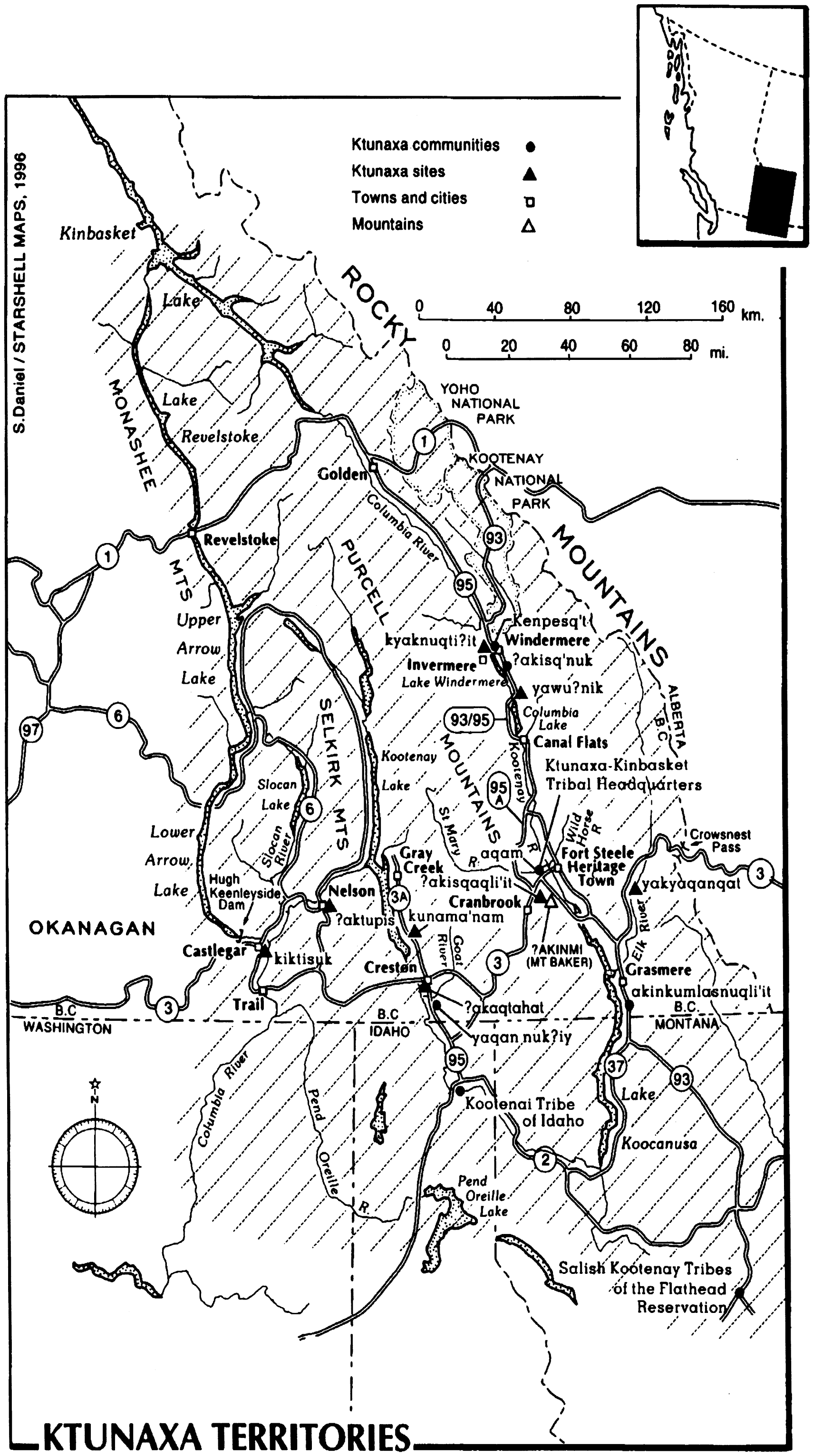


Figure 2-1. The Ktunaxa Terrirtories (Map Source: Coull, 1996)

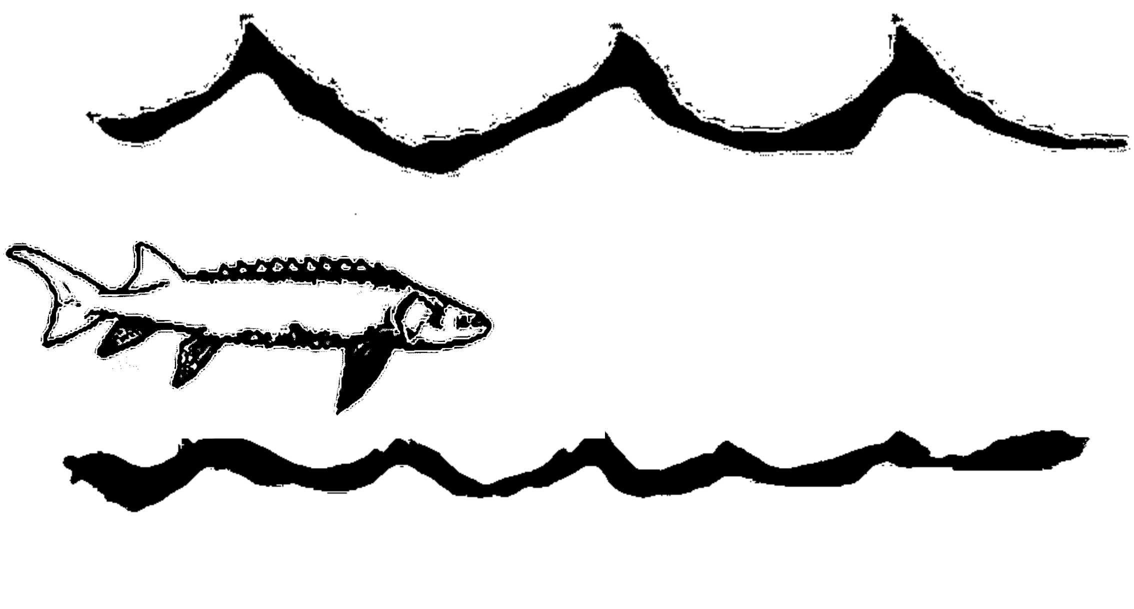
Table 2- 1. The USGS Hydrologic Unit Codes for the US Portion of the Kootenai River Basin

Name	HUC
Upper Kootenai Watershed	17010101
Fisher Watershed	17010102
Yaak Watershed	12010103
Lower Kootenai Watershed	17010104
Moyie Watershed	17010105

Table 2- 2. Agencies Responsible for Water Quality Monitoring in the Kootenai River Watershed

Agency	Acronym
BC Ministry of Environment, Lands and Parks	BC MELP
BC Ministry of Forests	BC MOF
BC Ministry of Health	BC MOH
Bonneville Power Administration	BPA
Cominco	Cominco
Crestbrook Forest Industries	CFI
Fisheries Renewal BC	FsRBC
Forest Renewal BC	FRBC
Idaho Department of Fish and Game	IDFG
Idaho Division of Environmental Quality	IDEQ
Kootenai Tribe of Idaho	KTOI
Montana Department of Fish and Game	MDFG
Montana Dept. of Environmental Quality	MDEQ
US Geological Survey	USGS
Water Survey of Canada	WSC

SECTION 3.0
POLLUTANTS AND HABITAT REDUCTION



3.0 POLLUTANTS AND HABITAT REDUCTION

3.1 Sources of Pollutants and Habitat Reduction

There are two major point source discharges on the Kootenai River north of the Canada-United States border: 1) Crestbrook Forest Industries' pulp mill at Skookumchuck, BC, and 2) Cominco's Sullivan Mine and Concentrator in Kimberley, BC. The fertilizer plant in Kimberley is closed, but is discussed below. A third major source of pollution, though technically non-point source in nature, is the complex of five major coal mines in the Elk Valley. As the coal is mined, selenium-bearing rock is oxidized. Water from snowmelt, rain or groundwater runs through waste dumps at these mines and carries the selenium to surface waters. The mines are, therefore, included here as a major source of pollution.

3.1.1 Skookumchuck Pulp Mill. Crestbrook Forest Industries' bleached kraft pulp mill, located in Skookumchuck, BC, started in 1968. The effluent from the pulp mill flows into the Kootenai River after treatment. Since 1968, the pulp mill has been the largest point source discharger directly into the Kootenai River. During the 1970s, angler use of the river below Skookumchuck decreased due to the adverse effects caused by the mill (discoloration of the river, toxicity and fish tainting problems). Since construction, the mill has undergone several upgrades including replacement of bleaching equipment (1975), addition of a ground infiltration effluent color treatment process (1981) and an upgrade to production capacity and quality (1985).

In 1991, Crestbrook mill embarked on another modernization, this time designed to bring the mill up to the highest environmental standards. Just under $300 million was spent to replace the recovery plant, install oxygen delignification and convert the mill to elemental chlorine-free bleaching. In addition, a novel decolorization process was installed that reduces effluent color to minimize color impact on the Kootenai River. Because it is fed by snow melt, the Kootenai has a very low winter flow. Effluent color is controlled by in-plant measures such as oxygen delignification and spill control, and by external methods such as tertiary treatment. The external method chosen by Crestbrook mill consists of a dissolved air flotation clarifier using polymers to remove color colloids from the effluent stream. The resulting sludge is recycled back to the chemical recovery plant where the inorganic constituents rejoin the mill chemicals. Odor has been reduced by about 90 percent with the addition of an odor collection system with a dedicated incinerator. Table 3-1 provides some data on the mill's environmental performance.

3.1.2 Mines.

3.1.2.1 Metal Mines.

3.1.2.1.1 Sullivan Mine. Cominco's oldest mine is the Sullivan mine at Kimberley, in southeastern British Columbia. Since 1909, the underground mine and mill have been supplying zinc and lead concentrates to Cominco's Trail Operations. The Sullivan mine uses a combination of conventional and mechanized mining methods. Pillar recovery currently constitutes the bulk of mine activity, although some primary mining still occurs.

The ore mined annually—1.6 million tons—produces 231,000 tons of zinc concentrate and 88,000 tons of lead concentrate. Over the decades, as ore production moved deeper into the mine, the ore composition changed. This required constant work on mill processing technology to improve concentrate grades and recovery. To this day, the concentrator is considered state of the art in technology. Due to ore reserve depletion, the Sullivan is scheduled to shut down permanently in 2002. In 1993, Cominco developed a comprehensive decommissioning and closure plan and also is working with the City of Kimberley to ensure the long-term viability of the city, including involvement in the increasing development of the area as both a destination resort and retirement area, plus the pursuit of commercial and industrial ventures. The Sullivan mine employs approximately 600 people.

3.1.2.1.2 Kimberley Fertilizer Operations. The Cominco fertilizer plant came into operation in 1953 and operated until 1987 in association with the Sullivan mine and concentrator. During that time it discharged wastes into the St. Mary River, a tributary of the Kootenai River. Fertilizer production doubled in 1962 and increased again in 1965. Water pollution control at the plant was improved by 1969, but it was not operating optimally until 1975 (Daley et al., 1981). Waste discharges from this plant increased phosphorus load throughout the Kootenai system, resulting in a four-fold increase from 1951 to the 1960s. By 1965, new production created more waste than the plant's disposal facilities could properly dispose of, and high levels of zinc, fluoride, ammonia and phosphate combined to create toxic conditions for aquatic organisms in the St. Mary River. In 1968, a waste disposal system was installed at the plant, which reduced the levels of toxic compounds being discharged into the Kootenai River. Fertilizer production decreased in the 1970s and 1980s until the plant closed in 1987 (Knudson, 1994). Interestingly, the phosphorus discharge from the Kimberley Fertilizer Operations is known to have had a positive effect on the productivity of Kootenay Lake, which supports a unique strain of kokanee salmon and Gerrard rainbow trout. Since the fertilizer plant closed and the Libby Dam was constructed, phosphorus levels and productivity levels have dropped to the point where artificial fertilization is now used to sustain the kokanee and trout populations in Kootenay Lake.

3.1.2.2 Coal Mines. There are five major coal mines in the Elk Valley: 1) Fording River, 2) Greenhills, 3) Coal Mountain, 4) Line Creek and 5) Elkview. All of these mines are in the Elk River drainage area. In 1996, coal production at these five mines was 20×10^6 tons. In order to generate this volume of cleaned coal, approximately 140×10^6 tons of rock is blasted and dumped into waste piles. Rain, snow and groundwater infiltrate these waste dumps and mobilize oxidized selenium into surface waters. McDonald and Strosher (1998) undertook a major review of selenium contamination in the Elk River as a result of a 1995 survey completed as part of a mine effluent permit amendment. The current criterion for total selenium for the protection of freshwater aquatic life in British Columbia is 1 μg/L (Nagpal, 1995). McDonald and Strosher found that "Various wastewaters at the coal mine [Fording River] contained total selenium from 19 to 54 μg /L. An average of 92% of the total selenium was in the dissolved form and not associated with particulate matter" (1998). Furthermore, "while summarizing 10 years of water quality sampling results taken at a site near the mouth of the Elk River, 65 km downstream of the coal mines, the Ministry of Environment, Lands and Parks found a rising trend in selenium concentrations. Total selenium, analyzed at a very low detection of 0.1 µg /L, rose from 0.5 µg /L in the early 1980s to 2 µg /L by 1994."

3.1.2.2.1 Fording River Operations. Located approximately 29 km northeast of Elkford, BC, Fording River's primary product is high-quality metallurgical coal used to produce coke for the international steel industry. The mine also produces and sells thermal coal for use by power utilities and associated industries. Fording River can produce more than 7.5 million tons of consistent high-quality coal per year. Fording River, Fording Coal Limited's largest metallurgical/thermal coal mine, began production in 1971 and made its first shipment of metallurgical coal in April 1972. Today, Fording River ships well over 7 million tons per year of Fording standard, medium volatile, high volatile and thermal coal to customers in 19 countries worldwide. Fording River produces Canada's widest range of bituminous coals from a single site. The mine's reserves consist of more than 515 million tons of cleaned coal in 20 different seams.

3.1.2.2.2 Greenhills Operations. Fording's second largest metallurgical/thermal coal mine is located 8 km northeast of Elkford, BC. Greenhills' primary products are medium volatile and standard metallurgical coal used to make coke for the international steel industry. The mine also produces and sells thermal coke for use by power utilities and associated industries. Greenhills has an annual production capacity of more than 4.5 million tons of cleaned coal. In December 1992, Fording purchased an 80 percent interest in the Greenhills coal mine in the Elk Valley of southeast British Columbia. The remaining 20 percent is owned by Pohang Steel Canada Limited, a subsidiary of Pohang Iron and Steel Company Limited of Korea.

The mine's reserves consist of approximately 128 million tons of cleaned coal in 13 different seams. Of this total, 90 percent of the reserves are contained within the Cougar North, South, Main and Raven pits of the Greenhills range. The seams that currently are being mined range in thickness from 1 m to 10 m. Reserves in other areas of the Greenhills mine are contained within 15 recoverable coal seams. These areas are scheduled for mining at a future date.

3.1.2.2.3 Coal Mountain Operations. Fording's third metallurgical/thermal coal mine is located 30 km southeast of Sparwood, BC. The mine produces and sells thermal, weak coking and pulverized coal injection coal products to international steelmakers and other industries. In October 1994, Fording embarked on a major mobilization and upgrading program that included pre-production stripping; exploration; the purchase of larger, more efficient mining equipment; and significant modifications to the processing plant. These enhancements have improved plant efficiencies and overall quality as Coal Mountain increases its production capacity for thermal and weak coking coals to 2.5 million tons.

The mine's reserves of approximately 45 million tons of cleaned coal are contained within three coal horizons, the largest being the "Mammoth" seam, which varies from 1 m to 200 m in thickness across the mine. A long-range mining plan has been developed to accommodate a mine life of more than 16 years.

3.1.2.2.4 Elkview Coal Mine. Elkview (previously known as the Balmer mine) is an open-pit coal mine located in the Elk Valley in southeastern British Columbia, 15 km from Sparwood. Mining at the Elkview site began with predecessor companies in the late 1960s. The former owner was Westar Mining Limited. Teck Corporation took over the mine in December 1992. Production resumed at the re-named Elkview mine in May 1993, and has steadily increased to a level of 3 million tons of metallurgical coal.

3.1.2.2.5 Line Creek Mine. The Line Creek Mine is an open pit coal mine located on Line Creek, a tributary of the Fording River. It is owned and operated by Manalta Coal Ltd. of Calgary, Alberta.

3.1.2.3 Other Mines. The W.R. Grace Co. mined and processed vermiculite from Vermiculite Mountain, northeast of Libby, MT. Water quality problems in Rainy Creek and the Kootenai River were caused by tailings pond drainage until 1971, when the facility constructed a closed-circuit re-circulation system.

There are estimated to be more than 10,000 abandoned mines located in the Kootenai watershed. These mines typically were small-scale hand-excavated lead, zinc, gold and silver mines that were operated by individual parties. There are no accurate watershed records that detail the locations of these abandoned mines. These mines are suspected to be a significant source of heavy metal pollution to the Kootenai River Basin as the discharge from these facilities, especially the tailing piles and contaminated groundwater, is not controlled or monitored.

3.1.3 Municipal Discharges. Major municipalities in the Kootenai River Basin that are served by secondary waste treatment facilities include Kimberley, Fernie, Creston, Sparwood and Elkford, BC; Libby, Troy and Eureka, MT; and Bonners Ferry, ID (Knudson, 1994). Cranbrook, BC, also has secondary sewage treatment but discharges waste to a spray irrigation system. The rest of the population in the basin use septic tanks or smaller community systems. Water quality effects downstream from Libby, Bonners Ferry and Troy are not as great as the effects from cities on smaller-scale tributaries due to the high volume of water and, therefore, greater dilution of the Kootenai River (Richards, 1997).

3.2 Data Gap Analysis.

3.2.1 Objectives. The objectives of the data gap analysis are to determine areas that require focused investigation as part of the water quality monitoring plan. The data gaps are issues that have not been sufficiently investigated by the regulatory agencies and First Nations due, primarily, to a lack of staff and funding. By focusing the efforts of a water quality monitoring plan on data gaps, a limited amount of effort and expense can tie significant collections of previously performed work together.

3.2.2 British Columbia.

3.2.2.1 BC Government Ministries.

3.2.2.1.1 BC Ministry of Environment, Lands and Parks. In 1995, the BC MELP initiated a two-part study to assess potential sources of water quality information in the Kootenai region, and to summarize and assess existing data and identify important eco-regions as they pertain to the Forest Practices Code (FPC) of British Columbia. Section 45, part 4, of the FPC prohibits forest practices that result in environmental damage or contravene the water quality objective established by BC MELP. The first part of the study was undertaken by Dobson Engineering and the second part was conducted by R.L. & L. Environmental Services.

The majority of water quality information collected by BC MELP exists in the System for Environmental Assessment and Management (SEAM) database. The database contains water quality information that has been collected for permitted and non-permitted sampling sites by provincial staff or licensees. SEAM provides the sample site location (Lat. & Long.), the site type (e.g., river/stream), method of sampling, date sampled, constituent analyzed and results. This database has been converted to a new format and has been renamed the Environmental Management System (EMS). EMS data records also contain the laboratory method used, identifier code of the laboratory and some quality assurance data. A second database, the Water Quality Data Management System (WQDMS), contains data collected by continuous monitoring stations and includes such parameters as temperature, water level, conductivity, turbidity and pH.

3.2.2.1.2 BC Ministry of Forests. Most of the surface water quality data collected by the BC MOF pertains to the effects of fertilizer and herbicide application, fires and cattle grazing. Data are available for Matthew Creek, which relate to the fire of 1985 (Toews, 1998). Data relating to the effects of forest fertilization are available for Gold Creek (McLaren, 1985). Current studies underway in Gold Creek examine the effects of road construction and timber harvest on suspended sediment yields. Though water quality monitoring is recommended under the FPC, most of the monitoring has not been conducted by BC MOF or timber licensees but by BC MELP under the Operational Inventory Water Quality Monitoring Program. These data are included in the EMS and WQDMS databases.

3.2.2.1.3 BC Ministry of Energy and Mines. Metals data and sediment data dating back to the early 1970s were collected as part of the British Columbia Geological Survey. Unfortunately, these data were based almost exclusively on single grab samples and are of limited use to a long-term monitoring program. More recent, and more useful, data collected to fulfill the requirements of mining permits were provided to BC MELP for inclusion in the EMS database and, therefore, do not require a separate review here.

3.2.2.1.4 BC Ministry of Health. The BC Ministry of Health (BC MOH) is responsible for collection of water quality data in community watersheds and some domestic drinking water supplies. The data primarily are total and fecal coliform counts and turbidity measurements and usually are taken at the point of intake to a distribution system rather than in the watershed itself. Some metals data also are available. The data are contained in a standalone computer system designed for BC MOH use. To date, information has not been successfully exported to spreadsheet or standard database format. Hard copy data summaries contain only values that exceed Canadian Drinking Water Guidelines and do not include data for samples that were within recommended guidelines.

3.2.2.2 Industrial Data Sources. Data collected for compliance with British Columbia waste management permits is forwarded to BC MELP to include in the EMS database. Data collected at the Skookumchuck Pulp Mill and Cominco Operations are included in the EMS.

Cominco Ltd. recently conducted a major water quality remediation project on Lower Mark Creek. The purpose was to isolate acid rock drainage from Mark Creek.

3.2.2.3 First Nations Data. The Canadian Columbia River Intertribal Fisheries Commission was developed to protect and restore fisheries resources on the Columbia River and its tributaries. The Canadian Intertribal Fisheries data are housed in the Ktunaxa's Tribal Council office located at the St. Eugene Mission, Cranbrook, BC.

3.2.2.4 Municipal/Private Data Sources. The City of Cranbrook has collected extensive physical and chemical data throughout the Joseph Creek and Gold Creek watershed since 1995. The City of Kimberley has a limited data set on upper Mark Creek and some data on Matthew Creek at the point of intake into the distribution system. Detailed temperature data for 1997/98 on the Lussier River are available from Aqua-Tex.

3.2.2.5 BC Summary. A summary of data availability for streams in the East Kootenay Region is presented in Table 3-2.

The SEAM database contains 481,810 records of information associated with 992 sampling stations collected between 1980 and 1996. Of these, approximately 10,000 records and 130 sampling stations are associated with surface water quality. It is not known how many of these records pertain directly to the Kootenai River or its tributaries.

3.2.3 Montana.

3.2.3.1 Data From Federal Sources.

3.2.3.1.1 US Environmental Protection Agency. The EPA maintains a database on watershed health based in the Upper Kootenai, Fisher and Yaak watersheds. The EPA uses Index of Watershed Indicators (IWI) to provide information for watershed health assessment. The EPA database lists 54 rivers and streams in the Upper Kootenai watershed and assigns an IWI score of 3 to the watershed indicating less serious water quality problems and a low vulnerability to stressors such as pollutant loadings. Table 3-3 summarizes the indicator IWI scores for the Upper Kootenai watershed.

The EPA database lists 15 rivers and streams in the Fisher watershed and assigns an IWI score of 5 to the watershed indicating more serious water quality problems and a low vulnerability to stressors such as pollutant loadings. Table 3-4 summarizes the indicator IWI scores for the Fisher watershed.

The EPA database lists 12 rivers and streams in the Yaak watershed and has not assigned an IWI score due to insufficient data. Table 3-5 summarizes the indicator IWI scores for the Yaak watershed.

3.2.3.1.2 United States Geological Survey. The stream-gauging and water quality monitoring program of the USGS provides hydrologic information to help define, use and manage the nation's water resources. The USGS and cooperating agencies maintain data from 23 monitoring stations in the Upper Kootenai watershed, six stations in the Fisher watershed, eight stations in the Yaak watershed, and one station in the portion of the Lower Kootenai watershed in Montana.

3.2.3.2 Data From State Sources. Section 303(d) of the 1972 Federal Clean Water Act requires states to develop a list of water bodies that need additional pollution reduction beyond that provided by the application of existing conventional controls. These waters are referred to as "water quality limited" and each state is required to establish total maximum daily loads (TMDL) according to a priority ranking.

The MDEQ currently is developing TMDLs for water bodies throughout Montana. Only one stream in the Kootenai drainage has a "moderate" TMDL development priority (Libby Creek) and there are none with a "high" priority. Table 3-6 outlines the TMDL summary for the 18 listed streams in the Upper Kootenai watershed.

Table 3-7 outlines the TMDL summary for the three listed streams in the Fisher watershed. Table 3-8 outlines the TMDL summary for the eight listed streams in the Yaak watershed.

No streams in the Lower Kootenai watershed were included in the TMDL listings as the listing document was in the process of being formulated by the IDEQ.

3.2.3.3 Industrial Data. The Stimson Lumber Company (Libby Mill) discharges water under National Pollutant Discharge Elimination System (NPDES) permit number MT0000221 and is listed as EPA facility number MTD006229876. As a permitted discharger, monitoring and reporting of the wastewater is required.

Champion International Corporation had previously owned the Libby Mill. Wood treating operations on the site from 1946 to 1969 caused contamination of soil and groundwater and the EPA added the Libby Groundwater Contamination Site to its National Priorities List in September 1983. Monitoring data associated with the site is available through the Lincoln County Sanitarian or the EPA office in Helena, MT. If the contaminant plume reaches the Kootenai River, or Flower and Libby Creeks, the pollutants could harm the wildlife in the area.

The USGS Mineral Resources Program has digital data files on active, inactive and abandoned mines with selected geochemical data. The data files have been compiled from databases maintained by the USGS and the US Bureau of Mines (US BOM). The data files include locations of 31 mines in Lincoln County. The data are available over the Internet in USGS Open File Report (OFR) 95-229.

The Montana State Library Natural Resources Information System (NRIS) maintains Geographic Information System (GIS) data on abandoned mines and mine locations. The data were generated from the Abandoned Mines Bureau and the USBOM Mineral Information Location System (MILS) database. The datasets include locations of 68 abandoned mines in Lincoln County, with information on water flow, water pH and distance to nearest stream. The datasets are available as Arc/Info export files or as ESRI Shape files on the Internet from the NRIS GIS data page.

3.2.3.4 First Nations Data. No First Nations data were found for Montana systems during the preparation of this plan.

3.2.3.5 Municipal/Private Data. The Montana University System Water Center provides data on permitted municipal mixing zones that includes the City of Libby for a 0.75 mile (1.2 km) mixing zone on the Kootenai River, and the US Corps of Engineers at Libby Dam for an 8,000 feet (2,438 m) mixing zone on the Kootenai River.

The City of Libby operates a wastewater treatment plant and discharges water under NPDES permit number MT0020494 and is listed as EPA facility number MTD000849067. As a permitted discharger, monitoring and reporting of the wastewater is required.

The EPA database on community water systems includes 30 facilities in the Safe Drinking Water Information System (SDWIS). Only one of those facilities (the City of Libby) has surface water as the source. Monitoring and reporting data associated with the facility is available through the EPA's SDWIS program.

3.2.3.6 Montana Summary. The EPA reported that insufficient data are available on sediments and ambient water quality including both toxic pollutants and conventional pollutants in all of the Montana Kootenai watersheds. Data from USGS water quality monitoring stations also are very limited. Available data indicate impaired aquatic life support and cold water fisheries caused by flow alteration, thermal modification, metals, siltation, habitat alteration, nutrients and suspended solids.

3.2.4 Idaho.

3.2.4.1 Data From Federal Sources.

3.2.4.1.1 US Environmental Protection Agency. The EPA maintains a database on watershed health based on both the Lower Kootenai and Moyie watersheds. The EPA database lists 17 rivers and streams in the Lower Kootenai watershed and assigns an IWI score of 6 to the watershed indicating that more serious water quality problems are present and the watershed has a high vulnerability to stressors such as pollutant loadings. Table 3-9 summarizes the indicator IWI scores for the Lower Kootenai watershed.

The EPA database lists four rivers and streams in the Moyie watershed and assigns an IWI score of 5 to the watershed. This indicates that more serious water quality problems are present and this system has a low vulnerability to stressors such as pollutant loadings. Table 3-10 summarizes the indicator IWI scores for the Moyie watershed.

3.2.4.1.2 United States Geological Survey. The USGS and cooperating agencies maintain data from 24 monitoring stations in the Lower Kootenai watershed and two stations in the Moyie watershed.

The USGS has been collecting and tabulating various water quality parameters for the longest time period and, in conjunction with the US EPA, maintains the largest database. The majority of the historical work centered on data collection for assessment of the environmental impacts of the Libby Dam and the general US Department of the Interior water quality baseline studies by USGS. Table 3-11 summarizes the active USGS monitoring stations in the Idaho segment of the Kootenai River Basin and their drainage area.

Five stations currently are considered active: 1) 12305000-Kootenai River at Leonia, Idaho; 2) 2309500-Kootenai River at Bonners Ferry, Idaho; 3) 12322000-Kootenai River at Porthill, Idaho; 4) 12321500-Boundary Creek near Porthill, Idaho; and 5) 12306500-Moyie River at Eastport, Idaho. The first three are located on the main Kootenai River and the last two are located on primary tributaries. The specific water quality parameters collected vary by station and monitoring year. There are 22 USGS stations that have been discontinued or are considered inactive within the Idaho segment of the Kootenai River Basin. The historical data can be found in various USGS publications and the annual water resources data reports by state and by water year.

The majority of water quality data collected by USGS and US EPA exists electronically in the STORET (Storage and Retrieval System of EPA) database. The database contains water quality information that has been collected for permitted and non-permitted sampling sites by agency staff or permitees. STORET provides the sample site location (Lat. & Long.), the site type (e.g., river/stream), method of sampling, date sampled, constituent analyzed and results. This database was converted to a new format and made available on the Internet in 1999. STORET data records also contain the laboratory method used, identifier code of the laboratory and some quality assurance data.

3.2.4.2 Data From State Sources. The IDEQ currently is conducting Kootenai River Basin water quality assessments addressing two state issues: 1) the bull trout problem assessment related to implementing the governor's bull trout conservation plan and 2) identifying water quality limited water bodies requiring TMDLs according to §303(d) of the Clean Water Act. Water quality limited means these water bodies do not support their beneficial uses and/or do not meet water quality standards. Idaho is required to furnish this list to the US EPA every 2 years. The 1998 list was compiled and provided to EPA and the public on January 22, 1999 (Idaho DEQ, 1999).

3.2.4.2.1 Bull Trout Problem Assessment. The Governor's Bull Trout Plan and the Kootenai River Basin Bull Trout Problem Assessment were in response to the 1995 US Fish and Wildlife Service (Service) status review that found listing bull trout (*salvelinus confluentus*) as threatened or endangered was warranted under the Endangered Species Act (ESA). In the same finding, the Service precluded listing bull trout [in 1995] due to higher priority listing actions.

The Idaho portion of the Kootenai River Basin is one of 59 key watersheds identified in the Governor's Plan. A working draft Kootenai River Basin Bull Trout Problem Assessment was completed in December 1998 (Panhandle Basin Bull Trout Technical Advisory Team, 1998). The IDEQ was reassessing their standards regarding bull trout every 3 years at the time of this report.

The Panhandle Basin Bull Trout Technical Advisory Team (1998) provided the remarks below.

> *On July 1, 1996, Governor Philip Batt and the State of Idaho issued an official plan to restore and conserve bull trout in Idaho waters. Governor Batt's Bull Trout Conservation Plan (Plan) emphasizes locally developed, site-specific programs, with appropriate professional technical assistance. The Service, after a court-ordered reconsideration of the earlier finding, issued a proposed rule to list in 1997. After reviewing the most current information and comments, the Service issued the final rule to list the Columbia River bull trout population segment as threatened in June 1998. The State of Idaho, with the cooperation of the Service, continues implementation of the Plan to meet the requirements of the ESA, local communities and the bull trout.*
>
> *The Plan uses the Basin Advisory Group (BAG) and Watershed Advisory Group (WAG) framework, as established by Idaho Code §39-3601 for dealing with water quality limited streams listed under section 303(d) of the Clean Water Act, to provide for local development of watershed specific plans to maintain and/or increase bull trout populations and meet the needs of the surrounding communities in Idaho.*
>
> *[The] problem assessment was drafted by the Technical Advisory Team (TAT) for use by the Kootenai River Bull Trout Watershed Advisory Group (KRBTWAG) in developing a conservation plan. [The assessment] presents information about bull trout population status in the Kootenai Basin, identifies factors that threaten the long-term persistence of bull trout populations in the Kootenai River key watershed, and further, provides initial suggestions for actions to reduce or eliminate these problems.*

> *Little quantitative information exists regarding historic bull trout abundance in the Kootenai River drainage. [The problem assessment recognizes] this as a major gap in our knowledge of the drainage.*
>
> *Historically, the Kootenai River bull trout population consisted of migratory fish using Kootenay Lake and the Kootenai River. It is unknown how many resident populations may have existed. Kootenai Falls was not likely a barrier to bull trout during high flow periods, giving migratory fish access to most of the river basin. In 1998, the Montana Department of Fish, Wildlife, and Parks documented radio tagged bull trout moving upstream past Kootenai Falls. It is known that bull trout pass downstream over Kootenai Falls. Libby Dam, constructed in 1972, cut off fish access to the upper portions of the watershed. Bull trout are known to pass downstream through Libby Dam, but survival of these fish is unknown. Historical access to Idaho tributaries was limited in many cases to the lower stream reaches due to natural barriers.*
>
> *The strongest bull trout population segment in the Kootenai Basin appears to be the migratory fish using Kootenay Lake and the Kootenai River upstream to Libby Dam. These fish probably spawn in tributaries draining British Columbia, Idaho and Montana and spend their adult life in Kootenay Lake and/or the Kootenai River. Resident populations are known to exist in Montana, and probably exist in the Moyie River. Few Idaho tributaries are believed to currently support bull trout spawning.*

Table 3-12 summarizes the working draft problem assessment information related to historical and current bull trout abundance in the Idaho part of the Kootenai River Basin.

Bull trout have been documented in the Kootenai River, Callahan Creek, Curly Creek, Moyie River, Deer Creek, Deep Creek, Fall Creek, Caribou Creek, Snow Creek, Myrtle Creek, Rock Creek, Trout Creek, Parker Creek, Long Canyon Creek and Boundary Creek (Panhandle Basin Bull Trout Technical Advisory Team, 1998).

The problem assessment authors comment that "Little information is available as the basis for attempting to quantify current bull trout abundance. This is an important research need. Limiting factors for bull trout can result from either human activities or natural events, acting separately or cumulatively… [I]nformation specific to the Kootenai River is…" limited, but the working draft identifies threats (not listed or prioritized in any specific order relating to the Kootenai River key watershed) related to the timber harvest, roads and railroads, livestock grazing, mining, dams/hydroelectric development and irrigation diversion, urbanization, wildfire, illegal harvest/fish mortality, disease, predation/competition and hatchery supplementation (Panhandle Basin Bull Trout Technical Advisory Team, 1998).

Table 3-13 summarizes various key physical attributes of selected Idaho Kootenai River Basin watersheds (provisional data from USFS, IDEQ and IDFG) (Panhandle Basin Bull Trout Technical Advisory Team, 1998).

The provisional data indicate that 16 percent of the Idaho Kootenai River Basin watershed has been logged and 33 percent of the Idaho section has highly erodible soil types. A preliminary review of the potential threats by sub-watershed indicates roads as a high-priority threat; however, more than half of the sub-watershed bull trout limiting factors are unknown within the Kootenai River Basin. Additional assessment and data gathering are needed (Panhandle Basin Bull Trout Technical Advisory Team, 1998).

3.2.4.2.2 The Idaho 303(d) List and Beneficial Use Reconnaissance Project Process. As a result of several Clean Water Act requirements, the IDEQ will assess 977 potentially impaired water bodies in Idaho. In cooperation with basin advisory groups and watershed advisory groups, IDEQ will evaluate the findings of assessments, prepare a TMDL for those water bodies that do not support their designated beneficial uses, and develop appropriate pollution allocation and control strategies to ensure beneficial uses are achieved. The IDEQ has scheduled TMDLs to be developed for the Lower Kootenai watershed by 2004 and for the Moyie watershed by 2005.

The IDEQ has developed a stream assessment program that does the following:

- Measures and incorporates physical, chemical and biological data
- Addresses basin water quality and beneficial use questions
- Produces an accurate assessment of the status of the state's waters.

The two major components that accomplish these tasks are the Beneficial Use Reconnaissance Project (BURP) and the Water Body Assessment Guidance process. The primary goal of these two programs is to provide consistency in data collection, monitoring and analysis of data throughout the state.

In 1993, IDEQ implemented BURP, which aimed to integrate biological and chemical monitoring with physical habitat assessment to characterize stream integrity and water quality. In addition, this program met the Clean Water Act requirements of monitoring and assessing biology as well as developing biocriteria. BURP relies heavily on protocols for monitoring physical habitat and macroinvertebrates and it closely follows the "Rapid Bioassessment Protocols for Use In Streams and Rivers" developed by EPA (Pflakin et al., 1989).

The points below outline the purpose and objectives of the 1993-1996 BURP program.

Purpose

- Provide consistency in monitoring, data collection and reporting as required by "Coordinated Nonpoint Source Water Quality Monitoring Program for Idaho" (Clark, 1990).

Objectives

- Document the existing beneficial uses of water bodies to the extent possible at a reconnaissance-level intensity.
- Determine beneficial use support status, which may include the characterization of aquatic reference conditions.
- Staff the BURP program. Currently one professional staff member from each of IDEQ's six regional offices and one member from the central office Water Quality Assessment and Standards Bureau form the BURP Technical Advisory Committee (TAC). These seven individuals are known as BURP coordinators and make up the backbone of the BURP program. Their responsibilities include development of field methodology, training and supervision of field crews.
- Create a yearly workplan. The BURP coordinators are responsible for creating the workplan. This workplan is published in the spring. It establishes the purpose, objectives, methods and rationale for parameter selection, quality assurance/quality control (QA/QC), and training for the field season.
- Gather and review data. Once the workplan is completed, the BURP coordinators locate and review existing information on perspective water bodies to be visited by the field crews. They also meet for coordinator training and review of field protocol.

The IDEQ 1998 303(d) list includes 60.4 miles of impaired stream segments within the Kootenai River Basin. Table 3-14 outlines the Idaho water bodies within the Kootenai River Basin considered "water quality limited; that is, they do not support their beneficial uses or exceed water quality standards" (Idaho DEQ, 1999).

The IDEQ has removed nine water body segments in the Idaho Kootenai River Basin that were listed on the 1996 303(d) list. These water bodies are shown in Table 3-15.
For the delisting, the IDEQ relied on various sources of information, either new or not previously available when the 1996 list was prepared. A total of 64.9 stream miles were delisted in the Idaho Kootenai River Basin.

The IDFG has conducted Kootenai River white sturgeon and burbot studies along the Idaho segment of the Kootenai River for several years. Reports detailing the results of these investigations are available for 1989 through 1998. The studies are funded by the Bonneville Power Administration (BPA) as part of the BPA's program to protect, mitigate and enhance fish and wildlife affected by the development and operation of hydroelectric facilities on the Columbia River and its tributaries. Specific parameters investigated vary from year to year based on available budget. In general, the studies include information regarding discharge flows, water temperatures, adult and juvenile sturgeon sampling, egg and larvae sampling, and behavior of monitored sturgeon.

3.2.4.3 Industrial Data. Two Idaho industrial facilities were identified as maintaining discharge permits within the Kootenai River Basin. Both are NPDES multisector stormwater discharge permits and neither requires monitoring other than visual observation of stormwater. The facilities are Burlington Northern Railroad and Crown Pacific Timber.

The USGS Mineral Resources Program has digital data files on active, inactive and abandoned mines with selected geochemical data. The data files have been compiled from databases maintained by the USGS and the US BOM. The data files include locations of 64 mines in Boundary County. The data are available over the Internet in USGS OFR 95-664.

3.2.4.4 First Nations Data. The Kootenai Tribe of Idaho has collected metals, turbidity and nutrient data on the Kootenai River and Moyie over the past 4 years. Data were collected during the following periods:

- June 1994 - December 1994 (monthly)
- February 1995 - June 1996 (monthly)
- August 1995 - August 1997 (monthly)
- September 1997 - October 1997 (monthly)
- November 1997 - July 1998 (monthly)
- March, September and October 1997 (quarterly)
- January 1998 - July 1998 (quarterly).

Sites and parameters varied by sampling period. The complete list of sites is below.

Kootenai River

- Porthill, Copeland, Deep Creek, Yaak River, Troy, Libby, Libby Dam, Eureka, Ferry Island, Rock Creek, Fleming Creek, Kootenay Lake, Shorty's Island, Crossport and the Fisher River

Moyie River

- Line Creek, Eastport, Meadow Creek, Moyie and Kootenai confluence

In general, these sites were sampled for metals, turbidity and nutrients. Chlorinated phenols, PAHs, pesticides, herbicides, PCBs and VOCs also were sampled periodically throughout this period. Soil analysis for metals, chlorinated phenols, PAHs, pesticides and herbicides were done between July 1994 and June 1996. Macroinvertebrate samples were taken between June 1996 and May 1997.

3.2.4.5 Municipal/Private Data. The EPA database on Community Water Systems includes 35 facilities in the SDWIS. Nineteen of these systems have surface water as their source. Monitoring and reporting data are available through the EPA's SDWIS program.

The City of Bonners Ferry collects water quality information on Myrtle Creek according to the requirements of a surface water public drinking water source. The City of Bonners

Ferry is permitted for a wastewater discharge to the Kootenai River. Monitoring of effluent from the sewage treatment facility is required and reported to the US EPA. Monitoring requirements include BOD_5, suspended solids, pH, fecal coliform and total residual chlorine. No actual Kootenai River monitoring is required in the NPDES permit.

3.2.4.6 Idaho Summary. There has been an increase in the Idaho Kootenai River Basin water quality and fisheries monitoring in the past 10 years; however, consistent, reliable basin-wide data are lacking. The IDEQ BURP monitoring often is a snap shot in time and not truly representative of the aquatic habitat being sampled. Very little riparian habitat assessment has been completed in Idaho. The existing bio-monitoring data need further analysis and consideration for increased basin-wide coverage. Data sets from various Idaho agencies and researchers need to be compiled to better identify areas of insufficient data or candidates for Idaho reference watersheds.

The EPA reported that insufficient data are available on sediments and ambient water quality including both toxic pollutants and conventional pollutants in all of the Idaho Kootenai watersheds. The USGS water quality monitoring station data also are very limited. The State of Idaho has not completed TMDL evaluations of the waters in the basin. The TMDLs are not scheduled to be complete until 2005.

Table 3- 1. Crestbrook Forest Industries' Environmental Performance

Parameter	Units	Before (1993)	After (1997)
Odor	t/day	0.97	0.02
Sulfur dioxide	t/day	5.6	0.02
Effluent BOD	t/day	2.9	0.65
AOX	t/day	0.24	0.13
Dioxin/furan	g/year	2.7	0.17
Water use	m3/day	52,000	37,380

Table 3- 2. Summary of Data Availability for Streams in the East Kootenay Region

Watershed	BC MELP WATERSHED PRIORITY	Resource Management Area	Community Watershed	Water Quality Data	Sediment Data	Biological/ Ecological Significance
Alexander Creek	Unclassified	Enhanced		Yes	No	
Big Horn Creek	1	Integrated		No	No	
Bull River	1	Integrated & Special		No	No	
Burnham Creek	1	Integrated		No	No	
Coal Creek	1	Enhanced		No	No	Important bull trout and cutthroat trout spawning stream
Couldrey Creek	1	Integrated		No	No	
Cow Creek	Unclassified	Integrated		No	No	
Cross River	2	Integrated		No	No	
Elk River	1	Integrated & Special		Yes	No	Concerns regarding status of bull trout and cutthroat trout stocks
Findlay Creek	1	Integrated		No	No	
Flathead River	Unclassified	Enhanced, Integrated & Special		Yes	No	
Fording River	Unclassified	Enhanced		Yes	No	
Goat River	1	Integrated		No	No	
Howell Creek	1	Integrated		No	No	
Inlet (To Whiteswan Lake)	2	Integrated		No	No	Important rainbow trout spawning stream
Joseph Creek	1	Integrated	Yes	Yes	Yes	Important cutthroat trout spawning stream; has been heavily impacted by land use activities

Table 3- 2. Summary of Data Availability for Streams in the East Kootenay Region (cont.)

Watershed	BC MELP WATERSHED PRIORITY	Resource Management Area	Community Watershed	Water Quality Data	Sediment Data	Biological/ Ecological Significance
Kid Creek	2	Enhanced, Special & Integrated		No	No	
Kilmarnock Creek	Unclassified	Enhanced		Yes	No	
Kishinena Creek	1	Special		No	No	
Lamb Creek	2	Integrated		No	No	
Leach Creek	Unclassified	Enhanced		Yes	No	
Line Creek	Unclassified	Enhanced		Yes	No	
Lizzard Creek	1	Enhanced		No	No	
Lodgepole Creek	1	Enhanced & Integrated		No	No	
Lussier River	2	Integrated		No	No	
Matthew Creek	1	Integrated		Yes	No	Important cutthroat trout spawning stream in St. Mary watershed
Michel Creek	Unclassified	Enhanced		Yes	No	
Moyie River	1	Integrated		No	No	
Palliser River	2	Enhanced & Integrated & Protected		No	No	
Perry Creek	1	Integrated		No	No	Important cutthroat trout spawning stream in St. Mary watershed
Sage Creek	1	Integrated		No	No	
Sand Creek	2	Integrated		No	No	
Sandown Creek	1	Special		No	No	
Skookumchuck Creek	1	Special		No	No	Resident cutthroat trout population and an important spawning stream for Kootenai River bull trout stocks

Table 3- 2. Summary of Data Availability for Streams in the East Kootenay Region (cont.)

Watershed	BC MELP WATERSHED PRIORITY	Resource Management Area	Community Watershed	Water Quality Data	Sediment Data	Biological/ Ecological Significance
St. Mary River	1	Enhanced & Special		No	No	Regionally important cutthroat trout population
Thompson Creek	Unclassified		Yes	No		
Wheeler Creek	Unclassified	Enhanced		Yes	No	

Table 3- 3. Upper Kootenai Watershed - Watershed Health Index

Condition Indicators	
Designated Use Attainment	Less Serious
Fish & Wildlife Consumption Advisories	Less Serious
Source Water Condition	Better
Contaminated Sediments	Insufficient Data
Ambient Water Quality – Four Toxic Pollutants	Insufficient Data
Ambient Water Quality – Four Conventional Pollutants	Better
Wetland Loss Index	Less Serious
Vulnerability Indicators	
Aquatic Species at Risk	Moderate
Toxic Loads Over Permitted Limits	Low
Conventional Loads Over Permitted Limits	Low
Urban Runoff Potential	Low
Index of Agricultural Runoff Potential	Low
Population Change	Low
Hydrologic Modification	High
Estuarine Pollution Susceptibility Index	Insufficient Data

Table 3- 4. Fisher Watershed - Watershed Health Index

Condition Indicators	
Designated Use Attainment	More Serious
Fish & Wildlife Consumption Advisories	Insufficient Data
Source Water Condition	Better
Contaminated Sediments	Insufficient Data
Ambient Water Quality – Four Toxic Pollutants	Insufficient Data
Ambient Water Quality – Four Conventional Pollutants	Insufficient Data
Wetland Loss Index	Better
Vulnerability Indicators	
Aquatic Species at Risk	Low
Toxic Loads Over Permitted Limits	Insufficient Data
Conventional Loads Over Permitted Limits	Insufficient Data
Urban Runoff Potential	Low
Index of Agricultural Runoff Potential	Low
Population Change	Low
Hydrologic Modification	Low
Estuarine Pollution Susceptibility Index	Insufficient Data

Table 3- 5. Yaak Watershed - Watershed Health Index

Condition Indicators	
Designated Use Attainment	Better
Fish & Wildlife Consumption Advisories	Insufficient Data
Source Water Condition	Better
Contaminated Sediments	Insufficient Data
Ambient Water Quality – Four Toxic Pollutants	Insufficient Data
Ambient Water Quality – Four Conventional Pollutants	Insufficient Data
Wetland Loss Index	Better
Vulnerability Indicators	
Aquatic Species at Risk	Low
Toxic Loads Over Permitted Limits	Insufficient Data
Conventional Loads Over Permitted Limits	Insufficient Data
Urban Runoff Potential	Low
Index of Agricultural Runoff Potential	Low
Population Change	Low
Hydrologic Modification	Low
Estuarine Pollution Susceptibility Index	Insufficient Data

Table 3- 6. Upper Kootenai Watershed - TMDL

Name	Estimated Length (mi.)	Assessment Date	TMDL Development Priority	Probable Impaired Uses	Probable Causes	Probable Sources
Kootenai River	52	11/89	LOW	▪ Aquatic Life Support ▪ Cold Water Fishery-Trout	▪ Flow Alteration ▪ Thermal Modifications	▪ Dam Construction ▪ Flow Regulation ▪ Upstream Impoundments
Stanley Creek	2	6/91	LOW	▪ Cold Water Fishery-Trout ▪ Aquatic Life Support	▪ Metals ▪ Siltation	▪ Resource Extraction ▪ Subsurface Mining
Dry Creek	2	11/89	LOW	▪ Cold Water Fishery-Trout ▪ Aquatic Life Support	▪ Flow Alteration ▪ Other Habitat Alterations	▪ Highway/Road/ Bridge Construction
Keeler Creek	7	11/89	LOW	▪ Aquatic Life Support ▪ Cold Water Fishery-Trout	▪ Flow Alteration ▪ Other Habitat Alterations ▪ Siltation	▪ Silviculture
Snowshoe Creek	3	11/89	LOW	▪ Aquatic Life Support ▪ Cold Water Fishery-Trout	▪ Metals ▪ Siltation	▪ Resource Extraction
Big Cherry Creek	19	11/89	LOW	▪ Cold Water Fishery-Trout ▪ Aquatic Life Support	▪ Metals ▪ Other Habitat Alterations ▪ Siltation	▪ Resource Extraction ▪ Siltation

Table 3-6. Upper Kootenai Watershed – TMDL (cont.)

Name	Estimated Length (mi.)	Assessment Date	TMDL Development Priority	Probable Impaired Uses	Probable Causes	Probable Sources
Libby Creek	28	11/89	MODERATE	▪ Cold Water Fishery-Trout ▪ Aquatic Life Support	▪ Flow Alteration ▪ Metals ▪ Nutrients ▪ Other Habitat Alterations ▪ Siltation	▪ Agriculture ▪ Land Development ▪ Pasture Land ▪ Resource Extraction ▪ Removal Of Riparian Vegetation ▪ Silviculture
Lake Creek	13	6/91	LOW	▪ Aquatic Life Support ▪ Cold Water Fishery-Trout	▪ Flow Alteration ▪ Metals ▪ Siltation ▪ Thermal Modifications	▪ Mill Tailings ▪ Natural Sources ▪ Resource Extraction
Quartz Creek	21	11/91	LOW	▪ Aquatic Life Support ▪ Cold Water Fishery-Trout	▪ Flow Alteration ▪ Other Habitat Alterations ▪ Siltation ▪ Suspend Solids	▪ Natural Sources ▪ Silviculture
Cripple Horse Creek	11	12/89	LOW	▪ Aquatic Life Support ▪ Cold Water Fishery-Trout	▪ Siltation	▪ Agriculture ▪ Natural Sources ▪ Silviculture
Bristow Creek	10	12/89	LOW	Cold Water Fishery-Trout	▪ Flow Alteration ▪ Siltation	▪ Silviculture
Edna Creek	11	12/89	LOW	▪ Cold Water Fishery-Trout	▪ Siltation	▪ Agriculture

Table 3-6. Upper Kootenai Watershed – TMDL (cont.)

Name	Estimated Length (mi.)	Assessment Date	TMDL Development Priority	Probable Impaired Uses	Probable Causes	Probable Sources
						▪ Silviculture
Swamp Creek	8	12/89	LOW	▪ Cold Water Fishery-Trout	▪ Flow Alteration ▪ Siltation	▪ Silviculture
Lime Creek	3	12/89	LOW	▪ Aquatic Life Support ▪ Cold Water Fishery-Trout	▪ Other Habitat Alteration ▪ Pathogens ▪ Siltation	▪ Agriculture
Grave Creek	9	12/89	LOW	▪ Aquatic Life Support ▪ Cold Water Fishery-Trout	▪ Flow Alteration ▪ Other Habitat Alteration ▪ Siltation	▪ Agriculture ▪ Silviculture
Therriault Creek	5	12/89	LOW	▪ Aquatic Life Support ▪ Cold Water Fishery-Trout	▪ Flow Alteration ▪ Siltation	▪ Agriculture ▪ Highway/Road/ Bridge Construction ▪ Silviculture
Tobacco River	5	12/89	LOW	▪ Cold Water Fishery-Trout ▪ Aquatic Life Support	▪ Siltation	▪ Agriculture ▪ Silviculture
Fortine Creek	32	3/91	LOW	▪ Cold Water Fishery-Trout ▪ Aquatic Life Support	▪ Other Habitat Alteration ▪ Siltation	▪ Agriculture ▪ Channelization ▪ Highway/Road/ Bridge Construction ▪ Silviculture
Lake Koocanusa	28850 acres	3/94	LOW	▪ Cold Water Fishery-Trout ▪ Aquatic Life Support	▪ Flow Alteration	▪ Dam Construction

Table 3- 7. Fisher Watershed – TDML

Name	**Estimated Length (mi.)**	**Assessment Date**	**TMDL Development Priority**	**Probable Impaired Uses**	**Probable Causes**	**Probable Sources**
Fisher River	47	11/91	LOW	▪ Aquatic Life Support ▪ Cold Water Fishery-Trout	▪ Nutrients ▪ Other Habitat Alterations ▪ Siltation ▪ Thermal Modifications	▪ Agriculture Channelizatio ▪ Removal of Riparian Vegetation ▪ Silviculture
Wolf Creek	29	11/91	LOW	▪ Cold Water Fishery-Trout ▪ Aquatic Life Support	▪ Nutrients ▪ Other Habitat Alterations ▪ Siltation ▪ Thermal Modifications	▪ Agriculture Channelizatio ▪ Removal of Riparian Vegetation ▪ Silviculture
Raven Creek	1	11/91	LOW	▪ Cold Water Fishery-Trout ▪ Aquatic Life Support	▪ Siltation ▪ Suspended Solids	▪ Silviculture

Table 3- 8. Yaak Watershed – TMDL

Name	Estimated Length (mi.)	Assessment Date	TMDL Development Priority	Probable Impaired Uses	Probable Causes	Probable Sources
Seventeen Mile Creek	12	12/90	LOW	▪ Cold Water Fishery-Trout	▪ Flow Alteration ▪ Other Habitat Alterations ▪ Siltation ▪ Suspended Solids	▪ Silviculture
Yaak River, East Fork	13	12/90	LOW	▪ Cold Water Fishery-Trout	▪ Flow Alteration ▪ Other Habitat Alterations ▪ Siltation ▪ Suspended Solids	▪ Silviculture
Yaak River, North Fork	5	12/90	LOW	▪ Cold Water Fishery-Trout	▪ Flow Alteration ▪ Other Habitat Alterations ▪ Siltation ▪ Suspended Solids	▪ Silviculture

Table 3- 8. Yaak Watershed – TMDL (cont.)

Name	Estimate Length (mi.)	Assessment Date	TMDL Development Priority	Probable Impaired Uses	Probable Causes	Probable Sources
Lap Creek	4	11/90	LOW	▪ Cold Water Fishery-Trout ▪ Aquatic Life Support	▪ Flow Alteration ▪ Other Habitat Alterations	▪ Harvesting ▪ Restoration ▪ Residue Management ▪ Logging Road Construction /Maintenance ▪ Silviculture
Spread Creek	10	12/90	LOW	▪ Cold Water Fishery-Trout	▪ Flow Alteration ▪ Other Habitat Alterations ▪ Siltation ▪ Suspended Solids	▪ Silviculture
Pete Creek	10	12/90	LOW	▪ Cold Water Fishery-Trout	▪ Flow Alteration ▪ Other Habitat Alterations ▪ Siltation ▪ Suspended Solids	▪ Silviculture

Table 3- 8. Yaak Watershed – TMDL (cont.)

Name	Estimate Length (mi.)	Assessment Date	TMDL Development Priority	Probable Impaired Uses	Probable Causes	Probable Sources
Yaak River, South Fork	12	12/90	LOW	▪ Cold Water Fishery-Trout	▪ Flow Alteration ▪ Other Habitat Alterations ▪ Siltation ▪ Suspended Solids	▪ Silviculture
Yaak River, West Fork	20	12/90	LOW	▪ Cold Water Fishery-Trout	▪ Flow Alteration ▪ Other Habitat Alterations ▪ Siltation ▪ Suspended Solids	▪ Silviculture

Table 3- 9. Lower Kootenai Watershed - Watershed Health Index

Condition Indicators	
Designated Use Attainment	More Serious
Fish & Wildlife Consumption Advisories	Insufficient Data
Source Water Condition	Better
Contaminated Sediments	Better
Ambient Water Quality – Four Toxic Pollutants	Insufficient Data
Ambient Water Quality – Four Conventional Pollutants	Better
Wetland Loss Index	Less Serious
Vulnerability Indicators	
Aquatic Species at Risk	Moderate
Toxic Loads Over Permitted Limits	Insufficient Data
Conventional Loads Over Permitted Limits	Insufficient Data
Urban Runoff Potential	Low
Index of Agricultural Runoff Potential	Moderate
Population Change	High
Hydrologic Modification	Insufficient Data
Estuarine Pollution Susceptibility Index	Insufficient Data

Table 3- 10. Moyie Watershed - Watershed Health Index

Condition Indicators	
Designated Use Attainment	More Serious
Fish & Wildlife Consumption Advisories	Insufficient Data
Source Water Condition	Better
Contaminated Sediments	Insufficient Data
Ambient Water Quality – Four Toxic Pollutants	Insufficient Data
Ambient Water Quality – Four Conventional Pollutants	Insufficient Data
Wetland Loss Index	Less Serious
Vulnerability Indicators	
Aquatic Species at Risk	Moderate
Toxic Loads Over Permitted Limits	Insufficient Data
Conventional Loads Over Permitted Limits	Insufficient Data
Urban Runoff Potential	Low
Index of Agricultural Runoff Potential	Low
Population Change	High
Hydrologic Modification	Low
Estuarine Pollution Susceptibility Index	Insufficient Data

Table 3- 11. Summary of Active USGS Monitoring Stations in Idaho HUCs of the Kootenai River Basin

HUC & Name	HUC Area (mi^2)	USGS Monitoring Station History	Active USGS Monitoring Stations Number & Name	Station Drainage Area (mi^2)	1997 Station Discharge (cfs)
17010104 Lower Kootenai	869.59	21 Discontinued 4 Active	12305000 Kootenai River @ Leonia, ID	11,740	Max. 48,200 Min. 5,210
			12309500 Kootenai River @ Bonners Ferry, ID	13,000	N/A
			12322000 Kootenai River @ Porthill, ID	13,700	Max. 61,400 Min. 5,640
			12321500 Boundary Creek near Porthill, ID	97	Max. 3,780 Min. 24
17010105 Moyie	207.90	1 Discontinued 1 Active	12306500 Moyie River @ Eastport, ID	570	Max. 8,890 Min. 65

(US EPA, 1998; USGS, 1998a; USGS, 1998b)

Table 3- 12. Bull Trout Habitat Information for the Idaho Segment of the Kootenai River Basin

Watershed	HUC	Bull Trout Distribution		Area Sub-Watershed	Average Annual	Mean Annual Estimated
		Historic (Prior to 1985)	Current (Since 1985)	(mi²)	Precipitation (in/yr)	Stream Flow (cfs)
Kootenai River		P	SAR			
Callahan Creek		P	SER			
Star Creek		U	U			
Boulder Creek	1701010407	U	SNF	63.3	51	169.0
E. Fork Boulder Creek	170101040707	U	SNP	15.5	61	52.3
Boulder Creek above E. Fork	170101040709	U	SNP	31.9	52	89.7
Curly Creek	17010104051800	P	SSR	11.4	32	21.4
Moyie River	17010105	P	SAR	204.8	37	380
American Creek	170101050208	U	U	12.8	41	30.2
Canuck Creek	170101050205	U	U	15.0	38	32.5
Spruce Creek	17010105020030	U	SNF	7.6	35	15.7
Round Prairie Creek	170101050201	U	SNF	37.5	38	77.3
Meadow Creek	170101050104	U	SNF	24.3	38	51.3
Placer Creek	17010105010209	U	SNF	3.9	35	8.2

Table 3-12. Bull Trout Habitat Information for the Idaho Segment of the Kootenai River Basin (cont.)

Watershed	HUC	Bull Trout Distribution		Area Sub-Watershed	Average Annual Precipitation	Mean Annual Estimated Stream Flow
		Historic (Prior to 1985)	Current (Since 1985)	(mi²)	(in/yr)	(cfs)
Deer Creek	170101050106	P	SSR	30.8	37	62.5
Skin Creek	17010105010209	U	U	10.2	34	20.1
Cow Creek	17010104054200	U	U	11.4	31	20.2
Fry Creek	1701010404	U	U	50.8	25	70.8
Deep Creek	1701010408	P	SSR	184.0	36	336.1
Dodge Creek	1701010408070720	U	SNF	11.5	35	23.3
Trail Creek	17010104080705	U	SNF	16.2	36	33.3
Fall Creek	17010104080709	U	SSR	22.2	37	46.0
Ruby Creek	170101040809	U	SNF	14.9	38	31.8
Twenty Mile Creek	17010104080507	U	SNF	10.0	37	21.2
Brown Creek	170101040805	U	U	25.6	33	46.8
Caribou Creek	170101040810	P	SSR	13.1	45	33.1
Snow Creek	170101040812	P	SSR	17.9	45	44.7
Myrtle Creek	1701010409	P	SSR	42.9	41	95.3
Ball Creek	1701010410	U	SNF	26.8	47	69.1
Fleming Creek	170101040310	U	U	18.6	26	27.3
Rock Creek	170101040301	P	SSR	16.4	29	27.5
Trout Creek	170101040214	P	SSR	19.5	46	50.4
Mission Creek	170101040203	U	SNF	30.9	34	58.1

Table 3-12. Bull Trout Habitat Information for the Idaho Segment of the Kootenai River Basin (cont.)

Watershed	HUC	Bull Trout Distribution		Area Sub-Watershed	Average Annual Precipitation	Mean Annual Estimated Stream Flow
		Historic (Prior to 1985)	Current (Since 1985)	(mi²)	(in/yr)	(cfs)
Parker Creek	170101040110	P	SSR	16.4	45	41.8
Long Canyon Creek	1701010411	P	SSR	30.3	46	76.3
Smith Creek	1701010412	U	SNF	71.6	51	188.7
Smith Creek above Cow Creek	17010104120111	U	SNP	30.7	53	88.7
Cow Creek	17010104120113	U	SNP	21.9	55	66.7
Boundary Creek	1701010414	P	SSR	94.6	53	256.1
Boundary Creek above Blue Joe	170101041415	P	SSR	10.5	49	29.7
Blue Joe Creek	170101041412	U	SNF	10.7	55	33.5
Grass Creek	170101041409	U	SNF	27.4	58	86.6
Saddle Creek	170101041405	U	U	10.3	58	33.9
Kootenai Drainage in Idaho	17010104, 17010105			1081	39	1975

(Panhandle Basin Bull Trout Technical Advisory Team, 1998)

Notes:
SER = spawning/early rearing
SSR = suspected spawning/rearing
SAR = sub adult & adult rearing
SNF = surveyed; not found
SNP = suspected not present
P = historically present
U = unknown

Table 3- 13. Physical Characteristics of Idaho Segments of the Kootenai River Basin

Watershed	HUC	Watershed Portion w/ Highly Erodible Soils %	Watershed Portion in Rain-on-Snow Sensitive Zone %	Road Density mi/mi^2	Riparian Roads to Riparian Area mi/mi^2	Road Crossing per Mile of Stream	Portion of Watershed in Hydrologic Openings %	Portion of Riparian Area in Hydrologic Openings %	Logged Portion of watershed %
Kootenai River									
Callahan Creek									
Star Creek									
Boulder Creek	1701010407	32	39	2.0	2.1	0.6	7	5	12
E. Fork Boulder Creek	170101040707	23	38	1.3	1.0	0.2	8	5	16
Boulder Creek above E. Fork	170101040709	37	35	2.1	2.7	0.8	7	5	6
Curly Creek	17010104051800	21	17	unknown	unknown	unknown	unknown	unknown	unknown
Moyie River	17010105	26	34	3.8	4.5	0.9	13	11	23
American Creek	170101050208	34	2	2.7	3.5	1.1	21	19	1
Canuck Creek	170101050205	23	7	5.4	6.0	1.3	33	37	16
Spruce Creek	17010105020030	20	23	3.5	3.9	0.8	14	12	26
Round Prairie Creek	170101050201	28	37	3.2	3.9	0.6	10	6	26
Meadow Creek	170101050104	19	60	3.4	3.8	0.7	13	11	24
Placer Creek	17010105010209	17	59	4.9	7.1	1.1	17	22	28
Deer Creek	170101050106	22	36	4.0	5.1	1.1	10	10	12
Skin Creek	17010105010209	20	32	4.3	7.2	1.1	9	7	6
Cow Creek	17010104054200	26	10	unknown	unknown	unknown	unknown	unknown	unknown
Fry Creek	1701010404	71	10	1.4	1.8	0.1	2	2	2

Table 3-13. Physical Characteristics of Idaho Segments of the Kootenai River Basin (cont.)

Watershed	HUC	Watershed Portion w/ Highly Erodible Soils %	Watershed Portion in Rain-on-Snow Sensitive Zone %	Road Density mi/mi^2	Riparian Roads to Riparian Area mi/mi^2	Road Crossing per Mile of Stream	Portion of Watershed in Hydrologic Openings %	Portion of Riparian Area in Hydrologic Openings %	Logged Portion of watershed %
Deep Creek	1701010408	25	37	3.4	4.0	0.4	6	5	5
Dodge Creek	1701010408070720	25	52	1.5	1.2	0.0	0	0	0
Trail Creek	17010104080705	28	62	4.8	5.8	0.8	4	4	5
Fall Creek	17010104080709	18	46	3.8	3.5	0.5	12	6	0
Ruby Creek	170101040809	17	46	2.9	4.0	0.3	9	4	0
Twenty Mile Creek	17010104080507	45	46	5.6	5.4	1.1	6	8	15
Brown Creek	170101040805	36	31	4.2	5.5	0.6	3	3	10
Caribou Creek	170101040810	19	36	2.8	3.4	0.6	23	8	3
Snow Creek	170101040812	21	41	3.2	3.9	0.8	14	21	24
Myrtle Creek	1701010409	28	28	2.6	3.3	0.8	10	6	3
Ball Creek	1701010410	29	19	1.8	3.0	0.7	13	15	8
Fleming Creek	170101040310	79	9	1.0	0.8	0.0	1	0	2
Rock Creek	170101040301	47	32	1.8	1.2	0.1	10	6	19
Trout Creek	170101040214	24	15	1.4	3.5	0.7	7	15	7
Mission Creek	170101040203	48	31	3.4	5.4	0.4	11	11	15
Parker Creek	170101040110	30	12	0.0	0.0	0.0	22	13	0
Long Canyon Creek	1701010411	22	18	0.0	0.0	0.0	10	2	0
Smith Creek	1701010412	23	24	1.7	2.8	0.5	22	20	8
Smith Creek above Cow Creek	17010104120111	25	18	1.0	2.4	0.4	4	8	2
Cow Creek	17010104120113	21	20	2.3	3.8	0.7	54	45	11
Boundary Creek	1701010414	22	16	2.3	2.6	0.5	14	11	23

Table 3-13. Physical Characteristics of Idaho Segments of the Kootenai River Basin (cont.)

Watershed	HUC	Watershed Portion w/ Highly Erodible Soils %	Watershed Portion in Rain-on-Snow Sensitive Zone %	Road Density mi/mi^2	Riparian Roads to Riparian Area mi/mi^2	Road Crossing per Mile of Stream	Portion of Watershed in Hydrologic Openings %	Portion of Riparian Area in Hydrologic Openings %	Logged Portion of watershed %
Boundary Creek above Blue Joe	170101041415	31	7	0.4	0.4	0.1	6	10	14
Blue Joe Creek	170101041412	30	13	2.9	3.8	1.0	18	9	35
Grass Creek	170101041409	21	16	3.7	3.3	0.7	23	16	37
Saddle Creek	170101041405	16	13	3.3	3.0	0.4	17	8	32

(Panhandle Basin Bull Trout Technical Advisory Team, 1998)

Table 3- 14. Kootenai River Basin Idaho Listed Limited Water Quality Segments

HUC & Name	HUC Area (mi^2)	Listed Limited Water Quality Segments (303(d))	Permitted Discharge Sources & Percent Landscape Types
17010104 Lower Kootenai	869.59	▪ Boulder Creek – Headwaters to Kootenai River – 16.60 mi Pollutants: sediment ▪ Deep Creek – McArthur L. to Kootenai River - 19.53 mi Pollutants: sediment ▪ Caribou Creek – Headwaters to Snow Creek – 9.92 mi Pollutants: sediment ▪ Blue Joe Creek – Headwaters to Canadian border – 6.38 mi Pollutants: metals, unknown pH, sediment ▪ Cow Creek – Headwaters to Smith Creek – 7.97 mi Pollutants: sediment	Permitted Discharge Sources: ▪ City of Bonners Ferry - Sewer Lagoon ▪ City of Bonners Ferry - Water Treatment ▪ Burlington Northern - Multisector Storm Water Discharge ▪ Crown Pacific - Multisector Storm Water Discharge Land Use Types: ▪ Urban – 0 percent ▪ Forest – 95 percent ▪ Crops – 5 percent
17010105 Moyie	207.9	Moyie River – Moyie Falls dam to Kootenai River – 1.64 mi Pollutants: sediment	Land Use Types: ▪ Urban – 0 percent ▪ Forest – 100 percent ▪ Crops – 0 percent

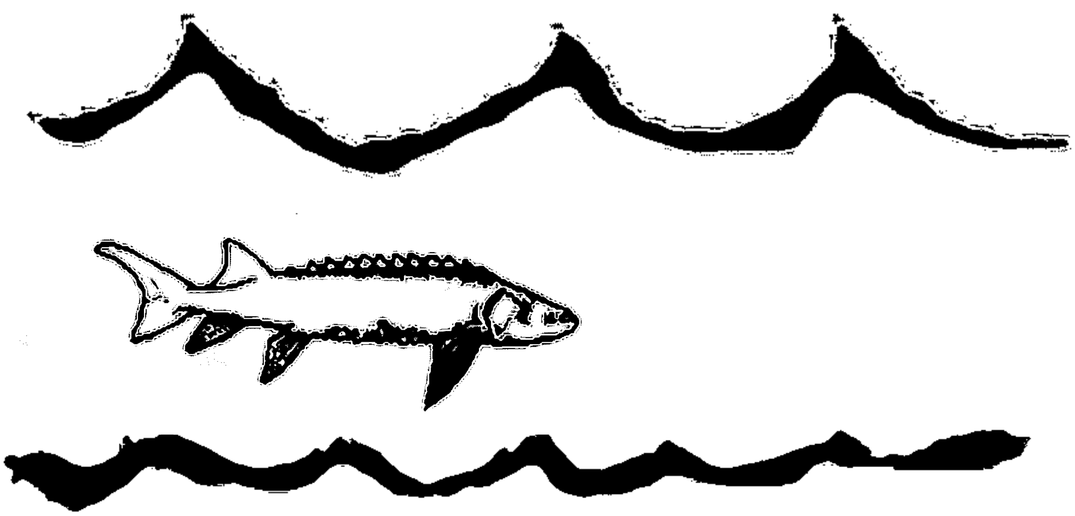
(Idaho DEQ, 1999)

Table 3- 15. Kootenai River Basin Idaho Water Bodies Proposed for Delisting from the 1996 303(d) List

HUC & Name	Water Bodies Proposed for Delisting from the 1996 303(d) List
17010104 **LOWER KOOTENAI**	Snow Creek – Headwaters to Deep Creek Twenty Mile Creek – Headwaters to Deep Creek Boundary Creek – Gauging Station to Canadian Border Boundary Creek – Headwaters to Gauging Station
17010105 Moyie	Canuck Creek – Canadian Border to Montana line Deer Creek – Headwaters to Moyie River Meadow Creek – Headwaters to Moyie River East Fork Meadow Creek – Headwaters to Meadow Creek Wall Creek – Headwaters to Meadow Creek

(Idaho DEQ, 1999)

SECTION 4.0
MONITORING STRATEGY



4.0 MONITORING STRATEGY

4.1 Introduction

A comprehensive review of the scientific and "gray" literature (here defined as non-peer, non-anonymous, reviewed studies/research typically conducted by government and industry scientists, which generally consists of limited publication runs and circulation) reveals that in the past decade, and especially in the past 5 years, problems with water quality databases and significant drawbacks in current monitoring regimens have resulted in planners and researchers rethinking the functional basis of their design procedures. In developed nations, with a 20-year history of water quality monitoring programs, there has been a serious attempt to reassess and redesign the programs and networks.

In a recent publication—*Assessment of Water Quality Monitoring Networks: Design and Redesign*— (NATO, 1998) senior water quality scientists from six countries have spent the past 3 years reevaluating how best, in these times of declining public support for science and shrinking financial resources, to develop efficient and affordable water quality monitoring networks that can provide the information crucial to make wise management decisions in both the short term and in the long term concerning how to best protect, preserve and restore the world's diminishing freshwater resources. The excerpt below is from the introduction to the NATO (1998) document, which clearly and concisely defines the central problem enunciated in much of the current literature.

> *...the major problem is that there are no universally confirmed guidelines to follow in the assessment and design of water quality monitoring networks. Upon this need, (a) significant amount of research has been initiated to evaluate current design procedures and investigate effective means of improving the efficiency of existing networks (Ward et al., 1990; Chapman, 1992; Harmancioglu et al., 1992; Adriaanse et al., 1995; Ward, 1996; Timmerman et al., 1996; Niederlander et al., 1996; Dixon and Chiswell, 1996).*

The following section is designed to be a review of the current literature largely, but not exclusively, post-1990, to examine the state of the present knowledge concerning water quality monitoring programs and networks. The subsequent sections have borrowed from numerous sources, and have resulted from extensive discussions with a number of colleagues, especially Dr. M.J.R. Clark (Senior Scientist; BC MELP), and from the NATO (1998) document noted above. This work represents one of the most comprehensive and thorough treatments of many of the issues described below and we hereby acknowledge our debt to both this document and Dr. Clark, one of its primary authors.

4.2 Definition of Water Quality Monitoring

Water quality monitoring comprises all sampling activities to collect and process data on water quality for the purpose of obtaining information about the physical, biological and chemical properties of water. Besides collecting data, monitoring activities cover the subsequent procedures, such as laboratory analyses, data processing and data analyses to produce the expected information. These procedures essentially are the basic steps of a data management system (Harmancioglu et al., 1998).

Water quality monitoring practices basically are designed to achieve special purposes that lead to various types of monitoring, i.e., trend monitoring, biological monitoring, ecological monitoring, compliance monitoring, etc. Among these types, collection of data to assure compliance with standards probably has been the oldest practice. In the past, these activities were carried out in a problem, project or user-oriented framework. Recently, however, as the emphasis is shifted more to water quality management and control efforts in a larger perspective, the major concern has become the assessment of the quality of surface waters in a wide area or a river basin. In achieving this specific purpose, trend monitoring is required to evaluate both changing quality conditions and the results of control measures.

One of the developments in the late 1980s with respect to the types of monitoring is that sampling for stream standard violations has gradually been replaced by effluent sampling. This is due to the inadequacies of the former in realistically detecting possible violations (Sanders et al., 1983). Compliance monitoring can be most efficiently realized only by means of continuous sampling, which in most cases is costly. On the other hand, intermittent sampling poses some difficulties in detecting what is a true violation and what is not, in addition to uncertainties in pinpointing the possible violators (Sanders et al., 1983). Under these conditions, the preference goes for effluent monitoring rather than for in-stream monitoring when the concern is compliance with standards. This also is a change in favor of trend monitoring because it enables the assessment of both prevailing and/or changing water quality conditions and the effectiveness of control measures. In fact, some researchers have claimed that the basic function of monitoring is to determine long-term trends in water quality once compliance is assured by effluent monitoring.

In some studies, two basic functions are defined for water quality monitoring: 1) prevention and 2) abatement (NATO, 1998). The first has the objective of maintaining the existing unpolluted or acceptable status of water quality, while the second puts the emphasis on a control mechanism by reducing or moderating pollution conditions. Prevention foresees the enforcement of effluent standards and, therefore, requires effluent monitoring plus trend monitoring. For abatement, compliance with in-stream standards is significant so that compliance monitoring has the highest priority among other types of monitoring.

Water quality monitoring is a process of temporal sampling, in an aquatic habitat, which is affected by random events, seasonal changes and serial correlations (Whitfield, 1988).

The majority of monitoring programs has resulted in collections of a limited number of samples, obtained at infrequent intervals, usually over irregular periods. The data profiles from such programs frequently do not reliably represent the aquatic habitat being sampled. Although water quality monitoring has increasingly become subjected to numerous statistical assessments, in the absence of a carefully crafted program of focused goals and data collection designs, such programs have minimal chance of detecting anything other than catastrophic change. Successful monitoring must be designed to link a clearly defined purpose for conducting the monitoring with the management of water quality—usable data must be convertible into useable information.

One of the principal concerns in designing water quality monitoring and water quality management programs has been the variable definition used by professionals. One definition, which has been used repeatedly in the literature, is that noted in Ward et al. (1986)—" water quality monitoring can be defined as any effort by government or private enterprise to obtain an understanding of the physical, chemical and biological characteristics of water via statistical sampling." This definition encompasses both routine (ongoing) and special survey (one of) programs conducted in support of water quality management—an essential element in effective management.

Unfortunately, the term can have many meanings. Water quality management can be the design, construction, operation and maintenance of wastewater treatment plants (sanitary engineer); or it can be basin planning, regional planning, planning for a specific treatment plant design, or planning for programs to control the quality of water. Water quality monitoring can be estimates of biota, diversity, community structure or function to a biologist; or it can be the variables in selected attributes used to establish standards or objectives to a lawyer. The statistician may see monitoring as a statistical estimate of an immeasurable population; the hydrologist often views water quality as flow-related processes. Thus, there is no widespread agreement on what constitutes effective water quality management or on how monitoring should support it; even the term "quality" is itself ambiguous (Ward et al., 1986). The literature does not yet provide clear understandings of the relationship and linkages between management and monitoring.

Successful monitoring programs are based on clearly defined objectives and goals within a broader strategy that has both a conceptual framework for collecting the data—the purpose for which the monitoring is being done—and a practical rationale for site-specific designations. The purpose of the monitoring must be linked to the management of a specific water body's quality. Data collection design on a site-by-site basis should have five essential elements (Whitfield, 1988), as follows:

1. Establishment of a monitoring goal, where each individual goal requires a) a sampling strategy, b) a data review strategy and c) an optimization strategy
2. Selection of a sampling strategy to meet the monitoring goal
3. Periodic review of adequacy of sampling including quality control studies
4. Optimization of sampling related to the goal over time
5. Review of adequacy of monitoring goal.

The monitoring framework is designed to address a specific goal of each monitoring program; specifically, what is being measured and why. Since the data being gathered must be converted into information to answer a specific water quality management problem or need, it is essential that the information required be identified before undertaking the monitoring. The numbers of reasons for conducting water quality monitoring are numerous and include the following:

- Assessment of trends in variables of concern
- Compliance with objectives or standards
- Estimation of mass transport
- Assessment of environmental impact
- General surveillance.

An examination of the published literature, and especially the gray literature, reveals that the vast majority of monitoring data has not been obtained on the basis of *apriori* defined goals and/or specific objectives (Ward et al., 1986). Ward et al. (1990) have codified the steps essential to the design of any generic water quality monitoring system. These steps appear below.

Step 1. Evaluate information expectations
a. Water quality goals
b. Water quality problems
c. Management goals and strategy
d. Monitoring role in management
e. Monitoring goals (as statistical hypotheses)

Step 2. Establish statistical design criteria
a. Statistically characterize population to be sampled
b. Variation in quality
c. Seasonal impacts
d. Correlations present (independence)
e. Applicable probability distributions
f. From many statistical tests, select most appropriate (match test requirements to population characteristics)

Step 3. Design monitoring network
a. Where to sample (from monitoring role in management)
b. What to measure (from water quality goals and problems)
c. How frequently to sample (from needs of statistical tests)

Step 4. Develop operating plans and procedures
a. Training of sampling technicians
b. Sampling routes
c. Field sampling and analysis procedures
d. Sample preservation and transportation
e. Laboratory analysis procedures

f. Quality assurance/control procedures
g. Data storage and retrieval hardware and database management systems
h. Data analysis software

Step 5. Develop information reporting procedures
a. Type of format of reports
b. Frequency of report publications
c. Distribution of reports (information)
d. Evaluation of report ability to meet initial information expectations

A review of both the scientific and gray literature reveals that there is a lack of agreement in what constitutes management's goal of protecting water quality; in fact, much of the legislation pertaining to management's role is ambiguous and contains conflicting objectives. Some managers perceive that their primary responsibility in achieving their water quality goal is to "maintain or improve water quality," where others believe they have been charged by society to "promote conservation and best use of natural water" (Ward et al., 1986). Frequently the terms "water quality" and "conservation" are not carefully defined, which further exacerbates the ambiguity inherent in defining management goals. As Ward et al. (1986) note, "an evaluation of the monitoring system design criteria required to support (the two management goals described above)…can greatly influence the design of a national (or international) monitoring system." Where elucidating one preeminent goal is not possible, it may be desirable to identify regional goals or dual monitoring systems. Whitfield (1988) identified that for each water quality monitoring goal, goal-specific strategies might be required and where there exist multiple goals at one site, strategies must be developed for achieving multiple goals. Table 4-1 outlines the implications of alternative goals for design and operation of a routine water quality monitoring program.

The authors of the NATO (1998) assessment of water quality monitoring networks note that

> *…the majority of developed countries have already started to redesign their networks. However, generally accepted guidelines do not exist on how the redesign process should be addressed. A multilateral project, supported by NATO International Scientific Exchange Programs in the form of a Linkage Grant project, was initiated in 1995 by research teams from six countries (Turkey, USA, Canada, Italy, Hungary, and Russia) to focus on the development of rules for network assessment and redesign. The purpose of the project has been to identify the basic guidelines of network design that may be followed by both developed countries in their redesign process and the developing countries in their efforts for initiating and expanding their monitoring practice. The methodology investigated has the potential for application to design and assessment of other types of networks, including air pollution, stream gauging, rainfall and soil moisture networks.*

The basic approach adopted in the project is that water quality monitoring should be evaluated within an integrated data management system. The process of data collection involves a number of activities that include not only the design of monitoring systems, but also physical sampling, data processing, data storage, data analysis and dissemination of information. Although the current state of technology has produced sophisticated means of handling each activity, there are still problems encountered in production of information from such a system. Accordingly, each research team participating in the Linkage Grant project was assigned a particular task to identify basic problems and needs relevant to each activity. These tasks comprise the following:

- Identification of information needs and setting of realistic goals
- Investigations of driving and modifying forces
- Identification of sources of noise
- Selection of proper sampling methods
- Statistical analysis of data
- Selecting and deciding on monitoring strategies as they relate to data quality
- Setting of operational rules.

The conclusions and recommendations resulting from the above research tasks essentially set the framework for general guidelines to be followed in the network assessment and redesign. An important feature of the work is that it merges both the theoretical and practical aspects of the problem.

The authors identify a number of aspects of water quality monitoring network design that can be characterized within a set of general constructs common to all such programs. These are as follows:

- An overview of the current status of water quality monitoring practices
- Shortcomings of current practices in contrast to requirements imposed on monitoring networks by various international programs, institutions and agreements
- Objectives, outline of tasks and basic approaches recommended for new or redesigned monitoring networks
- Definition of monitoring objectives
- Theoretical background and knowledge crucial to network design
- Observational and data collecting options
- Statistical tools in network assessment and design
- Network assessment procedures
- Database management.

4.3 Complexity of Water Quality Monitoring

Whatever the specific purpose of monitoring may be, it must first be recognized that water quality monitoring is a highly complex issue. Apart from technical features of monitoring, this complexity may be attributed to two factors: 1) uncertainties in the nature of water quality and 2) uncertainties in delineating a specific purpose for monitoring.

Uncertainties in the nature of water quality are due to the two fundamental mechanisms underlying these processes: 1) the natural hydrologic cycle and 2) man-made effects, which often are referred to as the "impact of society." The laws of chance affect both of these mechanisms, particularly the first one, so that water quality has to be recognized as a random process by nature (Sanders et al., 1983). Monitoring activities, then, are required to reflect the stochastic nature of water quality to efficiently produce the expected information. This is why most researchers like Sanders et al. (1983) specify the term "monitoring" further to mean "statistical sampling."

4.4 Significance of Water Quality Monitoring

As complex as it is, water quality monitoring also is highly significant because it is our only means of being informed about water quality. Thus, monitoring constitutes the link between the actual process and our understanding, interpretation and assessment of the highly complex phenomena. Therefore, water quality monitoring is the most crucial activity on man's side with respect to all management and control efforts.

This is a statement that holds true even today. According to Ward et al., 1990, our understanding of environmental processes and problems evolves quite rapidly, whereas monitoring systems develop at a slower pace, often becoming out of date with respect to recently emerging issues and purposes of water quality assessment. On the other hand, the decision-making process in water quality management is highly sensitive to the reliability and accuracy of available data. Unreliable data further the misinterpretation of the information they convey and may lead to wrong decisions. This situation apparently is worse than taking no action at all. In such a case, “the underlying data can be said to have a negative economic value” (Moss et al., 1985).

4.5 Water Quality Monitoring Networks

Assessment of water quality conditions over a wide area (such as a river basin) with respect to time and space requires the monitoring activities to be carried out in a network. A monitoring network comprises a number of sampling sites that collect data on particular water quality variables at selected time intervals. At this point, one has to distinguish between the terms "monitoring" and "network.” The former refers to the actual sampling process at a site, whereas the latter describes a number of monitoring stations at selected sites that operate in coordination with each other. Such coordination is realized by the selection of appropriate sampling sites, sampling frequencies and variables to be sampled. Therefore, monitoring a number of variables at random points with random time intervals does not constitute a network unless this coordination is established.

To be more specific, a network is a family of systematically operated monitoring stations, which, as a whole, represent the water quality conditions over a wide area. The systematic (or coordinated) operation of the network is realized by the selection of three basic factors: 1) sampling sites, 2) sampling frequencies and 3) variables to be sampled. Thus, network design covers basically the determination of these factors to produce the required information. Other components of monitoring, i.e., laboratory analyses, data processing and data analysis procedures, have to be evaluated as the subsequent steps of the network design problem and are essential components of information production.

4.5.1 Existing Networks—Background. Water quality observations date back almost 100 years. The need for systematic measurements, however, has only recently become eminent as a result of the recognition of water quality as a hydrologic process, the increased concern over water quality and, therefore, the demand for a better understanding of the process.

Regular observations coupled with necessary laboratory analyses were then started basically with a problem- or project-oriented approach to collect data as needed and where needed. These early attempts at monitoring water quality were by no means considered in connection with regular hydrologic networks. Several variables were observed at a large number of sites, but with temporal frequencies as low as four samples per site per year. Later, as the need arose for more data, the frequency of sampling has been increased to at least monthly and finally to daily observations.

The information needs of water quality variables are much more diverse than in the case of other hydrometeorological variables. For example, if one inquires about the quantity of water at a certain time and space along a river, the expected reply will be a single value to represent the discharge. However, the answer to the question "what is the quality of water" has to include the outcomes of several variables so that one has to deal with a "vector" of variables instead of a "single" discharge variable. Sanders et al. (1983) point out that "several hundred variables have already been identified that may be of interest to different users in a comprehensive description of water quality processes." Thus, in general, hydrological data network design is a fairly complicated issue and, in particular for water quality, it becomes more complex due to the nature of information needs on water quality processes.

4.5.2 Networks in Developed Countries. Several agencies in developed countries have established data networks to assess the quality of their surface waters. In the US, the USGS and the US EPA are the two institutions that have developed nationwide networks of fixed water quality stations on its major rivers. Apart from these two major networks, many states run fixed station water quality data collection networks (Lettenmaier, 1976). Similar institutions in other countries routinely collect water quality data at fixed stations, such as the Canadian Department of Environment (CDOE). Australia has developed networks to monitor and control water quality in streams and storages. For example, the existing network in Queensland dates back to the l960s and currently involves 400 sampling points. However, due to various inadequacies observed, the Water Resources Commission of Queensland recently has started to redesign the network to meet future needs. In European countries, similar activities are observed; however, monitoring practices on international rivers are of particular interest. Along these rivers, such as the Rhine, monitoring is realized in a river-based manner, with contributions from countries through which the river flows. Such practices are intensified when significant levels of pollution are observed. Equally important in developed countries are specific surveys carried out for a particular period of time. Often, these monitoring practices are problem- or project-oriented activities applied in polluted areas to measure the levels of particular effluents. For a more detailed review of current monitoring practices and recent trends in developed countries, refer to the extensive research report prepared by Harmancioglu et al., 1998.

One of the major problems in developed countries is the lack of coordination among monitoring agencies with respect to purposes of monitoring and activities involved in monitoring. Consequently, an overall perspective of the total monitoring system hardly can be preserved to evaluate the existing system or to add new objectives and activities. In the US, the local, state and federal governments have intensively emphasized the legal aspect of water quality management in recent years so that new objectives and methodologies for monitoring have developed. As a result, the evaluation of the total system becomes much more complicated since the new developments often lead to more sophisticated monitoring procedures. Furthermore, if each monitoring agency subscribes to a different perspective of goals and practices, this would eventually mean a proliferation of monitoring activities.

A natural consequence of the above-described situation is to have too much data. In fact, this appears to be the major problem in developing countries. Ward et al. (1986) express it as the "data-rich but information-poor syndrome in water quality monitoring." In early practices of water quality monitoring, every measurement was significant so that one could say "the more data the better." At those times, the problem was to conceive what available data showed about prevailing water quality conditions. Presently, the situation is reversed as new objectives have developed in water quality management. The question now is whether the available data convey information relevant to a certain objective. The failure of existing networks appears at this point. Monitoring activities have indeed become sophisticated with new methods and technologies. However, when it comes to using collected data, no matter how numerous they may be, often available samples fail to meet specific data requirements foreseen for the solution of a certain problem. In this case, the current monitoring practices may be described as being unsatisfactory. Yet the basic problem often is the failure to define before sampling what is expected from collecting data, rather than the failure of available data (Harmancioglu et al., 1998).

It appears that the basic problem in developed countries is the discrepancy between information expected from a monitoring network and the information produced by that network. That is, developed countries suffer from "data-rich but information-poor" networks. In view of the prevailing shortcomings, most developed countries have started assessment programs to evaluate the performance of existing networks. Within this framework, they also have begun to critically review their design methodologies and network assessment procedures. A significant output of these developments is the initiation of the redesign process, where the basic purpose of a monitoring network is considered to be the assessment of water quality trends on a basin-wide or even country-wide basis (Harmancioglu et al., 1998).

4.5.3 United States. In the US, water quality is monitored by several agencies at federal, state, regional and local levels. Among these are the USGS, US EPA, National Oceanic and Atmospheric Administration, U.S. Fish and Wildlife Service, Soil Conservation Service, U.S. Department of Agriculture Forest Service and others. Monitoring practices of state agencies differ from each other as water management strategies and regulations often are specific to each state. On the other hand, USGS and US EPA have developed nationwide networks.

As of 1984, USGS had 4,610 stations for monitoring lake and river water quality. Continuous monitoring has been applied at 784 of these stations, although types of variables monitored differ. There were 2,906 stations that monitored river water quality in a systematic framework with long-term programs. Wide ranges of variables are monitored including inorganic and organic constituents, trace elements, nutrients, pesticides and radioactive constituents. The sampling frequencies vary from daily to yearly. As of 1990, USGS has been cooperating with about 1,000 federal, state and regional agencies to monitor river water quantity and quality at 49,000 sites.

In 1973, the NASQAN (National Stream Quality Accounting Network) was initiated solely for water quality monitoring by including 50 of the above-mentioned 2,906 stations. The number of stations reached 516 in l978. The basic objectives of this network have been to provide informational basis for water quality management in the country, to determine the spatial variability of surface water quality across the continent, and to assess long-term trends in water quality. The specific feature of the NASQAN network is that it realizes a uniform monitoring practice across the country by observing the same variables at all stations with the same frequencies and the same sampling and analysis procedures. Such a practice permits comparisons among stations and regions. The sampling frequency at NASQAN stations varies from continuous to daily and monthly observations. On the other hand, recent assessments of the network have reflected certain deficiencies, e.g., incompatibility between information produced by the network and that required by data analysis and decision-making procedures. These deficiencies hindered the evaluation of the effects of various network modifications on monitoring objectives. Thus, USGS initiated the redesign of the network by adding to its objectives the requirements of consequent data analyses, particularly trend analyses.

Similar to NASQAN, US EPA runs the NWQSS (National Water Quality Surveillance System). This network included 200 stations with monthly sampling for the years between 1970-1981. Apart from NWQSS, EPA contributes to a significant amount of monitoring activities at state levels. The basic objective of EPA in monitoring water quality is to produce information for regulatory management, i.e., to assess compliance with state and federal standards.

Apart from USGS and EPA, several states run fixed water quality monitoring stations. Eventually, this practice resulted in several agencies monitoring the same river. Often, data from different agencies cannot be merged as they are incompatible in terms of sampling frequencies, variables monitored, sampling durations, units used and data reliability.

USGS and EPA also have developed national data banks called WATSTORE (National Water Data Storage and Retrieval System-USGS) and STORET. These two data banks comprise water quantity and quality data for both surface and ground waters. The data are made available to users in the form of tables, graphics and statistical analyses.

In 1976, USGS developed a more comprehensive data system called NAWDEX (National Water Data Exchange). WATSTORE, STORET and other data banks have been linked to this system via computer networking. The data bank WATDOC (Water Resources Document) of CDOE also has been connected to this system.

The US has developed and expanded its monitoring efforts within the last 20-30 years. From time to time, monitoring agencies have felt the need to assess the performance of their networks so they have started assessment programs at state and federal levels. Among these is the NAWQA (National Water Quality Assessment Program), which was initiated by USGS in 1986 as a pilot program in seven states. The program foresees the evaluation of surface water quality across the country to produce relevant information for water management, assessment of spatial and temporal trends in water quality, determination of monitoring needs by evaluating the performance of existing networks, and redesign and modification of existing networks with respect to specific information needs.

4.5.4 Canada. The CDOE is responsible for water quality management through its Water Quality Branch (WQB). WQB was initiated in 1970 to develop the scientific/technical basis for water quality management, and this basis foresaw the monitoring of major rivers in the country. In 1982, agreement was reached between provinces and the government to cooperate in monitoring activities.

The WQB considers major river basins as the basic monitoring units. Its objectives include the following:

- Development of an informational basis for water quality management
- Identification of trends in water quality
- Assessment of consequences of management decisions
- Assessment of consequences of water quality control efforts
- Development of an informational basis for revision of regulations.

The first and third objectives are served by fixed station networks and the others by specific survey stations. Thus, the first group stations constitute the Index Station Network, and the second group comprises the Recurrent River Basin Networks, which

are established on a basin scale. An ecosystem approach is adopted for selection of variables to be monitored in the two types of networks.
The WQB also has started the redesign of a National Reference Network, where the objectives of monitoring were reevaluated and network features redesigned as a result of basin studies based on advanced tools of modeling. In the meantime, the WQB also has developed a national data bank known as NAQUADAT (Canada's National Water Quality Data File, Water Survey of Canada, Ottawa).

4.6 Shortcomings of Current Monitoring Practices

Within the major problem of coordination between available data and objectives, others of a more specific nature may be cited. These difficulties are related to such questions as what to measure, where, when and for how long. In fact, these are the issues that cause the failure of available samples to meet data requirements (Harmancioglu et al., 1998).

First, the selection of water quality variables to be observed is a complicated issue since there are several variables from which to choose. Different approaches are used to handle this problem. In some cases, the chemical, physical and biological parameters of water quality that need to be observed are determined on the basis of various water uses (e.g., domestic, industrial, agricultural or multipurpose). Sometimes levels of monitoring efforts are defined to include different variables at each level. These levels may be surveillance, intensive control or project-oriented programs, respectively, in order of priority (Chapman, 1992). Another approach, more of a statistical character, is to investigate relationships between regularly observed water quality variables and those with a small number of sporadic observations to reduce the number of variables observed. Sanders et al. (1983) suggest ranking of water quantity and quality variables among which information may be transferred. In this ranking, water quantity appears as the basic variable followed by "associated quality variables of aggregated effects" (often regularly observed) and then by "quality variables that produce aggregated effects" (often unobserved or observed sporadically). If information transfer between the first and second group of variables is possible, the required number of variables to be observed may be reduced as long as there is no doubt as to the reliability of information transfer.

The next problem is the selection of temporal frequencies with which to observe quality variables. The major limitation of water quality data is that they often have short records. Worse is that there are gaps and missing data (Lettenmaier, 1976). Although some quality variables are regularly monitored, most of them are sampled sporadically for laboratory analyses. In this case, samples cover only a relatively short period of observations with many missing values. The situation is more serious when the variables are observed at highly unequal time intervals. The result is difficulty in the evaluation of available data for a reliable assessment of water quality conditions.

Another problem of prime importance is the selection of observation sites. This also is a controversial issue like the selection of sampling frequencies, although it has received the least attention. Early considerations on this matter led to problem-oriented selection procedures to detect the origin and levels of pollution at particular sites. Later, as new objectives of monitoring developed, several sites had to be observed. The basic problem with multisite monitoring is the realization of representative sampling. This means to select the sampling points in such a way that the river reach investigated is best represented by these sites. If this approach can be realized, then the variability of water quality along the reach may be assessed and information transfer among sites may effectively be carried out. However, most of the existing networks reflect shortcomings related to representative sampling.

The question of how long a station should run is another controversial issue. Station continuance is related basically to objectives of monitoring and information expectations from observed data. There are no definitive criteria established yet to decide whether monitoring should be continued or terminated at a particular site.

Other difficulties related to water quality data use are concerned with their reliability and accuracy. Water quality processes are strongly subject to non-homogeneities created by man while similar effects also occur naturally. Furthermore, some water quality variables can be easily monitored, yet some others require complex laboratory analyses. Errors in laboratory experimental analyses plus changes either in monitoring or laboratory practices may often lead to inconsistencies (systematic errors). Another problem is censored data, which occur when some concentrations are below detection limits and cannot be described numerically by laboratory practices. All these limiting factors eventually make the use of water quality data difficult. Furthermore, the reliability of the output information is poor. Chapman (1992) summarizes data limitations as follows:

- Missing values—these may occur due to equipment breakdowns, lost samples, contaminated samples, poor weather and employee illness; they may be random or systematic
- Sampling frequencies that change over the period of record—this limitation often occurs when monitoring agencies are faced with budget restrictions; shifting water quality problems or a new crisis also can cause this change
- Multiple observations within one sampling period—a common reason for this to occur in a water quality data record is when QA/QC results are stored in the same computer record as the original water quality observation
- Uncertainty in the measurement procedures—this uncertainty is due to random analytical errors; it varies with calibration of the measuring equipment
- Censored data—this problem becomes more complicated when the detection limit changes over the period of record; multiple censoring levels occur when different analytical techniques are used over the period of record, or when different laboratory protocols are used, or when data from different laboratories are analyzed as one data set
- Small sample sizes
- Outliers—these may be due to erroneous measurements or extreme events; it is difficult to differentiate between the two.

Recognition of data limitations during the design phase may help to minimize them; however, they often are recognized during the analysis of data.

The major problems associated with available water quality data are their incompleteness, inadequacy and lack of homogeneity. Much emphasis in water quality monitoring (physical, chemical and biological) has been put on sampling frequency and laboratory analyses, while the assessment and interpretation of available data have not developed at the same rate.

Further shortcomings related to water quality data also may be noted. In most cases, available data do not reflect a sufficient spatial coverage. A general deficiency is the lack of measurement of sampling errors, and data validation is overlooked. There are further problems in data presentation. Data may be available in incompatible formats; often, different disciplines involved in data collection and processing use different jargons. In general, data reporting is poorly realized with no reference given to the specifications of particular variables measured. Similarly, methodologies used in laboratory measurements are not indicated.

The above-mentioned shortcomings of existing networks in developed and the developing countries may be summarized as follows:

- Lack of coordination among various agencies running different networks
- Lack of agreement between collected data and water quality management objectives, resulting in "data-rich, information-poor" monitoring practices
- Problems related to
  --Selection of variables to be observed
  --Selection of sampling techniques
  --Selection of sampling sites
  --How long monitoring of certain variables at certain sites should be continued
- Lack of reliable and accurate data (messy data)
- Deficiencies in data presentation and reporting.

4.7 Current Methods in the Design of Water Quality Monitoring Networks

4.7.1 Review of the General Approach. As discussed in the previous sections, problems observed with available data and shortcomings of current networks have led researchers to focus more critically on the design methodologies used. In addition, recent advances in sampling and analysis techniques for water quality also have led to expansion of networks and thus to a growth in economic features of monitoring. Accordingly, researchers have started to question both the efficiency and the cost effectiveness of existing networks with regard to design methodologies used.

The first data collection procedures for water quantity foresaw the gauging of major streams at potential sites for water resources developments. The approach in initiating water quality observations has been practically similar, namely to collect data at potential sites for pollution problems. Thus, the early water quality monitoring practices were often restricted to what may be called "problem areas," covering limited periods of time and a limited number of variables to be observed. Recently, however, water quality-related problems have intensified so that the information expectations to assess the quality of surface waters also have increased. The result has been an expansion of monitoring activities to include more observational sites and a larger number of variables to be sampled at smaller time intervals. These efforts have indeed produced plenty of data, yet they also have led to the "data-rich, information-poor" networks as information expectations have not always been met.

The above considerations eventually led to the realization that a more systematic approach to monitoring is required. Following up on this need, monitoring agencies and researchers have proposed and used various network design procedures either to set up a network or to evaluate and revise an existing one.

Current methods of water quality monitoring network design basically cover two steps: 1) the description of design considerations and 2) the actual design process itself. Researchers emphasize the proper delineation of design considerations as an essential step before attempting the technical design of the network. This step is to provide answers to the questions of why we monitor and what information we expect from sampling water quality. In other words, objectives of monitoring and information expectations for each objective must be specified first. Various objectives or goals for monitoring have been proposed to date by different researchers, i.e., assessment of trends, delineation of water quality characteristics for water use, assessment of compliance, evaluation of water quality control measures, etc. (Whitfield, 1988; Ward et al., 1986; Sanders et al., 1983). In practice, the definition of objectives is not an easy task since it requires the consideration of several factors including social, legal, economic, political, administrative and operational aspects of monitoring goals and practices. Therefore, the delineation of design considerations inevitably includes assumptions and subjective views of the designers and decision makers no matter how objectively the problem is approached. In this case, design considerations often are presented as general guidelines rather than fixed rules to be pursued in the second step of the actual design process (Sanders et al., 1983).

The technical design of monitoring networks relates to the determination of the following:

- Sampling sites
- Sampling frequencies
- Variables to be sampled
- The period or duration of sampling.

Three groups of variables that have frequently been cited in the literature as worthy of being sampled are as follows:

- Base variables to be monitored at every station

- Variables that need to be monitored with respect to water use
- Variables that need to be monitored with respect to impact assessment.

Harmancioglu et al. (1998) recommended that this approach could be further modified to yield the following:

- Variables that need to be sampled at every station in a basin-wide network
- Variables that need to be sampled at each station.

4.7.2 Problems Associated with Current Design Methods. One of the major problems associated with current design methods relates to how the techniques are used in spatial and temporal design. The majority of current techniques are based on classical correlation and regression theory, which basically constitutes a means of transferring information in space and time. The use of regression theory in transfer of information has some justification. However, regression approaches transfer information on the basis of certain assumptions regarding the distributions of variables and the form of the transfer function such as linearity and non-linearity. Thus, how much information is transferred by regression under specified assumptions has to be evaluated with respect to the amount of information that actually is transferable. Harmancioglu et al. (1998) has reviewed a number of the issues pertaining to information transfer and defines the definition and provides examples of comparisons of the terms "*transferred information*" and "*transferable information*." Thus, the existing methods of water quality network design are deficient because of the following specific difficulties:

- A precise definition of "information" contained in the data and how it is measured is not given
- The value of data is not precisely defined and, consequently, existing networks are not optimal either in terms of the information contained in these data or in terms of the cost of getting the data
- The method of information transfer in space and time is restrictive
- Cost-effectiveness is not emphasized in certain aspects of monitoring
- The flexibility of the network in responding to new monitoring objectives and conditions is not measured and not generally considered in the evaluation of existing or proposed networks.

4.8 Requirements for Better Designs

The significance of environmental data, and that of water quality data in particular, lies in the fact that they are our only means of being informed about the environment. Data constitute the link between the actual process and our understanding, interpretation and assessment of the highly complex environmental processes. Therefore, data collection and information production are the most crucial activities on man's side with respect to all management and control efforts. Adequate and reliable data may serve to increase our knowledge on environmental processes and hence reduce the uncertainties, whereas lack of such data may lead to erroneous interpretations and decisions.

Another point to be stressed is that data needs undergo changes in time. Environmental problems become more and more varied as the impact of man on the environment changes. Accordingly, information expectations also vary, leading to changes in the nature and types of data needed. Environmental problems had previously been more of a local nature; thus, it was often sufficient to collect data at a single point in space. Recently, however, such problems reflect a significant spatial component so that environmental processes have to be evaluated in both the time and the space dimensions. Accordingly, data to be collected are expected to reflect the spatial variations of environmental processes as well as the temporal changes.

Another significant development is the recognition of the environmental continuum. This new outlook at the environment also has changed data needs. Environmental data have to be collected in such a way as to properly account for all components of the environment and their interactions. In other words, data on different components of the environment should be integrated to eventually produce complete information about the environmental continuum (Harmancioglu et al., 1998). It follows from the above that, as the complexity of environmental problems increase, information expectations and data needs become more varied and complicated.

As pointed out earlier, data availability is not a sufficient condition to produce the required information about the environment. It is the usefulness of data that contributes to production of information. In the past, the primary concern was to conceive what available data showed about prevailing conditions of the environment. The question now is whether the available data convey the expected information. Data collection systems have indeed become sophisticated with new methods and technologies. However, when it comes to using collected data, no matter how numerous they may be, one often finds that available samples fail to meet specific data requirements foreseen for the solution of a certain problem. In this case, the data lack utility and cannot be transferred into the required information.

The transfer of data into information involves several activities in sequence, such that each of these activities contributes to retrieval of the required information. Thus, all of these steps must be efficient to maximize data utility, which essentially means that such activities must be considered within an integrated data management system.

This issue was stressed at a recent workshop where an international and multidisciplinary group of experts delineated the need for an integrated approach.

> *There is a significant gap between information needs on the environment and information produced by current systems of data collection and management. The presence of this gap contradicts the nature of the information age we live in. We have now developed the most sophisticated means of collecting, processing, storing and communicating data, yet still we suffer from poor information when we attempt to use the available data. This gap can be filled in by appropriate monitoring and management of data. In view of numerous problems encountered in*

> *monitoring and information production, the adoption of integrated approaches so data management appears to be the only means by which the existing gap can at least be minimized.*

At a time when we need informational support the most, we find that our data management systems experience a declining trend. Recognition of this trend has brought focus to current monitoring systems, databases and data use. Accordingly, major efforts have been initiated at regional and international levels to improve the status of existing information systems.

4.9 Recommendations for Improvement of Water Quality Monitoring Systems

The above discussion on requirements for reliable information on the environment holds true for water quality, which is a significant component of the environment. At present, the adequacy of collected water quality data and the performance of existing monitoring networks have been seriously evaluated for two basic reasons. First, an efficient information system is required to satisfy the needs of water quality management plans and to aid in the decision-making process. Second, this system has to be realized under the constraints of limited financial resources, sampling and analysis facilities, and manpower.

Despite all efforts made on monitoring of water quality, the current status of existing networks shows that the accruing benefits are low. That is, most monitoring practices do not fulfill what is expected of monitoring. Thus, the issue still remains controversial among practitioners, decision makers and researchers for a number of reasons. First, proper delineation of design considerations often is overlooked. That is, objectives of monitoring and information expectations for each objective are not clearly identified. Second, there are difficulties in the selection of temporal and spatial sampling frequencies, the variables to be monitored and the sampling duration. Third, benefits of monitoring cannot be defined in quantitative terms for reliable benefit/cost analyses. There are no definite criteria yet established to solve these problems. Fourth, water quality data management systems are not considered as an integrated system of activities, such that the design of monitoring networks fails to satisfy the needs of each activity.

In view of these difficulties, water quality monitoring and network design has become one of the most significant problem areas in environmental management. The three questions below need to be resolved for better water management.

1. What minimum physical, chemical, biological and socio-economic information is required to plan and manage water resources?
2. What minimum data are needed to produce the required information?
3. How do we efficiently produce the required information from data?

The last question essentially relates to methods used to transfer data into information. The first two questions, however, impose significant requirements on the design of monitoring systems.

Regarding the design of water quality monitoring networks, the major conclusions derived at the NATO Workshop on Integrated Approach to Environmental Data Management Systems (NATO, 1998) are outlined below.

1. Environmental data networks can benefit from integrated approaches to their design. There are both philosophical and pragmatic reasons for the integration of environmental data networks across various environmental phenomena. The philosophical basis for this conclusion is that environmental processes are interdependent in nature. Thus, if one wants to understand any particular aspect of the environment, the data describing the web of processes whose interactions influence that aspect must be studied to attain adequate understanding. From a pragmatic point of view, integration of environmental data networks makes sense because the interdependencies of the environmental processes permit information transfer among the processes. Thus, synergy and cost effectiveness can result from integrated data networks.

2. Design of data networks should be based on the purposes for which the data are to be collected. There are many purposes for the collection of environmental data; therefore, many network design tools are required. However, multipurpose networks are difficult to design rationally, so an approach that permits interactive designs of single-purpose networks is the most feasible means of performing integrated design.

3. A taxonomy of environmental data network purposes is useful in developing a strategy for integrated network design. The use of the following taxonomy for the classification of network design purposes could highlight commonalties among network design technologies that would facilitate their use under a more robust set of situations:

    - Decision-support networks
    - Academic-curiosity networks
    - Contingency networks.

4. Basic understanding of environmental phenomena is the starting point for the design of environmental data networks. Knowledge of the phenomena of interest is required to select an appropriate suite of network design tools. The choice of the actual tool or tools to be used for the design should be based on any existing data from the region of interest.

5. Feedback from data collected in the initial network allows a more complete description of the environmental phenomena and the subsequent use of more

complex approaches to redesign the network. Knowledge and information gained from an environmental data network can be used for improvement of the network.

6. Network design is but one link in an integrated environmental data management chain, and it must be harmonized with the constraints and opportunities provided by the complementary links. The design of data networks should not be performed in isolation from the technologies that will be used to convert the data to environmental information.

7. There currently is a paucity of robust technologies for the design of environmental data networks, and technology transfer for the existing technologies is not being carried out satisfactorily on an international scale. Because of the great interest in the environment that exists today, there is a large investment internationally in the collection of environmental data. With the lack of adequate network design support, many of the data collection programs probably are not being conducted in a cost-effective manner.

The following points are recommended for the design of monitoring networks:

- Environmental data networks should be designed and operated in an integrated manner to take advantage of the international synergies that exist among environmental phenomena
- Environmental data networks should be redesigned periodically to incorporate the new knowledge that is contained in the added data
- The development of more robust technologies for the design of environmental data networks should be supported by international environmental agencies
- New vehicles for the transfer of the technologies of data network analysis and design should be sought and implemented as they are demonstrated to be effective.

4.9.1 Selection of Parameters. The selection of sampling and analytical procedures in ambient water quality monitoring could follow two approaches depending on the aim of the monitoring program, such as a) regular monitoring for establishing pollution levels and trends by manual sampling or b) early-warning monitoring by automatic field measurements and sampling. In the case of manual sampling, the collection of samples is flexible and may involve a large number of sites and positions without extreme increases in costs. On the other hand, establishment of automatic water quality monitoring stations is very costly; changing site/position is difficult and unfeasible, and there also are limitations in the detection and analytical techniques. Because of these reasons, a very scrupulous cost-benefit analysis is needed before the decision on the construction of an automatic monitoring station.

Table 4-2 lists common activities that trigger water quality monitoring as well as their potential effects on water quality and those parameters that should be monitored.

Table 4- 1. Implications of Alternative Goals for Design and Operation of a Routine Monitoring System (after Ward et al., 1990)

Information Requirements	**Goal - Maintain or improve water quality**	**Goal - Promote conservation and best use of natural water**
Information needed for design	Objective definition of *water quality*	Objective definition of desired *water uses*
Information expected from operation	Changes in that water quality over time	Compliance with standards for those uses
Design criteria	Sites "representative," tend to be spread uniformly Frequency related to trend detection Characteristics determined by definition of *water quality*	Sites concentrated where water use conflicts anticipated Frequency related to definition of compliance Characteristics related to water quality requirements of all desired uses
Reporting	Goal met when trends are either absent or improving	Goal met when probability of violation of water quality requirements in acceptable range

[a] Sites = where; frequency = when; and characteristics = what (e.g., BOD_5, pH, invertebrates and bacteria)

Table 4- 2. Potential Effects on Water Quality of Common Waste Discharges and Land Uses (Cavanagh et al., 1998)

Activity	Potential Effects	Recommended Parameters to Monitor
Forest harvest (cutting and yarding)	▪ Altered stream flow and runoff patterns (general increase of peak flows and summer low flows) (typically monitored by hydrologists) ▪ Altered stream channel characteristics (typically monitored by hydrologists or geomorphologists) ▪ Increase of total water ▪ Disturbance of soil, increasing potential for erosion ▪ Increased turbidity and suspended sediments ▪ Decreased intergravel dissolved oxygen concentrations; altered macroinvertebrate community structure; altered juvenile coldwater fish abundance ▪ Increase of organic material reaching stream systems ▪ Increased light penetration to stream systems ▪ Increased algal production in light-limited systems ▪ Increased water temperature	▪ Turbidity ▪ Suspended sediments ▪ Dissolved oxygen ▪ Benthic invertebrates ▪ Water temperature ▪ Chlorophyll *a*
Road building and use	▪ Increased rate of erosion ▪ Increased suspended sediments and turbidity ▪ Decreased intergravel dissolved oxygen ▪ Altered macroinvertebrate community structure ▪ Increased conductivity due to de-icing (salts)	▪ Turbidity ▪ Suspended sediments ▪ Dissolved oxygen ▪ Benthic invertebrates ▪ Conductivity

Table 4- 3. Potential Effects on Water Quality of Common Waste Discharges and Land Uses (Cavanagh et al., 1998) (cont.)

Activity	Potential Effects	Recommended Parameters to Monitor
Pulp and paper mills	▪ Altered temperature ▪ Increased carbon ▪ Increased ammonia ▪ Increased organics ▪ Increased bacterial contamination ▪ Increased oxygen demand (reduced dissolved oxygen) ▪ Altered biological community structures ▪ Increased color	▪ Temperature ▪ Color ▪ Dissolved oxygen ▪ pH ▪ Ammonia ▪ Benthic invertebrates, ▪ Coliform bacteria (*E. coli*) ▪ Organics (dioxins/furans in fish tissue and sediments ▪ Resin acids ▪ Chlorophenolics, AOX ▪ Sodium or chloride are often useful tracers of effluent location and dilution
Agriculture	▪ Altered timing and patterns of runoff ▪ Increased sediment load ▪ Altered sediment size distribution ▪ Increased bacterial contamination ▪ Increased nutrient levels (from livestock waste and application of fertilizers) ▪ Increased algal productivity or standing crop ▪ Increased temperature; increased BOD and COD (decreased dissolved oxygen) ▪ Altered macroinvertebrate community structure	▪ Turbidity ▪ Suspended sediments ▪ Coliform bacteria ▪ Phosphorus ▪ Nitrogen ▪ Dissolved oxygen ▪ Benthic invertebrates ▪ Temperature ▪ Chlorophyll *a* (standing crop) ▪ Pesticides ▪ Herbicides

Table 4- 4. Potential Effects on Water Quality of Common Waste Discharges and Land Uses (Cavanagh et al., 1998) (cont.)

Activity	Potential Effects	Recommended Parameters to Monitor
Urban development	▪ Altered timing and patterns of runoff ▪ Increased turbidity and suspended sediments ▪ Increased toxins (from storm drains - metals, organics, pesticides) ▪ Increased bacterial contamination (septic fields, stormwater, combined sewer overflows) ▪ Increased nutrients (septic fields, detergents and garden fertilizers) ▪ Increased light penetration to stream systems (stream bank clearing) ▪ Increased algal production and standing crop ▪ Increased temperature in stream systems	▪ Turbidity ▪ Suspended sediments ▪ Oil & grease ▪ Polycylic aromatic hydrocarbons ▪ Metals package ▪ Coliform bacteria ▪ Phosphorus ▪ Nitrogen ▪ Dissolved oxygen ▪ Benthic invertebrates ▪ Temperature ▪ Chlorophyll *a*
Sewage treatment - primary treatment	▪ Increased suspended and dissolved solids and turbidity ▪ Increased BOD and COD (decreased dissolved oxygen) ▪ Increased nutrients (particularly ammonia) ▪ Increased bacterial contamination ▪ Increased sediment PAHs; increased sediment metals	▪ Turbidity ▪ Non-filterable residue ▪ Filterable residue ▪ Dissolved oxygen ▪ Phosphorus ▪ Nitrogen (ammonia) ▪ Chlorophyll *a* ▪ Coliform bacteria ▪ Benthic invertebrates ▪ Sediment ▪ PAHs ▪ Metals package ▪ Sediment
Sewage treatment - secondary treatment	▪ Increased BOD and COD ▪ Increased nutrients (particularly ammonia) ▪ Increased algal productivity; increased bacterial contamination ▪ Increased sediment PAHs ▪ Increased sediment metals	▪ Dissolved oxygen ▪ Ammonia ▪ Carbon ▪ Chlorophyll *a* ▪ Bacteria ▪ Sediment ▪ Benthic invertebrates ▪ PAHs ▪ Metals Package ▪ Sediment

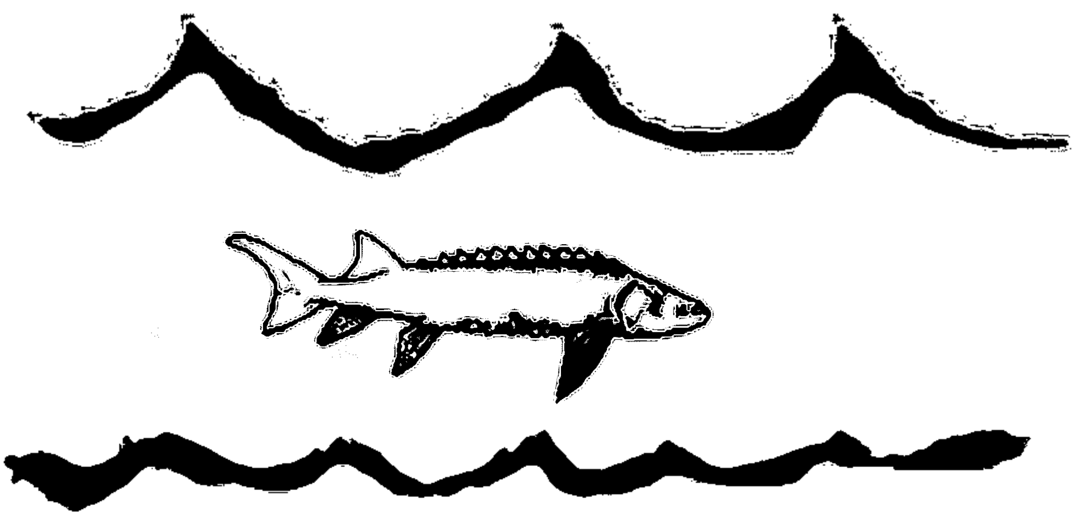
Table 4- 5. Potential Effects on Water Quality of Common Waste Discharges and Land Uses (Cavanagh et al., 1998) (cont.)

Activity	Potential Effects	Recommended Parameters to Monitor
Sewage treatment - tertiary treatment-A/O treatment facilities	▪ Low-level increase of nutrients	▪ Dissolved oxygen ▪ Ammonia ▪ Carbon ▪ Chlorophyll *a* ▪ Bacteria ▪ Sediment
Sewage treatment - barden-pho treatment facilities	▪ This treatment method should theoretically have a minimal impact on the ambient aquatic environment	As a precaution, occasional effluent sampling for dissolved oxygen, phosphorus and nitrogen should be monitored for tertiary treatment facilities to ensure that they are performing to specifications. Ambient monitoring for chlorophyll *a* should be conducted in conjunction with the above schedule.
Recreation	▪ Increased bacterial contamination ▪ Increased nutrients ▪ Increased algal productivity	▪ Phosphorus ▪ Nitrogen ▪ Coliform bacteria ▪ Chlorophyll *a*
Mining - placer mining	▪ Destabilization of stream channel ▪ Increased suspended solids and turbidity ▪ Altered conductivity; increased heavy metals concentrations ▪ Decreased intergravel dissolved oxygen ▪ Altered temperature ▪ Altered macroinvertebrate community structure ▪ Altered juvenile coldwater fish abundance	▪ Metals package ▪ Conductivity ▪ Turbidity ▪ Suspended solids ▪ Dissolved oxygen ▪ Temperature ▪ pH ▪ Benthic invertebrates

Table 4- 6. Potential Effects on Water Quality of Common Waste Discharges and Land Uses (Cavanagh et al., 1998) (cont.)

Activity	Potential Effects	Recommended Parameters to Monitor
Mining - hardrock mining	▪ Altered dissolved ions ▪ Altered temperature ▪ Increased heavy metals concentrations ▪ Increased turbidity and suspended solids ▪ Altered pH ▪ Altered conductivity ▪ Increased nitrogen (due to blasting) ▪ Altered macroinvertebrate community structure ▪ Altered juvenile coldwater fish abundance	▪ Metals package ▪ Conductivity ▪ Turbidity ▪ Suspended solids ▪ Ammonia ▪ Nitrate ▪ Temperature ▪ pH ▪ Benthic invertebrates
Mining-coal mining	▪ Increased turbidity and suspended solids ▪ Increased nitrogen (due to blasting) ▪ Altered pH ▪ Increased metals (if acid generation occurs) ▪ Altered macroinvertebrate community structure	▪ Metals package-especially selenium ▪ Turbidity ▪ Suspended solids ▪ Ammonia ▪ Nitrite ▪ pH ▪ Benthic invertebrates

Section 5.0
Sampling Plan



5.0 SAMPLING PLAN

5.1 Background

The need to reconcile aquatic habitat protection with multiple land uses in upland areas of interior watersheds has resulted in the need to understand how to protect in-stream water quality, habitat types, trophic webs, fisheries and other wildlife needs. The use of water quality monitoring programs has, since the early 1970s, been widely accepted as the primary method for obtaining data about changes in water quality as a result of land use activities and as a source of scientific information for use in promulgating policy and management decision-making. Unfortunately, the translation of data into useful information has not occurred as well as it should have, largely because the majority of monitoring programs have not been properly designed to facilitate this translation (Ward et al., 1986). These authors note that the lack of routine data analysis, and reporting of information derived from such analysis, points to the fact that the exact nature of the role of routine, fixed-station monitoring is poorly understood and that the majority of studies have poorly defined the rational for "why" the study is being conducted. Whitfield (1988) had previously observed that monitoring programs cannot provide all the needed information through a single collection or monitoring program. Further, that for every clearly defined information need, there should be a series of programs designed around specified goals and objectives on a site-by-site basis.

In defining the complex requirements essential when establishing the ecological characterization, classification and modeling of New Zealand rivers, Biggs et al. (1990) highlighted the need to provide adequate flows to ensure in-stream water quality (i.e., for the protection and preservation of salmonid fisheries). These authors noted that this has resulted in numerous techniques for assessing water quality and hydrological flow requirements, including the following:

- Proportional discharge methods (i.e., the Montana "rule of thumb"), where it is recommended that set proportions of certain flows be retained for the maintenance of the specified use
- Habitat correlation methods (i.e., discriminate modeling), where known correlations between the physical environment and biota are applied to predict biological responses
- Hydraulic habitat simulation methods (i.e., the incremental method), where detailed information on the hydraulic habitat characteristics of representative reaches is combined with habitat preference data to provide a prediction of the biologically "usable area" in a river.

The proportional discharge method can only provide a crude assessment of total flow and can lead to in-stream conditions that are detrimental to fish if uncritically applied. The habitat correlation method has been recommended (Biggs et al., 1990) as an effective technique for the cost-effective assessment of in-stream flow needs for fish and other wildlife. This technique has been used to relate physio-chemical environmental variables to invertebrate community groups and to estimate periphyton biomass in New

Zealand rivers (Biggs et al., 1990). In a special issue of the *New Zealand Journal of Marine and Freshwater Research*, a detailed series of articles describe the results of a major program of interrelated studies, which further investigated the habitat-correlation method of habitat assessment. This was conducted in relation to flow and other habitat features such as river catchments and water quality. The primary goal of the research was to develop quantitative links of the form:

Biological response = f [geology/climate, hydrology, water quality].

The formula can be expanded diagrammatically to identify the complex interactions that must be understood when planning such a program and, ultimately, interpreting the results of field data (Figure 5-1).

Biggs et al. (1990) noted that:

> *Catchment characteristics of geology and climate are the predominant "driving" variables in this model since these in turn influence the topography/slope, land use/vegetation, hydrology, and water quality. Both natural and human-induced changes in concentrations of the water constituents are closely linked with flow and the physical characteristics of rivers. The main catchment characteristics, flow and chemical aspects of biotic habitats were thus included in the studies. Biological responses were determined for periphyton, benthic-invertebrates and trout.*

One measure of a watershed's health can be determined by assessing the health of the streams that flow through it. Since the environmental processes within watersheds are all linked by the hydrological cycle (i.e., the flow of water through the uplands), stream habitat and valleys are inseparable from the rest of the landscape. The recent literature emphasizes that spatial scales of land use and watershed size are crucial driving forces that can affect water quality. (It should be noted that although this hydrologic model has a venerable history, it is, in fact, incorrect or incomplete.) In most coastal, and numerous interior streams and rivers, there is a significant movement of nutrients, most typically through anadromous (and landlocked, e.g., kokanee) fish, from the open ocean environment back onto the landscape with the completion of each salmonid lifecycle. The bodies of each spawning adult restores much of the nutrient load lost each year through erosion. Although little research has been conducted on this, it is a crucial component of many watersheds' nutrient dynamic. The recognition of this crucial link between the hydrologic energy and its control by the riparian vegetation community has only recently become understood as it affects stream quality and restoration.

While traditional stream health inventories and restoration efforts were based almost exclusively on in-stream processes, which have typically resulted in greater than 50 percent project failure, the U.S. Departments of Agriculture and the Interior have revised stream health assessments to reflect our new understanding of the linkages between hydrology and vegetation (US Department of the Interior, BLM TR 1737-15, 1998). The guidelines for assessing "Proper Functioning Condition" are designed to determine whether lotic areas and their supporting riparian habitats are healthy and, if not, why. While this approach does not directly include estimates of water quality, there is a relationship between functional stream and riparian habitat and good water quality. Thus, in developing a water quality monitoring program, we believe it is essential to recognize these interlinked relationships.

While there are literally hundreds of water quality parameters that can be measured, they often are grouped into the following common categories:

- Physical and chemical constituents
- Flow
- Sediment
- Channel characteristics
- Riparian
- Aquatic organisms
- Ecological or trophic linkages.

The term "water quality," therefore, often is taken to mean the complex interactions of all these categories, which ultimately provide some estimate of the health of the aquatic environment. The nature of water quality as it pertains to fish can be considered in terms of the following four basic considerations:

- Provision of nutrition or food (both quantitative and qualitative)
- Respiration (adequate supply of oxygen)
- Provision of characteristics conducive to growth and health (i.e., absence of pollution or toxins)
- Provision of habitat for reproduction.

Alterations of any of these basic water quality characteristics can exert varying degrees of stress to fish, either directly (absence of oxygen or smothering of spawning beds) or indirectly (i.e., turbidity, which prevents algal growth, which in turn reduces invertebrate abundance, and which ultimately reduces available food for juvenile fry). In a recent review of how government agencies and private companies should develop and implement monitoring guidelines to evaluate effects of forestry activities on streams in the Pacific Northwest and Alaska, MacDonald et al. (1991) provide a useful, generalized summary of the current knowledge of a number of water quality parameters. We are not aware of such a document that focuses on interior watersheds; given the differences in biogeoclimatic conditions between the coastal and interior biomes, caution must be urged in extrapolating processes between these two regions.

Physical and chemical parameters have long been measured as surrogate estimates of biological health and, until recently, have played a primary role in monitoring and evaluating water quality (Lucey et al., 1987). The water quality parameters selected for measurement during this study include those that have been commonly measured in forest streams, are sensitive to forest management activities, and likely will affect the use of forest stream waters by fish, especially salmonids, together with those organisms that are important to fish. It also is important to recognize that in the subwatersheds, as well as the main channel, there are a number of land use changes that historically have exerted a dominant driving force, or have been a dominant driving variable, influencing both water quality and trophic web function. These include agriculture, mining, pulp mills, large-scale impoundments, urban environs and transportation corridors, all of which affect both upland and riparian zones at varying scales.

Land use change may be the single greatest factor affecting ecological resources, including water quality. Since landscapes consist of heterogeneous communities, the function and structure of the landscapes themselves are scale-dependent. There is a history of organizing landscape spatial scale into hierarchically nested watersheds and ecoregions. Thus, the USGS has defined the HUC units as a four-level hierarchical arrangement of river basins, such that each larger unit consists of an aggregate of smaller units. Numerous studies have demonstrated that the proportion of land uses within a watershed can account for a portion of the variability in lotic water quality. In particular, the presence or absence, and health, of the riparian community can exert a significant influence on certain water quality parameters (i.e., nutrients and sediment movement). The size of the watershed unit also has been shown to influence the magnitude of these effects. Three basic questions concerning the use of nested watersheds as the hierarchical regional characterization scheme as it relates to water quality can be addressed.

1. Are both the proportions of land uses and the spatial pattern of land uses important for characterizing and modeling river water quality in watersheds of different sizes?
2. Can land use near the stream better account for the variability in water quality than land use for the entire watershed?
3. Does the size of the watershed influence statistical relationships between landscape characteristics and water quality or model performance?

In order to identify areas critical for management purposes, it is important to identify hydrologically active areas and use a distributed modeling method and fine data resolution procedure. Management of nonpoint-source pollution in large river systems (such as the Kootenai) could benefit from a two-stage approach. A lumped approach with coarse-resolution data could be used as a screening method to identify watersheds making the most significant pollutant contributions. Then, a high-resolution distributed modeling technique could be used for those smaller watersheds identified as critical for specific management actions (i.e., influence of grazing practices on riparian community structure, effects of logging and/or recreation on watersheds supplying a surface drinking water supply, influence of small abandoned mines and tailings dumps on heavy metal loading, contribution of treated sewage effluent on downstream nutrient loading, etc.). In the upper watershed above the reservoir, there are three major land use and industrial activities that have exerted a significant influence on water quality. In addition to these three point-source effects, there are numerous nonpoint-source activities that have been, or presently are, being monitored.

The presence of Cominco's lead-zinc Sullivan mine (and, until its closure, the associated fertilizer plant) have contributed significant heavy metal loadings into Mark Creek (initial receiving waters), the St. Mary River and, finally, the Kootenay River, into which the latter discharges. Ongoing water quality monitoring of Mark Creek and the St. Mary River indicate that the metal loadings have been dramatically reduced (Les McDonald, BC MELP, Cranbrook; personal comm., 1998). The presence of the Crestbrook Forest Industries pulp mill at Skookumchuck also has resulted in treated effluent discharges to the Kootenay River, above the confluence with the St. Mary River. These discharges also meet, or exceed, BC MELP discharge standards. Lastly, the presence of the Koocanusa Reservoir has significantly altered the hydrologic timing and magnitude of downstream flows, which has been shown to affect both water quality and trophic web function and structure (Daley et al., 1981; Hamilton et al., 1990).

Recent studies have shown that the rapid fluctuations in water depth, and thus wetted or flooded area, dictated by hydropower generation schedules, have had significant adverse affects on macroinvertebrate populations below the reservoir. These water-level fluctuations have resulted in changes in macroinvertebrate community structure, as well as reductions in population numbers (i.e., biomass available for higher trophic levels).

In the watersheds of Joseph and Gold Creek, which are the principal surface water supply for the City of Cranbrook (20,000 population), a wide range of land use activities are known to have affected the forest structure. Logging, recreation, transportation corridors, a gas pipeline, high-voltage hydroelectric transmission line and cattle grazing are some of the activities that regularly occur in these watersheds. During the past 4 years, a detailed water quality monitoring program has been conducted in both watersheds, together with the water supply reservoir that receives water from both creeks. This program includes both a discrete water quality sampling program (sediment loading, temperature, flows, nutrients, heavy metals, bacteriological, parasites, etc.) and a remote, continuous monitoring program consisting of temperature, conductivity, river stage and turbidity. In addition, there is an extensive array of temperature thermistors throughout the watersheds that continuously measure water, ground and air temperatures. A similar though less comprehensive program has begun in the Mark Creek watershed, which supplies the City of Kimberley. Mark Creek also flows through the Cominco mining operation before flowing into the St. Mary River.

The protection of water quality, aquatic habitat and aquatic wildlife requires that all aspects of an aquatic environment be monitored to provide an adequate database to predict trends, or changes, in water quality, especially in the long term. Additionally, it is not enough to simply monitor such changes—it is necessary to understand what caused the changes (i.e., natural vs. anthropogenic) and to have adequate knowledge of the ecosystem's function and structure to reliably recommend prescriptions and treatments to restore each damaged system to a healthy condition.

The following sections detail the specific parameters that traditionally have been measured, why and how they should be measured on a long-term basis, what is the most efficacious and cost-effective program for their monitoring, and provide a brief summary of the biological relevance of each parameter. This section has borrowed heavily from Dr. Literathy, Director, Institute for Water Pollution Control, Budapest, Hungary (Litherathy, 1998). In this section, Dr. Literathy has compiled a thorough review of the rationale for a wide range of water quality monitoring objectives, especially for large, transboundary watersheds, with varied land use practices in their upland regions.

It should be noted that while the authors of this report concur with Dr. Literathy's recommendations for a large-scale monitoring program, we also believe it is essential to conduct monitoring on selected smaller-scale watersheds to ensure that the influences of spatial scale and terrestrial processes and land uses, which are known to be important in developing and calibrating predictive models, can be measured to determine their effect on aquatic health. Without this level of study, it will be unlikely that water quality data can be translated into the necessary information crucial for improving and regulating management practices to preserve and protect future water quality and aquatic habitat. The recent literature reviews of two decades of worldwide water quality monitoring programs have shown that it is essential that the goals and objectives for each specific piece of information, required for a particular management or policy decision, be identified and form the basis for each monitoring or sampling program. Failure to use this approach as the basis for designing each monitoring program will likely result in the program being unable to efficiently and effectively provide the necessary information.

The need to ensure adequate data quality and the translation of analytical data into useful information requires that the data be summarized. This process, of expressing the data in terms of numerical expressions, using equations and statistics, in part for use in models, requires that the data evaluation process be incorporated into the monitoring plan as one of the initial design steps. Following this section is a review of some of the essential elements that should be included in using basic statistical and modeling tools. Finally, since this section has required an extensive review of the past two decades of published literature (both scientific and gray literature), we have included a detailed reference section, appended at the end of this document, to indicate the literature that has formed the basis of our approach in drafting this document.

5.2 Proper Functioning Condition

Riparian wetlands are among the most productive areas with a wide variety of resource uses (recreation, fish, wildlife, drinking water), which have a variety of values (cultural, historical, economic), and which are subjected to many different uses (livestock, timber, minerals, medicine). While traditional water quality assessments have focused on the physical, chemical and biological attributes of the water, recent attempts have been made to characterize the functional character of an aquatic system as a surrogate estimate of the system's health. The assumption is that aquatic, or wetland, habitats, if functionally healthy, will tend to have water quality profiles that reflect the normal attributes of systems within a specific biogeoclimatic zone. The underlying parent materials and landscape vegetation would also be important modifiers of water quality.

Thus, in many situations developing water quality monitoring programs could be assisted by knowing whether the wetlands in a specific region were functional or in a state of dysfunction.

The use of assessment techniques to characterize wetland health has a long history. The predominant feature of the majority of such processes has been the emphasis on collecting extensive morphological data on the physical attributes of the system being studied. Typically, such assessments were made by hydrological or fisheries personnel. Such systematic surveys resulted in large quantities of data, with limited useful information about the system's functional or structural stability. Additionally, if the system was dysfunctional the data were of limited use in determining why or how the system could be restored to a more stable state.

In order to provide an alternative process for assessing the functional status of wetland habitat, the Bureau of Land Management, the Fish and Wildlife Service and the Natural Resources Conservation Service, formerly the Soil Conservation Service, cooperatively developed a Proper Functioning Condition (PFC) technique. This technique is a qualitative method for auditing the condition of riparian-wetland areas. The process describes both the assessment process and a defined, in-situ condition of the riparian-wetland area.

The PFC technique refers to a consistent approach for determining whether the hydrology, vegetation and erosion/deposition (soils) attributes and processes are adequate to stabilize the energy inherent within a particular riparian-wetland area. The audit uses a checklist as the primary component of the PFC auditing process, which yields a synthesis of the information as the foundation on which the health of a riparian-wetland area can be determined. Central to this assessment is whether a riparian-wetland area has adequate resiliency to withstand the physical forces associated with high-flow events. The PFC is designed to predict the degree of resilience to high-flow events with a high degree of reliability. The resilience provides the riparian-wetland with the capacity to yield a wide range of resource values on a sustainable basis (i.e., fish habitat, drinking water, forage, neotropical bird habitat). Dysfunctional riparian-wetland habitat cannot provide these values on a prolonged basis.

The PFC audit is a qualitative process founded on quantitative science. The audit must be performed by an interdisciplinary team (aquatic ecologist, hydrologist, pedologist, botanist) with local, in-situ knowledge and experience of the type of quantitative sampling techniques that support the PFC checklist. The PFC audit is a useful adjunct to determine and prioritize the type and location of quantitative inventory or monitoring programs. The technique also is a useful communication device for helping a wide diversity of publics to speak a common aquatic language and vocabulary, and for resolving value-based disputes.

The authors strongly recommend that the PFC technique be incorporated into the basic water quality monitoring program and that it be used to develop a baseline health status of the numerous tributaries flowing into the main channel of the Kootenai River. The

PFC technique also will provide a detailed picture of which systems presently are healthy—and should be protected—and which systems require attention. The limited resources available for riparian-wetland conservation and restoration must be focused on those systems with the highest potential for being returned to a proper functioning condition in the most efficient manner possible. The authors further recommend that two Kootenai River PFC cadres be trained, consisting of both an American and Canadian team, which could conduct assessments of the tributaries and provide information on which systems should receive the highest priority for subsequent attention.

The compendium of literature compiled as part of this project, describing the wide range of studies conducted within the Kootenai River watershed, reveals a wide range of isolated, independent investigations. These investigations cover a wide range of study objectives with respect to upland and riparian areas, together with water quality and aquatic habitat issues. In reviewing the literature-cited sections of many of these studies, the overarching impression is that relatively few of the papers and reports routinely cite other studies conducted in the watershed. This suggests that the authors are unaware of previous studies, largely because they have received minimal circulation and often are difficult to obtain. A second observation arising from the literature review is that many of the studies would benefit from a collaborative approach among workers in different states, agencies and across the international boarder—one of the original reasons for establishing the KRN. In discussions with members of the KRN, agency personnel, municipal and post-secondary education staff, and members of the research community, there was a broad-based recognition of the need for a transborder conference on what information has been obtained, where the information is housed, how access to the information can be efficiently obtained and how best to prioritize future studies, together with how the necessary resources to undertake the studies should be acquired. The authors therefore make the recommendations below.

1. The KRN should undertake to convene a conference to assemble as many workers who have recently conducted studies within the Kootenai River watershed and that are germane to the group's objective of protecting the water quality of the river and its tributaries. The conference objective should be to review the work that has been undertaken and to provide a forum to help characterize what work should be conducted to provide information not presently available. The conference should reflect a multidisciplinary viewpoint and should bring together scientists, industry, NGOs, educational, government and political leaders.
2. The existing literature database of studies conducted within the Kootenai watershed should be housed in three public or post-secondary education libraries (college or university) in Libby, MT; Bonners Ferry, ID; and Cranbrook, BC. The literature database should be housed as both a hard copy and in an electronic format.
3. Consideration should be given to creating a web site at a post-secondary institution where the literature database could be made available in a read-only

format. This would make the existing information rapidly accessible to the widest possible audience.

The City of Cranbrook obtains its raw drinking water from two local, multiple-use watersheds. Since the majority of the watershed lands are Provincially–owned, the City has had minimal control over the type and extent of land use activities within these lands. As a consequence of a decade-long watershed planning process, the City undertook to adopt a water quality monitoring program and forest/riparian ecology studies as the basis for managing all watershed activities. The studies were designed to determine what data and information would provide adequate water supply protection and if (or when) filtration of the raw water supply would be required. It was determined that the Joseph and Gold Creek watersheds should be managed to provide water of the highest possible quality as this would protect the ecological integrity of the watershed and provide the citizens of Cranbrook with high-quality drinking water. Should water treatment or filtration become necessary in the future, keeping the incoming water as clean as possible will maximize its effectiveness.

In the summer of 1994, the City of Cranbrook commissioned a review of its water supply program. As part of this review, a water quality monitoring program was established to develop a water quality database and to ensure that the water supply would continue to meet the appropriate regulations and guidelines for the foreseeable future. The best management practices resulted in the following objectives being implemented:

- Ensure that the present water supply continues to meet the appropriate regulations and guidelines
- Establish a water quality monitoring program to provide a water quality database
- Determine whether the City's water supply could meet the more stringent regulations likely to be in force in the near future
- Identify land use activities that potentially could place public drinking water quality and aquatic habitat at risk.

The water quality monitoring program consists of three distinct components. The first is a traditional, discrete sampling program in which water samples are obtained at permanent sample site locations on a regular basis; water samples are then submitted to contract laboratories for analysis of physical, chemical and bacteriological or other biological parameters. A second water quality monitoring program consists of remote, continuous monitoring of selected parameters at two stream locations (one each in both Joseph and Gold Creek); the sample sites are synonymous with the discrete sampling program, which provides optimum quality control. The water quality parameter data can be compared with the trends established by the discrete sampling program. The third program consists of a meteorological sampling site at which a suite of standard parameters is measured continuously. The database being collected will permit the qualitative and quantitative hydrological modeling of the watershed in both time and space. The information being provided by this long-term study will help characterize the water quality of one of two major tributaries (Gold and Joseph Creeks) in the upper

Kootenai River watershed, as a consequence of the various land use activities within these two watersheds. The authors believe that having similar monitoring sites in at least two other sub-watersheds in the lower Kootenai River watershed would provide a watershed-based comparison of water quality trends. This would be valuable in assessing a wide range of best management practices within various segments of the watershed and also provide the basis for developing standardized monitoring protocols. Therefore it is recommended that two remote, continuous water quality and meteorological monitoring stations be established in two separate sub-watershed basins of the lower Kootenai River watershed. These two systems should be modeled after the systems presently being operated within the Gold and Joseph Creek watersheds in Cranbrook. Consideration should be given to using the same equipment to ensure maximum continuity and comparability of data.

5.2.1 The Green Line. The green line is defined as the specific area where a more or less continuous cover of perennial vegetation is encountered when moving away from the perennial water source. At times the green line may be at the water’s edge, or it may be part way back on a gravel or sandbar. The green line may be only a foot or two wide, or it may be many feet wide, depending on soil and water features. Natural plant species forming the green line (e.g., beaked sedge or water sedge) generally are good buffers of water forces. Disturbance activities, such as overgrazing or trampling by animals or people, result in changes to species such as Kentucky bluegrass or red top, both of which have a reduced ability to buffer water forces.

In most riparian settings, there is a continual effort by nature to form this green line of vegetation, even where the adjacent community types are composed of the more shallow-rooted species. Well-developed green line vegetation stabilizes channel banks and buffers water forces. This enhances channel stability, even for inherently unstable stream types. Therefore, an evaluation of the community-type composition of the green line can provide a good indication of the general health of the riparian area.

Sampling community-type composition along edges of live water can provide additional information over that collected by the cross-section process. Presence of permanent water in the plant-rooting zone allows more rapid recovery of vegetation after disturbances. This permits a land manager to make an earlier evaluation of management geared to improve riparian condition. Also, measurement of this portion of the riparian area provides an indication of short-term trend for the riparian area. This is where the forces of water, as influenced by total watershed condition, play their most prominent role. Additionally, there is a strong relationship between amount and kind of vegetation along the water’s edge and bank stability. Natural plant species in this permanently watered area have developed rooting systems that enhance bank stability. An evaluation of vegetation in this area can, therefore, provide a good indication of the general health of the entire watershed. A recent publication for using this technique exists—Monitoring the Vegetation Resources in Riparian Areas, Alma Winword, USDA, Forest Service, General Technical Report RMRS-GTR-47, April 2000 (Winword, 2000).

5.3 Ground-Based Photographic Monitoring

Ground-based photo monitoring allows monitoring of conditions or change using photographs taken on the ground. It may be divided into two systems: 1) comparison photographs, where a photograph is used to compare a previous condition (the photo) with current field conditions to estimate some parameter of the field condition, and 2) repeat photographs, where several pictures are taken of the same tract of ground over a period of time. The comparison system can deal with parameters such as fuel loading, herbage use and public reaction to scenery. The repeat photography can be applied to issues such as landscape-scale changes, site-specific vegetation changes and remote systems for monitoring wildlife activities.

Aqua-Tex Scientific Consulting, Ltd., has collaborated with Dr. Fred Hall of the USDA Forest Service for the past 3 years to develop a new Photopoint Monitoring Program. The objective of using this standardized technique is that it maximizes the information captured for a specific site, is of archival quality and provides a capability for obtaining quantitative data directly from the photograph. The technique uses off-the-shelf equipment, is inexpensive, efficient, effective and requires a single day to train practitioners. A recent publication describing these techniques is due for public release in the summer of 2000.

5.4 Project Organization and Responsibility

5.4.1 Strategies for Water Quality Sampling.

1. Produce a work plan and budget proposals to identify projects, work schedules and resource levels necessary for the effective operation of the field QA/QC program.
2. Use current standard and accepted procedures to collect representative aquatic samples to yield data and information for water resource managers and the public.
3. Acquire knowledge about the precision and integrity associated with samples collected from aquatic compartments for the scientific interpretation of data.
4. Establish the maintenance of minimum sample transit times and proper and appropriate procedures to preserve the integrity of the collected samples before analysis.
5. Provide an effective response capability to advances and changes in water quality sampling technology.
6. Provide appropriate and enforceable safety procedures for field sampling personnel (Gaskin, 1993).

5.4.2 Strategies for Laboratory Analysis.

1. Produce a work plan and budget proposals to identify projects, work schedules and resource levels necessary for the operation of the laboratory QA/QC program.
2. Maintain up-to-date laboratory methods and QA/QC manuals.
3. Achieve the production of reliable data that describe the quality characteristics of the samples submitted by the laboratory's clients.
4. Conduct analytical measurements as soon as possible.
5. Provide effective training for lab personnel to improve their analytical skills.
6. Encourage the ongoing process of method adaptation and evaluation to continually test the effectiveness of analytical procedures.
7. Continue internal and external QA/QC programs to ensure the production of analytical data of known quality and validity, and provide water quality data for interlaboratory comparisons (Gaskin, 1993).

5.5 Types, Numbers and Locations of Samples to be Collected

5.5.1 Types of Samples. A review of the literature reveals that the majority of water quality monitoring programs were designed to indirectly estimate the health of aquatic organisms by indirectly measuring physical and chemical water column parameters (Lucey et al., 1987). Such studies have shown that the concentration levels of heavy metals and some of the selected organic micropollutants, e.g., petroleum and chlorinated hydrocarbons, are relatively low and do not reflect the real quality of the aquatic ecosystem (Litherathy, 1998).

> *Most of the national and international monitoring programs aim to measure the quality and pollution in the water column, and majority of the results have revealed that the concentration levels of heavy metals and some of the selected organic micropollutants, e.g., petroleum and chlorinated hydrocarbons, are relatively low and do not reflect the real quality of the aquatic ecosystem.*
>
> *Although the dissolved forms of pollutants in the water are directly: (a) involved in biological processes (N.B. bioavailable forms), and (b) affect most of the water uses, particularly the drinking water supplies, the major part of the toxic pollutants, e.g., heavy metals, hydrophobic organic micropollutants, are associated with the particulate matter, which plays an important role in the pollution assessment. As a result of biological and chemical reactions forced by natural processes, toxic substances and nutrients could be mobilized and released from the sediment resulting in eutrophication or in a detrimental effect on the aquatic life and during water uses. Therefore, it is important to include*

all compartments of the aquatic environment and the sampling should include matrices as follows:

1. *Water column*
   a. *Abiotic: dissolved materials, suspended materials*
   b. *Biotic: bacteria, phyto- and zoo-plankton, fishes*
2. *Bottom sediment*
   a. *Abiotic: grain-size distribution, specific grain-size fraction for pollutant analysis*
   b. *Biotic: macrozoobenthos, periphyton.*

The characterization of water quality will require the use of different methods during field observations (visual for floating materials, oil, foam, color, turbidity; in-situ sensors such as temperature, D.O.; organoleptic, odor; photologs, aerial photo; remote sensing and anecdotal evidence) and laboratory analysis. Concerning the methodologies for observing in water quality monitoring, the following tasks should be considered:

- *Selection of constituents, pollution characteristics or variables to be monitored*
- *Selection of matrices, e.g., water, sediment and/or biota, to be sampled*
- *Selection of the appropriate sampling, sample treatment and analytical methods*
- *Quality control measures.*

5.5.2 Variables To Be Monitored.

Water quality variables could be listed in different categories. In this plan, constituents and pollutants are considered as variables to characterize the biogeochemical composition of the aquatic ecosystem (constituents), including those which characterize the natural driving forces and the anthropogenic impact (pollutants) representing the modifying forces. The group of nutrients are considered not only as constituents, but also as pollutants when their impact significantly disturbs the natural equilibrium between production and decomposition of the organic matter in the aquatic ecosystem.

Selection of the pollutants as target compounds for pollution monitoring requires: (1) pollutant inventories, (2) water quality guidelines and criteria for healthy aquatic life and intended water uses, (3) results of preliminary surveys to identify potential polluting compounds, and (4) identification of unrecognized pollutants. The determinants for pollution monitoring should be revised from time to time on the basis of (4) and the improvement of the analytical procedures.

Constituents and pollutants, usually determined during water quality/pollution monitoring programs, include:

1. ***Conventional water quality variables****, such as temperature, pH, conductivity, alkalinity, acidity, TDS (total dissolved solids), SS (suspended solids), dissolved oxygen, Na, K, Ca, Mg, Cl, SO_4, HCO_3, BOD, COD, nutrients: NH_4, NO_2, NO_3, organic N, PO_4 and total-P.*
2. ***Heavy metals,*** *such as Hg, Cd, Pb, Cu, Cr, Ni, Zn, As, Se, etc.*
3. ***Organic micropollutants,*** *such as petroleum compounds (oil), PAHs, phenols, detergents, pesticides (chlorinated hydrocarbons, organophosphorus compounds, carbamates, triazines, etc.), PCBs, phthalates, fecal sterols, etc.).*
4. ***Radioactivity indicators,*** *such as total beta and total alpha, Sr^{-90}, Cs^{-137}, etc.*
5. ***Microbiological indicators,*** *such as Fecal Coli, E. Coli, pathogens (Salmonella, etc.), viruses.*
6. ***Biological indicators,*** *such as algae, zooplankton, benthic organisms, fishes.*
7. ***Water quantity parameters,*** *such as discharge and flow velocity.*

In addition to the conventional water quality characteristics, pollution monitoring programs for international rivers should include all those heavy metals and trace organic compounds, as target compounds, which are proved to be or are likely to be characteristic pollutants along the river or its particular reach. (Litherathy, 1998)

Since one of the major practices affecting water and aquatic-habitat quality is agriculture, a number of publications have sought to evaluate these effects, recommend mitigation measures and outline monitoring protocols that effectively can be used to obtain the data and information necessary to manage these practices. One of the most potentially damaging agriculture practices in the Kootenai River watershed is that of cattle grazing. This activity is found throughout the watershed, in both the upland and riparian areas. In their document "Monitoring Protocols To Evaluate Water Quality Effects Of Grazing Management On Western Rangeland Streams," Mosley et al., 1997, provide a synthesis of commonly used monitoring procedures. These methods are presented as a functional process—stream/riparian attribute, parameter and protocol. Each protocol is then characterized by listing (in tabular format) sample frequency, time required for sampling, equipment required, cost of laboratory analysis and level of expertise required.

The format for monitoring grazing effects is as follows:

- Impacts of grazing on water quality and beneficial uses
- Monitoring plan procedure
- Stream classification, reconnaissance and classification

- Evaluation/recommendation of monitoring methods
- Monitoring protocols
    - Stream temperature and shade
    - Nutrients
    - Bacterial indicators
    - Stream channel morphology
    - Streambank stability
    - Substrate fine sediment
    - Pool quality
    - Streamside vegetation
    - Establishing permanent photo points
    - Biomonitoring: benthic macroinvertebrates
    - Biomonitoring: fish community.

While this document provides a clear outline of the sampling protocols, it does not address the specific goals of why such a monitoring program should be established, nor does it address how the data will be translated into information, especially information management and the problem of data quality for use in policy-relevant management.

Variables to be monitored at fixed-station sample sites could include nutrients, both nitrogen and phosphorus, as well as the easily degradable organics (domestic sewage), heavy metals, petroleum compounds, some of the chlorinated hydrocarbons and various other pesticides, etc. It is expected that the breakdown products (usually polar compounds), as they are described as secondary pollutants, should be included in the list of monitoring parameters in the future as soon as validated methodologies are developed. Table 5-1 outlines the traditional determinants that have been monitored in large drainage basins to characterize the general profile of water quality, as it is affected by large-scale watershed land changes, industrial discharges and urban-based influences. The actual location, sample frequency and communication of data quality will be dependent on the historical data, its quality and specific management needs.

5.5.3 Matrices to be Monitored.

> *It is important to emphasize that different polluting compounds behave differently in the aquatic environment, where they are distributed in the abiotic and biotic compartments, or between the dissolved and solid phases within the abiotic compartment. Depending on their abundance in the different matrices, sample collection should be extended to those matrices where the pollutant concentration levels are expected to be significant. In the case of toxic, persistent compounds, sediment is considered an important component where these pollutants accumulate.*
>
> *Due to its larger surface area, fine sediment is more liable to adsorb hydrophobic organic compounds, whereas the coarse sediment causes mainly a dilution effect. Comparability of the analysis of sediment-associated pollutants in the suspended sediment and in the bottom sediment can be achieved by analyzing the same grain-size fraction in*

> *both types of sediment. The suspended solids are separated from the "dissolved" fraction in the water column by filtration through a 0.45-micron pore size filter allowing the colloids to pass through into the solution. Usually, due to dependence of the sedimentation rates on the particulate size it is not likely that suspended solids will contain particles larger than 200 micron but will definitely include the clay particles, which, on the other hand, are not likely to settle to the bottom in a turbulent water body. In many water quality monitoring programs, the less-than-63 μm grain-size fraction of the bottom sediment is used for pollution monitoring. This grain-size fraction is obtained by wet sieving.*
>
> *Despite the agreement to analyze the less-than 63 micron bottom sediment fraction for pollution monitoring purposes, this fraction may show higher concentration of the pollutants in the suspended sediment due to the presence of the clay fraction, which may contain even higher concentration of the pollutants than the silt fraction. Therefore, it might be topics of future discussions to limit pollutant monitoring in the silt fraction (between 4 and 63 micron grain-size fraction) in both the suspended and the bottom sediment.* (Litherathy, 1998)

5.5.4 Water Quality Sampling Parameters. While the actual suite of parameters that should, or could, be measured is highly variable and dependent on the specific information required, there remain a number of basic parameters that could be monitored regularly at the principal sample sites noted above. Additional parameters would be added on an as-needed basis when specific information would be required. The parameters below are recommended for regular monitoring or during periods of freshet and summer low flows, when changes in background signal have a high probability of detection. The specific parameter suite should reflect historical sampling, especially as it relates to specific industrial concerns (i.e., pulp mill, mining, agricultural).

1. Physical
   - a Temperature – continuous (15-30 minute intervals); water, air (in shade) and groundwater, at each site
   - b Suspended solids (during high-turbidity events and low flows)
   - c Turbidity (continuously)
   - d Color
   - e Conductance
   - f Hardness
   - g pH
   - h Residue (filterable, non-filterable, volatile, total)
2. Channel Characteristics
   - a. Channel width, depth, cross-sectional profile (yearly)
   - b. Photopoint monitoring profiles of each bank, upstream and downstream
   - c. Bottom substrate – percent fines
   - d. Instream cover

3. Flow
    a. Velocity and Q measurements
    b. Continuous, remote sensing of depth (transducer type)
4. Chemical
    a. Nutrients
    b. Inorganic non-metallic
    c. Dissolved oxygen
    d. Toxins
    e. Metals (dissolved, suspended, total)
    f. VOCs
    g. Organics
5. Sediment
    a. Chemical constituents (toxins, organic extractable and volatile)
    b. Particle size fractionation
    c. Metals
6. Aquatic Biota
    a. Periphyton production and taxonomy
    b. Macroinvertebrates (rapid sampling assessment)
    c. Fish survey

5.5.5 Sampling Sites and Frequency.

5.5.5.1 Selection of the Sampling Sites. Many factors are involved in the proper selection of sampling stations for streams (Kittrell, 1969), including the following:

- Objectives of the stream study
- Water uses
- Access to desirable sampling points
- Entrance and mixing of wastes and tributaries
- Flow velocities and times of water travel
- Marked changes in characteristics of the stream channel
- Types of stream bed, depth and turbulence
- Artificial and physical structures such as dams, weirs and wingwalls
- Resources available for the study.

> *Sampling sites should be selected so as to allow the characterization of the quality of the water body longitudinally and in cross-section by taking samples at different points of the cross-section from different depths. This is particularly important at those sites where the waste discharges or tributaries are not fully mixed with the river.*
>
> *Sedimentation and resuspension in the river, controlled by the hydrodynamic characteristics of the river reaches and, therefore, the deposition of polluting compounds in the sediment, may occur far downstream of the discharge. This must be taken into account during sediment-bound pollution monitoring and data interpretation. One of*

the major problems is to locate representative sampling sites. This always requires a preliminary survey to identify the sites where the bottom sediment contains a significant clay-silt fraction. Bottom sediment must contain at least 10 percent clay-silt (less than 63 μm), and it can be concluded that the higher the fine fraction in the sample, the more representative the sediment-bound pollutant characterization.

Sampling positions, horizontally and vertically, should be selected considering the lack of homogeneity of the cross-section, caused by the incomplete mixing of waste discharges and tributaries. (Litherathy, 1998)

Pollution monitoring sampling sites should be established at the following locations:

- Border sections
- Upstream and downstream of major cities and tributaries
- Downstream of major industrial discharges or "hot-spots"
- Water intakes
- Ecologically vulnerable areas.

5.5.5.1.1 Sample Sites.

<u>Upper Kootenai River Main Stem</u>

1. **Sample site at the downstream edge of Kootenay National Park.** This site would provide information on water quality subjected to a minimal disturbance, reflecting the headwater sources.
2. **Sample site above Canal Flats.** This location is designed to provide water quality before the river flows past the heavy industrial activities located in reaches below this position. This location does reflect the activities associated with logging, agriculture, urbanization and transportation corridors that occur outside the headwaters.
3. **Sample site above inflow of St. May's River.** This site would capture the effects of the sawmill, pulp mill, agriculture and transportation corridors between Canal Flats and the receiving waters that receive discharges originating from the Cominco Mine in Kimberley.
4. **Sample site above Koocanusa Reservoir.** This site would provide information on the upper river before its entry into the reservoir and should integrate all activities occurring within the upper reaches the river.
5. **Sample site above and below the Yaak River.** This site would produce valuable information on the mainstem in an area where there has been recent extensive logging, historical mining, large historical fires and limited other activities.
6. **Sample site above and below the Fisher River.** Valuable information on the mainstem area that has been affected by habitat alterations resulting in nutrient

loading, siltation and thermal modifications as a result of agriculture, channelization, the removal of riparian vegetation and silviculture.

7. **Sample site above and below Libby, MT.** Valuable information on the mainstem area affected by lack of water quantity, heavy metals, nutrient loading, habitat alterations, siltation, agricultural development, land development, livestock grazing, resource extraction, riparian disturbance and silviculture.
8. **Sample site above and below the Moyie River.** Valuable information on the mainstem area heavily affected by heavy metals, nutrient loading, habitat alterations, siltation, resource extraction, riparian disturbance and silviculture.
9. **Sample site above and below Bonners Ferry, ID.** Valuable information on the mainstem Kootenai affected by heavy metals, nutrient loading, habitat alterations, siltation, agricultural development, land development, livestock grazing, resource extraction, riparian disturbance and silviculture.

<u>Tributaries</u>

1. **St. Mary's River.** This river has a large historical database reflecting the discharge of Mark Creek water, which passes through the Cominco mine. Mark Creek has a significant database in its lower reaches below the mining operation; however, there is minimal data for reaches above the mine, with the exception of water flow data for which there are extensive longitudinal records. The database consists of both company and BC MELP sampling data. The sub-watershed of Joseph Creek, whose upper reaches supply the City of Cranbrook's potable water, also has a very thorough water quality database. This database extends back to 1995, with only irregular data before this date. Joseph Creek is the site of an ongoing, extensive water quality monitoring program, including both discrete and continuous, remote monitoring studies.

   The paired watersheds of Joseph and Gold (which is adjacent to the former) have been designated as reference watersheds as part of a 1999 NSERC-Industry Research Chair in Environmental Management of Drinking Water at the University of Victoria. A multidisciplinary research program that will focus on applied ecology issues as they relate to aquatic and forest ecology and the preservation of water quality will augment the ongoing program of discrete and continuous monitoring in both creeks. Included in this program are both water and atmospheric monitoring stations. A second program, similar in design but less thorough, has been implemented in the Mark and Matthew Creek watersheds, adjacent to the City of Kimberley. The Joseph, Mark and Matthew systems all drain into the St. Mary River.

   As part of the long-term water quality monitoring program for the Kootenai River watershed, it is recommended that additional remote, continuous monitoring stations, including water and atmospheric stations, be established in sub-watersheds below the Koocanusa Reservoir. The stations should monitor at least the same suite of parameters as those on the Canadian side. Additionally, the stations should consist of either the same instrumentation (to ensure data compatibility) or be cross calibrated with the instruments on the Canadian side.

2. **Bull River.** This river has received water quality sampling from both industry and BC MELP. A new remote, continuous water quality monitoring program was initiated in 1999. There also are a number of fishery-based studies on this system. The installation of the remote-sensing water quality station should provide a comparable database to that presently being generated in the Joseph and Gold Creek watersheds. The systems should be periodically cross calibrated.
3. **Elk River.** This river has received water quality sampling from both industry and BC MELP. This system has significant heavy industrial activity within its borders.
4. **Yaak River.** Information would greatly supplement mainstem information by providing upstream data.
5. **Fisher River.** Information would greatly supplement mainstem information by providing upstream data.
6. **Libby Creek.** Information would greatly supplement mainstem information by providing upstream data.
7. **Moyie River.** Information would greatly supplement mainstem information by providing upstream data.

5.5.5.2 Sampling Frequency. Depending on the objectives of the pollution monitoring program, samples are collected in the water column via manual sampling with daily, weekly, fortnightly or monthly frequency. In the bottom sediment, quarterly or twice a year collection could be sufficient for biomonitoring or pollutants monitoring, respectively. Automatic sampling is another alternative and could be continuous or hourly, depending on in-situ sensors, on-line instruments or samplers collecting discrete samples (Litherathy, 1998).

An ideal sampling frequency will be determined by the budget restrictions of the program. In an ideal world, sampling will be conducted at numerous points during a day with remote in-situ sensors with telemetry relay. Given the anticipated budget restrictions of the KRN, a limited number (approximately 12-25 depending on budget) of remote-sensing stations without telemetry are anticipated as ideal with quarterly water quality sampling to flesh out the limited amount of in-situ stations. The number of quarterly monitoring locations will be totally dependent on the budget restrictions of the KRN. Ideally, at the start of the program samples will be collected simultaneously above and below three major tributaries in each of the three governances. The samples will be collected at the same time on the same day to ensure representative samples. The sampling frequencies also should include an event that takes the spring freshet and the fall low-water events into account. Assuming that budgets will increase in the future, additional sampling sites and an increase in frequency will be considered. Given the current budget condition, it is recommended that all sampling that occurs at each site be restricted to the same parameters to gather a common data set and establish areas of specific need for additional sampling effort.

Table 5-2 represents a basic sampling suite cost-estimate scenario for a general sampling location. Areas of special sampling needs such as known areas of hazardous materials contamination, excessive sedimentation or highly impacted tributaries will cost significantly more and will have to be estimated on a case-by-case basis.

5.6 Field Documentation

Documentation of each site should include the following:

- Name of lake, river or stream, county and township, province or territory
- Boundaries of segment sampled, basin, and sub-basin
- Universal Transverse Mercator or latitude-longitude coordinates of site
- Elevation of site above sea level
- Area of watershed
- Morphometric measurements for lakes (area, volume, mean depth and maximum depth)
- Topographic map showing site location
- For streams and rivers, location of nearest flow recorder; also stream classification
- Exact location of sampling point (e.g., distance from bank, whether midstream, location in lake)
- Distance of sampling point from point source discharges
- A general description of the area, including land use practices upstream of sampling location and ease of access
- Water quality objectives
- Availability of sediment surveys
- Data from other agencies (federal, provincial, territorial, interjurisdictional, international and private)
- Hydrologic data
- Major issues and concerns.

5.7 Methods (Refer also to Section 6.0)

5.7.1 Physical and Chemical. The selection of sampling and analytical procedures in ambient water quality monitoring could follow two approaches depending on the aim of the monitoring program, such as a) regular monitoring for establishing pollution levels and trends by manual sampling or b) early warning monitoring by automatic field measurements and sampling. In the case of manual sampling, the collection of samples is flexible and may involve a large number of sites and positions without extreme increases in costs. On the other hand, establishment of automatic water quality monitoring stations is very costly; changing site/position is difficult and unfeasible, and there also are limitations in the detection and analytical techniques. Because of these reasons, a very scrupulous cost-benefit analysis is needed before the decision on the construction of an automatic monitoring station.

One of the difficulties in conducting transboundary, international water quality monitoring programs is ensuring standardized analytical procedures. Therefore, since there are a variety of recommended sampling and analytical techniques within the numerous jurisdictions in the Kootenay River watershed, consideration should be given to using those recommended under the International Organization for Standardization (ISO) convention. The use of ISO standard reference materials whenever possible will ensure comparability of data sets, regardless of the analytical techniques used. Duplicate samples should be analyzed using both the ISO and regional techniques to provide a data calibration set.

Characterization of oil pollution is particularly important in a number of river basins because the largest amount of organic pollution relates to petroleum products. Sources of oil pollution include refinery wastes, transportation of petroleum and petroleum products by vessels, pipelines, municipal wastes, etc. Determination of the petroleum compounds is a problem for environmental analysts. This is because petroleum, as well as its refined products, is a complex mixture of different compounds, hydrocarbons and oxygen-, nitrogen-, sulphur- and metal-containing heteromolecules. Complexity of sources, processes and degradation mechanisms must be considered to choose the appropriate analytical approach for quality/pollution monitoring purposes.

There is no single analytical method that can be used to characterize all petroleum components or petroleum-related pollution. Selection of a particular analytical method is always a compromise between the feasibility of the analysis, e.g., instrumentation and available resources, and the degree of chemical detail, selectivity, sensitivity and accuracy. Analytical approaches include screening tests using spectrophotometric techniques and specific methods (e.g., chromatographic for PAHs). The spectrophotometric method selected on the basis of UV absorption measurement allows detection of unsaturated, aromatic compounds and is calibrated to a reference oil standard. It would be desirable in the future to extend this measurement to fluorescence spectrophotometry because of its high sensitivity and the qualitative information that could be achieved. The application of the infrared spectroscopic method loses its importance because of the ban on the halogenated solvents (e.g., it requires carbon tetrachloride or freon as solvent).

5.8 Biological

5.8.1 Benthic Macroinvertebrate Monitoring. Until recently, most water quality monitoring programs have placed emphasis on the physical and chemical components of aquatic systems, while the living organisms (the biological component) in these systems were largely ignored. These physio-chemical approaches yield an incomplete understanding of aquatic systems and, unless a program encompasses the physical, chemical and biological integrity of a system, our understanding of the system is incomplete. The most comprehensive programs often are the most effective potential for enhancing our aquatic ecosystems.

Using aquatic macroinvertebrates will enhance biological monitoring of the Kootenai River watershed. The biological assessment field has produced volumes of research in the last decade, spurred in part by the EPA guidance document *Rapid Bioassessment Protocols for Use in Streams and Rivers: Benthic Macroinvertebrates and Fish* (Pflakin et al., 1989). Since publication of this document, most states have developed and adopted statewide biological assessment programs to help monitor the biological health of their aquatic ecosystems (Davis and Simon, 1995). A recent summary of the status of benthic macroinvertebrate science now is available in EPA's *Revision to Rapid Bioassessment Protocols for Use in Streams and Rivers* (Barbour et al., 1999). Refer to Chapters 7, 9 and 10 of that document for exhaustive details regarding macroinvertebrate monitoring in North America. This document also is available on the web via the EPA website (http://www.epa.gov; once at the EPA homepage, search for "rapid bioassessment protocols").

5.8.1.1 Rationale for Macroinvertebrate Monitoring. Using benthic macroinvertebrates as water quality indicators has many advantages. First, they are sensitive to a variety of chemical and physical impacts, as they live in water and are dependent on favorable conditions for their survival. Second, since they live in the water, they integrate ambient water chemistry conditions over a period of months (or even years); they can also rapidly bioaccumulate pollutants and provide a measure of pollutant bioavailability (Johnson et al., 1993). Hence, intermittent discharges that may be missed by routine "grab sampling" of chemical parameters often can be detected by sampling aquatic macroinvertebrates. Essentially, macroinvertebrates act as nature's continuous monitors of water quality (Hawkes, 1979). Third, macro-invertebrates are very abundant and relatively easy to sample. Fourth, they occupy a central position in the food chain, being a vital pathway for energy flows and processes, and make this energy available to higher trophic levels, including fish. Finally, macroinvertebrate monitoring programs are cost effective. Compared to water chemistry sampling and analyses, collecting and analyzing macroinvertebrate samples costs very little.

It is important to note, however, that using macroinvertebrates as indicators of water quality does have some limitations. Macroinvertebrates are not sensitive to all potential impacts (e.g., herbicides; Hawkes, 1979). In addition, their distribution is influenced not only by water quality, but also by hydrological processes. Finally, they exhibit seasonal shifts in abundance and distribution. These factors need to be considered when designing a study and analyzing the results. Aquatic macroinvertebrates, when used in conjunction with physical and chemical monitoring data, can be a valuable tool for assessing the condition of an aquatic system.

5.8.2 General Sampling Approaches.

5.8.2.1 Single Habitat vs. Multiple Habitat Sampling. Many macroinvertebrate monitoring programs follow a single habitat sampling approach. Typically, riffles are the target habitat as they tend to provide high macroinvertebrate diversity and abundance. In addition, single habitat sampling helps standardize biological assessments of streams of similar habitat type; it is more valid to compare physically similar streams than those that, by nature, are distinct. Riffle-only sampling is a valid approach in higher-gradient, cobble-bottom streams that are dominated naturally by riffle habitat.

If a stream is low gradient by nature and riffle habitat represents only a portion of the total habitat available, then only sampling riffles would be inappropriate (Barbour et al., 1999). In stream reaches where cobbles are limited, as is the case in low-gradient stream reaches, it is necessary to sample alternate habitats. One potential confounding situation occurs when high-gradient streams are heavily impacted by land use activities and the cobble bottom is overwhelmed by fine sediment. In these cases, the stream should still be compared to high-gradient, cobble-bottomed sites (as this was its natural condition) and the biological condition of the site will reflect the impairment.

5.8.2.2 Quantitative vs. Qualitative Macroinvertebrate Sampling. The decision to conduct quantitative or qualitative macroinvertebrate sampling will depend on a study's objectives. Quantitative sampling typically involves sampling a known area of stream bottom so that an estimate of macroinvertebrate numbers and a statistical confidence of the estimate can be calculated. Replication is an important aspect of these studies, as the number of samples to collect will depend on the size of the mean, the degree of aggregation of the population and the desired precision of estimates (Merritt et al., 1996). A common theme among these studies is an estimate of some population, which is not the same as biological assessment.

A drawback of quantitative sampling is the potential cost of such studies when tight constraints are applied to the precision of estimates (i.e., the 95 percent confidence interval). As an example, Schwenneker and Hellenthal (1984) found that a range of 3 to 1,560 Hess samples would be needed to detect a 100 percent change in density for populations of macroinvertebrates in a midwestern stream. Canton and Chadwick (1988) found that a large number of replicates would be needed to estimate most benthic measures; six replicates would provide a 95 percent confidence interval of ±40 percent of the mean for total macroinvertebrate density. Quantitative studies of this nature would be out of the scope of routine macroinvertebrate monitoring programs and would present an impossible financial constraint that would prevent most programs from getting started.

The most common quantitative sampling devices used in streams include the Surber sampler and the modified Hess sampler. The Surber has a sample area of 1ft^2 (0.9 m^2) and the Hess sampler encompasses a circular area of 0.10 m^2. These sampling devices are most effective in flowing, shallow water habitats such as riffles and runs. Water deeper than 0.5 m will limit their usefulness. In deeper waters, quantitative sampling can best be accomplished by the use of a backpack suction dredge. Idaho Power Company uses a diver-operated suction dredge to sample deepwater habitats in the Snake River and reservoirs.

An alternative approach, which is used by many water quality monitoring programs to accomplish their goals, is qualitative sampling. Qualitative sampling produces adequate estimates of species composition, relative abundance, ratios of functional groups, etc. Monitoring these measures over time can be quite effective in determining trends at specific sites, as well as differences between sites. Several state agencies (e.g., MDEQ, Washington DOE, New York DEC, North Carolina DEP, among others) effectively use qualitative sampling methods to stimulate positive changes (i.e., best management practices) in aquatic systems. Successful use of qualitative sampling in state regulatory arenas is a compelling argument of the effectiveness of these methods.

The most widely used qualitative sampling device is the D-frame or rectangular-frame kicknet. The kicknet can be used to sample virtually any wadeable habitat type. Truly quantitative density estimates are not obtainable with this method; however, standardizing the sampling effort (length of stream bottom kicked, number of sweeps through aquatic vegetation, duration of sampling, etc.) can yield reliable estimates of species richness, composition, relative abundance, etc.

5.8.2.3 Data Analysis—Basic Approaches. In essence, the multitude of data analysis techniques can be boiled down to two basic approaches: 1) multivariate and 2) multimetric (Norris, 1995; Gerritsen, 1995). European and Australian workers advocate multivariate approaches, in addition to a small following in North America. These approaches frequently try to group sites using species composition data set against an array of environmental variables (stressors). The end results are the clustering of sites used to establish an *a posteriori* classification system and/or a predictive model of where subsequent test sites will fall (Norris et al., 1993).

The majority of US state water resource agencies have adopted a multimetric analysis approach (Davis and Simon, 1995). Performing data analysis using a multimetric approach occurs in two phases: 1) metric selection, calibration and compilation into an index, and 2) assessment of biological condition or impairment at sites. Fore et al. (1996) developed a multimetric index for forested watersheds in Oregon and demonstrated how a multimetric index is properly constructed, calibrated and verified.

A complete review of these two approaches is beyond the scope of this project. For further information on the subject, refer to Barbour et al. (1999), Rosenberg et al. (1992), and Davis et al. (1994). These texts provide chapters dealing with multivariate and multimetric data analysis, in addition to providing extensive lists of literature references. In following with the majority of North American workers, we recommend the KRN use a multimetric approach for assessing the biological condition of waterbodies in the Kootenai River watershed.

Based on a review of this introduction and the sampling approaches explained above, we can compare the processes currently being undertaken in the Kootenai River watershed.

5.8.3 Biological Assessment Protocols Currently Being Used in the Kootenai River Watershed. There are several aquatic macroinvertebrate protocols currently being used to evaluate streams in this region of North America. State regulatory agencies, such as IDEQ and MDEQ, have existing protocols to monitor macroinvertebrate communities and assess the biological condition of waterbodies. In addition, a protocol developed by Mr. Robert Wisseman, an independent consultant, is widely used in the western US. Research at the University of Washington (Dr. James Karr) has been widely applied throughout the region and around the world. This section provides a synopsis of the bioassessment protocols considered when developing the biological monitoring component of the Kootenai River Basin Water Quality Monitoring Plan.

5.8.3.1 Aquatic Biology Associates, Inc. The Aquatic Biology Associates, Inc. (ABA), bioassessment protocol was developed to assess macroinvertebrate communities in montane streams of western North America. It is conceptually similar to the B-IBI (Fore et al., 1996). It is designed to detect impacts and trends in biological and habitat integrity where cumulative impacts from land management activities occur.

5.8.3.1.1 Sampling Methods. A semi-quantitative, multi-habitat sampling approach is used. The three habitats sampled are riffles (erosional habitat), stream margin and coarse particulate organic matter (CPOM). The samples are non-random; that is, they are collected from the best available habitat within a reach. This gives a conservative assessment of the site, giving a “benefit of the doubt” to the biological assessment.

5.8.3.1.2 Analysis of Data. A multimetric approach is used to evaluate the macroinvertebrate community. The general concept is to use several metrics, score them individually and sum them for an overall biological score for the site.

5.8.3.1.3 Indices. A separate set of metrics is used to evaluate samples from each type of habitat: 53 metrics for riffle samples, 30 for margin samples and 27 for CPOM samples. A three-tiered approach is used to group the metrics for each sample: 1) primary metrics, 2) positive indicators and 3) negative indicators. The primary metrics evaluate the overall community, while the positive and negative indicators are individual taxa or groups of taxa whose ecological requirements are used to evaluate instream habitat and water quality conditions.

The primary metrics used in the bioassessment scheme commonly are used in various protocols throughout North America. These metrics include those discussed below.

1. Total Abundance (#/m^2): ABA’s erosional sample gives a rough estimate of density. Sterile streams, or those with heavy toxic pollution, will have low densities. Healthy streams can have densities of 500/m^2 to several 1,000/m^2, while organically enriched streams can have extremely high densities.
2. Total Taxa Richness: This simplest measure of community diversity is very useful when comparing sites or monitoring the same site over time.
3. EPT Taxa Richness: The subset of species belonging to the mayfly (E), stonefly (P) and caddis fly (T) orders are generally sensitive to various stressors. However, since several species in each order can be quite tolerant, species-level taxonomy will identify whether tolerant or intolerant species (or both) are present.

4. Percent Dominant Taxa: The percent contribution of the dominant species is a simple measure of community diversity. As communities become stressed, the more tolerant species will dominate.
5. Hilsenhoff Biotic Index (HBI): This is a weighted average of the community's tolerance to organic enrichment. Each species has a tolerance value ranging from 0-10. Highly intolerant species are 0s and 1s, while highly tolerant ones are 9s and 10s. Those that are more tolerant to organic enrichment also tend to be more tolerant of sediment, warm water and heavy algal/fungal growth. The index can range from 0-10; higher scores indicate more organic enrichment.

5.8.3.1.4 Scoring Criteria. Within each habitat (sample) type, each metric is scored 0-4 based on specific numeric criteria. The scores are summed and the assessment is expressed as a percent of maximum. Maximum scores for each habitat are 124, 99 and 97 for erosional, margin and detritus habitats, respectively. The "model" stream used for comparison has the following characteristics:

- A dense riparian overstory
- Moderate- to high-stream gradient
- Cobble- or boulder-dominated
- Year-round flow of cool or cold water
- Narrower, deeper channel with highly diverse habitat
- Moderate to high amounts of large wood
- High production of diatoms to support scrapers; low filamentous algae production
- High amounts of terrestrial inputs of leaves and conifer needles
- Low amounts of fine sediment
- Limited scour and bedload movement
- Hyporheic zone open to invertebrate use (not silted in)
- High amount of cobble interstices (crevices) around and under cobbles.

5.8.3.1.5 Applicability to Kootenai River Watershed. This method is widely applicable to mountainous streams in the western US and Canada and more than 3,000 sites have been analyzed with this method. However, the model stream is admittedly unattainable by most watersheds even in the absence of human disturbance. Low-gradient reaches naturally will score lower and large rivers are out of the scope of the model.

5.8.3.2 Benthic Index of Biotic Integrity. (B-IBI, Fore et al., 1996)

5.8.3.2.1 Sampling Methods. Three quantitative Surber samples are collected from one representative riffle. The primary modification (by Fore) from Karr's method is that samples are identified to species whenever possible, as opposed to genus.

5.8.3.2.2 Analysis of Data. As with many other bioassessment protocols, a multimetric index (B-IBI) is used to evaluate the macroinvertebrate community.

5.8.3.2.3 Indices. The multimetric index consists of 10 component metrics. The description below of metrics is from a draft report to the City of Belleview (Fore, in prep.) and describes the component metrics.

1. Total Taxa Richness: The biodiversity of a stream declines as flow regimes are altered, habitat is lost, chemicals are introduced, energy cycles are disrupted and alien taxa invade. Total taxa richness includes all the different invertebrates collected from a stream site: mayflies, caddis flies, stoneflies, true flies, midges, clams snails and worms.
2. Mayfly (Ephemeroptera) Taxa Richness: The diversity of mayflies declines in response to most types of human influence. Many mayflies graze on algae and are particularly sensitive to chemical pollution (e.g., from mine tailings) that interferes with their food source. Mayflies may disappear when heavy metal concentrations are high, while at the same time caddis flies and stoneflies are unaffected. In nutrient-poor streams, livestock feces and fertilizers from agriculture can increase the numbers and types of mayflies present. If many different taxa of mayflies are found while the variety of stoneflies and caddis flies is low, enrichment may be the cause.
3. Stonefly (Plecoptera) Taxa Richness: Stoneflies are the first to disappear from a stream as human disturbance increases. Many stoneflies are predators that stalk their prey and hide under and between rocks. Hiding places between rocks are lost as sediment washes into a stream. Other stoneflies are shredders and feed on leaf litter that drops from an overhanging tree canopy. Most stoneflies, like salmonids, require cool water temperatures and high oxygen to complete their life cycles.
4. Caddis fly (Trichoptera) Taxa Richness: Different caddis fly species (or taxa) feed in a variety of ways. Some spin nets to trap food while others collect or scrape food from the tops of exposed rocks. Many caddis flies build gravel or wood cases to protect themselves from predators while others are predators themselves. Even though they are very diverse in habit, taxa richness of caddis flies declines steadily as humans eliminate the variety and complexity of their stream habitat.
5. Intolerant Taxa Richness: Animals identified as intolerant are the most sensitive taxa; they represent approximately 5-10 percent of the taxa present in the region. These animals are the first to disappear as human disturbance increases.
6. Clinger Taxa Richness: Taxa identified as clingers have physical adaptations that allow them to hold onto smooth substrates in fast water. These animals typically occupy the open area between rocks and cobbles along the bottom of the stream. Thus they are particularly sensitive to fine sediments that fill these spaces and eliminate the variety and complexity of these small habitats. Clingers may use these areas to forage, escape from predators or lay their eggs. Sediment also prevents clingers from moving down deeper into the stream bed, or hyporheos, of the channel.

7. <u>Long-Lived (Semi-Voltine) Taxa Richness:</u> These invertebrates require more than 1 year to complete their life cycles; thus, they are exposed to all the human activities that influence the stream throughout one or more years. If the stream is dry part of the year or subject to flooding, these animals may disappear. Loss of long-lived taxa may also indicate an on-going problem that repeatedly interrupts their life cycles.
8. <u>Percent Tolerant:</u> Tolerant animals are present at most stream sites, but as disturbance increases, they represent an increasingly large percent of the assemblage. Invertebrates designated as tolerant represent the 5-10 percent most tolerant taxa in a region. In a sense, they occupy the opposite end of the spectrum from intolerant taxa.
9. <u>Percent Predator:</u> Predator taxa represent the peak of the food web and depend on a reliable source of other invertebrates that they can eat. Predators may have adaptations such as large eyes and long legs for hunting and catching other animals. The percentage of animals that are obligate predators provides a measure of the trophic complexity supported by a site. Less disturbed sites support a greater diversity of prey items and a variety of habitats in which to find them.
10. <u>Percent Dominance (3 Taxa):</u> As diversity declines, a few taxa come to dominate the assemblage. Opportunistic species that are less particular about where they live replace species that require special foods or particular types of physical habitat. Dominance is calculated by adding the number of individuals in the three most abundant taxa and dividing by the total number of individuals collected in the sample.

5.8.3.2.4 Scoring Criteria. Biological indices are scored a 1, 3 or 5 based on numeric criteria for each and a total biological score for the site is obtained (maximum score=50). Level of impairment is determined based on what range of values the overall score falls within. Numeric criteria have been modified to accommodate species-level determinations, as opposed to the genus-level work proposed by Fore et al. (1996).

5.8.3.2.5 Applicability to the Kootenai River Watershed. The component metrics used in the B-IBI improve on some of those used by ABA. For instance, EPT taxa are used separately as E, P and T, which allows for better detection of impacts (each group responds differently to human disturbances). By lumping all orders into one group (EPT), as is the case with other protocols, some sensitivity to impacts is sacrificed. The B-IBI is directly applicable to streams in the Kootenai River watershed. Once again, however, large rivers are out of the scope of the B-IBI.

5.8.3.3 Idaho DEQ. Idaho's BURP program, initiated in 1993, relies heavily upon benthic macroinvertebrates to determine whether stream sites are meeting designated beneficial uses. Between 500-800 sites per year are sampled, making it the largest statewide program of its kind in North America. Most sites are wadeable streams; however, recent sampling efforts have included large rivers, lakes and reservoirs.

5.8.3.3.1 Sampling Methods. In wadeable streams a single-habitat (riffles only), quantitative-sampling approach is used. Three individual Hess samples are collected in riffle areas on transects (total area sampled = 0.3 m). When riffles are unavailable, runs or glides are substituted. In large rivers and reservoirs, quantitative sampling equipment varies depending on substrate conditions. In most cases the Slack sampler, developed by the National Water Quality Assessment Program (Cuffney et al., 1993), is used. A total of nine quantitative samples are collected, three samples on each of three transects, and are composited in the field. Total bottom area sampled varies depending on the sampler used. In all cases, total macroinvertebrate densities can be estimated, if needed.

5.8.3.3.2 Analysis of Data. As with many state monitoring programs, and many other monitoring protocols in the Northwest United States, Idaho uses a multimetric Macroinvertebrate Biotic Index (MBI) to obtain an overall biological score for a site. The waterbody assessment procedure relies heavily on MBI scores when determining whether or not a stream supports its designated beneficial uses.

5.8.3.3.3 Indices. Biological indices are calculated for each site. The indices (metrics) were selected based on a literature review. The metrics used in the MBI are described below.

1. Percent EPT Abundance: Proportion of mayflies (Ephemeroptera), stoneflies (Plecoptera) and caddis flies (Trichoptera) in the sample. These orders represent many of the intolerant taxa encountered in streams.
2. HBI: This index measures the community tolerance to organic enrichment. It is an average (weighted by abundance) of the tolerance values assigned to each taxa. HBI scores can range from 0-10, with zero meaning a community is highly intolerant of organic enrichment (Hilsenhoff, 1987).
3. Percent Scrapers: These invertebrates scrape diatoms, algae and organic films off the top of rocks or wood surfaces. Their relative abundance has been shown to decline with sedimentation or organic pollution. Margin habitats often contain a higher proportion of scrapers, as they are important rearing areas for early instar scrapers.
4. Percent Dominant Taxon: High abundance of a single taxon can indicate a stressed benthic community, which allows one or a few tolerant taxa to dominate the community.
5. EPT Taxa Richness: The number of mayfly, stonefly and caddis fly species present in a sample is a good indicator of habitat and water quality.
6. Taxa Richness: Taxa richness (total number of discrete taxa) is directly correlated with habitat diversity and water quality. Monitoring taxa richness over time can help determine if conditions are improving, declining or stable.
7. Shannon-Weiner Index: A diversity index based on information theory. As with other diversity indices, higher values correspond to greater diversity. This index can be calculated using the natural log (ln), $\log_2$ or $\log_{10}$ (Shannon and Weaver, 1949). It has been widely used in ecological studies as a method to simplify comparisons.
8. Percent Collector-Gatherers: This feeding group collects fine particles of organic materials as their food source. They prefer depositional areas or areas with soft

substrates. High numbers in riffle areas indicate that fine particulates are being deposited in excess of "normal" amounts.

9. Density: Density is a basic measure of relative productivity in a stream. Extremely low levels indicate a harsh environment for invertebrates due to low nutrient levels, chemical or toxic contamination, or ephemeral stream flow. Very high densities can occur due to excessive organic enrichment.

5.8.3.3.4 Scoring Criteria. The MBI score can range from 0-7. Status of beneficial use support is determined based on what range of values the overall score falls within. Three categories currently are used: 1) full support, 2) needs verification and 3) not full support.

5.8.3.3.5 Applicability to the Kootenai River Watershed. The sampling methods used by the BURP program could easily be applied throughout tributary streams in the Kootenai River watershed; indeed, Idaho tributaries to the Kootenai River currently are being sampled this way. The MBI, however, has not been rigorously evaluated as to its performance and effectiveness in separating impacted and non-impacted sites. Until a thorough analysis of this index is complete, it should best be viewed as a tentative tool for bioassessment of wadeable streams in the watershed. Comparing reference sites to impaired sites within the Kootenai River watershed will help determine the effectiveness of the MBI.

5.8.3.4 Idaho DEQ—Large River Bioassessment. Idaho has developed a river index of biotic integrity, called the Idaho River Index (IRI), using benthic macroinvertebrates (Royer and Minshall, 1996). Once again, a multimetric approach is used to obtain an overall biological score for a river site. The work is considered preliminary and additional research results will be used to refine the index.

5.8.3.4.1 Indices. Five macroinvertebrate metrics passed statistical and performance analyses and were included in the index, although additional metrics may be incorporated in the future as more sites are sampled. The indices included are as follows:

1. Taxa Richness: Degraded water or habitat quality in rivers yields lower taxa richness scores
2. Percent Elmidae: The elmidae, or riffle beetles, appear to be a sensitive indicator group in river systems, as they were significantly reduced in impacted rivers
3. EPT Richness: see previous description of this measure
4. Percent Dominance: see previous description of this measure
5. Percent Predators: see previous description of this measure.

5.8.3.4.2 Scoring Criteria. Each metric is scored either a 1, 3 or 5 depending on how the score compares to reference (least impacted) conditions. One exception is percent predators, which is less able to discriminate between impacted and unimpacted sites. To compensate for this shortfall only two scores, 1 or 3, are possible. Scores for each metric are summed to obtain an overall index score for a site (maximum score=23) and, subsequently, the impairment status.

5.8.3.4.3 Applicability to the Kootenai River Watershed. This protocol will be quite useful for biological monitoring of the mainstem Kootenai River, as it represents the only regional tool of its kind. Incorporating data from the Kootenai River also will help refine further development of the IRI.

5.8.3.5 Montana DEQ. The MDEQ uses a qualitative sampling approach for wadeable streams. A traveling kick sample is used to collect aquatic macroinvertebrates. Only riffle habitat is sampled in high-gradient streams. A linear length of 20 feet is kicked for a duration of 1 minute. This standardizes the sampling effort.

In low-gradient streams, a qualitative, multi-habitat approach is used. Once a representative reach is delineated, a 20-jab sample is collected. This involves allocating a number of jabs to riffles, snags, vegetation and bank margins in the same proportion as the occurrence of these habitats within the reach. When riffles are sampled in low-gradient streams, one “jab” is equal to a 1-meter traveling kick sample.

5.8.3.5.1 Analysis of Data. Streams are grouped into one of three categories for data analysis: 1) plains, 2) intermountain valley and foothills, and 3) mountain. A multimetric index for each category is used to determine an overall biological score and impairment level for a site.

5.8.3.5.2 Indices. The number and composition of indices used to assess streams varies by stream category (7-10). For details regarding the biological assessment process, refer to the latest working draft of Montana’s macroinvertebrate protocols (Bukantis, 1998).

5.8.3.5.3 Scoring Criteria. As with most multimetric indices, a 3-score system is used to evaluate component measures of the index (1, 3 or 5). The total maximum score for each of the three stream categories is 30, 24 and 21 for plains, intermountain valley and foothills, and mountain, respectively. A site is considered to fully support its beneficial uses if the total score is at least 75 percent of its maximum. A score of less than 25 percent represents severe impairment and a violation of water quality standards. Values from 25 percent to 75 percent of maximum are considered a moderate violation of standards.

5.8.4 Macroinvertebrate Monitoring Plan for the Kootenai River Watershed. To produce a meaningful biological assessment program, there must be an accurate, meaningful stratification of potential sites to monitor. Looking at the major aquatic habitats within the watershed, one can reasonably come up with four primary strata: 1) mainstem Kootenai River, 2) wadeable tributaries, 3) lake or reservoir and 4) wetlands. A step-by-step approach should be used to build an effective biological assessment program. Since regional protocols are looking primarily at wadeable streams and non-wadeable rivers, the KRN should focus on these two habitats for now. Once a network of reference and test sites has been established and an initial monitoring program is underway, additional habitats can be included later.

5.8.4.1 Framework for Sampling Network. Unless the KRN has an unlimited budget, it is impossible to monitor every tributary and every mile of river every year. This limiting factor is what will determine the number of sites per year that can be sampled. Since wadeable tributaries account for the majority of waterway miles in the watershed, this is where the most potential monitoring sites will be. Faced with fiscal constraints and the potential volume of sites, a Rotating Basin Intensive Survey approach is recommended. Using this approach, a percentage of sites (suggest 20 percent) are sampled intensively each year on a rotating basis. The result is that each site is sampled every 5 years and any trends from improvements or degradation in the tributary watershed that occur in the interim can be documented. Priority sites (i.e., those of special concern) can be monitored more closely and more frequently, if so desired.

5.8.4.2 Field Sampling—Mainstem Kootenai River. A pilot macroinvertebrate study on the mainstem Kootenai River was conducted by Hopkins and Lester (1995). A variety of sampling gear was used to sample macroinvertebrate communities due to the different substrates present in the river. A more detailed, follow-up study was conducted by Richards (1998). Multiple sampling gear was used to accommodate the variety of habitats present in the river.

Ideally, mainstem macroinvertebrate monitoring stations should coincide with chemistry monitoring sites. These sites could be located above and below key tributary watersheds that are potentially contributing significant sources of pollution. Additional stations can be established if there are specific concerns along the river itself (point discharges or other instream disturbances).

A minimum of three replicates should be collected to obtain an estimate of sampling variability and repeatability of the biological assessment process. The only sampling method available that would be consistent among all sampling stations in the mainstem river is a modified Hester-Dendy multiplate sampler suspended in the water column (Bode et al., 1996). This device, when suspended in the water column, will collect drifting macroinvertebrates.

In order to effectively sample the actual bottom habitats in the river, multiple devices will be needed (Hopkins et al., 1995; Royer et al., 1997). The drawback of using multiple devices is the sampling biases associated with each; investigators need to account for this in the final analysis of data. A minimum of three replicates must be collected and enough bottom area should be sampled to collect at least 500 invertebrates. Based on previous work in the Kootenai River, three ponar grabs should be collected on a transect and composited into one sample in the field. A total of three transects per site will fulfill minimum replication requirements (a total of nine ponar grabs should be collected per site). Field sampling protocols are outlined in Royer et al., 1997.

5.8.4.3 Field Sampling—Wadeable Tributary Streams. The MDEQ protocols for high- and low-gradient streams (described above) will be a useful method to obtain representative samples of macroinvertebrate communities in these situations. Once again, a minimum of three replicates need to be collected per site—three traveling kick samples in high-gradient streams or three multiple habitat samples in low-gradient streams.

5.8.4.4 Sampling Season. As with any monitoring program, consistency is needed to produce reliable results. Macroinvertebrate communities are dynamic, gradually changing in species richness, trophic composition and total abundance annually. Dramatic shifts occur in a matter of a day or two when larval insects "hatch" and leave the benthic community. Considering this, program managers need to keep between-year sampling dates as consistent as possible. The most optimal time window for macroinvertebrate sampling is late summer or early fall, after baseflow conditions have been stable for a time. This allows the macroinvertebrate community to adjust to the available habitat conditions and reduces the effects of natural hydrology on the macroinvertebrate community and subsequent biological assessments.

5.8.4.5 Macroinvertebrate Sample Processing. In order to get consistent, accurate macroinvertebrate data, it is recommended that a proven, qualified contract laboratory be hired to process macroinvertebrate samples. Although many people have some experience with aquatic macroinvertebrate taxonomy, few do it well. Considering the importance of this data and the effort expended to collect it, using a poor or average taxonomist to process the samples can compromise the final utility of the dataset. An aggressive QA/QC program is necessary to ensure taxonomic accuracy and consistency.

Mainstem river samples should be processed according to IDEQ's BURP contract with a private laboratory. Maintaining this consistency is critical if results are to be compared with other Idaho rivers. Wadeable stream samples should be processed according to MDEQ protocols. The vast majority of tributaries (if not all) in the watershed will fall within the mountain category of stream discussed above.

5.8.4.6 Data Analysis. Biological assessment of the mainstem Kootenai River will be best accomplished by using the IRI. Wadeable tributary streams should be assessed using the MDEQ bioassessment protocols (discussed above).

5.9 Field Sampling Protocols

1. Rinse the vial with sample water both before actual sample collection and preservation.
2. Avoid excessive aeration and agitation of the sample by pouring the sample slowly down the edge of the sample vial.
3. Fill vial so that a reverse (convex) meniscus is present (in the case of water in a glass container).

4. Place septum on the vial so the Teflon™ side is in contact with the sample and then tighten the cap.
5. Immediately invert the vial and lightly tap to locate air bubbles.
6. If air bubbles are present, discard the sample and recollect the sample. Check the recollected sample for air bubbles. If air bubbles are present, additional sample water may be added to the vial in an attempt to eliminate the air bubbles. The presence of air bubbles after three consecutive attempts to rid the sample of the condition should result in the use of a new sample container and recollection of the sample. Regions vary in their approach to rinsing the sampling vial and recollecting the sample in the same vial. BE SURE TO FOLLOW REGIONAL GUIDANCE.
7. Do NOT mix or composite samples.
8. Immediately transfer the sample container to a sample cooler once it has been collected. Do not allow ice to touch the vials.

5.10 Sample Identification

A sample label will be affixed to each sample container before sample collection. Include the following information on each sample label:

- Sample number
- Initials of person collecting the sample
- Date and time of sample collection
- Type of preservative (if any)
- Analyses to be conducted.

Water quality monitoring is a process of temporal sampling, in an aquatic habitat, which is affected by random events, seasonal changes and serial correlations (Whitfield, 1988). The majority of monitoring programs have resulted in collections of a limited number of samples obtained at infrequent intervals, usually over irregular periods. The data profiles from such programs frequently do not reliably represent the aquatic habitat being sampled. Although water quality monitoring increasingly has become subjected to numerous statistical assessments, in the absence of a carefully crafted program of focused goals and data collection designs such programs have minimal chance of detecting anything other than catastrophic change. Successful monitoring must be designed to link a clearly defined purpose for conducting the monitoring with the management of water quality—usable data must be convertible into usable information (i.e., reversal of the data-rich, information-poor syndrome; Ward et al., 1986). The past few years have evidenced a significant change in the manner in which data are analyzed and in carefully designing *a priori* objectives that can be rigorously tested (Whitfield, 1988).

Ecosystem response to stress can be quite variable (Cairns and Niederlehner, 1992) and range from perturbation-dependent systems (e.g., natural processes—fires, floods, disease, etc.) to perturbation-independent systems (e.g., tropical rain forests). Thus, a primary ecosystem risk assessment objective should be an estimation of ecosystem elasticity or resiliency—the recover potential from either functional or structural norms (Cairns and Niederlehner, 1992; Whitfield and Clark, 1997). Whitfield and Clark (1997) note "for specific environments, such ecosystem responses may be characterized either in terms of 'sensitivity,' which is the amount of stress which generates an ecosystem response, or in terms of 'resilience,' which is the ability of an ecosystem to recover from stress." In particular, these authors note that:

> *Intensive environmental studies through the recent decades have given us a fairly good understanding of those forces both which drive and which modify ecosystems. The purpose of (management) is to (understand) how this knowledge of driving forces may be employed to target data most likely to yield sensitivity and resilience information, whether interpreting large data compilations, or designing more cost-efficient monitoring programs.*

Since any variable that fluctuates over time can be perceived as a signal (and evaluated using signal analysis techniques) (Whitfield and Clark, 1997), environmental data can be assessed using primary signal analysis; this work describes in detail the theory of this approach. The value of this approach, however, is that a "force analysis technique" can be used to target sample collection or data interpretation (i.e., historical data sets) with significantly enhanced efficacy. These authors note that:

> *To target sample collection or data interpretation according to a force analysis approach, we need to characterize the forces in the environment in such a manner that the "transmitted signal" results in the magnitude of "received signal" exceeding any "received noise." Ideally we look for a situation where a small signal change will result in some large change in response, i.e., "signal amplification." Sampling programs and data evaluations which focus on stationary data sets are far more likely to return useful sensitivity and resilience inferences than similar effort on non-stationary data sets. The transition points at the end of stationary signals sometimes can yield valuable insights, as one force supersedes another force as dominant in the particular ecosystem.*

The force analysis approach inventories and characterizes those forces that can be expected to drive the system, such that this technique can isolate critical periods for further study. Whitfield and Clark (1997), in describing the use of force analysis to detect "environmental signals," describe a number of example applications pertinent to the KRN's objective of developing a water quality monitoring program for the Kootenai River watershed.

- Case 1—climate change impact on streamflow and water quality in British Columbia. In this case study the authors outline the theoretical design of a monitoring program and then validate the design through an analysis of existing data inventory records. Their analysis suggests that there is a statistically significant change in the environmental variables of concern and that the change (while proven to be caused by global warming) does reveal that the targeted rivers are vulnerable—sensitive and not resistant—to global warming. The signal signature does appear consistent with that of global warming.

- Case 2—anthropogenic impact to the St. Mary River (downstream of Cranbrook, BC), which flows into the Kootenay River. The effect of the Sullivan mine site on the chemistry of the river through acid mine drainage (lead-zinc mine) and wastes from a former fertilizer previously associated with the mine. Analysis of iron data (known to be in statistical control) revealed that the control sites remained stationary (no change), whereas the downstream sites appear to be moving from non-stationary to stationary (improvement in quality).

Since any environmental variable that exhibits temporal fluctuations can be characterized as a signal, Whitfield and Clark (1997) provide the argument that appears below.

> *Those signals which show strong episodic or periodic autocorrelation are indicative of transitions from domination by one type of driving or modifying force to another type. We can optimize our return of information per investment of resources by targeting either stationary segments of signal which are dominated by the force of interest, or upon the transitional point at the end of such piece-wise stationary signals where one force replaces another as dominant in the system. This force analysis approach may usefully be applied both to the design of cost efficient new monitoring programs, and as an effective means to target relevant information in large data files. (We) believe it may not be widely appreciated that the fact global warming impacts cause loss of signal stationarity implies that greater effort and costs will be required in future years to characterize impacted environmental signals.*

The following section describes a general-level approach to developing a water quality monitoring sampling program, with particular attention to sample frequency. Given the comments noted above—using signal analysis to both review old data sets, as well as new ones, together with the need for cost-efficient programs—development of a new sampling program must be based on clearly identified objectives with a high likelihood of sensitivity detection. Recent reviews of the water quality monitoring literature reveal that the historical approach of sampling a wide range of parameters—largely dependent on the availability of physical and chemical analytical techniques—and subsequent "statistical fishing expeditions" to determine what was found, have proven expensive and inefficient and left management and society information poor (Ward et al., 1986).

The concepts that follow have been largely obtained from the 1998 NATO document section describing "Statistics As A Tool in Network Assessment and Redesign," compiled by NATO (1998). A review of the statistical literature reveals that this chapter represents an excellent review of the current thinking concerning sample frequency, while the comments by Whitfield and Clark (1997) detail recent recognition that signal analysis is a powerful new analytical tool. These approaches have been designed to decrease the quantity of data collected, while increasing the quantity of information.

NATO (1998) suggests that "design of a water quality monitoring network is an iterative process. It evolves in time in response to changing data needs, objectives of monitoring, economic vagaries, changing force functions, etc. When designing or redesigning a water quality monitoring network system, it is often necessary to gain a clear understanding of the dynamic behaviour of the water quality processes involved." One framework that can be used to relate the linkages among the various design processes is shown in Figure 5-2 in a proposed water quality monitoring network design scheme.

> *Each component of the design process is expressed in terms of numbers and/or equations and statistics are used to express the data in summary form. When the information is summarized in the form of plots or tabulated data, etc., we say it is of non-parametric form. When it is summarized in the form of an empirical (black-box) model, it is of parametric form. In what follows the parametric statistics will be discussed. Although statistical descriptors employed in water quality monitoring network design are well established and can be found in standard statistical texts, for the sake of completeness, a brief discussion of them is appropriate here. It should be emphasized that different statistics are relevant to the different components of the design process, as will be clear later in the discussion.*
>
> *First, we define autocorrelation and cross-correlation functions for stationary stochastic water quality processes. A stochastic process is a phenomenon that evolves in time following the laws of probability. A stochastic process is strictly stationary if its statistical properties are unaffected by a change in time origin, i.e., if the joint probability density function associated with n observations made at a set of times is the same as that associated with n observations made at any other set of times. Thus, a stationary stochastic process will have a fixed or constant mean and a constant variance. The covariance between the values of the process separated by k periods of time will be constant and only a function of the lag k of separation. While the terms of reference for this study did not require a detailed description of current statistical theory, regarding monitoring network design, the reader is directed to an excellent description of basic statistical approaches contained in Chapter VIII (Basic Tools – Statistics and modeling; V.P. Singh and M. Fiorentino, NATO, 1998).*
>
> *In practice we only have available a finite water quality time series of N observations, which can be regarded as a particular realization of some underlying stochastic water quality process. From these observations, we estimate the auto and cross correlation functions. The most satisfactory estimate of the autocovariance is usually taken (Jenkins and Watts, 1968).*

One of the objectives of a water quality monitoring network is to monitor the actual state of water quality. This is accomplished through (1) detection of trends, (2) determination of periodic fluctuations, and (3) estimation of mean values of the stationary component. Indeed the sampling frequency will be dictated by the trend detectability, the accuracy of estimation of periodic fluctuations and the accuracy of the estimation of the mean values. Each of these components will have its own frequency and the sampling frequency will be the highest of three frequencies. The power of the Student's t test is used as a quantitative criterion for detection of a linear or step trend (Lettenmaier, 1976). The power of the test is the probability of trend detection, i.e., trend detectability. For a sample size of N independent observations, the power of trend detection can be calculated (Lettenmaier, 1976). At a given location, the standard deviation and correlation structure are estimated from the sample of observations. The trend magnitude and the length of time must be determined from observations. Then the Lettenmaier (1976) equation is applied, and together with the sampling frequency, the trend detection is specified.

Due to seasonal variations in climate, e.g., rainfall, temperature, prevailing wind direction and speed, water quality parameters may exhibit periodic fluctuations. These fluctuations may be determined using harmonic series analysis. The frequency of the harmonics to be chosen for fitting the data series must be restricted to cases which have been determined to fit the Nyquist frequency model. The Nyquist frequency gives the minimum sampling frequency required. The harmonic analysis may reveal the highest frequency of significant periodic fluctuations in the real time series.

For determination of sampling frequency, a quantitative measure of network effectiveness is needed, which, in turn, is related to monitoring objectives. Zhou (1996) proposed the sampling frequency to be the highest of f_T and f_p, and f_m. Table 5-3 shows the criteria for analysis of these frequencies.

In using statistics in network design and assessment, a variety of mathematical tools are available for each step in the design of a water quality monitoring network. Below is a brief synopsis of some of the statistics commonly used (NATO, 1998).

Driving Forces – These provide the input to the watershed. The input can be natural such as acid precipitation, or man-made both point source and non-point source, such as waste discharge from an industry, city sewage water, agricultural pollution due to chemical fertilization, etc. The data expressing the driving forces must be checked for quality, trend, completeness, homogeneity or consistency. Frequently, there are gaps in the data and they must be filled in. Mass curves are used for checking the homogeneity or consistency of data. Normal ratio method, inverse *distance squared method, and correlation methods are among the methods for filling in missing values. Entropy method is also used for this purpose (Singh and Harmancioglu, 1997). The data must also be checked for their errors, representativeness, and sampling strategy. All data are not collected at the same temporal frequency. Some are collected more frequently than others. The question then arises: How to transform them to the same base frequency, as may be needed by the design methodology, without undue loss of information. Statistics help accomplish this objective. Statistical methods for trend detection are employed if data have any persistence.*

Watershed System – When dealing with a watershed, soil, vegetation, land use, morphology, and geology must be known or specified. These characteristics influence the pollutant transport and storage within the watershed. Complicating specification of these characteristics is their spatial variability. Statistics aid in characterizing this variability. Furthermore, statistics help classify basins based on similarity and homogeneity measures. These latter measures are useful when transposing results from one watershed to another. Here the correlation methods and kriging are helpful.

Observed Data – Once a water quality monitoring network has produced some data, these data are analyzed for information extraction. Using these data, the network design is checked for optimality. In other words, if sampling frequencies in space and time are acceptable and are in accord with the design objectives, and the cost of data collection is not prohibitively large, then the designed network is satisfactory. To that end, entropy and correlation methods are employed. Other statistical measures, such as spectral methods and information content, can also be employed.

Selection of Methods – Statistics gives criteria to check robustness of methods and then predicate the basis for selection of suitable models. The criteria most frequently employed are the bias, root-mean-square error, and coefficient of efficiency. The first two are added to define a robustness criterion.

Modeling Techniques – Water quality data are essential for environmental management as well as for model building, calibration, verification and real-time application. Data requirements of different models are, however, different since these models are intended for different purposes. On the other hand, depending on the availability of the type and quality of data, different types of models are developed. Thus, data and models are interdependent. In practice, two criteria can be distinguished by which models and their data requirements are identified: 1) spatial and temporal resolution, and 2) level of analysis.

Two broad categories of temporal resolution include continuous and discrete, and those of spatial resolution include lumped and distributed types. Water quality variables are sampled mostly at discrete time intervals, meaning that water quality models can, strictly speaking, be only discrete-time models. Continuous-time water quality models have to be based on temporal interpolation between sampled points. Water quality models are either lumped or distributed. Again, availability of data was, until recently, the primary limitation on the development of distributed models. Most water quality models are either lumped or quasi-distributed, for water quality variables are measured at only a limited number of points and not continuously in space.

The level of analysis is determined by the amount and resolution of the data (both quantity and quality) on one hand and by the purpose of the assessment and availability of resources on the other. Thus, water quality models can be classified according to the level of analysis to be achieved by their use: screening, primary and secondary models. Screening models provide a quick examination of the environmental fate of a water quality variable and are, therefore, used to provide a qualitative assessment about the behavior of the variable at a specific site. Example applications of such models for water quality analysis are as follow:

- *Evaluation of the relative erosion potential of different soil types in a watershed*
- *Evaluation of the relative effect of the rainfall characteristics on chemical washoff*
- *Comparison of the relative chemical migration in variable climatic regimes*
- *Evaluation of health hazards of different chemicals and so on.*

The data requirements of such models are rather limited.

The objective of primary models is to provide a more detailed representation of predominant environmental fate processes at an intermediate level. In other words, their results are a little more meaningful and quantitative than those of screening models. Example applications include the following:

- *Evaluation of the risk of exposure to contaminants above a certain threshold*
- *Evaluation of surface and subsurface transport of chemicals applied during cropping*
- *Estimation of chemical loading downstream due to human activities upstream, etc.*

Primary models can help identify dominant processes and variables. Thus, they constitute a good management tool. Their data requirements are intermediate.

Secondary models are used for performing comprehensive analyses of water quality processes. Example applications include the following:

- *Evaluation of the fate and transport of agricultural chemical*
- *Quantification of the effect of agricultural practices on non-point source pollution*
- *Estimation of the import of human activity upstream on chemical loading downstream, etc.*

The data requirements of these models are high.

5.11 Summary

Since the health of an ecosystem is the sum total of its environmental parameters and ultimately is a reflection of the health of the wildlife that reside there, physical and chemical parameters are only indirect measures of what is biologically important. Thus, these parameters are only indirect estimates useful in making a diagnosis of whether a system is likely to be biologically healthy. Therefore, monitoring the effects of land use activities on aquatic health will require that the four general components be measured: 1) physical, 2) chemical, 3) biological and 4) ecological. The latter category comprises how the first three interact in a dynamic fashion through time. Since we are proposing to monitor streams in which the vast majority of biota is associated with the benthos, we believe that the benthic biology refers to fish, macroscopic invertebrates and meiofauna, periphyton, fungi, bacteria and hyporheic organisms (below substratum surface). The periphyton community consists of the microscopic benthic algae (Wetzel, 1983), whereas benthic algae are those species that form filamentous mats. The principal difficulty in studying these communities is that they are complex and it is not always possible to identify indicator species as analogues of community function. Additionally, there is a serious shortage of qualified people who can provide the necessary level of taxonomic identifications, especially in a timely manner, at affordable costs. The structure of the trophic levels will be used to predict the health and likelihood of a sustainable fishery within each watershed. Since the latter is a reflection of both the watershed production capabilities and anthropogenic disturbances, which can significantly reduce production potentials, each system must be studied separately—no single system can be used to predict how every other system should perform.

Since the traditional discrete monitoring programs can only provide narrow windows of understanding, we propose the use of remote, continuous monitoring of selected environmental parameters. The continuous data stream will permit a comparison of long-term water quality trends, predicted from a discrete monitoring profile, calibrated with those provided by continuous monitoring. The continuous monitoring program then will be compared with the biological database to assess water quality trends; trends will be compared with other data from the watershed and from other interior watersheds.

The water quality monitoring program proposed here will result in the compilation of baseline information concerning the effects a wide range of land uses have or could have on the aquatic health within the subwatersheds of the Kootenai River watershed, above Kootenay Lake. Undertaking a broadly based study—monitoring trophic-level interactions—on a watershed scale should significantly enhance the realism of predictive models. Employing a large number of environmental parameters could permit the models to be tested to determine whether the appropriate parameters were selected or whether additional ones should be added or subtracted in subsequent years of testing. Thus, one of the most important aspects of the study is both its longitudinal nature (multiyear) and its comprehensiveness. It is crucial to recognize that the problem with such programs is that the more broadly based and long-term the study, the more expensive it is to conduct—and for which to obtain long-term funding. Another problem is that such studies are increasingly likely to have funding either reduced, or eliminated, as the study progresses, which may reduce the value of the data collected in the initial stages of the study. Change in government also can affect long-term funding, as can public perceptions of the role of government in conducting such studies.

Since this project proposal is designed to be conducted over an extended period of time (3 to 10 years), we propose that senior research scientists and graduate students conduct a significant portion of the work. There are a number of benefits to be derived from this approach including reduced personnel costs; dedicated, long-term commitment to the project; state-of-the-art knowledge and external peer review; expanded laboratory and equipment facilities; and a thorough, up-to-date critical literature review. Additionally, in this type of project there is an important training piece where the graduate student receives both theoretical knowledge and invaluable training in conducting field studies.

We recommend that the sampling program be a cooperative venture with the proposed NSERC-Industry Research Chair in Environmental Management in Drinking Water. The Chair has proposed that the subwatersheds of Gold, Joseph, Matthew and Mark Creeks be used as reference watersheds.

We also believe that the long-term protection of these watersheds can only be accomplished through diligent, local community-based study and monitoring of watershed activities through a comprehensive training program to enable them to conduct much of the field work. This approach, we believe, is best conducted through the training of municipal staff who would conduct a major portion of the sample collection as part of their regular duties.

5.12 Recommendations

- The PFC technique should be incorporated into the basic water quality monitoring program. It should be used to develop a baseline health status of the numerous tributaries flowing into the main channel of the Kootenai River.

- The KRN should convene a conference to assemble people who recently have conducted studies within the Kootenai River watershed. The conference objective should be to review the work already undertaken and provide a forum to help determine what additional work should be conducted. The conference should reflect a multidisciplinary viewpoint and bring together scientists, industry, NGOs, educational, government and political leaders.
- The existing literature database of studies conducted within the Kootenai River watershed should be housed in three public or post-secondary education libraries in Libby, MT; Bonners Ferry, ID; and Cranbrook, BC. The literature database should be housed as both a hard copy and in an electronic format.
- Consideration should be given to creating a web site at a post-secondary institution where the literature database could be made available to the widest possible audience.

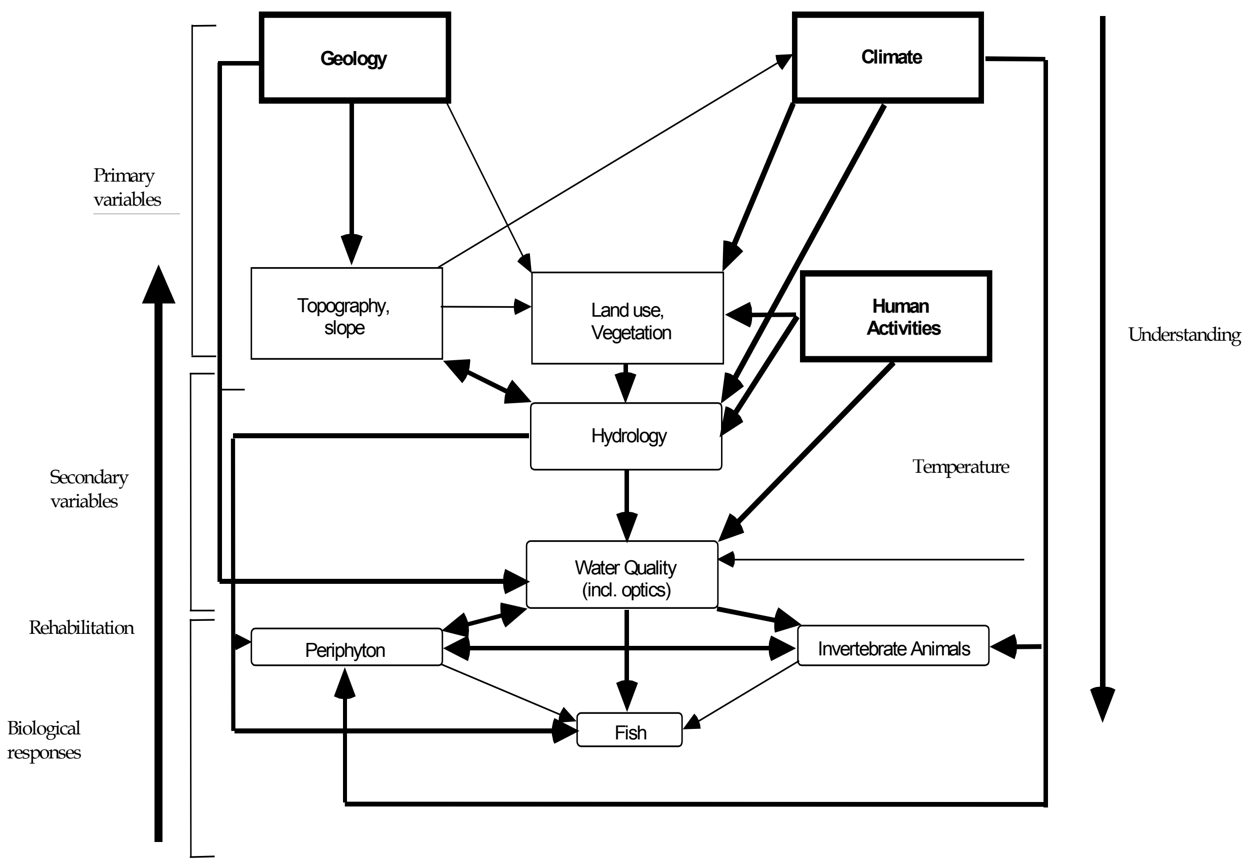


Figure 5- 1. Sampling Plan Flow Chart (after Biggs et al., 1990)

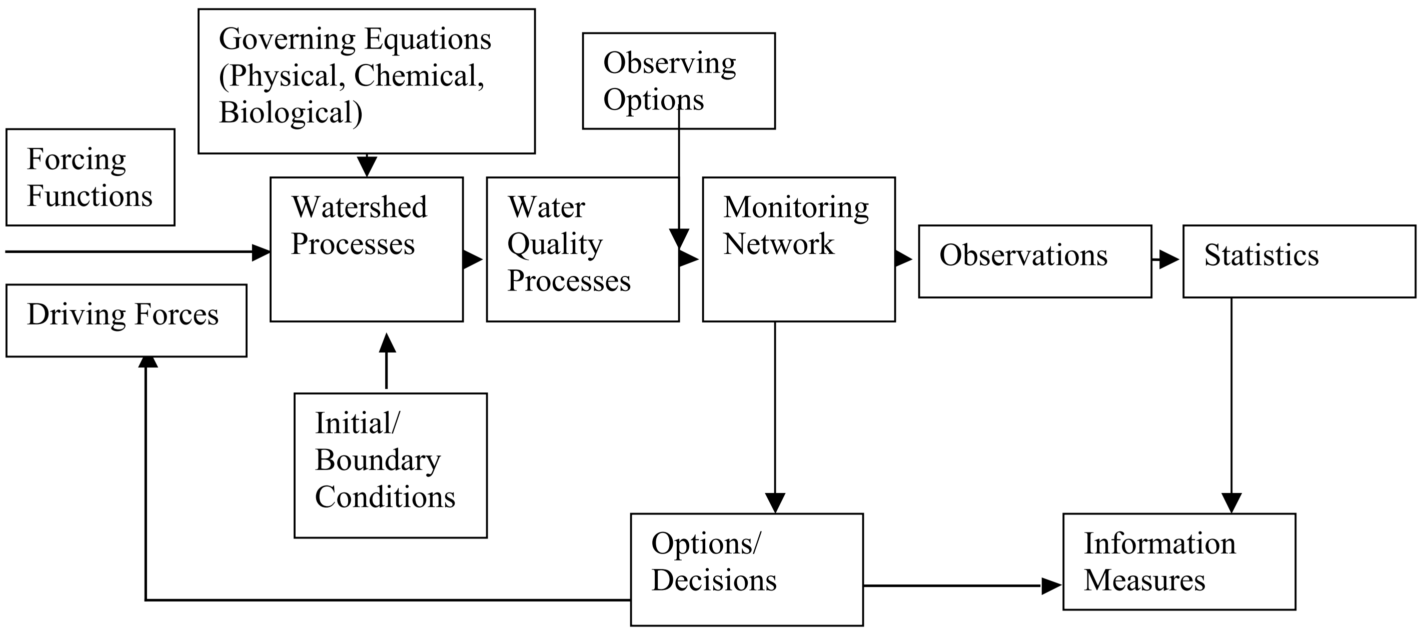


Figure 5- 2. Water Quality Monitoring Network Design Scheme

Table 5- 1. Traditional Determinants Monitored in Large Drainage Basins

Determinants	Water Column	Bottom Sediment
1. General, physics and chemical	temperature DO, pH, conductivity alkalinity suspended solids	particle size distribution carbonates
2. Nutrients	NH4-N, NO2-N, NO3-N Kjeldahl-, or total-N PO4-P, total-P	Kjeldahl-, or total-N total-P
3. Inorganic – major ions – elements	Na, K, Ca, Mg chloride, sulphate Fe, Mn, Al Hg, Cd, Pb, Zn, Cu, Ni, Cr	Fe, Mn, Al Hg, Cd, Pb, Zn, Cu, Ni, Cr
4. Organic – non-specific, sum-parameters – specific	BOD_5, COD_{Cr}, COD_{Mn}, DOC, AOX, phenol-index Anionactive surfactants Petroleum hydrocarbons Lindane, DDTs, atrazine CHCl3, CCl4, C2HCl3, C2Cl4	TOC, EOX Total extractable matter Petroleum hydrocarbons Lindane, DDTs PAHs, PCBs
5. Radioactivity	Total-beta activity	Cesium-137
6. Biological	Chlorophyll-*a* Phyto- and zooplankton Macrophytes, fish Saprobic/biotic index	Macrozoobenthos Microzoobenthos Phytobenthos
7. Microbiological	Total and fecal coliforms Fecal streptococci salmonella	Clostridium

Table 5- 2. Cost Estimate by Quarterly Sampling Event and Sampling Location (Water Quality Monitoring Sample Collection, Kootenai River Network, British Columbia, Montana, Idaho)

Task I: Sample Collection Preparation (including field instrument calibration)

Staff	Hours	Rate	Direct Labor	Expenses	Total
Field Technician	8	$35	$280	$0	$280
TASK I TOTAL	**8**		**$280**	**$0**	**$280**

Task II: Sample Collection (excluding travel to the sampling site, but including all field sample collection, field data analysis, and field data collection)

Staff	Hours	Rate	Direct Labor	Expenses	Total
Field Technician	10	$35	$350	$0	$350
EXPENSES					
Equipment rental, mileage, per diem will depend on the location and cannot be estimated					
TASK II TOTAL	**10**		**$350**	**$0**	**$350**

Task III: Analytical Cost Estimates

Laboratory Analysis	Quantity	Rate	Direct Labor	Expenses	Total
Group A: Conventional Water Quality Variables	2	$400	$0	$800	$800
Group B: Heavy Metals Total and Dissolved	2	$350	$0	$700	$700
Group C: Organic Micropollutants	2	$1,800	$0	$3,600	$3,600
Group D: Radioactivity Indicators	2	$800	$0	$1,600	$1,600
Group E: Microbiological Indicators	2	$500	$0	$1,000	$1,000
Group F: Biological Indicators (Basic)	2	$1,600	$0	$3,200	$3,200
Group E: Water Quantity Parameters	Collected in the field with hand-held equipment; no analytical expense				
TASK III TOTAL	**12**		**$0**	**$10,900**	**$10,900**

Table 5- 2. Cost Estimate by Quarterly Sampling Event and Sampling Location (Water Quality Monitoring Sample Collection, Kootenai River Network, British Columbia, Montana, Idaho) (cont.)

Task IV: Data Evaluation and Report Preparation

Staff	Hours	Rate	Direct Labor	Expenses	Total
Professor	4	$91	$364	$0	$364
Senior Scientist	8	$65	$520	$0	$520
Scientist	32	$55	$1,760	$0	$1,760
Intern	4	$25	$100	$0	$100
Clerical	2	$37	$74	$0	$74
Expenses					
Copying, phones, etc.				$50	$50
TASK IV TOTAL	**50**		**$2.818**	**$50**	**$2.868**

Project Total in US Dollars- $14,398

Table 5- 3. Criteria for Determining Sampling Frequency

Technical Objectives	Quantitative Criterion	Characteristics of Time Series	Sampling Frequency
Detection of trend	Trend detectability	Type of trend Magnitude of trend Standard deviation Autocorrelation	f_T
Determination of periodic fluctuation	Nyquist frequency & accuracy of parameter estimation	Periodicity Standard deviation Autocorrelation	f_p
Estimation of mean	Accuracy of estimation information Content of mean	Standard deviation Autocorrelation	f_m
Monitoring actual state			$f=\max\{f_T,f_p,f_m\}$

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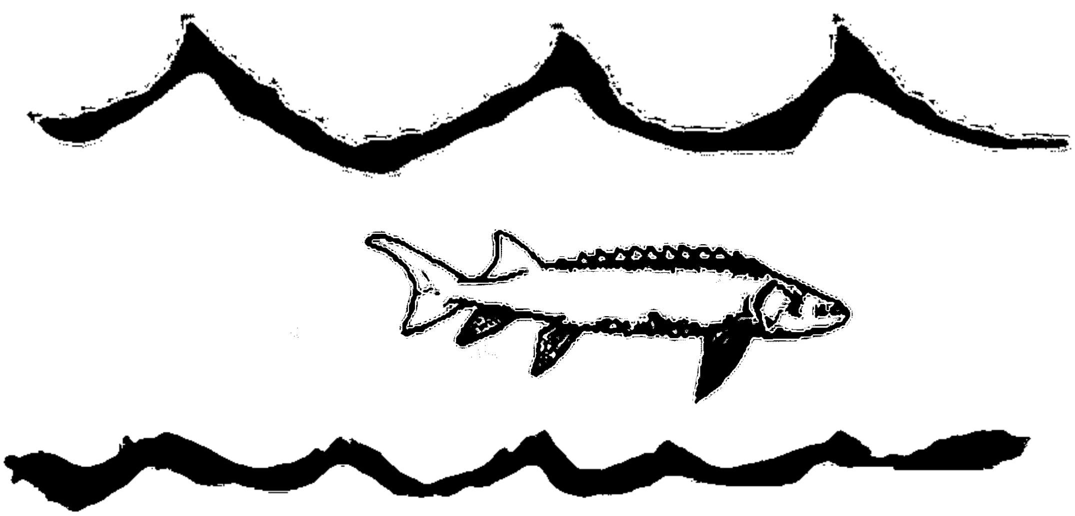
Section 6.0
Analytical Procedures



6.0 ANALYTICAL PROCEDURES

The ISO is a worldwide federation of national standards bodies from approximately 130 countries. ISO is a non-governmental organization established in 1947. The mission of ISO is to promote the development of standardization and related activities in the world with a view to facilitating the international exchange of goods and services, and to develop cooperation in the spheres of intellectual, scientific, technological and economic activity (ISO, 1998).

The ISO's work results in international agreements that are published as International Standards. These standards are widely adopted by North American government agencies and regulatory bodies. We suggest, therefore, that the ISO standard method be adopted by the KRN wherever possible for both sampling and analytical methods. Where an ISO standard does not exist, methods published in *Standard Methods for the Examination of Water and Wastewater 19th ed*. (APHA, 1985) the most current edition should be used. Both ISO standards and those in APHA (1985) are reviewed regularly and upgraded to reflect changes in scientific knowledge and practice. Neither is current "up-to-the-minute" as there is considerable delay in vetting and publishing new methods; however, they represent the most widely available, current, peer-reviewed methods of which we are aware. The KRN may wish to use these standards as a starting point and modify (and document) the techniques to suit the needs of member organizations.

> *As far as the analytical methods are concerned, there are internationally accepted procedures for most of the conventional water quality parameters, heavy metals, radioactive characteristics, microbiological and hydrobiological indicators, and some of the organic micropollutants, e.g., phenols and some pesticides. In many cases, it is also important to agree on the sample pretreatment methods, particularly when one wants to differentiate between dissolved and particulate matters, i.e., filtration is needed, or specification of heavy metals in the sediment (fractionation by leaching test) is required.*
>
> *In the case of several determinants, the results depend on the analytical method. It is particularly important to specify the method in the case of aggregate variables, or in the case of a group of compounds characterized by selected individuals, such as a few individual compounds (e.g., fluoranthene, benzo[a]pyrene, etc.) from the group of the polycyclic aromatic hydrocarbons, or the selected congeners (e.g., PCB-28; 52; 111; 138; 153 and 180) from the PCBs.*
>
> *Internationally accepted analytical methods, e.g., ISO, are available for most of the determinants which are usually monitored in water quality monitoring programs* (Table 6-1). *Analytical problems exist in the case of determination of sediment-associated pollutants in general and of the oil (petroleum) pollutants in particular.* (Litherathy, 1998)

Table 6- 1. List of ISO Standards Related to Water Quality Monitoring (Listed by Guide Number) (ISO, 1998)

Laboratory Testing QA/QC			
ISO Guide #	**Category**	**Description**	
ISO/IEC Guide 25:1990	General requirements for the competence of calibration and testing laboratories		
ISO Guide 32:1997	Calibration in analytical chemistry and use of certified reference materials		
ISO Guide 34:1996	Quality system guidelines for the production of reference materials		
ISO/IEC Guide 43-1:1997	Proficiency testing by interlaboratory comparisons	Part 1: Development and operation of proficiency testing schemes	
ISO/IEC Guide 43-2:1997	Proficiency testing by interlaboratory comparisons	Part 2: Selection and use of proficiency testing schemes by laboratory accreditation bodies	
ISO/IEC Guide 56:1989	An approach to the review by a certification body of its own internal quality system		
ISO/IEC Guide 59:1994	Code of good practice for standardization		

Water Quality			
ISO Guide #	**Category**	**Description**	
ISO 5663:1984	Water quality	Determination of Kjeldahl nitrogen	Method after mineralization with selenium
ISO 5664:1984	Water quality	Determination of ammonium	Distillation and titration method
ISO/DIS 5666	Water quality	Determination of mercury	
ISO 5666-1:1983	Water quality	Determination of total mercury by flameless atomic absorption spectrometry	Part 1: Method after digestion with permanganate-peroxodisulfate
ISO 5666-2:1983	Water quality	Determination of total mercury by flameless atomic absorption spectrometry	Part 2: Method after pretreatment with ultraviolet radiation
ISO 5666-3:1984	Water quality	Determination of total mercury by flameless atomic absorption spectrometry	Part 3: Method after digestion with bromine
ISO 5667-1:1980	Water quality	Sampling	Part 1: Guidance on the design of sampling programs
ISO 5667-2:1991	Water quality	Sampling	Part 2: Guidance on sampling techniques
ISO 5667-3:1994	Water quality	Sampling	Part 3: Guidance on the preservation and handling of samples

Table 6- 1. List of ISO Standards Related to Water Quality Monitoring (Listed by Guide Number) (ISO, 1998) (cont.)

Water Quality			
ISO Guide #	**Category**	**Description**	
ISO 5667-4:1987	Water quality	Sampling	Part 4: Guidance on sampling from lakes;natural and man-made
ISO 5667-5:1991	Water quality	Sampling	Part 5: Guidance on sampling of drinking water and water used for food and beverage processing
ISO 5667-6:1990	Water quality	Sampling	Part 6: Guidance on sampling of rivers and streams
ISO 5667-7:1993	Water quality	Sampling	Part 7: Guidance on sampling of water and steam in boiler plants
ISO 5667-8:1993	Water quality	Sampling	Part 8: Guidance on the sampling of wet deposition
ISO 5667-9:1992	Water quality	Sampling	Part 9: Guidance on sampling from marine waters
ISO 5667-10:1992	Water quality	Sampling	Part 10: Guidance on sampling of waste waters
ISO 5667-11:1993	Water quality	Sampling	Part 11: Guidance on sampling of groundwaters
ISO 5667-12:1995	Water quality	Sampling	Part 12: Guidance on sampling of bottom sediments
ISO 5667-13:1997	Water quality	Sampling	Part 13: Guidance on sampling of sludges from sewage and water-treatment works
ISO 5667-14:1998	Water quality	Sampling	Part 14: Guidance on quality assurance of environmental water sampling and handling
ISO/DIS 5667-15	Water quality	Sampling	Part 15: Guidance on preservation and handling of sludge and sediment samples
ISO 5667-16:1998	Water quality	Sampling	Part 16: Guidance on biotesting of samples
ISO 5813:1983	Water quality	Determination of dissolved oxygen	Iodometric method
ISO 5814:1990	Water quality	Determination of dissolved oxygen	Electrochemical probe method
ISO 5815:1989	Water quality	Determination of biochemical oxygen demand after 5 days (BOD_5)	Dilution and seeding method
ISO 5961:1994	Water quality	Determination of cadmium by atomic absorption spectrometry	
ISO 6058:1984	Water quality	Determination of calcium content	EDTA titrimetric method
ISO 6059:1984	Water quality	Determination of the sum of calcium and magnesium	EDTA titrimetric method

Table 6- 1. List of ISO Standards Related to Water Quality Monitoring (Listed by Guide Number) (ISO, 1998) (cont.)

Water Quality			
ISO Guide #	**Category**	**Description**	
ISO 6060:1989	Water quality	Determination of the chemical oxygen demand	
ISO 6107-1:1996	Water quality	Vocabulary	Part 1
ISO 6107-2:1997	Water quality	Vocabulary	Part 2
ISO 6107-3:1993	Water quality	Vocabulary	Part 3
ISO 6107-4:1993	Water quality	Vocabulary	Part 4
ISO 6107-5:1996	Water quality	Vocabulary	Part 5
ISO 6107-6:1996	Water quality	Vocabulary	Part 6
ISO 6107-7:1997	Water quality	Vocabulary	Part 7
ISO 6107-8:1993	Water quality	Vocabulary	Part 8
ISO 6107-9:1997	Water quality	Vocabulary	Part 9: Alphabetical list and subject index
ISO 6222:1988	Water quality	Enumeration of viable micro-organisms	Colony count by inoculation in or on a nutrient agar culture medium
ISO/DIS 6222	Water quality	Enumeration of culturable micro-organisms	Colony count by inoculation in a nutrient agar culture medium
ISO 6332:1988	Water quality	Determination of iron	Spectrometric method using 1,10-phenanthroline
ISO 6333:1986	Water quality	Determination of manganese	Formaldoxime spectrometric method
ISO 6340:1995	Water quality	Detection of salmonella species	
ISO 6341:1996	Water quality	Determination of the inhibition of the mobility of Daphnia magna Straus (Cladocera, Crustacea)	Acute toxicity test
ISO 6439:1990	Water quality	Determination of phenol index	4-Aminoantipyrine spectrometric methods after distillation
ISO 6461-1:1986	Water quality	Detection and enumeration of the spores of sulfite-reducing anaerobes (clostridia)	Part 1: Method by enrichment in a liquid medium
ISO 6461-2:1986	Water quality	Detection and enumeration of the spores of sulfite-reducing anaerobes (clostridia)	Part 2: Method by membrane filtration
ISO 6468:1996	Water quality	Determination of certain organochlorine insecticides, polychlorinated biphenyls and chlorobenzenes	Gas chromatographic method after liquid-liquid extraction
ISO 6595:1982	Water quality	Determination of total arsenic	Silver diethyldithiocarbamate spectrophotometric method
ISO 6703-1:1984	Water quality	Determination of cyanide	Part 1:Determination of total cyanide

Table 6- 1. List of ISO Standards Related to Water Quality Monitoring (Listed by Guide Number) (ISO, 1998) (cont.)

Water Quality			
ISO Guide #	**Category**	**Description**	
ISO 6703-2:1984	Water quality	Determination of cyanide	Part 2:Determination of easily liberatable cyanide
ISO 6703-3:1984	Water quality	Determination of cyanide	Part 3:Determination of cyanogen chloride
ISO 6703-4:1985	Water quality	Determination of cyanide	Part 4:Determination of cyanide by diffusion at pH 6
ISO 6777:1984	Water quality	Determination of nitrite	Molecular absorption spectrometric method
ISO 6778:1984	Water quality	Determination of ammonium	Potentiometric method
ISO 6878:1998	Water quality	Spectrometric determination of phosphorus using ammonium molybdate	
ISO 7027:1990	Water quality	Determination of turbidity	
ISO/DIS 7027	Water quality	Determination of turbidity	
ISO 7150-1:1984	Water quality	Determination of ammonium	Part 1: Manual spectrometric method
ISO 7150-2:1986	Water quality	Determination of ammonium	Part 2: Automated spectrometric method
ISO 7346-1:1996	Water quality	Determination of the acute lethal toxicity of substances to a freshwater fish [Brachydanio rerio Hamilton-Buchanan (Teleostei, Cyprinidae)]	Part 1: Static method
ISO 7346-2:1996	Water quality	Determination of the acute lethal toxicity of substances to a freshwater fish [Brachydanio rerio Hamilton-Buchanan (Teleostei, Cyprinidae)]	Part 2: Semi-static method
ISO 7346-3:1996	Water quality	Determination of the acute lethal toxicity of substances to a freshwater fish [Brachydanio rerio Hamilton-Buchanan (Teleostei, Cyprinidae)]	Part 3: Flow-through method
ISO 7393-1:1985	Water quality	Determination of free chlorine and total chlorine	Part 1: Titrimetric method using N,N-diethyl-1,4-phenylenediamine
ISO 7393-2:1985	Water quality	Determination of free chlorine and total chlorine	Part 2: Colorimetric method using N,N-diethyl-1,4-phenylenediamine, for routine control purposes
ISO 7393-3:1990	Water quality	Determination of free chlorine and total chlorine	Part 3: Iodometric titration method for the determination of total chlorine

Table 6- 1. List of ISO Standards Related to Water Quality Monitoring (Listed by Guide Number) (ISO, 1998) (cont.)

Water Quality			
ISO Guide #	**Category**	**Description**	
ISO 7704:1985	Water quality	Evaluation of membrane filters used for microbiological analyses	
ISO 7827:1994	Water quality	Evaluation in an aqueous medium of the "ultimate" aerobic biodegradability of organic compounds	Method by analysis of dissolved organic carbon (DOC)
ISO 7828:1985	Water quality	Methods of biological sampling	Guidance on handnet sampling of aquatic benthic macro-invertebrates
ISO 7875-1:1996	Water quality	Determination of surfactants	Part 1:Determination of anionic surfactants by measurement of the methylene blue index (MBAS)
ISO 7875-2:1984	Water quality	Determination of surfactants	Part 2:Determination of non-ionic surfactants using Dragendorff reagent
ISO 7887:1994	Water quality	Examination and determination of color	
ISO 7888:1985	Water quality	Determination of electrical conductivity	
ISO 7890-1:1986	Water quality	Determination of nitrate	Part 1: 2,6-Dimethylphenol spectrometric method
ISO 7890-2:1986	Water quality	Determination of nitrate	Part 2: 4-Fluorophenol spectrometric method after distillation
ISO 7890-3:1988	Water quality	Determination of nitrate	Part 3: Spectrometric method using sulfosalicylic acid
ISO 7899-1:1998	Water quality	Detection and enumeration of intestinal enterococci in surface and waste water	Part 1: Miniaturized method (Most Probable Number) by inoculation in liquid medium
ISO 7899-2:1984	Water quality	Detection and enumeration of fecal streptococci	Part 2: Method by membrane filtration
ISO/DIS 7899-2	Water quality	Detection and enumeration of intestinal enterococci	Part 2: Membrane filtration method
ISO 7980:1986	Water quality	Determination of calcium and magnesium	Atomic absorption spectrometric method
ISO 8165-1:1992	Water quality	Determination of selected monovalent phenols	Part 1: Gas chromatographic method after enrichment by extraction
ISO/DIS 8165-2	Water quality	Determination of selected monovalent phenols	Part 2: Method by derivatization and gas chromatography
ISO 8192:1986	Water quality	Test for inhibition of oxygen consumption by activated sludge	
ISO 8199:1988	Water quality	General guide to the enumeration of micro-organisms by culture	

Table 6- 1. List of ISO Standards Related to Water Quality Monitoring (Listed by Guide Number) (ISO, 1998) (cont.)

Water Quality			
ISO Guide #	**Category**	**Description**	
ISO 8245:1987	Water quality	Guidelines for the determination of total organic carbon (TOC)	
ISO/DIS 8245	Water quality	Guidelines for the determination of total organic carbon (TOC) and dissolved organic carbon (DOC)	
ISO 8265:1988	Water quality	Design and use of quantitative samplers for benthic macro-invertebrates on stony substrata in shallow freshwaters	
ISO 8288:1986	Water quality	Determination of cobalt, nickel, copper, zinc, cadmium and lead	Flame atomic absorption spectrometric methods
ISO 8402:1994	Vocabulary	Quality management and quality assurance	
ISO 8466-1:1990	Water quality	Calibration and evaluation of analytical methods and estimation of performance characteristics	Part 1: Statistical evaluation of the linear calibration function
ISO 8466-2:1993	Water quality	Calibration and evaluation of analytical methods and estimation of performance characteristics	Part 2: Calibration strategy for non-linear second order calibration functions
ISO 8467:1993	Water quality	Determination of permanganate index	
ISO/DIS 8689-1	Water quality	Biological classification of rivers	Part 1: Guidance on the interpretation of biological quality data from surveys of benthic macroinvertebrates
ISO/DIS 8689-2	Water quality	Biological classification of rivers	Part 2: Guidance on the presentation of biological quality data from surveys of benthic macroinvertebrates
ISO 8692:1989	Water quality	Fresh water algal growth inhibition test with Scenedesmus subspicatus and Selenastrum capricornutum	
ISO 9000-1:1994	Quality management and quality assurance standards	Part 1: Guidelines for selection and use	
ISO 9004-1:1994	Quality management and quality system elements	Part 1: Guidelines	
ISO 9174:1998	Water quality	Determination of chromium	Atomic absorption spectrometric methods
ISO 9280:1990	Water quality	Determination of sulfate	Gravimetric method using barium chloride

Table 6- 1. List of ISO Standards Related to Water Quality Monitoring (Listed by Guide Number) (ISO, 1998) (cont.)

Water Quality			
ISO Guide #	**Category**	**Description**	
ISO 9297:1989	Water quality	Determination of chloride	Silver nitrate titration with chromate indicator (Mohr's method)
ISO 9308-1:1990	Water quality	Detection and enumeration of coliform organisms, thermotolerant coliform organisms and presumptive Escherichia coli	Part 1: Membrane filtration method
ISO/DIS 9308-1	Water quality	Detection and enumeration of Escherichia coli and coliform bacteria	Part 1: Membrane filtration method
ISO 9308-2:1990	Water quality	Detection and enumeration of coliform organisms, thermotolerant coliform organisms and presumptive Escherichia coli	Part 2: Multiple tube (most probable number) method
ISO 9308-3:1998	Water quality	Detection and enumeration of Escherichia coli and coliform bacteria in surface and waste water	Part 3: Miniaturized method (Most Probable Number) by inoculation in liquid medium
ISO 9390:1990	Water quality	Determination of borate	Spectrometric method using azomethine-H
ISO 9391:1993	Water quality	Sampling in deep waters for macro-invertebrates	Guidance on the use of colonization, qualitative and quantitative samplers
ISO 9408:1991	Water quality	Evaluation in an aqueous medium of the "ultimate" aerobic biodegradability of organic compounds	Method by determining the oxygen demand in a closed respirometer
ISO/DIS 9408	Water quality	Evaluation of ultimate aerobic biodegradability of organic compounds in aqueous medium by determination of oxygen demand in a closed respirometer	
ISO 9439:1990	Water quality	Evaluation in an aqueous medium of the "ultimate" aerobic biodegradability of organic compounds	Method by analysis of released carbon dioxide
ISO/DIS 9439	Water quality	Evaluation of ultimate aerobic biodegradability of organic compounds in aqueous medium	Carbon dioxide evolution test
ISO 9509:1989	Water quality	Method for assessing the inhibition of nitrification of activated sludge micro-organisms by chemicals and waste waters	

Table 6- 1. List of ISO Standards Related to Water Quality Monitoring (Listed by Guide Number) (ISO, 1998) (cont.)

Water Quality			
ISO Guide #	**Category**	**Description**	
ISO 9543:1989 Information processing systems	Information exchange between systems	Synchronous transmission signal quality at DTE/DCE interfaces	
ISO 9562:1998	Water quality	Determination of adsorbable organically bound halogens (AOX)	
ISO 9696:1992	Water quality	Measurement of gross alpha activity in non-saline water	Thick source method
ISO 9697:1992	Water quality	Measurement of gross beta activity in non-saline water	
ISO 9698:1989	Water quality	Determination of tritium activity concentration	Liquid scintillation counting method
ISO 9887:1992	Water quality	Evaluation of the aerobic biodegradability of organic compounds in an aqueous medium	Semi-continuous activated sludge method (SCAS)
ISO 9888:1991	Water quality	Evaluation of the aerobic biodegradability of organic compounds in an aqueous medium	Static test (Zahn-Wellens method)
ISO/DIS 9888	Water quality	Evaluation of aerobic biodegradability of organic compounds in aqueous medium	Static test (Zahn-Wellens method)
ISO 9963-1:1994	Water quality	Determination of alkalinity	Part 1:Determination of total and composite alkalinity
ISO 9963-2:1994	Water quality	Determination of alkalinity	Part 2:Determination of carbonate alkalinity
ISO 9964-1:1993	Water quality	Determination of sodium and potassium	Part 1:Determination of sodium by atomic absorption spectrometry
ISO 9964-2:1993	Water quality	Determination of sodium and potassium	Part 2:Determination of potassium by atomic absorption spectrometry
ISO 9964-3:1993	Water quality	Determination of sodium and potassium	Part 3:Determination of sodium and potassium by flame emission spectrometry
ISO 9965:1993	Water quality	Determination of selenium	Atomic absorption spectrometric method (hydride technique)
ISO 9998:1991	Water quality	Practices for evaluating and controlling microbiological colony count media used in water quality tests	
ISO 10048:1991	Water quality	Determination of nitrogen	Catalytic digestion after reduction with Devarda's alloy

Table 6- 1. List of ISO Standards Related to Water Quality Monitoring (Listed by Guide Number) (ISO, 1998) (cont.)

Water Quality			
ISO Guide #	**Category**	**Description**	
ISO 10229:1994	Water quality	Determination of the prolonged toxicity of substances to freshwater fish	Method for evaluating the effects of substances on the growth rate of rainbow trout (Oncorhynchus mykiss Walbaum (Teleostei, Salmonidae))
ISO 10260:1992	Water quality	Measurement of biochemical parameters	Spectrometric determination of the chlorophyll-a concentration
ISO 10301:1997	Water quality	Determination of highly volatile halogenated hydrocarbons	Gas-chromatographic methods
ISO 10304-1:1992	Water quality	Determination of dissolved fluoride, chloride, nitrite, orthophosphate, bromide, nitrate and sulfate ions, using liquid chromatography of ions	Part 1: Method for water with low contamination
ISO 10304-2:1995	Water quality	Determination of dissolved anions by liquid chromatography of ions	Part 2:Determination of bromide, chloride, nitrate, nitrite, orthophosphate and sulfate in waste water
ISO 10304-3:1997	Water quality	Determination of dissolved anions by liquid chromatography of ions	Part 3:Determination of chromate, iodide, sulfite, thiocyanate and thiosulfate
ISO 10304-4:1997	Water quality	Determination of dissolved anions by liquid chromatography of ions	Part 4:Determination of chlorate, chloride and chlorite in water with low contamination
ISO 10359-1:1992	Water quality	Determination of fluoride	Part 1: Electrochemical probe method for potable and lightly polluted water
ISO 10359-2:1994	Water quality	Determination of fluoride	Part 2:Determination of inorganically bound total fluoride after digestion and distillation
ISO 10523:1994	Water quality	Determination of pH	
ISO 10530:1992	Water quality	Determination of dissolved sulfide	Photometric method using methylene blue
ISO 10566:1994	Water quality	Determination of aluminium	Spectrometric method using pyrocatechol violet
ISO 10634:1995	Water quality	Guidance for the preparation and treatment of poorly water-soluble organic compounds for the subsequent evaluation of their biodegradability in an aqueous medium	

Table 6- 1. List of ISO Standards Related to Water Quality Monitoring (Listed by Guide Number) (ISO, 1998) (cont.)

Water Quality			
ISO Guide #	**Category**	**Description**	
ISO/DIS 10695-1	Water quality	Determination of selected organic nitrogen and phosphorus compounds	Part 1: Gas-chromatographic methods
ISO 10703:1997	Water quality	Determination of the activity concentration of radionucilides by high resolution gamma-ray spectrometry	
ISO 10705-1:1995	Water quality	Detection and enumeration of bacteriophages	Part 1: Enumeration of F-specific RNA bacteriophages
ISO/DIS 10705-2	Water quality	Detection and enumeration of bacteriophages	Part 2: Enumeration of somatic coliphages
ISO/DIS 10706	Water quality	Determination of long term toxicity of substances to Daphnia magna Straus	
ISO 10707:1994	Water quality	Evaluation in an aqueous medium of the "ultimate" aerobic biodegradability of organic compounds	Method by analysis of biochemical oxygen demand (closed bottle test)
ISO 10708:1997	Water quality	Evaluation in an aqueous medium of the ultimate aerobic biodegradability of organic compounds	Determination of biochemical oxygen demand in a two-phase closed bottle test
ISO 10712:1995	Water quality	Pseudomonas putida growth inhibition test (Pseudomonas cell multiplication inhibition test)	
ISO 11083:1994	Water quality	Determination of chromium(VI)	Spectrometric method using 1,5-diphenylcarbazide
ISO 11348-1:1998	Water quality	Determination of the inhibitory effect of water samples on the light emission of Vibrio fischeri (Luminescent bacteria test)	Part 1: Method using freshly prepared bacteria
ISO 11348-2:1998	Water quality	Determination of the inhibitory effect of water samples on the light emission of Vibrio fischeri (Luminescent bacteria test)	Part 2: Method using liquid-dried bacteria
ISO 11348-3:1998	Water quality	Determination of the inhibitory effect of water samples on the light emission of Vibrio fischeri (Luminescent bacteria test)	Part 3: Method using freeze-dried bacteria
ISO 11369:1997	Water quality	Determination of selected plant treatment agents	Method using high performance liquid chromatography with UV detection after solid-liquid extraction

Table 6- 1. List of ISO Standards Related to Water Quality Monitoring (Listed by Guide Number) (ISO, 1998) (cont.)

Water Quality			
ISO Guide #	**Category**	**Description**	
ISO 11423-1:1997	Water quality	Determination of benzene and some derivatives	Part 1: Head-space gas chromatographic method
ISO 11423-2:1997	Water quality	Determination of benzene and some derivatives	Part 2: Method using extraction and gas chromatography
ISO 11731:1998	Water quality	Detection and enumeration of Legionella	
ISO 11732:1997	Water quality	Determination of ammonium nitrogen by flow analysis (CFA and FIA) and spectrometric detection	
ISO 11733:1995	Water quality	Evaluation of the elimination and biodegradability of organic compounds in an aqueous medium	Activated sludge simulation test
ISO 11734:1995	Water quality	Evaluation of the "ultimate" anaerobic biodegradability of organic compounds in digested sludge	Method by measurement of the biogas production
ISO 11885:1996	Water quality	Determination of 33 elements by inductively coupled plasma atomic emission spectroscopy	
ISO 11905-1:1997	Water quality	Determination of nitrogen	Part 1: Method using oxidative digestion with peroxodisulfate
ISO/TR 11905-2:1997	Water quality	Determination of nitrogen	Part 2:Determination of bound nitrogen, after combustion and oxidation to nitrogen dioxide, chemiluminescence detection
ISO 11923:1997	Water quality	Determination of suspended solids by filtration through glass-fiber filters	
ISO 11969:1996	Water quality	Determination of arsenic	Atomic absorption spectrometric method (hydride technique)
ISO 12020:1997	Water quality	Determination of aluminium	Atomic absorption spectrometric methods
ISO/DIS 12890	Water quality	Determination of embryo-larval toxicity to freshwater fish	Semistatic method
ISO 13358:1997	Water quality	Determination of easily released sulfide	

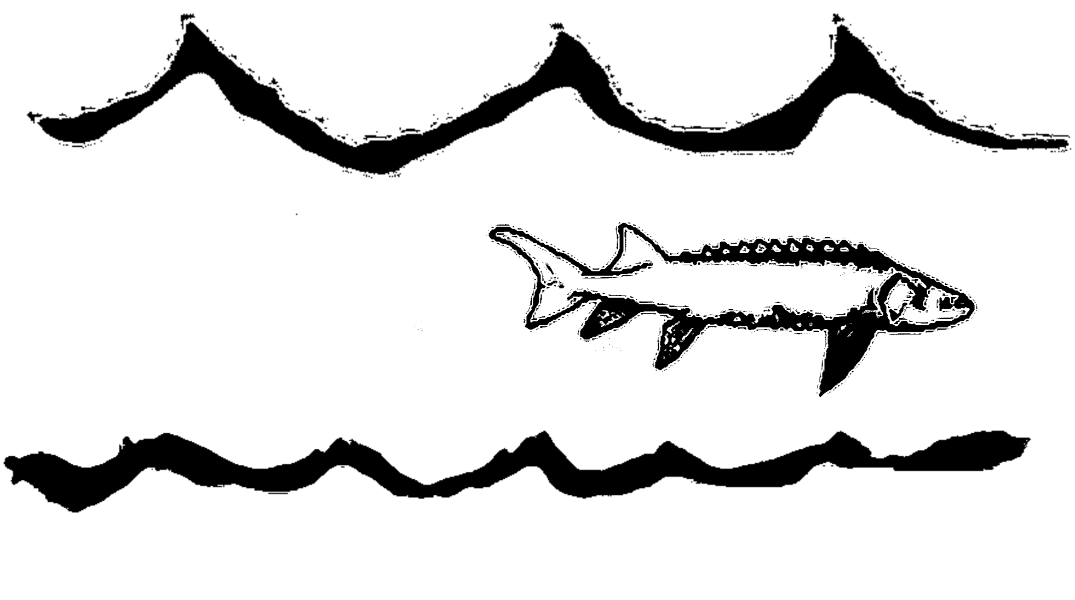
Table 6- 1. List of ISO Standards Related to Water Quality Monitoring (Listed by Guide Number) (ISO, 1998) (cont.)

Water Quality			
ISO Guide #	**Category**	**Description**	
ISO 13395:1996	Water quality	Determination of nitrite nitrogen and nitrate nitrogen and the sum of both by flow analysis (CFA and FIA) and spectrometric detection	
ISO/TR 13530:1997	Water quality	Guide to analytical quality control for water analysis	
ISO/DIS 13829	Water quality	Determination of genotoxicity of water and waste water using the umu-test	
ISO/DIS 14402	Water quality	Determination of phenol index by flow analysis (FIA and CFA)	
ISO/DIS 14403	Water quality	Determination of total cyanide and free cyanide by continuous flow analysis	
ISO/DIS 14442	Water quality	Guidance for algal growth inhibition tests with poorly soluble materials, volatile compounds, metals and waste water (publié en anglais seulement)	
ISO/DIS 14593	Water quality	Evaluation of ultimate aerobic biodegradability of organic compounds in aqueous medium	Method by analysis of released inorganic carbon in sealed vessels
ISO/DIS 14669	Water quality	Determination of acute lethal toxicity to marine copepods (Copepoda, Crustacea)	
ISO 14911:1998	Water quality	Determination of dissolved Li+, Na+, NH4+, K+, Mn2+, Ca2+, Mg2+, Sr2+ and Ba2+ using ion chromatography	Method for water and waste water
ISO/DIS 15089	Water quality	Guidelines for selective immunoassays for the determination of plant treatment and pesticide agents	
ISO/DIS 15178 Soil quality	Determination of total sulfur by dry combustion		
ISO/DIS 15522	Water quality	Determination of the inhibitory effect of water constituents on the growth of activated sludge microorganisms	

Table 6- 1. List of ISO Standards Related to Water Quality Monitoring (Listed by Guide Number) (ISO, 1998) (cont.)

Water Quality			
ISO Guide #	**Category**	**Description**	
ISO/DIS 15682	Water quality	Determination of chloride content	Method by flow analysis (FIA and CFA) and photometric or potentiometric detection (available in French only)
ISO/DIS 15913	Water quality	Determination of selected phenoxyalkanoic herbicides, bentazone and hydroxynitriles by gas chromatography and mass spectrometry after solid/liquid extraction and derivatization	
ISO/DIS 15522	Water quality	Determination of the inhibitory effect of water constituents on the growth of activated sludge microorganisms	
ISO/DIS 15682	Water quality	Determination of chloride content	Method by flow analysis (FIA and CFA) and photometric or potentiometric detection (available in French only)
ISO/DIS 15913	Water quality	Determination of selected phenoxyalkanoic herbicides, bentazone and hydroxynitriles by gas chromatography and mass spectrometry after solid/liquid extraction and derivatization	

SECTION 7.0
QUALITY ASSURANCE PROJECT PLAN



7.0 QUALITY ASSURANCE PROJECT PLAN

7.1 Introduction

To assure the validity, reliability and comparability of monitoring data, quality control measures should be enforced during sampling, analysis and data processing. In the case of transboundary river basins, the design of the monitoring program and data interpretation as well as dissemination should be done in an internationally coordinated way. (Litherathy, 1998)

Separate quality assurance (QA) programs exist for both the field sampling procedures (collection, preservation, filtration and shipping components) and analytical procedures (laboratory component). Therefore, QA is essentially the management system that operates to ensure credible results. The quality control (QC) component of this system is a set of activities intended to control the quality of the data from collection through to analysis. It consists of day-to-day activities such as: the adherence to written protocols; up-to-date and suitable training of personnel; the use of reliable, well maintained and properly calibrated equipment; the regular use of QC samples (blanks, reference samples, spikes and replicates); and, diligent record keeping. (Pommen, 1995, and Cavanagh et al., 1998)

Quality assessment is an evaluation process that focuses on the quality of the data measurements. It attempts to identify introduced variability (sampling and analytical) through estimates of accuracy, precision, and bias. Together, quality control and quality assessment operate as a feedback system throughout the duration of the sampling program to provide early warnings of dubious data. Additionally, this feedback is the primary tool to determine if the current monitoring effort (i.e., site locations, sample frequency, selected variables) meets the program objectives. (Pommen, 1995, and Cavanagh et al., 1998)

Obviously, the validated data set is the easiest to obtain when it comes from a single laboratory, or team, which collects samples at all sampling locations and then carries out analyses in the same laboratory. This approach, however, is not feasible in the long-term particularly due to the national interests of the riparian countries in an international river basin. Therefore, reliability and comparability of the monitoring results should be ensured by using agreed sampling and analytical methods and enforcing intralaboratory and interlaboratory (intercalibration) quality control measures as part of the monitoring program. (Litherathy, 1998)

The major elements of the QA program should include the following:

- Sampling and analytical protocols
- Validation of the methodology used and establishment of performance characteristics of the methods in every laboratory used in the monitoring program
- Uniform or equivalent instrumentation
- Skilled personnel (training)
- Intralaboratory quality control, including regular analyses of
    - calibration standards
    - reference materials, including certified reference materials
    - spiked samples
- Interlaboratory quality control and performance testing with analysis of check-samples in intercalibration exercises
- Quality control in data processing, including an expression of the analytical results and rounding, and interpretation (Litherathy, 1998).

7.2 Project Organization And Responsibility

An effective monitoring program should be designed to accomplish combinations of or, in some circumstances, all of the following:

1. *Delineate and identify sources of natural variability and define the limits of this variability*
2. *Provide data leading to an accurate assessment of the state or health of the aquatic ecosystem(s)*
3. *Portray trends in water quality and provide warning of abnormal changes or conditions that might be damaging to the aquatic environment and associated species*
4. *Identify the potential agent(s) of any abnormal change that is detected*
5. *Identify the locations within the watershed that are most sensitive to abnormal changes or conditions.*

Given these requirements, the program designer must:

1. *Adopt the operational responsibility of developing and implementing a program*
2. *Be aware of the necessity to consider normal variation and strive to delineate the limits of this variation for the watershed under consideration*
3. *Be aware of current and proposed activities that have the potential to abnormally alter water quality*
4. *Recognize symptoms and diagnose abnormal conditions*
5. *Be capable of analyzing and interpreting data.* (Pommen, 1995, and Cavanagh et al., 1998)

7.2.1 Responsibilities of the Project Manager.

7.2.1.1 Phase One: Pre-Contract Period.

At the outset, the project manager must clearly define the project objectives and the data quality required to meet these objectives. Adequate QA clauses must be included in all contracts. The following clauses should be included in all analytical contracts issued by project managers:

1. *A sound quality control program must be developed and documented by the contractor. All quality control data must be made available to the Scientific Authority and the project manager upon request.*
2. *The proposed sample collection, handing, storage, preservation procedures and analytical methodologies must be documented and approved by the Scientific Authority before work is initiated.*
3. *The contractor must participate in, and perform satisfactorily in, pertinent quality control round robins in a timely manner under the guidance of a Departmental Quality Assurance Laboratory designated by the project manager. Failure to comply with this requirement could result in partial withholding of funds and/or cancellation of the contract.*
4. *Contract laboratories are encouraged to participate in appropriate external quality assessments on a continuous basis to establish their credibility.* (Gaskin, 1993)

Before any consideration of a contract, a laboratory must be able to provide the evidence or information below for review.

1. Clear documentation of analytical and sample handling methodologies (see checklist below) including, wherever applicable, extraction/digestion, cleanup, derivatization, evaporation and quantitation procedures used. Such methodologies must be available for review at any time.
2. Statements of method detection limits (MDL) and laboratory performance (i.e., precision and accuracy) on replicate analyses of samples fortified at or close to MDLs as well as at higher levels.
3. The availability of relevant laboratory instrumentation and analytical standards.
4. Records of instrumentation performances, e.g., calibration curves, response factors, detector linearity, resolution, instrument detection limit, etc.
5. Documented in-house QA protocols and, where appropriate, records of in-house QA data for previous contracts on the same parameters in the same matrices at similar concentration levels.
6. Performance on previous interlaboratory comparison studies or participation in a qualifying pre-contract QC study.

7. Evidence that the appropriate methods, based on the various regulatory requirements, for each of the following basic parameters have been addressed:
    a. Sample
        i. Sample handing procedure
        ii. Sample holding time until analysis
        iii. Sample preservation procedure (if needed)
        iv. Sample storage conditions
    b. Analytical Method
        i. Method documentation
        ii. Ruggedness*
        iii. Application*
        iv. Specificity*
        v. Sensitivity*
        vi. Detection limit (definition and statement)
        vii. Precision data at min. 2 levels*
        viii. Accuracy data (or recovery) at min. 2 levels*
        ix. Description of how the above-method specifications were generated.

* Demonstration at realistic levels

7.2.1.2 Phase Two: During the Contract Period. During the contract period, the project manager must ensure that the contractor carries out the activities below.

1. To demonstrate the precision of data generated, the contract laboratory should perform duplicate analyses of every 10th, 15th or 20th sample, depending on the situation.
2. To demonstrate the accuracy of data generated, the contract laboratory should analyze a certified reference material (CRM) (if available) or a check sample provided by the scientific authority once every 10, 15 or 20 samples. The agreement with the "true value" must be ±25 percent or better, or must meet the objectives of the Scientific Authority.
3. For large contracts, the contractor should provide preliminary results or data sheets to the Scientific Authority at regular intervals (e.g., monthly) rather than just a final report at the end of the contract. If obvious analytical errors are found, the Scientific Authority has the right to reject all or part of a batch of analyses and request reanalysis, in whole or in part, of the batch of samples.
4. Blind samples in the form of CRMs, reference materials, field split samples, sample extracts, etc. (incorporated in the sample set by the Scientific Authority), must be analyzed and reported with the data set.
5. All sample data and chromatograms (or digitally stored data sufficient to regenerate the original chromatograms) should be retained by the contractor for all analyses unless otherwise authorized in writing by the Scientific Authority.
6. The contractor should participate in relevant interlaboratory QC studies whenever possible during the contract.
7. The contract laboratory should not change analytical methodologies in the middle of the contract unless authorized by the Scientific Authority (Gaskin, 1993).

7.2.1.3 Phase Three: Post-Contract Period.

1. The Scientific Authority shall have the right to take possession of all raw data.
2. The final report must contain all data, including QA data (Gaskin, 1993).

7.3 Data Quality Objectives

Data generated from the sampling program must possess a number of quality factors if they are to be used objectively in judging water quality and if correct and unbiased management decisions are to be made.

All data used in examining and diagnosing water quality should be accompanied by the following characteristics and should be suitable to meet network objectives:

- Accuracy
- Precision
- Completeness
- MDL
- Representativeness
- Traceability.

Accuracy, precision, completeness and the MDL are established through accepted statistical principles and are distinguishable from other quality characteristics by their quantifiability.

Another aspect of data quality relates to data comparability and compatibility among similar data sets from agencies involved in water quality monitoring. To achieve data comparability and compatibility, a number of steps must be taken, including the following:

- Employing techniques and practices that can be duplicated at different locations and times and by different agencies
- Providing results that can be understood and tested on a comparative basis
- Reducing systematic errors and increasing comparability between measurements by additional interlaboratory sample testing exercises
- Using CRMs or carefully selected natural areas as common reference sites, especially when there is a need to compare the results from different existing measurements.

The achievement of data quality objectives often can be difficult. Limitations of resources, methodologies, equipment and technical expertise may reduce quality and amount of data collected. However, any consideration of the limitations associated with the data collection process should lead to the establishment of objectives that adequately satisfy the goals of the project.

Gaskin (1993) summarizes the goals of a data quality program as follows:

- Formulating work plans and budget proposals that identify projects, work schedules and resource levels necessary for the effective operation of the WQB monitoring programs
- Ensuring the maintenance of up-to-date manuals in which methodologies and procedures are kept current
- Ensuring that current procedures are used for the collection of representative aquatic samples to yield data and information for water resource managers and the public
- Ensuring there is comprehensive QA/QC monitoring program that leads to the acquisition of data that have a known quality and meet program needs
- Ensuring that the most appropriate interpretive techniques will be used to examine data
- Ensuring that data validation and verification procedures will be used to examine and certify the quality of the data before release to data users
- Establishing an audit program encompassing sampling, laboratory analysis and data management
- Encouraging training of operational personnel continuously to provide consistency and efficiency in all operations.

7.3.1 Field Quality Assurance.

The prime objective of the field QA program is to maximize accuracy by reducing introduced variability. Accuracy is the degree of agreement of a measured value with the true value of the quantity (variable) of concern (Csuros, 1994). Both random and systematic errors are factors that reduce accuracy and, therefore, these errors must be minimized. Random errors refer to the precision (or random variation) of the data, while systematic errors refer to bias (or systematic deviation) in the data (Keith, 1991). Precision describes the degree of mutual agreement among repeated individual measurements under the same condition. Imprecise data is primarily the result of inconsistent field techniques and lab analysis, and the introduction of contaminants. ***Therefore, the best means of ensuring high precision is to maintain consistency during the sample collection, filtration, preservation and analytical processes. Bias describes a repeated skewed error in the measurement. An example of bias would be data values that are repeatedly higher (or lower) than true values due to the use of equipment that has been calibrated incorrectly. Other sources of bias include: unrepresentative sampling; instability of analyte (variable) over time; interference (such as temperature effect); and contamination from any number of sources. Accurate samples are ones, therefore, that exhibit high precision and low bias. An appropriately designed field QA/QC program will operate to maximize precision while minimizing bias (for the sampling portion of the program).*** (Pommen, 1995, and Cavanagh et al., 1998)

The range of anthropogenic and natural inputs, and the variability of physiogeographic conditions, precludes the development of an optimal water quality monitoring program on the first attempt.

> *Both natural and introduced variability requires that the development of each new monitoring program be considered an iterative process. Iterative cycles are required to establish and refine the program. It is unrealistic to expect that the selection of variables, sampling locations, and sampling frequency will be optimal from the program outset. Feedback loops are critically important as a quality assessment technique for the design and execution of monitoring programs. Therefore, ongoing analysis of data is essential. The information obtained from regular analysis of data dictates where program resources should be directed in the future. The ability to adapt the program to conditions and variability found in the field ensures efficiency and quality of data collection efforts. A monitoring program should never be considered a static, fixed process.* (Pommen, 1995, and Cavanagh et al., 1998)

The 14 iterative steps of an ongoing water quality monitoring program are shown in Figure 7-1.

7.4 Quality Control Procedures for Sample Collection, Handling and Preservation

The field QA program is a systematic process that, together with the laboratory and data storage quality assurance programs, ensures a specified degree of confidence in the data collected for an environmental survey. The field QA program involves the series of steps, procedures and practices described below (Pommen, 1995, and Cavanagh et al., 1998).

The quality of data generated in a laboratory depends, to a large degree, on the integrity of the samples that arrive at the laboratory. Consequently, the field investigator must take the necessary precautions to protect samples from contamination and deterioration.

There are many sources of contamination. Some basic precautions are provided below.

1. Field measurements should always be made using a separate sub-sample, which is then discarded once the measurements have been made. They should never be made on a water sample that is returned to the analytical laboratory for further chemical analyses. For example, specific conductance should never be measured in sample water that was first used for pH measurements. Potassium chloride diffusing from the pH probe alters the conductivity of the sample. Similarly, pH should not be measured from a sample that will be analyzed for phosphorus, as some pH buffers contain phosphorus. Use a separate bottle for water temperature if not in-situ. Dissolved oxygen measurements (by DO probe) should be made in-situ rather than in a separate container.

2. Sample bottles, including bottle caps, must be cleaned according to the recommended methods and certified by the issuing laboratory as “contamination free” (if pre-cleaned by the laboratory) for the intended analysis. Sample bottles that are pre-cleaned by the laboratory must **not** be rinsed with the sample water being collected. Bottles must be supplied with cap in place. Note that cleaned reused bottles are not suitable for some trace constituents. If you are using a mixture of pre-cleaned, not pre-cleaned, and/or reused bottles, label each bottle type to avoid confusion.
3. Use only the sample bottle recommended by the laboratory for each analysis.
4. Reagents and preservatives must be analytical grade and certified by the issuing laboratory to be contamination free. Containers holding chemical reagents and preservatives should be clearly labeled both as to contents and as to expiration date. No reagent or preservative should be used after the expiration date. Return expired reagents to the laboratory for proper disposal.
5. If conditions dictate that samples from multiple sites be preserved at the same time (such as when returning to shore after sampling several deep stations in a lake), the possibility of adding the wrong preservative to a sample or cross-contaminating the preservative stocks should be minimized by preserving all the samples for a particular group of variables together. Color-coded bottles and matching preservatives prevent mixups.
6. The inner portion of sample (and preservative) bottles and caps must not be touched with anything (e.g., bare hands, gloves, thermometers, probes, preservative dispensers, etc.) other than the sample water and preservative. Remove caps only just before sampling and re-cap right away.
7. Keep sample bottles in a clean environment away from dust, dirt, fumes and grime. Bottles must be capped at all times and stored in clean shipping containers (coolers) both before and after the collection of the sample. Vehicle cleanliness is an important factor in eliminating contamination problems. During sample collection, store bottle caps in a clean, resealable plastic bag, not in pockets, etc.
8. Petroleum products (gasoline, oil, exhaust fumes) are prime sources of contamination. Spills or drippings (which are apt to occur in boats) must be removed immediately. Exhaust fumes and cigarette smoke can contaminate samples with lead and other heavy metals. Air conditioning units also are a source of trace metal contamination.
9. Filter units and related apparatus must be kept clean using routine procedures such as acid washes and soakings in de-ionized water. Store cleaned filter units in labeled, sealed plastic bags.
10. Samples must never be permitted to get warm. They should be stored in a cool, dark place. Coolers packed with ice packs are recommended (most samples must be cooled to 4°C during transit to the laboratory). Conversely, samples must not be permitted to freeze unless freezing is part of the preservation protocol. Cool samples as quickly as possible. A common mistake is to forget that a large volume of warm water soon melts a small amount of ice.
11. Samples must be shipped to the laboratory without delay so that they arrive within 24 hours of sampling. Certain analyses must be conducted within 48 hours or

within specified time limits set out in the method (24 hours for most bacteriological parameters).
12. Sample collectors should keep their hands clean and refrain from eating or smoking while working with water samples.
13. Sample equipment and shipping coolers must be cleaned after each sampling round. Field cleaning often is not as effective as cleaning equipment at a support facility. Depending on the analyte and concentration (i.e., metals or organics), it may only be possible to conduct effective cleaning procedures at a support facility, rather than in the field. Avoid using bleaches and strong detergents. Specialty cleaning compounds are available.
14. De-ionized water should not be used after 6 months (shelf-life period), and the containers should be clearly labeled with both the filling date and disposal date.
15. Bottle cap liners of composite materials such as Bakelite must not be used due to high potential for contamination.

7.5 Quality Control Samples

In order to minimize potential imprecision and bias in the data, the program design must incorporate appropriate QC techniques. Diligence and consistent adherence to protocols are the best means of reducing both these forms of errors. Bias in water quality studies can be introduced through various mechanisms including poor equipment calibration, unrepresentative sampling, instability of analyte, interference and contamination. The first four of these mechanisms can be dealt with by ensuring strict adherence to the sampling protocols (Pommen, 1995, and Cavanagh et al., 1998).

> *Equipment must be regularly calibrated as specified by the manufacturer's instructions. Unrepresentative sampling will be mitigated if sample collection techniques are thorough. The instability of analyte (or variable) is dealt with through appropriate filtration and preservation. Interference can be addressed through appropriate preservation and documentation of site conditions (i.e., temperature measurements).* (Pommen, 1995, and Cavanagh et al., 1998)

Contamination is a more complex problem to address. The major sources of contamination include the following:

- Contamination by field staff during sample collection
- Contamination from the sampling device
- Contamination from the preservative
- Contamination from the sample bottle
- Contamination during sample processing such as from atmospheric deposition during filtering and preserving (Pommen, 1995, and Cavanagh et al., 1998).

> *The use of QC samples is the prime means of identifying the stage in the process during which the contamination was introduced. There are different forms of QC samples. Field blanks and replicate samples are*

> *specifically intended to detect contamination introduced throughout the sampling component of the program. Spiked and reference samples are intended to detect contamination introduced during the analytical process (lab component of the program).* (Pommen, 1995, and Cavanagh et al., 1998)

As much as 35 percent of the program budget can be allocated to QA/QC measures.

> *As a general rule, all new monitoring programs should incorporate rigorous QA/QC until a consistent, acceptable level of data quality has been demonstrated. The standard for program variability requires that analytical variance be less than 4 percent of the observed variance in the concentrations of the selected variables, and that the sum of the sampling variance plus analytical variance be less than 20 percent of the observed variance. See Clark et al. (1996) for a discussion of how the different forms of variability can be estimated. Once data quality is assured, a less rigorous (less costly) QA/QC program can be adopted.* (Pommen, 1995, and Cavanagh et al., 1998)

The amount of funding allocated to QA measures ultimately will depend on one or more of the items below.

- The level of experience of the field staff and familiarity with the analyzing laboratory. When both the lab and field staff are unfamiliar to the program designer, then funds directed toward QA/QC should be divided equally between the two (17.5 percent each). Conversely, if either has demonstrated consistency and reliability in the past, then funding requirements can be decreased for that component (to about 5 percent each).

- The type of program. Impact assessment and survey (or baseline) monitoring generally require more QA/QC funds than compliance and trend monitoring. Compliance monitoring usually is conducted as an extension of an existing monitoring program. Consequently, previous QA/QC efforts have established a satisfactory degree of accuracy and precision. For trend monitoring, there usually is more consistency in the field techniques, personnel and laboratory analytical techniques.

- State of the aquatic environment. There is no need to invest significant funds for QA/QC when the values obtained for particular variables are consistently well above the MDL or, conversely, well below levels of concern for defined water uses. When values are well above the MDL, a false positive is highly unlikely and, therefore, the funds might be of better use if directed elsewhere (e.g., toward more frequent monitoring). When the water body exhibits no evidence of unusual concentrations of water quality characteristics (i.e., values are well below the level of concern to protect the designated water uses), then a portion of the budget might be of better use when allocated to a separate program (i.e., a different watershed that is of higher priority) (Pommen, 1995, and Cavanagh et al., 1998).

7.5.1 Blanks. Blanks may be of paramount importance in the event that erratic results are obtained. Blanks may identify unsuspected contaminants associated with de-ionized water purity, improper cleaning procedures, preservatives, samplers, filters, travel, sampling technique or air contaminants that may have been sorbed by the samples during collection. Four common types of blanks are discussed below (Pommen, 1995, and Cavanagh et al., 1998).

1. **Trip blanks** are meant to detect any widespread contamination resulting from the container or preservative during transport and storage.

   Protocol
   a. Before a field sampling trip, one or more sample bottles for each type being used during the trip are selected at random, filled with de-ionized water that is provided by an analytical lab (preferably one different from the one samples are being sent to) and preserved in the field in the same manner as field samples.
   b. These bottles are capped and remain unopened throughout the sampling trip. They are transported to the field with the regular sample bottles and submitted with the field samples for the analysis of interest.

2. **Field blanks** are exposed to the sampling environment at the sample site and handled in the same manner as the real sample (e.g., preserved, filtered). Consequently, they provide information on contamination resulting from the handling technique and from exposure to the atmosphere.

   Protocol
   a. If the blank was prepared by the lab, then open the bottle to expose the de-ionized water to the air for as long as the sample was exposed when it was collected. Otherwise, when the blank is prepared in the field, pour de-ionized water into the pre-labeled field blank bottle and recap it (this simulates sample collection). Document whether it was a lab-prepared or field-prepared blank.
   b. Filter the sample according to protocol if the associate sample requires filtration.
   c. Add preservative if the associated sample requires preservation.
   d. Ship to the lab with the remaining samples.

3. **Equipment blanks** are samples of de-ionized water that have been used to rinse sampling equipment. This type of blank is useful in documenting the effectiveness of the cleaning or decontamination of equipment.

   Protocol
   a. Pour the rinse (de-ionized) water that was used for the last rinsing into a pre-labeled bottle that identifies the piece of equipment that was cleaned.

4. **Filtration blanks** (or rinsate blanks) are de-ionized water that has passed through the filtration apparatus in the same manner as the sample. Analysis of the filtrate provides an indication of the types of contaminants that may have been introduced

through contact with the filtration apparatus. Filtration blanks also are used as a check for potential cross-contamination through inadequate field filtration/cleaning techniques.

Protocol

a. When the sampling objective is to determine concentrations of dissolved metals, low-level nutrients (e.g., phosphorus) or chlorophyll *a* in a water system, the sample must be filtered through a non-metallic 0.45-µm (or 0.63-µm as specified) membrane immediately after collection. The guiding principle is to filter and preserve as soon as possible.

7.5.2 Spiked Samples.

Spiked samples for each variable being tested can be prepared by spiking aliquots of a single water sample with pre-measured amounts of the variable of interest. An aliquot of the same sample is left un-spiked. The difference in the analytical results between the two samples should equal the theoretical spike addition. The information gained from spiked samples is used to reveal any systematic errors (or bias) in the analytical method. (Pommen, 1995, and Cavanagh et al., 1998)

7.5.3 Reference Samples.

Reference samples are used to document the bias and precision of the analytical (laboratory) process. There are two types of reference samples. The choice as to which reference sample is selected depends on the expected concentrations being measured, and whether comparable concentrations are available in existing reference samples.

The first, and simplest type of reference sample, is provided by a laboratory that is not involved in the analysis of the "real samples." This independent laboratory prepares a reference sample by adding a known quantity of the variable of interest to a given quantity of pure water (this allows for a calculated concentration and verifies the concentration by analysis). Aliquots of this bulk sample are then submitted to recognized laboratories for analysis to obtain a mean concentration and standard deviation. The values for the calculated concentration, the mean concentration and the standard deviation are provided with the sample.

The second type of reference material is a certified reference sample. It is obtained from a scientific body such as the National Research Council. The sample is an aliquot of a very large batch sample that was collected from one place at one time. The batch sample has been preserved to ensure stability of the certified variables, and has been subjected to analysis by a large number of independent laboratories using several *different analytical techniques. Consequently, the distributing agency can provide a mean value and confidence interval for the variable of concern. Laboratories will use certified reference samples for their own QC. However, when implementing a monitoring program, it is desirable to submit additional reference samples "blind" to the analyzing laboratory so that the reported value obtained under routine analytical conditions can be compared to the "true" value. Reference samples can be submitted non-blind, but these samples will usually receive special attention and represent the best quality that the laboratory is capable of producing. Simultaneous submission of multiple samples of the same reference batch yields the laboratory precision.* (Pommen, 1995, and Cavanagh et al., 1998)

7.5.4 Replicate Samples.

Replicate samples (usually duplicates - at a minimum) are often collected at one or more sites to assess precision of the entire program (field and laboratory components). Replicate measurements on a single sample (normally every 20th sample) or the use of multiple submissions of spike or reference samples yield the laboratory precision. Replicate field samples collected in quick succession yields the field laboratory precision. Consequently, the subtraction of the values for laboratory precision from the values obtained for field and laboratory precision yields the field precision. The use of replicates for this purpose assumes that the variability among replicates is affected by the sampling method or technician. In most cases natural variability (heterogeneity) between samples collected in close succession at a single point will be low. The pilot study should assess short-term variability to confirm that this is the case for all sites. (Pommen, 1995, and Cavanagh et al., 1998)

7.6 Quality Control Procedures for Sample Custody

The possession of samples should be documented from sample collection through laboratory analysis unless there will be no need to verify handling procedures at any time in the future. Recording basic information during sample handling is good scientific practice even if formal custody procedures are not required. Sample custody procedures, including examples of forms to be used, should be described in the QA project plan. Minimum requirements for documentation of sample handling and custody on simple projects should include the following information:

- Sample location, project name and unique sample number
- Sample collection date (and time if more than one sample may be collected at a location in a day)
- Any special notations on sample characteristics or problems
- Initials of the person collecting the sample
- Date sample sent to laboratory.

For large or sensitive projects, a strict system for tracking sample custody should be used to ensure that one individual has responsibility for a set of samples at all times. For these projects, only data that have clear documentation of custody can be accepted without qualification.

A strict system of sample custody implies the following conditions:

- The sample is possessed by an individual and secured so that no one can tamper with it
- The location of the sample is known and documented at all times
- Access to the sample is restricted to authorized personnel only.

Chain-of-custody forms often are used to document the transfer of a sample from collection to receipt by the laboratory (or between different facilities of one laboratory). Although not always required, these forms provide an easy means of recording information that may be useful weeks or months after sample collection. When these forms are used, they are provided to field technicians at the beginning of a project. The completed forms accompany the samples to the laboratory and are signed by the relinquisher and receiver every time the samples change hands. After sample analysis, the laboratory returns the original chain-of-custody form. The form is filed and becomes part of the permanent project documentation. Additional custody requirements for field and laboratory operations should be described in the QA project plan, when appropriate.

When in doubt about the level of documentation required for sampling and analysis, a strict system of documentation using standard forms should be used. Excess documentation can be discarded. Lack of adequate documentation in even simple projects sometimes creates the unfortunate impression that otherwise reasonable data are unusable or limited. Examples of formal chain-of-custody procedures are outlined briefly in the statements of work for laboratories conducting analyses of organic and inorganic contaminants under EPA's Contract Laboratory Program.

In addition to field operations overseen by the project manager, a strict system of sample custody for laboratory operations should include the following items:

- Appointment of a sample custodian authorized to check the condition of and sign for incoming field samples, obtain documents of shipment and verify sample custody records
- Separate custody procedures for sample handling, storage and disbursement for analysis in the laboratory
- A sample custody log consisting of serially numbered, standard laboratory reporting sheets.

7.7 Quality Control Procedures for Sample Analysis

7.7.1 Analytical Quality Control. To achieve the objectives of quality assurance, the major concern is on the analytical quality control. For this purpose, intra- and interlaboratory quality control has to be used during the implementation of the monitoring program. In addition to the preparation of standard operational procedures, the program should include recommendations for similar laboratory facilities, the provision of necessary analytical instrumentation in the laboratories (at least for National Reference Laboratories), the implementation of an integrated training program, and the importance of proficiency testing carried out in interlaboratory comparison studies.

The information below should be requested from each contract laboratory as part of the quality assurance program.

- Indicate what method will be used for each variable.
- Indicate what turnaround time will be used for each variable, both for normal samples and for emergency samples.
- Indicate the method MDL for each variable. The detection limit must be in-house validated, not based on quotes from standard methods for similar methodologies. Instrument detection limits are not acceptable, except as supplementary information.
- Provide cutoff times for analysis. What are the cutoff times for same-day analysis? What are laboratory work hours?

7.7.2 Internal Quality Control Checks. As part of their internal quality control program, all laboratories should provide the information below on request.

- Results from any inter-laboratory studies will be considered part of the laboratory's QA performance. The contract laboratory must submit a comprehensive list of inter-laboratory studies the laboratory has recently (within the last 2 years) participated in or is participating in, and provide access to the documents relating to performance in these studies.
- Indicate standards and calibration routines that will be in place for instrument calibration (including microscope calibration if applicable).
- Indicate the “calibration control” procedures that will be in place to verify instrument calibration before commencing analyses, particularly for those samples arriving on Fridays.
- Indicate the “control limits” that will be used for calibration.
- Indicate “batch quality control” procedures that will be in place within the analytical runs to monitor and verify precision and accuracy (duplicate controls, recovery controls, blank controls, accuracy of IDs, reference collection comparison, etc.).
- Indicate the frequency of control samples within the analytical runs.
- Indicate the “control criteria/limits” that will be applied to “batch quality control” procedures. Provide information on a variable-specific basis.
- Indicate the procedures that will be in place if “control criteria” are not met.
- Indicate the “sample container blank criteria” that will be applied to cleaning sample containers.
- Provide details regarding testing sample containers, reagents, etc.

- Indicate the “preservatives and DI water purity criteria” that will apply to preservatives and reagent water supplied.
- Describe who is responsible for delivery of the lab QA/QC.
- Describe staff training and re-training programs for QA/QC.
- Describe sample tracking and capability of holding key QC parameters and dates.

7.8 Data Reduction And Validation

7.8.1 Production of Information. Measurements made of environmental variables result in the collection of “data,” which reveal imperfect, or incomplete, aspects of the system under study. Clark and Whitfield (1994) note that “data are essentially signals from the ecosystem; however, they do not represent perfect information about the natural system due to various sources of noise. Essentially, there is uncertainty between the real world (water quality in the environment) and the information we have about it (understanding of water quality conditions). Part of this uncertainty cannot be identified or quantified. The part that can be identified or quantified is noise.”

Thus, in reporting and, subsequently, using data or information, it is essential to understand what the sources of noise are and how they can affect our vision of the system under investigation. In reporting the results of a monitoring program, it is essential to recognize and characterize the uncertainties associated with each program—recognizing that each sampling and/or monitoring program will have different noise sources and uncertainties. Harmancioglu (1998) have observed that such uncertainties can result from the following:

- Mistaken assumptions and bias in the conceptual description of the ecological system as well as in the evaluation of data representativeness
- Detectability of true signals (detection limits)
- Failure to accomplish representative sampling
- Failure to select the proper methods in measurement
- Various interferences that occur during sampling and laboratory analyses
- Failure to look at the right place for the right material (e.g., water, air, biota, bottom sediments, etc.)
- Lack of quality assurance at various stages of monitoring
- Lack of consistency with respect to sampling methods and sampling sites
- Changes in sampling programs with respect to changing objectives or funding
- Errors in sampling
- Changes in sampling and analytical techniques (e.g., changes in methods, equipment or detectability)
- Lack of completeness in information production due to missing data.

Clark and Whitfield (1994) have discussed the issues associated with “error accumulation” or the principal that

> *…if noise is defined as ‘blurring of information,’ then all steps in data management (i.e., steps of data collection through transfer of data into*

> *information) have noise components because each has its own uncertainties. Thus, all problems relevant to each step constitute a source of noise. Each step imposes conditions on the type and quality of information flowing from the previous element. This implies that in each element (step), criteria for accepting the results of the previous element (step) have to be established. Also, each step is subject to changes and enhancements over time, reflecting changes in knowledge or goals, or improvements in methods and instrumentation. Thus, each step must have defined quality assurance activities to monitor these changes.*

In producing information from raw or processed data, it is necessary to identify where the noise in each system originates. There are three principal sources of noise, or uncertainty, in water quality monitoring programs (Chapman, 1992):

- Conceptual understanding of basic processes
- Available data
- Statistical noise.

"When dealing with noise in any of the areas above, it must be recognized that noise cannot be totally eliminated but can be minimized. The important thing is to be aware of the sources of noise and to be able to assess them" (Clark and Whitfield, 1994). In a recent paper reviewing the present state of water quality monitoring as a resource management tool (Dixon and Chiswell, 1996), the authors highlight that not understanding how ecosystems function can result in poorly designed monitoring programs and, ultimately, information that either is incorrect, erroneous or misleading. Such incorrect information will then be reported and used to make resource management decisions that could damage the very ecosystem services society wished to protect and preserve. Whitfield (1988) and Whitfield and Clark (1997) recommend that "to handle this problem, one has to investigate the basic driving and modifying forces acting on the ecosystem. A very recent problem that complicates such an investigation is the possible impact of an expected global climate change on basin hydrologic and meteorological processes." Chapman (1992) characterizes a number of possible sources of water quality assessment errors (noise) and suggests a number of actions that can be taken to remediate or avoid the problem (Table 7-1).

The issue of data limitations has been thoroughly reviewed by Clark and Whitfield (1994), Whitfield and Clark (1997), Whitfield (1988), Ward et al. (1986), and Dixon and Chiswell (1996). The following section has been extracted from a number of these sources. The specific problems and remedies are included here to indicate what specific issues should be addressed when designing a water quality monitoring program and how the data should be used and finally reported to potential end users.

Data limitations as sources of noise include (Timmerman et al., 1996):

1. *Missing values: may occur due to equipment breakdowns, lost samples, contaminated samples, poor weather, and employee illness; they may be random or systematic*
2. *Sampling frequencies that change over the period of record: often occur when budget restrictions are applied in monies devoted to sampling; shifting water quality problems or new crisis also can cause this change*
3. *Multiple observations within one sampling period: a common reason for this to occur in a water quality data record is when QA/QC results are stored in the same computer record as the original water quality observation*
4. *Uncertainty in the measurement procedures: this basically is the result of random analytical errors and varies with calibration of the measuring equipment*
5. *Censored data: this is a problem related to detection limits and becomes more complicated when the detection limit changes over the period of record; multiple censoring levels occur when different analytical techniques are used over the period of record or when different lab protocols are used or when data from different labs are analyzed as one data set (Clark and Whitfield, 1994)*
6. *Small sample sizes*
7. *Outliers: may be due to erroneous measurements or extreme events; it is difficult to differentiate between the two*
8. *Problems related to quality of data: data should be validated and measurement of sampling errors should be presented; otherwise, the reliability and accuracy of data remain doubtful*
9. *Problems related to data presentation: poor reporting of data reduce their reliability and accuracy; this refers to formats, units, and specifications used in data presentation.*

Recognition of data limitations during the design phase may help to minimize them; however, they often are (only) recognized during the analysis of data that are already monitored. Once the program is operational, site-specific conditions will determine the extent to which local variability will contribute to the total error or uncertainty associated with each measured parameter.

7.8.1.1 Requirements for Noise Reduction. It is apparent that error or noise cannot be completely eliminated, but it can be minimized if certain precautions are adhered to and if the processes to do so are carefully documented when data and information are reported. The process of minimizing and documenting processes of error or noise control consist primarily of QA/QC programs developed for both sample collection (total sample error) and laboratory analysis (total assay error), together with data interpretation and handling procedures.

7.8.2 Sampling and Analytical Errors. In the monitoring of an ecosystem, samples are taken to represent the temporal and spatial variability of the process observed. Clark and Whitfield (1994) define "local variability," represented by the quantitative results of sampling, as "the heterogeneity of the environment within a specified small area and time frame which one or more samples represent." They also define "total environmental variability" as "a measure of the gross or overall variability as estimated from a large number of such samples."

> *There are several procedures to be realized until a particular datum is obtained. Clark and Whitfield (1994) divide this total procedure (total assay procedure) into sampling and analytical procedures, the former covering all steps until the sample arrives at the laboratory and the latter involving those steps until the presentation of analytical results* (Figure 7-2). *These two procedures are subject to errors, i.e., sampling errors and analytical errors, the sum of which make up the total assay error. These errors are due to sampling uncertainty (sampling variance) and analytical uncertainty (analytical variance). Their sum is the total assay uncertainty (total assay variance), which, as stressed by Clark and Whitfield (1994) and Clark et al. (1996), must be significantly smaller than local variability and definitely smaller than total environmental variability if the results of monitoring are to be reasonable. Often there are no measurements of sampling errors to be presented with the monitored data. In general, investigations on analytical errors are more detailed.* (Harmancioglu et al., 1998)

The sources of total assay error are presented in Figure 7-2.

7.8.3 The Nature and Sources of Analytical Errors. The issue of reporting accuracy is contingent on two principal concerns. The first is that

> *…several factors contribute to the production of analytical data of adequate quality. Most important is the recognition of the standard of accuracy that is required of the analytical data and which should be defined with reference to the intended uses of the data.*

The second is that

> *…the results of chemical analyses of waters and effluents are subject to errors; that is, the measured concentrations differ from the true concentrations. The Total Error, E, of an analytical result, R, is defined as the difference between that result and the true value, T (Timmerman et al., 1996):* $E = R - T$. (Harmancioglu et al., 1998)

Thus, accuracy increases as the total error is diminished. Since the "total error" consists of the addition of the random error plus systematic error, and each contributes a different effect on how the analyzed data is used, Clark and Whitfield (1994) caution that each error must be dealt with differently. The following section contains observations about random and systematic errors and outlines how each should be addressed with respect to data use and reporting.

7.8.3.1 Random Error.

Repeated analyses of identical portions of the same, homogenous sample do not, in general, lead to a series of identical results; results are scattered about some central value. The scatter results from random error. This type of error is called "random" because the sign and magnitude of the error of any particular result vary at random and cannot be predicted exactly.

The statistical population parameter used to quantify random error is the standard deviation.

Random errors occur due to uncontrolled variations in the conditions of the analytical system during analyses. These are short-term variations, e.g., instrumental noise, detector noise, operator-induced variations in reading scales. While many of these factors causing random errors can be more closely controlled to achieve better precision, they can never be totally eliminated so that all results are subject to some degree of random error. (Harmancioglu et al., 1998)

7.8.3.2 Systematic Error.

Systematic error (or bias) occurs when there is a persistent tendency for results to be greater or smaller than the true value (results are subject to positive and negative biases respectively). "As the systematic error or bias of results decreases, trueness is said to increase" (Timmerman et al., 1996).

There are five main sources of systematic errors (Timmerman et al., 1996).

1. *Instability of samples between sample collection and analysis: The concentrations of many determinants may change between sampling and analysis.*
2. *Inability to determine all relevant forms of the determinant: Many substances in water exist in a variety of species. Within each of these physical categories, a variety of chemical species may be present, e.g., free ions and complexes. An inability of the analytical system to determine some of the forms of interest leads to a bias when those forms are present in the samples.*
3. *Interferences: Few analytical methods are completely specific for the determinant. It is, therefore, important to know the effects of substances likely to be present in the samples.*

4. *Biased calibration: Most methods require the use of a calibration function to convert the primary analytical response for a sample to the corresponding determinant concentration. If samples and calibration standards are treated differently, this can represent a serious source of error.*
5. *Biased blank: The same considerations as in (4) apply to blanks. However, there is, another source of bias arising from blank correction. If the water used for the blank contains the determinant, results for the samples will be biased low by an equivalent amount.* (Harmancioglu et al., 1998)

7.8.4 The Use of Statistical Analysis. One of the basic aims of a monitoring plan is to provide representative water quality data that can be understood and tested on a statistical or comparative basis. The most appropriate statistical techniques must be employed to produce comprehensive analyses and interpretations.

The choice of appropriate statistical analyses should flow logically from the objective(s) of the sampling or monitoring study, the null hypothesis and the sampling plan. The hypothesis model should determine the statistical model.

An efficient statistical analysis method should be as conservative, powerful and robust as possible (Green, 1979). If it is conservative, it will have a low probability of making a Type I error. If the statistical method is powerful, it will have a low probability of making a Type II error. If it is robust, the stipulated error levels will not be seriously affected by the kinds of data commonly encountered in environmental studies.

Overcomplicated statistical approaches should be avoided as much as possible, and results of the statistical analysis should always be reported in a form that is understandable by the data users.

7.9 Database Management

The goals of good database management should be as follows (Gaskin, 1993):

- Provide databases that are accurate, well documented and complete
- Ascertain data quality after the data have been recorded to provide timely feedback to laboratory analysts so analytical and recording errors can be corrected
- Ensure that the best interpretive techniques are used in examining the laboratory-generated data with project objectives in focus, and ensure that the data reported are of known and acceptable quality
- Promote and develop uniform approaches to data storage and retrieval
- Establish an evaluation system for ascertaining the quality and reliability of the data produced, ensuring that all data are accompanied by estimates of their precision and accuracy.

7.9.1 Archival Data Storage.

7.9.1.1 Establishment of a Reference Library. The loss of archival data and information is an important subject that has, unfortunately, received less attention than the subject warrants. The majority of scientific information that has been produced has occurred since the Second World War, with most of the information being less than 15 years old. Since one of the most crucial tasks of environmental scientists is to reveal long-term trends or cycles in specific environmental parameters, the value of historical data and information is essential. These data are valuable for at least two reasons. First, the data were collected during a period that normally cannot be revisited other than through surrogate parameters. Second, it generally is cheaper to use historical data (that is accurate) than to try and obtain such information at a latter date. For these reasons, and many others, the preservation of historical data is essential if we are to make informed, wise land use decisions now or in the future.

Included in the preservation of historical data is the need to preserve whatever QA/QC data are available. Since QA/QC data were either not collected or as carefully preserved as the actual databases being generated, it is valuable to review what protocols were used through discussions with the actual researchers that conducted the sample programs. Since the older databases were collected decades ago, the chance of actually engaging in discussions with the scientists themselves becomes more difficult as the databases become older. The majority of the working scientists alive today were trained in the 1960s and 1970s and are now beginning to retire, move away or die. The following is a discussion of some of the issues relating to this important topic. It conveys concerns about this very serious problem using a specific example of what could happen if the problem is not addressed.

The problem is even more acute in the case of databases obtained in the Kootenai Basin since the number of jurisdictions is substantially higher and reflects the international and multistate nature of the political dimension. Another confounding aspect is that there were, and remain, a large number of agencies that historically did not make any serious attempt to coordinate their sample collections, laboratory analysis, data storage or electronic systems. Having reviewed a portion of this database, we are concerned that unless a concerted effort is made to assemble, compile and preserve the historical data files, they will become lost. One of the more important problems we have discovered is the difficulty in trying to convert biological data into meaningful information. While the extent of this problem is basinwide, the following discussion is based on the British Columbia experience, which we believe applies to the rest of the watershed’s political regions.

Biomonitoring programs increasingly are being designed, as part of larger monitoring networks, to protect the integrity of aquatic ecosystems. Given that natural ecosystems are complex, multivariate systems being exposed to a multitude of stressors whose mechanisms and cumulative effects are poorly understood, successful ecosystem management cannot be achieved without encompassing integrated objectives.

The dilemma the manager then faces is that precisely when more information is required on biodiversity to protect aquatic habitat, the constraint of fewer taxonomists—and efficient access to existing biotic databases—diminishes the likelihood of such information becoming available. Thus, every effort must be made to immediately establish database repositories for aquatic data that has been collected within the Kootenai Basin.

7.10 Recommendations

With respect to all water quality and other related aquatic environmental data, we recommend the actions below.

- Establish a database repository housing all historical water quality data obtained within the Kootenai River watershed. These data should be identified, catalogued, copies obtained (hard and electronic) and physically stored in already established public libraries (municipal libraries or publicly funded post-secondary institution libraries). The function of the library should be based on the following:
    - Systematic accumulation of environmental data using common standards and procedures
        - maintained access to data
        - efficient use of the accumulated materials to facilitate environmental planning, management and protection-related decisions.

Three libraries should be established: 1) Cranbrook, BC; 2) Libby, MT; and 3) Bonners Ferry, ID.

Funding to establish the long-term, archival libraries should be sought from both Canadian and American government sources. The actual process of establishing the libraries should follow the recommendations outlined elsewhere in this document.

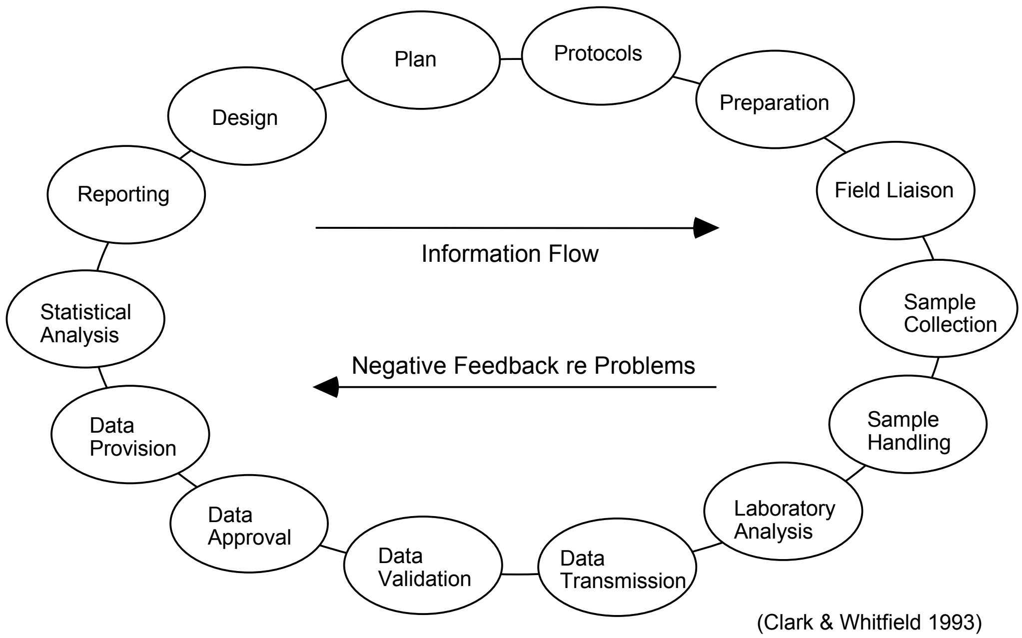


Figure 7- 1. Fourteen-Element Iterative Cycle Model of the Environmental Study Process (Clark and Whitfield, 1993)

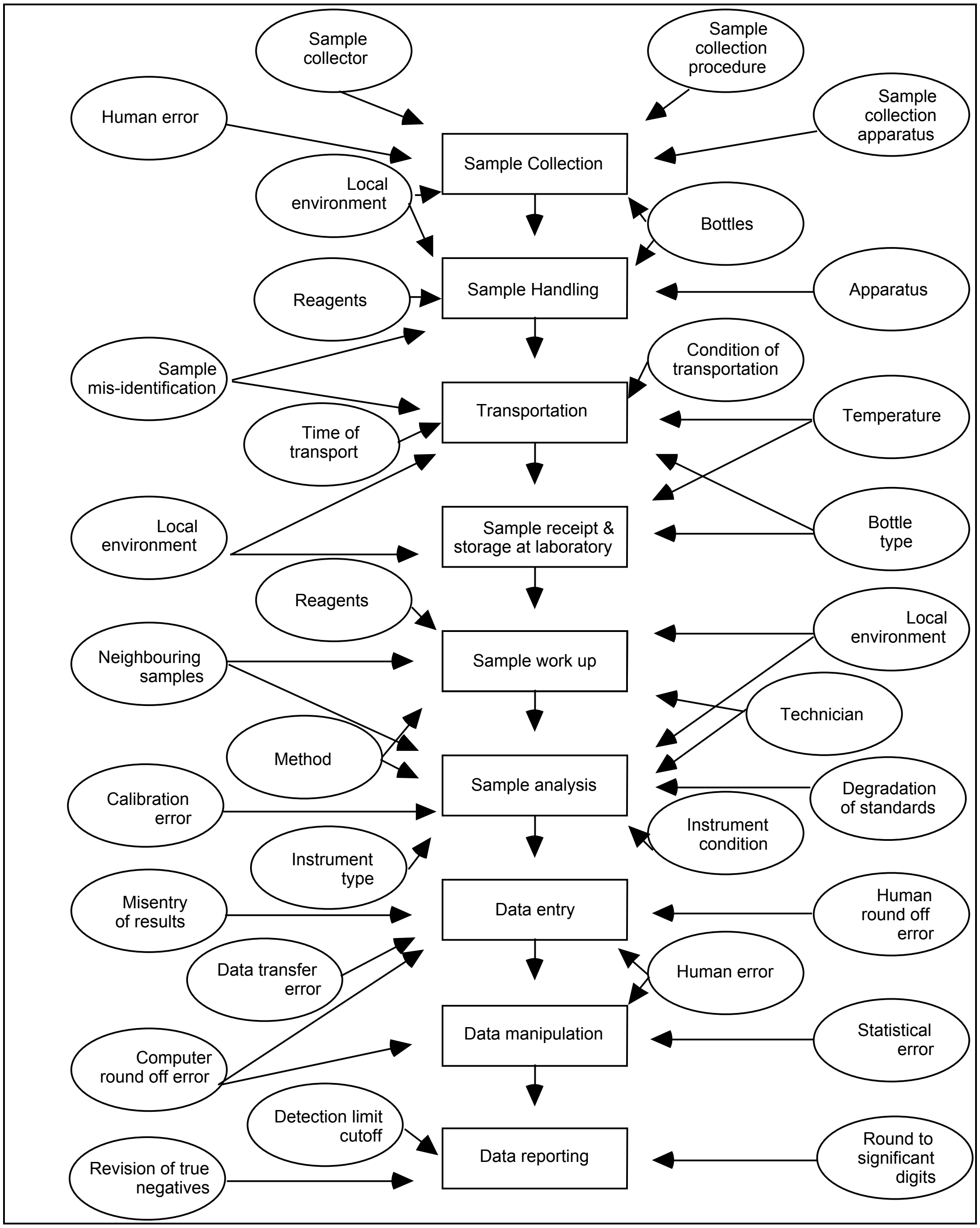


Figure 7- 2. Sources of Total Assay Error; Total Assay Error is the Sum of Sampling Error Plus Analytical Error (Clark and Whitfield, 1994)

Table 7- 1. Some Possible Sources of Errors in the Water Quality Assessment Process (Chapman, 1992)

Assessment Step	Operation	Possible Source of Error	Appropriate Actions
Definition of objectives	Statement	Lack of specific objective	Clearly specify & state objective
Conceptual understanding	Forces & interactions	Lack of understanding or conceptualizing	Field work, investigation, training
Monitoring design	▪ Site selection ▪ Frequency determination	▪ Station not representative (e.g., poor mixing in rivers) ▪ Sample not representative (e.g., unexpected cycles or variations between samples)	Preliminary surveys
Field operations	▪ Sampling ▪ Filtration ▪ Field measurement	▪ Sample contamination (micropollutant monitoring) ▪ Contamination or loss ▪ Uncalibrated operations (pH, conduct, temp) ▪ Inadequate understanding of hydrological regime	▪ Decontamination of sampling equipment, containers, preservatives ▪ Running field blanks ▪ Field calibrations Replicate sampling ▪ Hydrological survey
Sample shipments to laboratory	Sample conservation and identification	▪ Error in chemical conservation ▪ Lack of cooling ▪ Error in biological conservation ▪ Error and loss of label ▪ Break of container	▪ Field spiking ▪ Appropriate field pretreatment ▪ Field operator training

Table 7- 2. Some Possible Sources of Errors in the Water Quality Assessment Process (Chapman, 1992) (cont.)

Assessment Step	Operation	Possible Source of Error	Appropriate Actions
Laboratory computer facility	▪ Preconcentration ▪ Analysis ▪ Data entry and retrieval	▪ Contamination or loss ▪ Contamination ▪ Lack of sensitivity ▪ Lack of calibration ▪ Error in data report ▪ Error in data handling	▪ Decontamination of laboratory equipment and facilities ▪ Quality control of laboratory air, equipment, and distilled water ▪ Quality assurance tests (analysis of control sample, analysis of standards) ▪ Check internal consistency of data (e.g. with adjacent sample, ionic balance, etc.) ▪ Checks by data interpretation team
Interpretation	Data interpretation	▪ Lack of basic knowledge ▪ Ignorance of appropriate statistical methods ▪ Omission in data report	Appropriate training of scientists
Publication	Data publication	▪ Lack of communication and dissemination of results to authorities, the public, scientists, etc.	Setting of goals and training to meet the need of decision makers

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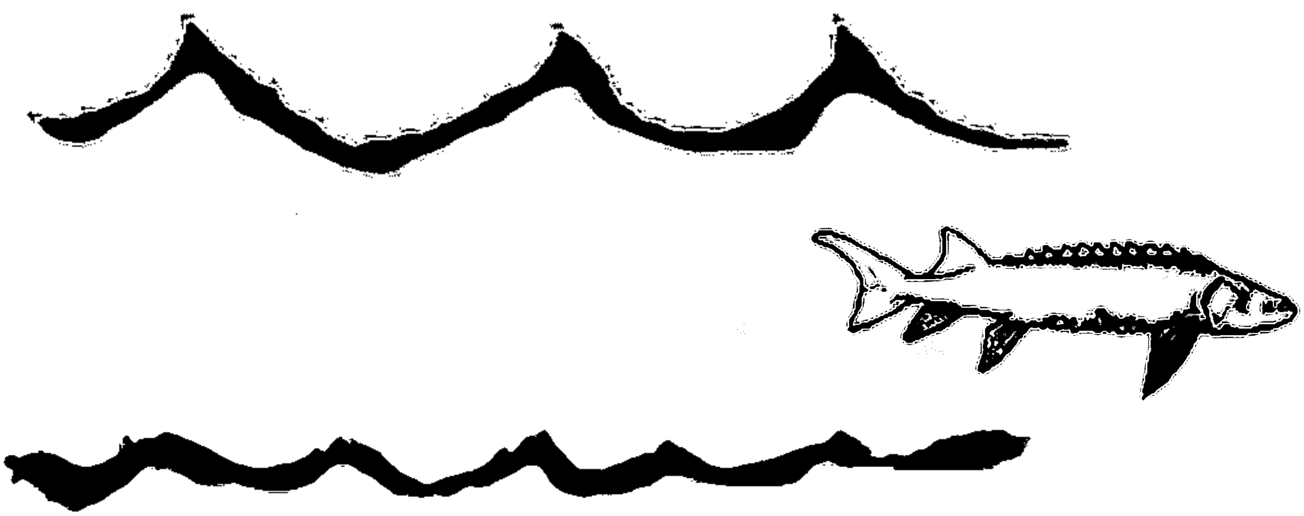
SECTION 8.0
DATA USE AND REPORTING



8.0 DATA USE AND REPORTING

8.1 Reporting

The framers of the NATO-sponsored *Assessment of Water Quality Monitoring Networks – Design and Redesign* (1998) stressed that the lack of universal guidelines on developing water quality monitoring programs is increasingly understood by those charged with protecting freshwater resources. The absence of such guidelines makes provision of timely, cost-effective, useful information problematic at best and unlikely at worst. Thus, if data are to be converted into information and reported in a useful manner for use by resource management staff, there must be standardized, universally agreed upon protocols for designing, establishing and maintaining water quality monitoring programs, the data from which can be used by as wide a group of end users as possible. The NATO authors note the following:

> *The present work has derived its impetus from the recommendations expressed at international levels towards improved availability of information on the water environment for better water management. Examples include the Dublin Statement of the International Conference on Water and Environment; Agenda 21 of UNCED; various workshops and meetings held by WMO, WHO, UNESCO, UNEP, the World Bank, IAHS, and LAWQ; recent Directives foreseen by the EU Community; and a number of international programs such as the EEA (European Environmental Agency) work program, WHYCOS of WMO and the World Bank, GRID and GEMS of UNEP.*

One of the most crucial issues that must be addressed is that water quality data and information must be made available to a wide variety of users—both scientific and non-scientific—and that the data must be of the highest possible quality. The authors further note the following:

> *Environmental data management should be considered as an activity for handling data so that they are available where they are needed, when they are needed, and have with them all the supporting information that is necessary for the user to understand and use the data at their full potential. Thus, the prospects for environmental data management are associated with the creation of the specialized information system called SISEM. SISEM can be used to implement the information technology represented by an integrated sequence of operations for acquisition, accumulation, modeling and transformation of environmental data in order to obtain information required for decision making and planning of environmental and other actions.*

The development of a specialized information system to improve the reporting of information and to facilitate its easy accessibility by as wide an audience as possible should ensure that, at a minimum, the items below are accomplished (NATO, 1998).

1. **Systematization and accumulation of different environmental data using common standards and procedures.** All procedures, standards and information expectations should be documented for traceability; personnel involved in the monitoring program should be skilled and trained; each organization and agency involved in different steps of data management should check for the quality of their inputs and outputs; regarding data quality, specifications and methods of laboratory analyses used in production of data should be encoded into the data series when they are presented to the users; similarly, information on QA/QC results also should be encoded into the available data sets; one should not collect any data that is purposeless; historical data should be used with caution since stationarity of most natural processes have become questionable due to the recent problem of global climate change, and methods and technologies in data sampling and analytical procedures have changed since sampling for existing networks was begun; changing the monitoring practice from chemical monitoring to biological monitoring

2. **Maintaining and providing access to environmental data.** An important consequence of monitoring practices should be the production of status reports on water quality of surface waters; the basic objective of these reports should be to inform the public about water quality instead of preserving such information in scientific reports only; data should be validated before they are disseminated to users; risks in the monitoring system should be identified.

3. **Efficient use of the accumulated materials to support environmental planning, management and protection-related decisions.** Care should be given to collection of validated data that have a purpose and that produce the required information; in the redesign phase decrease the number of sampling sites, increase the sampling frequencies and select the "best" variables that reflect water quality conditions at the site in the most effective way; the "data-rich, information-poor" syndrome prevailing in current networks should be changed in favor of "less data and more information;" improve the cost-effectiveness of the network; monitoring should be regarded as a basic tool for integrated basin management plans.

4. **Design of data networks should be based on the purposes for which the data are to be collected.** From a pragmatic point of view, there are many purposes for the collection of environmental data, and thus many network design tools are required; multipurpose networks are difficult to design rationally, so an approach that permits interactive designs of single-purpose networks is the most feasible means of performing integrated design.

5. **Solicit feedback from data collected and information produced by the initial network.** Developing functional feedback loops permits a more complete description of the environmental phenomena and the subsequent use of more complex approaches to redesign the network; knowledge and information gained from an environmental data network can be used for improvement of the network; the design of data networks should not be performed in isolation from the

technologies that will be used to convert the data to environmental information or from identified end users and their specific knowledge requirements.

6. **Monitoring system redesign recommendations should be included in reports and documents originating from an existing network.** Continual system refinement should be a data use and reporting objective; improvements to institutional and administrative aspects of monitoring should be made whenever possible; design and recommend when and where test cases can be used to form the basis of case studies to be used as a feedback mechanism to facilitate monitoring network refinement.

8.2 Maximizing the Usefulness of Information

Timmerman et al. (1996) outline the steps below as useful practices in monitoring design and recommend that detailed descriptions of specific procedures employed to minimize noise be included in all reporting documents.

1. All procedures, standards and information expectations should be documented for traceability or for finding the origins of discrepancy.

2. Personnel involved in data management should be skilled (training required).

3. Each step of data management is realized by different organizations or different parts of organizations, and different disciplines. Each should check for the quality of their inputs and outputs.

4. There is a need for standards and standardized procedures in each step of data management (different people carrying out the same process must obtain the same result). If there are differences between the outcomes of similar processes, there must be a way to account for the difference. "This means that there is a need for protocols. The use of protocols makes it possible to trace back the processes to the point where the deviation starts. In this way, the absence of a measurement in a series can be traced back" (Timmerman et al., 1996).

5. Preliminary sampling and analysis programs may be required to better understand the problem (e.g., for selecting representative sites, etc.).

6. Risks in the monitoring system should be identified for possible failures.

7. With respect to laboratory analyses, the analytical QA/QC program should be set to include the following:

a. The use of validated methods
b. Properly maintained and calibrated equipment
c. The use of reference materials to calibrate methods

d. Effective internal quality control (control charts)
e. Independent audits of quality control procedures.

8. With respect to data handling, the following may constitute sources of noise:

a. Malfunctioning of computers and software used
b. Missing values
c. Sampling frequencies that change over the period of record (which basically are the data limitations described earlier)
d. Multiple observations within one sampling period
e. Uncertainty in the measurement procedures
f. Small sample sizes
g. Outliers
h. Measurement data rounding
i. Data at or below the limit of detection, censoring.

9. With respect to data analysis, several statistical methods exist. It is important to understand the theory, assumptions and consequences of violating of these assumptions for each method.

10. Variations in hydrological, meteorological, physical, biological and chemical factors have to be documented for the final interpretation and production of information.

11. If analytical methods change, comparability between new and old methods should be established; otherwise, this may cause problems in statistical analyses.

12. Data validation should be accomplished to ensure that inaccuracies in the data are traced on a timely basis before they are included in a database. Data validation checks include statistical analysis of replicate and spiked sample data, of blanks and standard reference materials data, and also of the historical data records. Protocols for data validation must include details as to what methods and checks are to be used to ensure that the recorded data are valid. If data are found to be questionable, they should be flagged or moved to a secondary file rather than be destroyed. Documentation of irregularities of deviations from protocols can provide helpful information in this case. Checking of data for "outliers" may also be part of data validation as well as be a part of data interpretation (Timmerman et al., 1996). Finally, data approval must be carried out as a formal process where the reviewers take responsibility for the data being of scientific-level quality. If data are not validated, this should be indicated in the final data reports.

13. Regarding data storage, most errors are due to human errors during written transcription or during "keying-in" via a computer keyboard. Therefore, it is important to have databases checked periodically by an expert who is capable of spotting obvious errors. Another common problem is the loss of data due to

accidental erasure of computer files. Thus, backup files should always be prepared and kept.

14. Another significant issue is censoring of data. Timmerman et al. (1996) state that the lack of measurement precision encountered near the limit of detection (LOD) generally is resolved by censoring the data. However, censoring removes information that may be useful for statistical data analysis and often creates the false impression that results near but above the LOD are sufficiently precise. Such results usually are reported as not detected, less-than values, half limit-of-detection (0.5 LOD) or zeros. Further complications when censoring data may occur if the detection limit has changed over the period of record. Multiple censoring levels generally occur when different analytical techniques have been employed over the period of record. As a result, censored data should always be recognizable as such and information should be included on the type of censoring that has been used.

15. Regarding data interpretation, the use of a data analysis protocol also is recommended. This protocol should specify the statistical analysis methods to be used, the reporting formats for the resulting information and means of handling data limitations.

Minimization of noise by the above considerations should lead to reliable and accurate information. It is worthwhile to mention here the basic rules stated by Timmerman et al. (1996) toward production of reliable information.

- The objectives of monitoring must be defined first and the program adapted to them, not vice versa. Adequate financial support must then be obtained.
- The type and nature of the water body must be fully understood particularly with respect to the spatial and temporal variability in the water body.
- The right media must be chosen for sampling (water, particulate matter, biota).
- The variables, type of samples, sampling frequency and sites must be chosen with respect to the objectives.
- The field, analytical equipment and lab facilities must be chosen in relation to the objectives, not vice versa.
- A complete and operational data treatment scheme must be established.
- The analytical quality of data must be regularly checked through internal and external control. Essentially, QA/QC procedures should be applied in each phase of the monitoring and data management system (Clark and Whitfield, 1993).

8.3 Reporting Checklist

The following information, at a minimum, should be included with all published reports and all archived data (Charles, 1990; Csuros, 1994):

1. Water quality objectives and goals of the monitoring plan

2. Criteria for assessing whether the objectives and goals were met including specific statistical criteria
3. Site identification (topographic map showing every sample site location, county and township, province or territory; append a list of parameters sampled at each site with sampling frequency)
4. Exact location of sampling point (e.g., distance from bank, whether midstream, location in lake) including major and minor landmarks
5. Wherever possible sites should contain GIS information and/or latitude-longitude coordinates and elevation, as determined from a GPS instrument or Universal Transverse Mercator
6. Boundaries of segment sampled, basin and sub-basin area of watershed
7. Morphometric watershed measurements for lakes (area, volume, mean depth and maximum depth) and reach profile maps for streams and rivers; location of nearest flow recorder (gauge station) for streams and rivers; stream classification
8. Distance of sampling point from point source discharges
9. General description of study region (e.g., vegetation, soils, geology, physiography, land use) including land use practices upstream of sampling location and ease of access
10. Sample source (groundwater, drinking water, surface water, wastewater, reservoir, lake, sediment, soil, etc.)
11. Number and matrix of samples
12. Duration of survey
13. Frequency of sampling (monthly, quarterly, etc.)
14. Type of sample (grab or composite)
15. Method of sample collection (manual, automatic)
16. Needed analytical parameters with method numbers and references
17. List of taxonomic references used in analyses of biological samples
18. Detailed outline of field QC measures
19. Availability of sediment surveys
20. Data from other agencies (federal, provincial, territorial, interjurisdictional, international and private)
21. Hydrologic data
22. Names and initials of sample collectors and sampling agency(ies)
23. Major issues and concerns.

In addition, the report should contain the following:

1. All original field notes or very clear (verified) photocopies of field notes
2. Original or very clear (verified) photocopies of original data sheets
3. An electronic copy of all data used in the production of the report including an indication of which data have been verified and which have not; the electronic copy should be provided in text or ASCII format for ease of translation by future users
4. Copies of all maps used in the production of report or those required for location of the sample sites

5. A list of where all backup copies of data files (hard copy and electronic) and reports are located with the name of a contact person or agency
6. A reliable list of where copies of methods manuals and equipment manuals can be obtained; if there is any doubt as to the long-term security of these manuals, copies should be made and archived with the original copy(ies) of the report
7. A list of all acronyms, abbreviations, symbols or codes used anywhere in the report, field notes, lab analysis or data analysis and their meaning
8. The data validation process used described in detail
9. Complete, detailed copies of all QA or QC protocols should be included in the report
10. All QA data must be included with the data; it is not sufficient to indicate where this can be found, it must be included with the original data.

Other considerations are below.

1. All electronic data should be backed up in a simple (e.g., text or ASCII) format as well as in its original format and archived in at least three different secure locations.
2. Provision must be made to refresh and transfer electronic data to new media periodically to prevent deterioration and loss of electronic files. This may be accomplished by archiving the data with an agency that has staff who routinely back up and refresh data files in their care.
3. Copies of all software packages used in the production or maintenance of a database must be archived with that database.
4. At least three complete copies of each report should be printed on acid-free (archival quality) paper and archived with a reliable (i.e., university or museum) agency. Hard copies also should be made of all databases and archived.
5. All QA data must be included with the sample data to which it pertains. It must be included with all electronic and hard copies of the data.
6. Publicly accessible databases must be designed in such a way that raw (unverified or unvalidated) data cannot be accessed and so that data cannot be accessed without its companion QA data.

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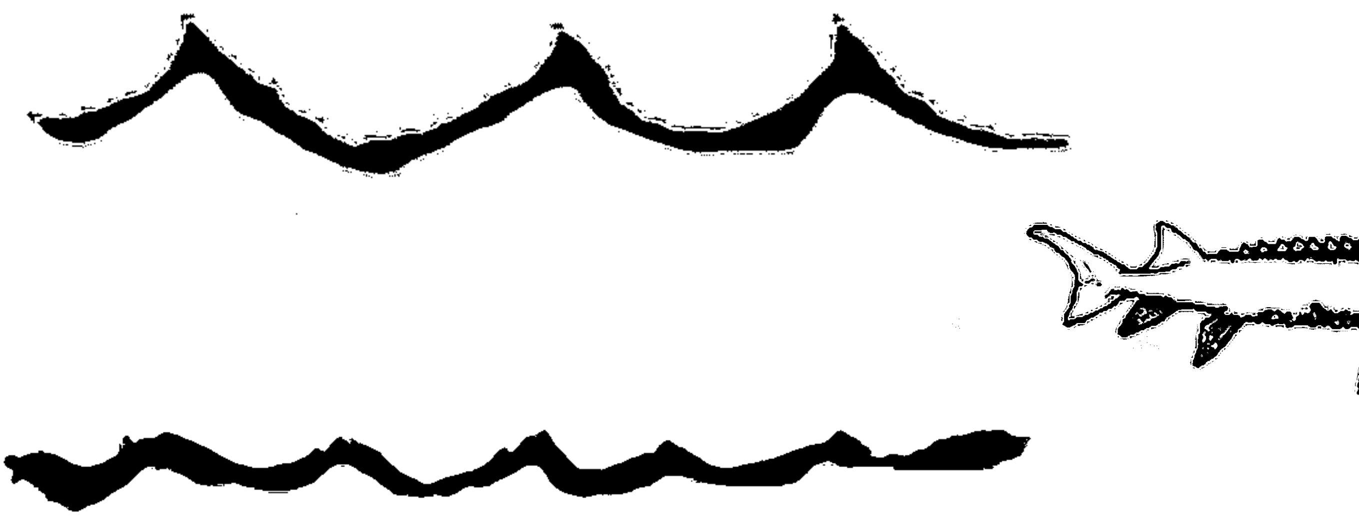
APPENDIX I
REFERENCES



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APPENDIX II
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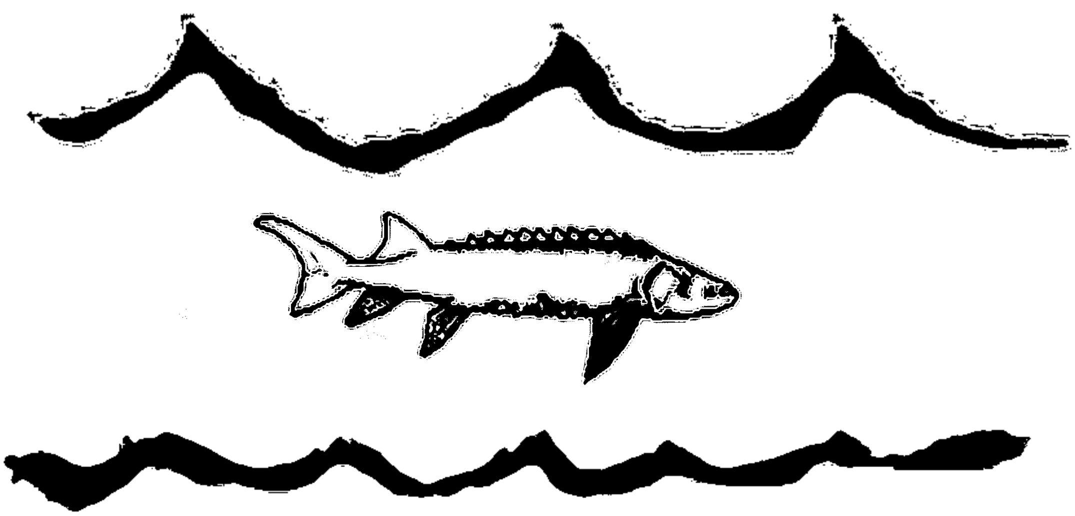

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The bibliography is sub-divided into a series of separate sections, as follows:

- STDs Federal Register - Drinking Water Quality
- STDs - Total Coliform Rule - Drinking Water Quality
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