Salmon River: Water Quality Assessment and Recommended Objectives

Technical Appendix - Volume I

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ABSTRACT

This document is one in a series that describes the ambient water quality objectives that have been developed for various waterbodies in British Columbia. The report has two parts, including the following technical appendix and a summary report (MacDonald et al. 1997), which is available separately. The overview is intended both for technical readers and for readers who may not be familiar with the process for establishing water quality objectives. The overview provides general information about water quality conditions in the Salmon River watershed and a summary of the recommended water quality objectives and monitoring program for the watershed. The technical appendix presents more detailed information on water uses, aquatic ecosystem structure, contaminant sources, and ambient environmental conditions in the Salmon River watershed. In addition, the water quality objectives and the detailed monitoring recommendations for the river system are presented in the technical appendix.

The Salmon River is an important tributary of Shuswap Lake, which drains into South Thompson River. In addition to supporting anadromous salmonids, resident fish species, and other aquatic organisms, the Salmon River and its tributaries provide important sources of raw water for domestic water supplies, irrigation, and livestock watering. Recreation and aesthetics also represent important uses of the aquatic environment, both of which generate social and economic benefits to area residents.

Concerns related to environmental quality conditions in the Salmon River are primarily associated with non-point source contaminant discharges. Such contaminants arise from a variety of land use activities, including forest management, agriculture, and urban development. Contaminants of concern in the watershed include suspended solids, turbidity, ammonia, phosphorus, nitrogen, metals, and faecal coliforms. In addition, water withdrawals from the river and nearby infiltration galleries have resulted in decreased streamflows and associated effects on water temperatures and other habitat features in the river.

This report describes the water quality objectives that have been recommended for the Salmon River watershed. These objectives specify the water quality conditions that are necessary to protect aquatic life, wildlife, livestock watering, irrigation, drinking water supplies, and aesthetic and recreational water uses in this river system. The objectives also represent targets which can be used to determine whether remediation efforts have been successful.

RÉSUMÉ

Ce document fait partie d'une série de rapports sur les objectifs de qualité de l'eau établis pour diverses masses d'eau de la Colombie-Britannique. Le présent compte rendu se divise en deux parties comprenant l'annexe technique suivante et un rapport sommaire (MacDonald et al. 1997), disponible séparément. Le sommaire est destiné à un public de lecteurs initiés et non initiés au processus d'établissement des objectifs de qualité de l'eau. Il donne de l'information générale sur la qualité de l'eau dans le bassin de la rivière Salmon et un synopsis des objectifs de qualité de l'eau et du programme de surveillance recommandés pour le bassin. L'annexe technique donne des renseignements plus détaillés sur les diverses utilisations des eaux, la structure du système aquatique, les sources de contamination et les conditions du milieu environnant dans le bassin de la rivière Salmon. De plus, l'annexe technique présente les objectifs de qualité de l'eau et des recommandations détaillées concernant la surveillance du bassin hydrographique.

La rivière Salmon est un important tributaire du lac Shuswap, qui se jette dans la rivière Thompson Sud. En plus de fournir un habitat pour les salmonidés anadromes, pour les diverses espèces de poissons résidents et autres organismes aquatiques, la rivière Salmon et ses tributaires assure une importante fonction d'approvisionnement domestique et agricole (travaux d'irrigation, abreuvement du bétail, etc.). Les fonctions récréatives et esthétiques sont également importantes et procurent de nombreux avantages sociaux et économiques aux résidents de la région.

Les préoccupations suscitées par la qualité de l'environnement dans la rivière Salmon concernent principalement les sources diffuses de pollution liées à diverses activités économiques (aménagement forestier, agriculture, développement urbain, etc.). Les formes de contamination les plus préoccupantes sont les taux de matières en suspension et de turbidité, d'ammoniac, de phosphore, d'azote, de métaux et de coliformes. De plus, les prélèvements hydriques et les galeries d'infiltration pratiqués dans les environs ont entraîné une diminution des débits qui a eu à son tour des effets perturbateurs sur la température des eaux et diverses autres caractéristiques de l'habitat aquatique.

Ce rapport décrit les objectifs de qualité de l'eau proposés pour le bassin hydrographique de la rivière Salmon. Ces objectifs établissent les conditions qualitatives nécessaires pour protéger la vie aquatique et la faune, et pour assurer l'abreuvement du bétail, les travaux d'irrigation, l'approvisionnement en eau potable, et les fonctions esthétiques et récréatives de ce bassin hydrographique. Ils représentent également les objectifs qui peuvent servir à déterminer si les mesures correctives ont été fructueuses.

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1.0 INTRODUCTION

1.1 Study Area

The Salmon River flows approximately 120 km from its headwaters near Bouleau Mountain to Salmon Arm of Shuswap Lake (Figure 1.1). The river's headwaters are located in Monte Hills Provincial Forest (elevation 2033 m), some 15 km northeast of Salmon Lake. Some of the river's flow is diverted into Salmon Lake; much of that flow returns to the river via McInnis Creek, the outlet from Salmon Lake. From the confluence with McInnis Creek, the Salmon River flows northeast to Falkland, then southeast and east to Glenemma, and finally north to Salmon Arm of Shuswap Lake (elevation 349 m). The total drainage area of Salmon River is 1510 km^2.

1.2 Environmental Issues and Concerns

The Salmon River is an important river system that generates a host of benefits to residents of and visitors to the area alike. The river system provides an important source of water for irrigation, livestock watering, and drinking water supplies. The Salmon River and its tributaries also support a variety of fish species and other aquatic life, including the spawning and rearing activities of several anadromous fish species (coho salmon, chinook salmon, and some stray Adams River sockeye salmon). Traditionally, these fish species have been used for food and ceremonial purposes by the indigenous peoples (i.e., First Nations) who reside in the area. Various plant and animal species also rely on the river and riparian areas for habitat and food resources.

Balancing the diverse and often conflicting land and water uses in the Salmon River watershed represents a formidable environmental management challenge. A variety of resource use and development activities have placed increasing pressure on aquatic and riparian ecosystems within the river basin. With respect to aquatic ecosystem management, some of the most important issues and concerns include:

- over-allocated water withdrawals for agricultural and domestic water uses, which have resulted in extreme low flows in the river;
- forest management activities in headwater areas, which have the potential to alter hydrological and water quality conditions;
- conversion of forested land to agricultural uses, which can increase suspended sediment, faecal bacteria contamination, and nutrient loadings to the river;
- removal of riparian vegetation, which can affect stream channel stability and morphology, and alter water temperature regimes;
- unrestricted access to the river by livestock, which can decrease streambank stability and increase sediment transport, faecal bacteria contamination and nutrient loadings; and
- disposal of automobiles, auto parts, and other refuse (i.e., appliances, shopping carts, plastic bags) in the river and in riparian areas.

Together, these activities have significantly affected environmental conditions in the Salmon River watershed. The existing information on the physical, chemical, and hydrological conditions in the Salmon River and its tributaries indicates that serious degradation has already occurred in many areas of the basin. The influence of degraded environmental conditions is reflected in the current status of resident and anadromous fish populations.

It is likely that other species that depend on aquatic and riparian ecosystems have also been adversely affected by environmental degradation. Without decisive and timely action, these changes in the aquatic ecosystem could result in serious impacts on people who reside within the river basin (e.g., damage to roads, land, bridges, and property by flooding, degradation of water supplies, reduced access to fish and wildlife, etc.) Fortunately, efforts to address these challenges have already been initiated by the community and its partners.

1.3 Background

The Salmon River Watershed Roundtable, Environment Canada, Fisheries and Oceans Canada, British Columbia Ministry of Environment, Lands, and Parks (BCMOELP), and the Vancouver Foundation have initiated a multistakeholder demonstration project in the Salmon River watershed. This project is designed to demonstrate how social, economic, and environmental goals can be effectively integrated using an ecosystem-based framework to support planning and management activities in the watershed. Application of this model involves a step-wise approach that includes:

- identification and assessment of issues and concerns;
- collation of the existing information and knowledge on the ecosystem;
- development of long-term management goals and objectives for the ecosystem;
- identification of ecosystem maintenance indicators (including targets and/or performance standards);
- identification of data gaps and research needs; and,

- implementation of focussed monitoring programs to track progress towards sustainability.

The document, ***A Framework for Developing Ecosystem Health Goals, Objectives, and Indicators: Tools for Ecosystem-Based Management*** (CCME 1996), provides more information on the ecosystem approach and the national framework that has been developed to support its implementation.

In the Salmon River watershed, activities in support of ecosystem-based resource and environmental management were initiated in 1989. To support these efforts, McPhee *et al.* (1996) compiled the available information on the current status of the watershed and on the issues and concerns related to the aquatic resource management. This information was published in a report entitled, ***The Salmon River Watershed - An Overview of Conditions, Trends, and Issues*** (McPhee *et al.* 1996). A verbal history of the Salmon River watershed was also compiled to document information that was not available in the contemporary scientific literature (Christiansen and Romaine 1995). Together, these documents provided watershed residents and other stakeholder groups with much of the information necessary to participate in deliberations regarding the management of aquatic and terrestrial ecosystems.

In December of 1995, a workshop was held in the watershed to facilitate the establishment of ecosystem goals and objectives for the Salmon River basin. The broadly-based management goals and more specific objectives that were established at this workshop addressed the community's environmental, economic, and social needs related to sustainability. These goals and objectives were widely circulated to interested parties in the watershed. A subsequent workshop was convened in the watershed in March of 1997 to identify priority indicators of ecosystem health and to establish relevant monitoring requirements. The results of this workshop are reflected in the water quality and water quantity objectives that are presented in this document.

1.4 Purpose of the Report

This report is intended to document existing environmental conditions and establish water quality objectives for the Salmon River watershed. The report is intended to provide environmental managers and the public with some of the tools that are required to manage human interactions with aquatic ecosystems in the study area. For this reason, the available information on existing and future water uses has been compiled and summarized. In addition, background information on river hydrology, the structure of the aquatic ecosystem, land use patterns, and known waste discharges have also been assembled. Water quality objectives have also been developed to identify the physical, chemical, and biological characteristics of the aquatic environment needed to support the designated uses of the Salmon River and its tributaries. These objectives will be used in conjunction with ambient water monitoring data to assess water quality conditions in the system. Finally, a water quality monitoring program has been recommended to assess attainment of the objectives.

2.0 A FRAMEWORK FOR IMPLEMENTING ECOSYSTEM-BASED ENVIRONMENTAL MANAGEMENT IN THE SALMON RIVER WATERSHED

Implementation of the ecosystem approach on a site-specific basis requires a framework in which to express the environmental management policies that have been established for the ecosystem. In general, this framework is comprised of three functional elements. The first element is a statement of broad management goals for the ecosystem. These goals must reflect the importance of the ecosystem to local area residents and other Canadians. The second element of the framework is a set of objectives for the various components of the ecosystem which clarify the scope and intent of the ecosystem goals. The final element of the framework is a set of ecosystem maintenance indicators and ecosystem metrics, which provides an effective means of measuring the level of attainment of each of the ecosystem goals and objectives.

2.1 Development of Ecosystem Goals and Objectives for the Salmon River Watershed

Ecosystem goals are broad narrative statements that define the management goals that have been established for a specific ecosystem. Definition of management goals for the aquatic ecosystem is a fundamental step towards the development of defensible ecosystem maintenance indicators. Definition of these ecosystem goals requires input from a number of sources to ensure that societal values are adequately represented. Open consultation with the public is considered to be a primary source of information for defining these goals. Government agencies, non-government agencies, and other stakeholders may also be consulted during this phase of the process.

Specifically, information on the existing and potential uses of the aquatic resources within the basin and on concerns regarding resource developments (e.g., water diversions, hydroelectric projects, etc.) which could affect these uses should be solicited.

By definition, ecosystem goals are too general to support the development and implementation of meaningful planning, research, and management initiatives. To be useful, these ecosystem goals must be further clarified and refined to establish ***ecosystem objectives*** that are linked more closely with ecosystem science (Harris *et al.* 1987). In turn, ecosystem objectives support the identification of indicators, which provide important information for evaluating the health and integrity of the ecosystem, as a whole.

The ecosystem goals and objectives for the Salmon River watershed were developed during a multistakeholder workshop that was held in Salmon Arm during December of 1995. Based on the results of this workshop, the 13 ecosystem goals and associated ecosystem objectives for the Salmon River watershed fall into three general areas (Stavinga and MacDonald 1997). These goals and objectives are listed below.

2.1.1 Managing for Ecosystem Health

Forests managed for human and natural needs:

- Sustained yield of all forest products (timber, range, medicinal herbs etc.) based on reliable inventories and realistic growth and yield projections; and,
- Maintenance of all life forms by maintaining all stages of plant succession (from bare ground to old growth forest).

Agriculture managed for human and natural needs:

- Encouraging local consumption;
- Use of best agricultural practices;
- Maintenance of the agricultural land base; and
- Agriculture which is ecologically sustainable and diverse.

A diverse and sustainable economy through:

- Encouraging products and services of high value added;
- Supporting new initiatives on products, marketing and training; and,
- Encouraging diverse, local control of economic resources.

A healthy river having:

- Clean water;
- Reduced peaks and troughs in surface and groundwater flow patterns; and,
- Re-established riparian corridors and wetlands.

Mentally, physically, emotionally and spiritually healthy people through:

- An empowered citizenry;
- Medical, environmental and social preventative and curative health care;
- Clean air, water and food; and,
- A spiritual approach to living as individually expressed.

Healthy and diverse natural species and their habitats through:

- Maintenance and increase of habitats to support all life forms; and,
- Maintenance and restoration of species and populations.

2.1.2 Active community social life

A strong sense of the watershed as a community with:

- Resource management recognising watershed boundaries when resource use overlaps into adjacent watersheds;
- Residents and others recognising and taking responsibility for their actions on the watershed;
- Collective empowerment and involvement in watershed planning and action; and,
- Participation and co-operation in watershed wide events and celebration.

Accessible and appropriately located recreation opportunities through:

- A recreational plan for the watershed.

Community pride in rural roots and lifestyle with:

- Residents expressing their pride in the watershed.

Co-operation to control local resources with:

- Community members participating in shared land use and resource management decision-making.

2.1.3 Developing Knowledge and Support

Government supporting watershed community needs through:

- Providing information for watershed decision making (e.g. water withdrawals);
- Continuity of technical and financial support of community groups in watershed management and resource use;
- Training and quality control and quality assurance for community monitoring of watershed development; and,
- Supporting community empowerment leading to shared decision making.

Sustaining the visioning process for the watershed with:

- Regular feedback to residents on progress towards vision; and,
- Community participation in vision, goals, and objectives adjustment.

Gaining and spreading knowledge of the watershed with:

- Pro-active education and awareness programs;
- Open communications between citizens and agencies;
- Citizen data gathering; and,
- Encouragement of innovative programs (e.g. demonstration programs)

These ecosystem goals and objectives have been broadly accepted and recognized within and outside the Salmon River watershed and will be used as a basis for directing management decisions regarding natural resource management now and in the future.

2.2 An Approach to the Development of Indicators of Ecosystem Health

The ecosystem objectives that have been proposed are narrative statements that reflect and focus the ecosystem goals for the Salmon River watershed. However, it is not possible to measure attainment of these objectives directly. For this reason, physical, chemical, and biological indicators are also required to provide a direct means of measuring the most important attributes of the ecosystem.

The term '**indicator**' is used in a variety of environmental applications and is, generally, defined as a feature of the environment which provides managerially and scientifically useful information on the quality of the ecosystem as a whole. If measurements of these attributes fall within acceptable bounds (i.e., if targets are met), it is reasonable to conclude that the ecosystem as a whole is being protected. In this study, ecosystem health indicators (EHIs) are defined as components of aquatic and riparian ecosystems which provide information on the health and vitality of the ecosystem as a whole.

The choice of EHIs is of paramount importance if the biological integrity and the human uses of the ecosystem are to be adequately assessed and protected. Stavinga and MacDonald (1997) describe the physical, chemical and biological indicators of aquatic ecosystem health that were identified by the Salmon River Watershed Roundtable. In addition, ecosystem metrics, which identify acceptable ranges or targets, are needed for each of the EHIs.

Such metrics provide a means of focussing environmental monitoring programs and determining if the ecosystem goals and objectives have been achieved. The following EHIs have been established for the Salmon River watershed (Stavinga and MacDonald 1997):

Recommended Indicators for Clean Water:

A. *Physical, Chemical and Biological Health*:

High Priority EHIs:

- water clarity;
- water temperature (e.g., *in situ* measurement at critical periods such as spawning and migration);
- dissolved oxygen levels; and,
- bio-indicators (e.g., algae, coliforms, insects, fish, reptiles, amphibians, birds, and mammals).

Medium Priority EHIs:

- nutrients and contaminants (e.g., trace metals) relative to background levels.

Other EHIs - No Rank Given:

- suspended sediment concentrations and loadings;
- turbidity;
- non-filterable residues;
- nutrient concentrations and loadings;
- chlorophyll *a*;
- phosphorus;
- total ammonia;
- organic carbon concentrations and loadings;

- pH and water hardness;
- trace metal concentrations and loadings;
- extractable iron and lead concentrations;
- organic contaminant concentrations;
- microbial indicators;
- faecal coliforms (e.g., *Escherichia coli*);
- microbacterial levels, as they relate to the potential for water contact recreational activities (e.g., fishing, swimming); and,
- aquatic macroinvertebrates (including caddisflies, stoneflies, mayflies, riffle beetles, trueflies).

Recommended Indicators for Reduced Peaks and Troughs in Surface and Groundwater Flow Patterns:

A. Flow Related EHIs:

High Priority EHIs:

- magnitude of peak discharge;
- duration of peak discharge;
- magnitude of low flow;
- duration of low flow;
- mean monthly discharge;
- mean annual discharge;
- water level;
- variability in water level; and,
- snow pack measurements and weather data.

Medium Priority EHIs:

- estimate of groundwater withdrawal and timing;

- amount of surface flow withdrawals; and,
- upper watershed snow melt patterns.

B. *Policy and Protection Agreements*:

- quantity of water withdrawn from the system based upon licensed water withdrawals versus minimum flow requirements for sustaining salmon reproduction requirements;
- number of licensed diversion points and logged wells, and quantity of water withdrawn;
- total effective expenditure on public and user education of the needs and benefits of more conservative use of water;
- number of incentive programs to encourage licensees to find alternative water sources or to develop more efficient works measured against participation rate; and,
- number of agreements with licensees to achieve voluntary reductions in historically allocated quantities.

Recommended Indicators for Re-Established Riparian Corridors and Wetlands:

A. *Riparian Corridor Health:*

- quality of shoreline habitat;
- size of delta areas;
- sedimentation rate in delta areas;
- quantity of wetlands;
- biodiversity (e.g., plants, animals);
- extent of flooding;

- duration of flooding;
- timing of flooding; and,
- frequency of flooding.

B. *Instream Geomorphic Variables*:

- wetted width;
- stream depth;
- stream gradient;
- pool to riffle ratios;
- wetted areas in side channels;
- depth in side channel;
- substrate stability;
- quantity of large organic debris;
- quantity of instream cover;
- channel stability (e.g., eroding banks and ice scour);
- extent of log jam related problems;
- runoff; and,
- bank stability.

C. *Riparian Policy and Protection Agreements*:

- number of participatory landowner agreements for stream bank restoration projects;
- number and extent of restoration projects including bank stabilization, revetments rip rap, and tree planting; and,
- degree of continuity and connectedness of riparian habitats.

D. Wetland Ecosystem Diversity:

- inventory of wetlands (e.g., percentage and extent in area of wetland types to total wetland area, and level of fragmentation and connectedness); and,
- area, percentage and representativeness of wetland types in protected areas.

E. Wetland Species Diversity:

- number of known wetland-dependent species classified as extinct, threatened, endangered, rare or vulnerable relative to total number of wetland dependent species;
- frequency of occurrence within selected indicator species (e.g., vegetation, birds, mammals, fish; also an indicator for healthy land/air/water linkages);
- population levels and changes over time of selected species and species groups (e.g., amphibians, such as frogs and toads); and,
- number of known wetland dependent species that occupy only a small portion of their former range.

F. Wetland Genetic Diversity:

- extent to which a strategy is in place to conserve endangered wetland vegetative species.

G. *Wetland Policy and Protection Agreements*:

- number of cooperative agreements to participate in wetland restoration or protection projects and areal extent providing for setbacks restricting agricultural production and livestock access.

Recommended Indicators for Maintenance and Increase of Habitats to Support All Life Forms:

Very High Priority EHIs:

- depth and width of channel at mouth for fish migration;
- number of replanting and restocking activities;
- area or extent of riparian vegetation shown by reaches on the river; and,
- water quality (e.g., temperature) and presence of contaminants (e.g., toxic substances, phosphates, nitrates, and algae).

High Priority EHIs:

- nature, extent and changes over time of critical habitats (e.g., forests by age classification, marsh, and wetlands);
- rates of loss of particular habitats (e.g., conversion of land uses);
- amount of habitat;
- number of sensitive habitats enhanced, maintained and restored;
- number and extent of land stewardship covenants;
- acreage of protected habitat through demonstration reserve areas; and,
- changes in human harvesting of fauna and flora (e.g., logging, hunting, fishing, and private clearing).

Low Priority EHIs:

- extent of physical barriers to wildlife movement along and across habitat.

Recommended Indicators for Maintenance and Restoration of Species and Populations:

Very High Priority EHIs:

- population densities of species (e.g., shrubs, plants through vegetation surveys and birds, mammals, amphibians, reptiles, fish, and insects through wildlife surveys) recognizing that some species (e.g., threatened endangered or unique species) will provide more insightful information than others;
- number of vulnerable and sensitive species (i.e., blue-listed species);
- number of threatened or endangered species (i.e., red-listed species);
- population densities of salmon species; and,
- population densities of benthic invertebrates (e.g., special counts targeting intolerant bugs).

3.0 DESCRIPTION OF THE SALMON RIVER WATERSHED

3.1 Location

The Salmon River watershed is located within the Interior Plateau of south-central British Columbia. Its headwaters originate in the vicinity of Tahaetkun and Bouleau Mountains, south of Westwold and northeast of Merritt. From its headwaters, the river flows westward to Salmon Lake and then in a northeasterly direction to Salmon Arm of Shuswap Lake.

The Salmon River watershed lies within four of the fourteen biogeoclimatic zones that exist in British Columbia (Meidinger and Pojar 1991; B.C. Ministry of Forests 1988). These zones are described below:

- Most of the Salmon River lies in the **Interior Douglas Fir (IDF) Biogeoclimatic Zone**. The IDF is the second warmest forest zone in the dry B.C. interior, where it occurs in the rain-shadow of the Coast, Selkirk, and Purcell Mountains. Coniferous trees include Douglas fir, lodgepole pine, balsam fir and spruce, mixed with deciduous slopes of aspen, willow, cottonwood and poplar. Fires have frequented the higher elevations where lodgepole pine is dominant. Ponderosa pine exists at lower elevations. Other vegetation that exists in the IDF zone are pinegrass and feathergrass understory, soopolallie and kinnikinnick shrubs and savannah-like bunchgrasses. The primary resource usages of IDF are cattle grazing, fur harvesting, and municipal, domestic and agricultural water use. The representative wildlife species that inhabit the IDF zone are outlined in Appendix I.

- The biogeoclimatic zone that surrounds Falkland and the nearby western hills (Martin Mountain Provincial Forest, Shuswap Provincial Forest and Fly Hill Provincial Forest) of the Salmon River is the **Montane Spruce (MS) Biogeoclimatic Zone**. This zone-type occurs in the B.C. south-central interior at middle elevations and plateau areas. Usually, winters are cold and summers are moderately short and warm. Characteristically, Engelmann spruce, hybrid spruce, and subalpine fir are the dominate tree species, while lodgepole pine, Douglas fir and trembling aspen are characteristic species of wild-fire successional forests. The primary resource usages for the MS biogeoclimatic zone are forest harvesting, both for saw-logs and pulpwood, cattle grazing and fur harvesting. This zone produces a large amount of spring and early summer run-off for the surrounding watersheds. The representative wildlife species that inhabit the MS zone are outlined in Appendix I.

- The biogeoclimatic zone that encompasses the smallest land area within the Salmon River watershed is the **Interior Cedar-Hemlock (ICH) Biogeoclimatic Zone**. This zone lies approximately five kilometres east of the communities of Silver Creek and Yankee Flats near Mount Ida Provincial Forest. Typically, the ICH zone occurs at lower to middle elevations in the interior wet belt of the province. Western hemlock, western red cedar, spruce, subalpine fir, skunk cabbage and devil's club occur in wetter, poorly drained sites, while Douglas fir, and lodgepole pine are found on drier sites. The primary resource usages of the ICH are forestry and fur harvesting. The ICH is the most productive zone in the interior of the province for wood fibre production. Most areas of the ICH zone have a low potential for agriculture use because of the surrounding mountainous topography. The representative wildlife species that inhabit the ICH zone are outlined in Appendix I.

- The biogeoclimatic zone that occurs in the high elevation mountainous terrain of the Salmon River watershed is the **Engelmann Spruce-Subalpine Fir Zone** (ESSF). The cold, moist, and snowy conditions that characterize this zone make growing seasons cool and short. In addition to the dominant tree species, Engelmann spruce and subalpine fir, several other species are found in the ESSF. These include lodgepole pine, whitebark pine, limber pine, alpine larch in the dry region; western white pine, Douglas fir, western hemlock, western red cedar at lower elevations; mountain hemlock in areas of heavy snowfall; and amabilis fir in areas adjacent to the Coast Mountains. Timber and fur harvesting are the primary resource usages in ESSF. This zone has the highest production of fur in the province. The representative wildlife species that inhabit the ESSF zone are outlined in Appendix I.

3.2 Physiography

The Salmon River weaves through a diverse topography of grasslands, rocky gullies and fertile valleys, which open into Shuswap Lake. Upstream from Westwold, the Salmon River disappears underground for up to 13 kilometres during low flow periods. During the annual high-water period, the river flows above the stream-bed; however, during the remainder of the year the water in this section of the stream-bed is stored as groundwater (International Pacific Salmon Fisheries Commission 1954). In the area near Westwold, the river flows through a broad valley (KPA Engineering 1991). At Falkland, the

Salmon River joins its largest tributary, Bolean Creek, with the valley becoming narrower as the river reaches from Glenemma to the community of Silver Creek. The valley then broadens substantially until it reaches the mouth and empties into Shuswap Lake (KPA Engineering 1991). The Salmon River valley ranges in width from 3.2 km at Westwold, gradually narrowing to 0.33 km between Falkland and Haines Creek, then widening again to 3.2 km at Salmon Arm (Obedkoff 1976).

The northern portion of the Salmon River watershed, rich in glacial deposits, has extensive drumlin formations, clay-rich soils and is dotted with glacial lakes. Gravel, instead of bedrock, forms much of the river bed and floodplain area. From Silver Creek to Shuswap Lake, for a distance of 20 km, the stream slope is gradual and the stream bottom consists largely of unstable lacustrine sand and silt. An indication of considerable erosion and channel change is apparent near the mouth, where the shallow and slow moving stream flows through an unstable marsh area with extensive mud flats.

3.3 Geological Features

Bedrock in the upper reaches of the Salmon River watershed is primarily basaltic lava, with sedimentary, granite and schist rocks in the western regions. Glacial moraines cover much of the upper and western reaches of the basin, with fan and terrace deposits of both sand and gravel along the valley sides (Le Breton 1977). The bedrock of the lower half of the river consists of argillite (compact sedimentary rock composed of clay materials), schist (crystalline rocks resulting from metamorphic processes), and gypsum. Surrounding the communities of Falkland and Glenemma are schists and granite bedrock, while Tertiary volcanics are present near the district of Salmon Arm (Le Breton 1977).

The Salmon River watershed geology generally consists of volcanic (i.e., basalt lava) and metamorphic (i.e., schist) rock with a continuous belt of unconsolidated deposits on the surface occurring at depths between 5 to 15 metres throughout the valley bottom. Due to the low permeability of volcanic basaltic lava in the upper reaches of the river and metamorphic rock in the lower reaches, a low groundwater table is evident throughout the basin (Obedkoff 1976). Alluvial and colluvial deposits along the river consist of relatively coarse textured material, although areas of finer textured soils occur downstream of Silver Creek. The narrow valley in this area combined with accumulated snow-melt keeps the soils wet for a significant period during spring, particularly in the low slopes adjacent to the river. However, the soils on the fluvial and colluvial fans are more rapidly drained.

The coarse material limits adsorption of phosphate and ammonia, which allows subsurface movement of nutrient-containing groundwater to the river. The extent of subsurface input depends on the land-to-river hydraulic gradient, which may be negative during the water surplus period (Gregory 1987).

Overland flow occurs when the precipitation or snow-melt exceeds the infiltration capacity of the soil. The steeper the slope, the greater the chance of overland flow. The river valley has a gentle slope but fluvial fans frequently approach the river, resulting in more pronounced slopes. Steeper slopes also occur where the river has been trained or straightened. A good example of such conditions occurs downstream from Salmon Lake. Flow is rapid in these areas, particularly during high flow period, where deep channels are cut. Accumulation of materials on the slopes suggests that input to the river may occur during the water surplus period. This is counteracted to some extent by the presence of vegetation, such that materials added 40 m from the river are unlikely to reach the river unless drainage ditches are present (Moore and

Madison 1985). Much of the irrigation along the river is from ditches fed by gravity. The relatively slow movement of these waters and their location within fertilized fields suggests that they could be important transport routes for fertilizers and pesticides.

Large alluvial fans and remnants of gravel terraces at the bottom of small stream valleys suggest that the Salmon River and some of its tributaries carried greater discharges at some time. These features explain why certain valley-bottom areas are not usually flooded by the Salmon River. Other changes in the river over the decades have occurred when farmers have straightened certain channel reaches. As a direct result of these man-induced changes, the river has deepened its channel bank for some distance upstream, erosion occurs more often, and the river bed has become raised (KPA Engineering 1991).

3.4 Climate

The climate of the Salmon River watershed is greatly influenced by the surrounding topography of both the western Coast Mountains and the eastern Monashee Mountains. According to climatological statistics, the western section of the basin has a lower mean annual precipitation (320 mm) than the northeastern portion of the basin and its surrounding highlands (770 mm; Obedkoff 1976; Crippen Consultants Ltd. 1990; KPA Engineering 1991). Westwold has a mean annual precipitation of 320 mm, while Falkland and Salmon Arm average 450 mm and 530 mm per year, respectively. The months of October through January have the highest precipitation of the year while June has the lowest levels.

Mean monthly air temperatures in Salmon Arm range from -5.5°C in January to 19.3°C in July. Overall, air temperatures reportedly range from -18°C (January 30, 1996) to 31°C (July 31, 1996; Environment Canada unpublished data). Rainfall and snowfall precipitation for the municipal district of Salmon Arm combine for a total of 533.7 mm, with 357.7 mm of rainfall and 175.8 mm of snowfall (Statistics Canada 1993). At Salmon Arm, apart from the low precipitation in the 1920's and the 1930's, precipitation appears to have been relatively constant (Dorcey and Griggs 1991). On average, there are 40-60 frost-free growing season days along the Salmon River, which occur between the months of April to November (Barber *et al.* 1973).

Following the river north towards the mouth, there is a slight but gradual increase in both temperature and precipitation from Westwold to Falkland and on to Salmon Arm (Figure 3.1; Table 3.1). In the summer, the weather systems over the Salmon River valley are consistently influenced by high pressure systems over the Pacific Ocean while low pressure systems are modified by continental arctic air masses in the winter. These variations in climate are largely due to a decrease in elevation from Westwold (616 m) to Falkland (457 m) and Salmon Arm (396 m), and the proximity of the Rocky Mountains and Shuswap Lakes. The mean monthly temperatures in Westwold, Falkland and Salmon Arm are presented in Figure 3.2. Differences in precipitation between areas are important to the water-mediated movement of contaminants and streamflows. Precipitation is greatest at all three locations in the winter months, when the mean temperature is below freezing and snow accumulates. Considering precipitation and potential evapotranspiration, there is a water surplus from September through to March (Gregory 1987). In March, the mean air temperature is above freezing. This suggests that the condition of the land during the water surplus period, but particularly during March, will dictate the potential for inputs to the river.

3.5 History

Prior to the early 1800's, the watershed remained relatively undeveloped and was used primarily by the local First Nations peoples. When the European settlers arrived, they began draining soils and farming in the valley bottom. Logging of the upland areas was also initiated, with the open areas used for grazing cattle. Settlers also used the river for such activities as fishing, transportation, and water diversion. Water was diverted from the river by the settlers for drinking water, irrigation and livestock watering. The settlers also engaged in hunting and trapping activities.

The development trends which began when the settlers arrived continues today, although these activities are more restricted by government regulations. Between 1981 and 1991, the watershed's population grew from 7415 to 7845; the number of homes increased from 2660 to 3095 (McPhee *et al.* 1996). Population growth has created several towns along the river, but the only major urban centre is Salmon Arm. The First Nations population has also grown, but their community is centred around their reserves.

Active mining in the watershed commenced in 1926. These activities have been limited to several gypsum/anhydrite mines, a marble mine, and quarrying at construction sites. The potential for future mining operations is high, as several good mineral deposits are known to occur in the watershed (McPhee *et al.* 1996).

3.6 Demography

According to the 1991 census, the population of the municipal district of Salmon Arm was 12,115 people, which represents an 8.2 % increase from

1986 (Statistics Canada 1993). Comparatively, a 13.8 % increase in population occurred province-wide during the same time period. In 1991, the population of the Columbia-Shuswap Regional District - Subdivision C, which includes the smaller communities bordering the Salmon River (Falkland, Sweetsbridge, Silver Creek and Glenemma) was 11,017 people, showing a 9.2% increase from 1986. The population for the communities of Falkland and Westwold are 700 and 220 people, respectively (Statistics Canada 1993). The total land area for the Salmon Arm municipal district was 153 km^2 in 1991, while the land area in the Columbia-Shuswap Subdivision C Region is 5717 km^2.

3.7 Major Economic Activities

A total of 3,900 people are employed in all industries in the Salmon River watershed, including mining, manufacturing, construction, transportation, wholesale, retail, finance, real estate and accommodations. Of these, 250 employees work in the logging and forestry industries (including both contract logging and forest services). In the agricultural industry, which includes various types of livestock farming, field crops, horticultural farms and related services and specialities, 495 people were employed in 1991. Twenty five people were employed in the fishing and trapping industries in 1991 (McPhee *et al.* 1996). Table 3.2 summarizes the main agricultural land uses in the Columbia-Shuswap Regional District Subdivision C. In 1993, there were 539 farms in this area, which represented 2.8% of the provincial total. The total number of acres in production was estimated at 62 399 in the region, representing 1.1% of the provincial total (Statistics Canada 1993).

4.0 STRUCTURE OF THE AQUATIC AND RIPARIAN ECOSYSTEM

4.1 Periphyton and Macrophytes

No information was located on the diversity or abundance of algal or macrophyte communities in the Salmon River watershed.

4.2 Benthic Macroinvertebrates

The results of a recent study by the National Hydrology Research Institute of Environment Canada has provided important information on benthic macroinvertebrate communities in the Salmon River watershed (Culp *et al.* 1997). The results of this study indicate that five taxonomic groups dominate invertebrate communities in the Salmon River, including Trichoptera (caddisflies), Plecoptera (stoneflies), Ephemeroptera (mayflies), Coleoptera (beatles), and Diptera (trueflies).

Caddisflies inhabit a diverse array of habitats throughout the watershed and are present in significant numbers. The families of caddisflies represented in the watershed include Brachycentridae, Glossosomatidae, Hydropsychidae, Hydroptilidae, Lepidostomatidae, Limnephilidae, Polycentripodidae, and Rhyacophilidae (Culp *et al.* 1997).

The second group, the stoneflies, are very good indicator species due to their low tolerance for poor water quality. The five families of stoneflies represented in the watershed include Capniidae, Chloroperlidae, Perlidae, Perlodidae, and Pteronarcyidae (Culp *et al.* 1997)

The third group, the mayflies are able to use a number of different habitats, including ones with higher temperatures than most stoneflies can tolerate (Culp *et al.* 1997). Baetidae, Ephemerellidae, Heptageniidae, Leptophlebidae, and Siphlonuridae are the five families that are known to occur within the basin.

Beetles are indicators of good water quality conditions, particularly because they have high oxygen requirements (Merritt and Cummins 1995). The five families of Coleoptera present in the Salmon River watershed include Dryopidae, Dytiscidae, and Elmidae. Of these, Elmidae is the most common family (Culp *et al.* 1997).

Seven families of Diptera are also present in the Salmon River watershed in significant numbers, including Athericidae, Ceratopogonidae, Chironomidae, Empididae, Simulidae, Tabanidae, and Tipulidae. This diverse group of organisms includes some pests to human and animals, some species with very pollution tolerant larvae, and the most abundant invertebrate family found in the Salmon River watershed, Chironomidae (Culp *et al.* 1997).

4.3 Fish

Several studies have been conducted on the distribution and utilization of fish habitats in the Salmon River watershed. The most comprehensive studies were conducted on coho and chinook salmon by Whelen *et al.* (1982), Whelen *et al.* (1983), and Whelen and Olmsted (1982). More recently, Bison (1991) examined rainbow trout production characteristics of the Salmon River and Bolean Creek. Ross (1993) conducted the most recent fisheries investigations, focussing on riparian habitat assessment and escapement monitoring. The Department of Fisheries and Oceans (DFO) also conducts spawning counts each year (Anonymous 1990), using a counting fence on the river. Escapement figures for salmon utilizing the Salmon River were complied from DFO sources and are presented in Table 4.1 and Figure 4.1.

The results of the various investigations that have been conducted indicate that 16 fish species utilize habitats within the watershed (Table 4.2). Of this total, five salmonid species utilize the river throughout a portion or all of their life histories. The salmonid species that occur in the watershed include coho salmon (*Oncorhynchus kisutch*), chinook salmon (*Oncorhynchus tshawytscha*), sockeye salmon (*Oncorhynchus nerka*), rainbow trout (*Oncorhynchus mykiss*), and mountain whitefish (*Prosopium williamsoni*). Despite their importance to the ecosystem, no information was located on the distribution or abundance of the 11 non-salmonid species that are also present in the basin.

Among the anadromous salmonids, chinook are the first to enter the Salmon River each year, generally by the end of August. Spawning occurs soon thereafter and may extend to the beginning of October. Coho and sockeye salmon usually arrive somewhat later, with spawning extending from the middle of October to the middle of November. The two main barriers to upstream migration include the shallow wetland areas near the mouth of the river and the dry reach near Westwold. As a result, the best spawning habitat for the three salmon species is located in the stream reaches roughly between Silver Creek and Falkland (McPhee *et al.* 1996). Some use of Bolean Creek by coho salmon has also been documented (Whelen *et al.* 1983). However, rainbow trout utilize much of the mainstem upstream of the dry reach for spawning activities.

Anadromous salmonid embryos incubate in streambed substrates throughout the winter prior to their emergence in the spring. The results of fisheries studies conducted in the early 1980's showed that the emergence of both coho and chinook salmon fry begins in early April and peaks at the beginning of May (Whelan *et al.* 1982). No information was located on the timing of sockeye salmon fry emergence. Upon emergence, coho salmon fry utilize rearing habitats in the vicinity of spawning locations for at least a year prior to migrating to the ocean. Chinook salmon fry have more variable rearing strategies, with some fry out-migrating as underyearlings and others spending up to a year in the river. In contrast, sockeye salmon utilize rearing habitats in Shuswap Lake prior to smoltification. Little is known about the life history patterns of rainbow trout in the Salmon River; however, there is some information to suggest that both stream-resident and lake-resident populations utilize spawning and rearing habitats within the mainstem and its tributaries. Table 4.3 presents a summary of the life history information for salmon found in the Salmon River.

4.4 Wildlife

The Salmon River watershed contains a number of unique habitats which are utilized by a variety of wildlife species. For example, the foreshore and nearby uplands associated with the mouth of the Salmon River have been identified as the largest undeveloped delta in interior British Columbia which is surrounded by an urban area (Ducks Unlimited Canada 1992). This area is unique in that it includes both riparian and aquatic habitats that can be utilized by many mammal and bird species. The area is rated high in both species diversity and waterfowl abundance. The delta is significant in that it provides flocks of geese and ducks with a staging area during spring and fall migrations. It was concluded that these two diverse habitats provide an excellent wildlife enhancement potential and that these areas have been threatened for several years, primarily due to poor cattle grazing management (Ducks Unlimited Canada 1992).

Birds

The Salmon River/Shuswap Lake area is a popular destination for bird watching because 223 species have been observed and at least 160 species are known to nest in the area (McPhee *et al.* 1996). Appendix I outlines selected wildlife habitats and representative species of each of the four biogeoclimatic zones that occur within the Salmon River watershed (Interior Douglas Fir zone; Montane Spruce zone; Interior Cedar-Hemlock zone; and Englemann Spruce-SubAlpine Fir Zone). Some of the bird species that occur within the watershed include (Meidinger and Pojar 1991):

- *old-growth and mature coniferous forest:* northern pygmy-owl, blue grouse, pileated woodpecker, and red crossbill;
- *young seral forest:* ruffed grouse, Steller's jay, pine grosbeak, yellow-rumped warbler, rufous hummingbird, and dusky flycatcher;
- *riparian areas, lakes, and streams:* sharp-tailed grouse, American kestrel, trumpeter swan, American avocet, harlequin duck, tundra swan, and common loon;
- *clearcuts, grasslands, and agricultural areas:* long-billed curlew, mountain bluebird, golden eagle, black-backed woodpecker, northern harrier, and eastern kingbird.

An excellent breeding habitat for the western grebe occurs on the eastern shore of the Salmon River, near Tappen Bay - one of only three such areas known to exist in British Columbia (Ducks Unlimited Canada 1992). The District of Salmon Arm is participating in the protection of the western grebe's local nesting sites by adopting the western grebe as the official bird of Salmon

Arm. Salmon Arm is also promoting wildlife viewing of both migratory birds and terrestrial wildlife as a local tourism activity. Osprey, golden eagles and bald eagles are especially numerous in the vicinity of Great Beaver Creek. Smaller birds, such as cliff swallows, warblers, kingfishers and Canada jays, are scattered throughout the basin (Barber *et al.* 1973).

Mammals

The Salmon River watershed supports a variety of terrestrial mammals which inhabit the surrounding forest region, adjacent pastures, and glaciated terrain. According to McPhee *et al.* (1996), there are approximately 57 terrestrial wildlife species that inhabit the delta near the municipality of Salmon Arm. The larger mammals that inhabit both the riverine and estuarine habitats include moose, white-tailed deer, mule deer, black bear, and grizzly bear. The smaller terrestrial mammals present in the basin include beaver, river otter, six species of bats, several species of microtine rodents, martin, mink, wolverine, weasel, fisher, and squirrel (Barber *et al.* 1973; Ducks Unlimited Canada 1992). Some mammals which may be found within the watershed are (Meidinger and Pojar 1991):

- *old-growth and mature coniferous forest:* mule deer, black bear, bobcat, cougar, hoary bat, southern red-backed vole, masked shrew, moose, and martin;
- *young seral forest:* coyote, northern pocket gopher, porcupine, and deer mouse;
- *riparian areas, lakes, and streams:* mink, big brown bat, muskrat, beaver, meadow jumping mouse, water vole, gray wolf, and badger; and,
- *grasslands, clearcuts, and agricultural areas:* yellow-bellied marmot, ermine, and columbian ground squirrel.

Reptiles and Amphibians

The Salmon River watershed also provides habitats for several species of reptiles and amphibians that are found in each of the three biogeoclimatic zones described earlier. Some reptiles and amphibians which may be found within the watershed are (Meidinger and Pojar 1991):

- *old-growth and mature forest:* rubber boa, pacific treefrog, western yellow-bellied racer, and long-toed salamander;
- *riparian areas, lakes, and streams:* northern alligator lizard, wood frog, painted turtle, western terrestrial garter snake, western skink, tailed frog, and tiger salamander; and,
- *grasslands, clearcuts, and agricultural areas:* great basin spadefoot toad, spotted frog, western toad, western rattlesnake, and gopher snake.

5.0 LAND AND WATER USES IN THE SALMON RIVER WATERSHED

5.1 Land Uses

The land uses described below identify the major activities that may influence the Salmon River and its uses. These categories were derived from Gregory (1989), who conducted a survey of non-point source pollution along the Salmon River. This survey included written descriptions of specific activities, as well as photographic records. The data were collected during three time periods: December 1988, January 1989, and February 1989.

5.1.1 Logging

This land use is prevalent in the upper reaches of the river valley. Since 1995, clearcut harvesting has been conducted by Riverside Forest Products on the western side of Weyman Creek, south of Blackwell Lake. Some harvesting is also anticipated in the Nash Creek area. The harvest rate is estimated to be in the order of 610 hectares per year (McPhee *et al.* 1996). Other logging operations are also being planned for the area. A 1991 inventory provided information for assessing the status of forest resources in the watershed (McPhee *et al.* 1996), as follows:

- Non-forested land 134.4 sq. km. (8.95%)
- Potentially forested land 1366.8 sq. km. (91.05%)
- Recently logged land 161.4 sq. km. (10.75%)
- Older logging land 439.1 sq. km. (29.25%)
- Total area logged 600.5 sq. km. (40.00%)
- Forest remaining 766 sq. km. (51.05%)

The influence of logging on stream hydrology and water quality are discussed in detail by Hetherington (1987). Increased water temperatures, suspended sediments, faecal contamination (i.e., due to increased grazing by cattle in logged areas), and nutrient loading are commonly associated with logging activities.

5.1.2 Overwintering Cattle and Summer Hay Fields

Lands that were used for overwintering cattle and summer hay fields had observable signs of cattle use during the winter, but not to the extent that there was bare soil. In all cases, the cattle obtained water directly from the river or from side channels. Frequently, access to the river was not limited. Sometimes access was limited by vegetation barriers or topography; but the cattle could move a distance upstream and downstream from the primary access point. The direct access to the river results in erosion of stream banks and increased sediment transport. In addition, defecation in the river and on adjacent streambanks results in increased nutrient loadings and biochemical oxygen demand. It was assumed that the fields were used for hay in the summer. This land use was prevalent along the Salmon River between Westwold and Salmon Arm, and along lower Bolean Creek (McPhee *et al.* 1996).

5.1.3 Hayfields and Cornfields

Hayfields and cornfields include lands which did not contain livestock or there were no signs of livestock activity. Although these two uses (hayfields and cornfields) are considered together, the potential water quality issues associated with these activities differ. In particular, leaching losses of fertilizers and herbicides from fallow soil (corn fields were either fallow or with stubs), particularly to groundwater can be significant. In contrast, the grass tends to retain moisture in hayfields, which limits the movement of contaminants to groundwater. Importantly, corn production requires higher rates of fertilizer application, which increases the potential for losses to surface water and/or groundwater. In 1991, there were 25,359 acres of land in cultivation within the watershed (McPhee *et al.* 1996).

5.1.4 Dairy Farms and Beef Cattle Feedlots

Dairy farms and beef cattle feedlots were not considered to be dissimilar land uses at the time of the survey (Gregory 1989). However, they were distinguished from one another because it was assumed that the dairy pens were used year around, whereas the feedlot pens were used only during the winter. On the dairy operations, the animals were in close proximity to the milking stations and there is year-round accumulation of manure. The manure is typically applied to the fields in a recycling process, both as soil conditioner and fertilizer. Historically, manure was often spread on top of snow or on frozen ground, which resulted in contaminated runoff. However, efforts are being made to improve manure handling by dairies and feedlots. There have been some important trends in cattle production in the watershed. Specifically, land use for dairying increased between 1981 and 1991, while beef production dropped dramatically. In 1991, there were 30 dairy and 132 beef cattle operations in the watershed (Table 5.1; McPhee *et al.* 1996).

5.1.5 Other Farms

The Salmon River watershed also supports a number of agricultural activities that do not fit into the previously noted categories. For example, there were eight poultry and three hog producers in the watershed in 1991. Fieldcrops, vegetables, fruit and ginseng also contributed to the total agricultural production in the area. Interestingly, the number of special plant and animal producers increased from 32 farms in 1981 to 84 in 1991 (McPhee *et al.* 1996). This change reflects a shift towards the production of high value agricultural products. There are also a large number of hobby farms in the watershed.

5.1.6 Undisturbed Land

Undisturbed land includes areas where there was a significant amount of undisturbed vegetation on either side of the river. This forested land was primarily located in the headwater areas. However, undisturbed land is also present in the upland areas in the more northerly portions of the basin.

5.2 Water Uses

Surface water and groundwater resources in the Salmon River watershed are inextricably linked. In fact, groundwater recharge represents a primary source of the surface water flow, with alpine meltwaters of secondary importance (Regnier and Shaw 1997). For this reason, any discussion of water uses must consider the utilization of both surface and groundwater resources.

5.2.1 Industrial Water Uses

There are no known industrial water uses in the Salmon River basin.

5.2.2 Municipal and Domestic Water Supplies

There are a number of municipal developments within the Salmon River watershed, including Salmon Arm, Monte Lake, Westwold, Glenemma, and Falkland. In addition, several First Nations have settlement lands within the river basin. Of these settlements, only Salmon Arm maintains a public water supply from a surface water source (Shuswap Lake). The other communities in the basin obtain their water supplies from groundwater sources. Individuals residing in rural areas obtain their water supplies from either surface water or groundwater sources.

The available information on surface water withdrawals from the Salmon River and its tributaries is summarized in Table 5.2. The table shows a summary of water withdrawals from 13 reaches in the watershed (reported in m^3/s). These data show that 284 water licences have been issued for domestic water uses in the basin, which collectively permit withdrawal of 0.014 m^3/s (or 269,200 gallons per day) of surface water. Another 0.651 m^3/s of groundwater is withdrawn for domestic uses in the watershed (Table 5.3).

5.2.3 Agricultural Water Uses

Irrigation and livestock watering are the main water uses associated with most agricultural operations in Canada. These water uses account for most of the water withdrawals from the Salmon River and its tributaries. Based on the information complied in Table 5.2, it is apparent that 425 licences have been issued to permit surface water withdrawals within the basin. These licences permit withdrawal of up to 1.628 m^3/s of surface water from the Salmon River and its tributaries. In addition, 58 groundwater wells yield in the order of 0.6409 m^3/s for irrigating various crops. It is likely that some of this water is also used for livestock watering. Irrigation is usually considered to be a partially consumptive water use; as a portion of the water diverted re-enters the stream as return flow. While flood irrigation (by ditches and flumes) is no longer used extensively, it was believed that this irrigation method allowed up to 30% of the water that used to flow back to the river. However, the sprinkler and drip/trickle irrigation methods that are currently used do not produce as high a return flow to the river.

Water licenses are not required for the use of groundwater. Therefore, exploitation of this water resource is largely unregulated, which can lead to water tables being overdrawn and an increasing conflict among neighbouring well owners (Dorcey and Griggs 1991). In addition, most water users do not keep accurate records of the quantities of water that are taken from surface waters (Obedkoff 1976). Therefore, it is difficult to estimate the actual amount of water withdrawn by individual water users (Obedkoff 1976).

5.2.4 Fish and Aquatic Life

Fish and aquatic life represent an important water use in the Salmon River watershed. In addition to five salmonid species, the basin also supports eleven other fish species (Table 4.2). Furthermore, a wide variety of benthic invertebrates, algae, macrophytes, and other organisms inhabit aquatic ecosystems within the watershed. The watershed community, through the Salmon River Watershed Roundtable, has identified the conservation and restoration of fish and other aquatic organisms as a high priority goal. However, a number of water quality and water quantity issues must be resolved before this goal can be achieved. Broader salmon management issues will also influence the degree to which the Salmon River watershed goals can be achieved.

5.2.5 Recreation and Aesthetics

The Salmon River is located within three forest recreation districts, including the Salmon Arm Forest District (at the northern portion of the river), the Vernon Forest District, and the Merritt Forest District (which includes Salmon Lake). The primary outdoor recreational activities along the Salmon River include hunting, fishing, swimming, hiking, camping, nordic skiing, and some canoeing (Barber *et al.* 1973). Recent regulations have been passed which prohibit angling for rainbow trout and char below the Highway 97 bridge at Falkland. However, angling for this species is permitted in upstream areas. Currently, fishing for chinook or coho salmon is not permitted in the Salmon River (BCMOELP 1997).

The B.C. Ministry of Forests divides outdoor recreation opportunities into four categories in the Recreation Opportunity Spectrum (B.C. Ministry of Forests 1991):

- ***Primitive:*** More than 8 km from a road on which a highway vehicle can be driven; a natural environment, minimal evidence of human use; non-motorized access;
- ***Semi-primitive:*** Less than 8 km from a road on which a highway vehicle can be driven; a natural appealing environment, some evidence of human use; may or may not have motorized access;

- ***Roaded Resource Land:*** Accessible with highway vehicle, but with a natural environment and no more than moderate evidence of human use; and,

- ***Rural:*** Accessible by highway vehicles, substantially modified and extensive evidence of human use.

Most of the Salmon River watershed is classified as rural. However, there is some recreational potential for wilderness canoeing in both the upper and lower portions of the Salmon River. Average to experienced canoeists would find the river both challenging and scenic. Unfortunately, canoeing activities are limited by the length of routes and by the presence of low water levels and log jams, which are common and necessitate portaging (Barber *et al.* 1973).

Two small forest recreation sites have been established alongside the Salmon River, both of which are within the boundaries of the Vernon Forest District. The southern-most site is situated at the junction of Weyman Creek and Salmon River. This site is designated as a picnic site and trail-head to Weyman Falls. The second site, located five kilometres north at the junction of Twig Creek, is situated at an old Dominion Ranger Station. The Twig Creek site has only minimum facilities and low use (D. MacIntosh. Pers. Comm.).

According to DPA Group Inc. (1989), the Thompson-Okanagan Region, (which encompasses, among other areas, the Salmon River watershed) has an estimated population of 348,800 (36% of which reside in Kelowna and Kamloops), which represents 12% of the province's total population. Development of Shuswap Lake watershed for industrial, residential, and recreational purposes is rapidly increasing. The desirability of the Shuswap area for retirement and/or recreational residences has resulted in the rapid population growth and expansion of marinas, resorts, and service industries (Russell *et al.* 1980). The Okanagan Valley, which also encompasses portions of the Salmon River watershed, is developing a destination tourism industry and is one of the most popular summer vacation destinations in Western Canada. Forty six percent of the region's visitors cited outdoor/wilderness activities as their main purpose for visiting the valley (DPA Group Inc. 1989).

Generally, most of the Salmon River is not classified as having high recreational opportunities or high tourism potential. One of the major constraints on outdoor recreation is associated with the low water flows and dry river beds found during the late summer and early autumn months. In particular, few boating and fishing opportunities are available within the middle portion of the basin. The most popular recreational access route is found along the Salmon River road to Douglas Lake, where dude ranching, trail riding, and freshwater fishing are the major attractions (D. MacIntosh. Pers. Comm.; DPA Group Inc. 1989).

6.0 CONTAMINANT SOURCES

6.1 Point Sources of Environmental Contaminants

There are no permitted waste discharges to the Salmon River or any of its tributaries (D. Jeske. Pers. Comm.). However, there are a number of permitted tile field waste discharges, which could contribute contaminants to the Salmon River. Additionally, the Salmon Arm Sewage Treatment Plant discharges treated effluent into Shuswap Lake. It is mentioned here because there is some public concern about the impacts of wastewater discharges on the quality of receiving waters.

6.2 Diffuse Sources of Environmental Contaminants

6.2.1 Tile Fields

There are four permitted commercial tile field discharges to the Salmon River. These include discharges from two abattoirs, a cheese-making facility, and a mobile home pack (Table 6.1). There are also an unknown number of domestic tile field discharges. Domestic (septic) tile fields are permitted by the Ministry of Health and are inspected before and after construction (L. D'Andrea. Pers. Comm.). After approval for use is given by the inspector, no regular inspections are made. Should a complaint be made about seepage in the river, the matter is usually referred to the Ministry of Health. Nutrients, coliforms, and biochemical oxygen demand are the main water quality concerns associated with tile field discharges.

6.2.2 Agriculture

The Salmon River watershed is used intensively for agriculture. The types of agriculture and the associated concerns were identified by Gregory (1989; see Section 5). In general, these concerns include degradation of riparian habitats, erosion of streambanks, and inputs of manure, inorganic fertilizers, and pesticides to the Salmon River. These contaminants can enter the river by overland flow (i.e., surface runoff) or subsurface flow (i.e., groundwater).

The results of several studies provide a means of identifying the water quality variables and stream habitat characteristics that are most likely to be influenced by agricultural activities (Le Breton 1976a; 1976b; 1977; Gregory 1987). These include nutrients, coliforms, suspended sediments, temperature, and possibly dissolved oxygen. High loadings of organic material can quickly utilize available oxygen and have detrimental effects on dissolved oxygen levels. Specific information on pesticide use in the watershed was not located; however, those substances with slow degradation rates and low soil adsorption potential (i.e., K_{oc}) could be released into the river.

6.2.3 Forest Management

Logging and silvicultural activities occur in many upslope areas within the Salmon River basin. Removal of forest cover has a number of potential impacts on aquatic and riparian ecosystems, including increased nutrient loading and suspended sediment levels (Sidle *et al.* 1985; Verry 1986; Hornbeck *et al.* 1987). Elevated levels of sediment transport can also result in degradation of streambed substrates in low gradient areas. Elevated water temperatures can also result from removal of the canopy cover nearby small streams. In some cases, plant nutrients (fertilizers), herbicides, and other pesticides can be transported into stream systems as a result of silvicultural activities (Lindsay 1987; Klein and Perkins 1987).

7.0 APPROACHES TO THE DEVELOPMENT OF WATER QUALITY OBJECTIVES

In British Columbia, water quality objectives are being prepared for specific freshwater, estuarine, and marine ecosystems by Environment Canada and the B.C. Ministry of Environment, Lands, and Parks. These agencies share the responsibility for the management of water and other aquatic resources throughout much of the province. In general, objectives are prepared only for those waterbodies and water quality characteristics that may be affected by human activities, either now or in the future.

Water quality objectives are science-based tools that provide an effective basis for managing the resources in aquatic ecosystems. These tools describe conditions that environmental managers have agreed should be met to protect the most sensitive designated uses of freshwater, estuarine, and marine ecosystems. They are used in conjunction with other management tools, such as effluent controls and best available or practicable technology, to achieve water quality conditions that support sustainable resource use.

Water quality objectives are numerical concentrations or narrative statements that establish the conditions necessary to support and protect the most sensitive designated use of water, sediment, and biota at a specified site. Objectives are typically based on generic water quality guidelines and criteria, which may be modified to account for local environmental conditions or other factors.

Water quality objectives have no legal standing and, therefore, are not enforced directly. Instead, discharges of contaminants into surface water systems are regulated through permits issued under the Waste Management Act. Water withdrawals are regulated by licences issued under the Water Act. While the mechanism has not been formalized, the objectives are often used in the permitting and licensing processes in the Province. In addition, the objectives can be employed to support fisheries management and land use management decisions. Furthermore, decisions on the need for habitat restoration and other remedial actions may be based, in part, on the water quality objectives. Importantly, the objectives provide target levels for assessing the Ministry's performance in protecting water uses. Therefore, the objectives are used to support a variety of water management initiatives in British Columbia.

7.1 Provincial Philosophy on Water Quality Objectives

Water quality objectives are to be established in British Columbia for water bodies on a site-specific basis (BCMOELP 1984). These objectives are to be based on the provincial water quality criteria (Nagpal *et al.* 1995) and Canadian water quality guidelines (CCREM 1987). Such water quality criteria and guidelines are developed for the physical, chemical, or biological characteristics of aquatic ecosystems and define the conditions necessary to support specific water uses. The uses of aquatic ecosystems that are considered in the development of the criteria and guidelines include:

- drinking, public water supply, and food processing (for raw water sources prior to treatment);
- aquatic life and wildlife;
- agriculture (irrigation and livestock watering);
- recreation and aesthetics; and,
- industry.

There are other valid water uses (e.g., power generation, water storage, waste assimilation, navigation, etc.), but they are not as sensitive as those listed above and may impair the more sensitive water uses. Recognizing that there is a virtually limitless number of waterbodies and characteristics for which objectives could be established, objectives are developed on a priority basis for waterbodies and water quality characteristics that may be affected by human activities, either now or in the foreseeable future (BCMOELP 1984).

Water quality objectives are intended to consider the water use(s) to be protected and the existing water quality in the waterbody. Other factors that are considered in the objectives development process include: the temporal and spatial variability in water, sediment, and biological characteristics; existing and potential aquatic life in the waterbody; the flow pattern of the waterbody; and, the fate and existing loadings of contaminants from point and diffuse sources.

Permanent water quality objectives are established when sufficient scientific information is available; however, provisional objectives may be set when insufficient data exists to develop formal, definitive objectives. The provisional objectives are deliberately conservative and are accompanied by a recommended monitoring or study program that will lead to the establishment of permanent objectives. In some cases, both short-term and long-term objectives are identified. The long-term objectives represent the conditions that are needed to fully support and maintain the designated water uses in the system. In contrast, the short-term objective provide near term targets that can be used to assess progress toward full protection of the designated water uses. Therefore, the short-term objectives can be used to establish management priorities for improving water quality conditions, including source control, watershed restoration, and other remedial measures. A monitoring program is also recommended with the permanent objectives to determine the level of compliance and to identify situations where designated water uses may be endangered.

While the water quality objectives are intended to protect the designated uses of the aquatic ecosystem, they may allow for changes from background conditions. However, such alterations in ambient water quality are permitted only when the B.C. Ministry of Environment, Lands, and Parks considers that some waste assimilative capacity can be used without compromising use protection. Consistent with this philosophy, the objectives do not apply within the initial dilution zone for point source wastewater discharges. Where water quality has already been degraded, the objectives will establish the goal to be met by corrective measures. Therefore, the objectives provide an effective basis for water management (including setting effluent permit limits) when used in conjunction with other regulatory tools.

7.2 Federal Policy on Water Quality Objectives

Water quality objectives form a cornerstone of the Federal Water Policy (CCREM 1987). In addition, the need for water quality guidelines is explicitly recognized in the Canadian Environmental Protection Act [Section 8(1)]. To guide federal government staff, Environment Canada and Fisheries and Oceans Canada jointly developed a policy statement on the use and application of water quality objectives in the Pacific and Yukon Region. In addition, the policy statement outlines the federal approach for reviewing water quality objectives.

In the federal policy, a water quality objective is defined as a numerical concentration or narrative statement that has been established to support and protect the designated uses of water at a specified site (CCREM 1987). Such objectives are based on the best scientific information available. When insufficient information exists, provisional objectives are applied until the data required to develop scientifically-defensible objectives are available. Provisional objectives are deliberately conservative and implemented with due caution.

Water quality objectives are developed to conserve and protect the designated water uses in the waterbody under consideration. The designated water uses recognized in the federal policy include:

- raw water for drinking water supply;
- recreation and aesthetics;
- freshwater, estuarine, and marine fish;
- migratory birds and other aquatic life;
- agriculture (including irrigation and livestock watering); and,
- industrial water supplies.

While the provincial philosophy recognizes waste assimilation as a valid water use, a non-degradation policy has been adopted by the federal government. This policy states that all reasonable and preventative measures should be taken to maintain existing conditions when they are better than the conditions specified by the water quality objectives. Hence, the existing conditions should be adopted as the objectives for waters of superior quality. For waters with impaired quality, the objectives may be used as a basis for improving water quality.

The federal policy identifies a number of applications for the water quality objectives. For example, evaluation of compliance with the objectives provides a useful means of predicting and assessing whether effluent standards (which are based on best available or practicable technology) provide adequate protection for a designated water use. However, the objectives cannot be used to derive allowable effluent contaminant concentrations if they result in relaxation of effluent treatment requirements such that legislated effluent standards are no longer met. The objectives also provide a basis for identifying emerging water quality problems resulting from multiple point and diffuse sources and determining the need to address such problems.

The federal policy recognizes that the management and control of certain toxic substances cannot be achieved using water quality objectives. For many toxic and/or bioaccumulative substances, it is not feasible to develop objectives due to the lack of aquatic toxicity data. For those substances that exhibit high acute toxicity or bioaccumulative potential, it may be necessary to establish objectives at levels below current analytical detection limits. In these cases, more information will be needed to prescribe appropriate objectives.

The federal policy also affirms the concept of the initial dilution zone, wherein effluents mix with receiving waters. According to the policy, the extent of the initial dilution zone should be defined on a site-specific basis and should be located to avoid impairments to designated water uses (e.g., not located near important fish or migratory bird habitat). The policy stipulates that no toxic substance should be release into the river (that is, wastewater discharges should not be acutely toxic to indicator species). While the water in the initial dilution zone should not be acutely toxic to fish, contaminant concentrations may exceed the water quality objectives. However, the objectives should be met outside the initial dilution zone.

8.0 WATER QUALITY OBJECTIVES

The identification of use protection goals is an essential element of the water quality objectives (WQOs) development process. In Canada, generic water quality criteria and guidelines have been derived for the protection of five major water uses (CCREM 1987; Nagpal *et al.* 1995), including:

(i) raw water for drinking water supply;
(ii) recreational water quality and aesthetics;
(iii) freshwater, estuarine, and marine aquatic life;
(iv) agricultural water uses (irrigation and livestock watering); and,
(v) industrial water supplies.

These generic guidelines and criteria have been developed to provide basic scientific information about the effects of water quality variables on water uses in order to assess water quality issues and concerns and to establish water quality objectives (CCREM 1987). These guidelines and criteria are designed to be conservative and, hence, are likely to be applicable to the vast majority of sites in this country. The broad applicability of these management tools makes them useful for assessing the condition of surface water and groundwater sources and for adopting as provisional water quality objectives. However, the unique characteristics of some sites necessitate the modification of these criteria to reflect site-specific conditions.

The water quality objectives recommended in this study were developed in the following manner. First, the information on existing and potential contaminant sources was reviewed to identify priority water quality variables in the Salmon River watershed. Next, the available guidelines and criteria for these variables were assembled and reviewed. In general, the lower of the values recommended by CCREM (1987) or Nagpal *et al.* (1995) was recommended as the water quality objective for that variable. If the available information suggested that a guideline or criterion should be modified to account for local conditions, then a site-adapted objective was established accordingly for that substance.

Using this procedure, water quality objectives were recommended for the protection of aquatic life and other water uses in the Salmon River watershed. The recommended objectives apply explicitly to mainstem of the Salmon River; however, they may also be applicable for use in the tributaries to the river. These objectives will be reviewed and revised as necessary. In some cases, short term objectives were derived to reflect the current conditions in the Salmon River (i.e., the concentration of certain substances greatly exceeded the water quality objectives). These short term objectives provide interim targets that can be used to prevent further degradation of the river system and to develop remedial action plans to improve water quality conditions.

Based on a review of the available information, the following water quality variables were identified as the high priority in the Salmon River watershed. The priority variables were identified as those that have the greatest potential to be affected by historic and existing land and water uses in the basin.

- water temperature;
- dissolved oxygen;
- pH;
- suspended solids and turbidity;
- streambed substrate composition;
- total phosphorus;
- total ammonia;
- algal growth and biomass; and,

- microbial indicators.

The water quality objectives for the Salmon River watershed are summarized in Table 8.1. In most cases, the water quality objectives specify maximum and/or average concentrations which are calculated from at least five approximately weekly samples taken in a period of 30 days. The generic water quality guidelines (CCREM 1987) and/or criteria (Nagpal *et al.* 1995) are considered to be applicable for the substances that are not included in Table 8.1. The recommended objectives and associated rationale are presented below.

8.1 Water Temperature

The maximum water temperature in the Salmon River and its tributaries should not exceed 15.6 °C to protect freshwater aquatic life. Average water temperatures should not exceed 14.2 °C during any 30-day period. In addition, maximum water temperatures should not exceed 12.8 °C between October 1 and November 30 to protect spawning salmonids.

Rationale:

Canadian water quality guidelines and B.C. water quality criteria for temperature have been developed for raw water for drinking water supplies, recreation and aesthetics, fish and aquatic life, and industrial water uses. The maximum acceptable temperature in drinking water is set at 15 °C. The thermal requirements for freshwater aquatic life vary for the protection of adults, juveniles, spawning, and embryo survival. The objective should reflect these differences in sensitivity by life stage and at different times of the year.

The optimum temperature ranges that are recommended for migration, spawning and rearing life stages of salmon in order to maximize productivity are presented in Table 8.2. To minimize stress and mortalities in spawning and rearing salmonids, maximum water temperatures should not exceed 12.8 °C and 15.6 °C, respectively (Ralph 1976). As anadromous salmonids initiate spawning activities in October, the water quality objective for spawning salmonids applies between October 1 and November 30. The maximum water quality objective for salmonid rearing applies during the rest of the year. It is also recommended that 30-day average water temperatures not exceed 14.2 °C. This corresponds with the temperature optima for salmonid rearing.

Data collected at Highway 1 Bridge on the Salmon River indicate that the objective is not being met during portions of the summer months, during the critical migration and pre-spawning period for salmon. Substantial changes in the management of the watershed will be required to assure that the objective is met in the future.

8.2 Dissolved Oxygen

Minimum and 30-day average water quality objectives of 9.0 mg/L and ≥ 11.0 mg/L, respectively, are recommended for dissolved oxygen to protect aquatic life in the Salmon River, including all life stages of anadromous salmonid species. In the near-term, minimum and 30-day average water quality objectives of 5.0 mg/L and ≥ 8.0 mg/L, respectively, are recommended to protect rearing salmonids and other aquatic organisms.

Rationale:

Dissolved oxygen (DO) is an essential component of aquatic ecosystems. Among the aquatic organisms that utilize habitats within the Salmon River watershed, salmonid fish are the least tolerant of depressed DO levels. Data from several studies show that the early life stages of these species are particularly sensitive to low DO levels, particularly the eggs and larvae (Davis 1975; USEPA 1985; Rombough 1986).

Nagpal *et al.* (1995) summarized the available information on the effects of DO on freshwater aquatic life. Based on these data, no production impairment of embryo and larval stages is anticipated when DO levels remain above 11 mg/L. Slight production impairment can occur to these life stages at DO levels of below 9.0 mg/L. Other life stages are likely to be protected when DO levels remain above 8.0 mg/L. The minimum and 30-day average DO objectives were established at 9.0 mg/L and 11.0 mg/L, respectively, to protect the early life stages of anadromous salmonids. Since the Salmon River watershed is 349 to 1520 metres above the sea level, saturation levels of DO may be lower than the recommended objectives during portions of the year (i.e., summer). At these times , DO should be at or above 90% saturation.

It is recognized that elevated water temperatures and high biochemical oxygen demand have the potential to depress DO levels during portions of the year. For this reason, short-term WQOs are also recommended to support remedial actions in the basin. The recommended minimum and 30-day average WQOs for DO are 5.0 mg/L and ≥8.0 mg/L, respectively. Attainment of this objective will protect the post-incubation life stages of salmonid fish and other aquatic organisms.

8.3 pH

A water quality objective for pH of 6.5 to 8.5 units is recommended for the protection of aquatic life. This objective will also protect other water uses in the Salmon River watershed.

Rationale:

Canadian water quality guidelines for pH have been developed for drinking water supplies, recreation and aesthetics, fish and aquatic life, and industrial water uses. Of these uses, the guidelines for fish and aquatic life are the most restrictive (i.e., 6.5 to 8.5 pH units). Pommen (1991) and McKean and Nagpal (1991) recommended that unrestricted change within this range be permitted only when free carbon dioxide does not exceed 60 mg/L. As no information was located on the levels of carbon dioxide in the Salmon River watershed or its tributaries, rapid pH changes within the stated range should be avoided. More information on carbon dioxide is needed to refine the objective for pH.

8.4 Suspended Solids and Turbidity

Induced turbidity should not exceed 5 nephelometric turbidity units (NTU) over background levels. Induced suspended solids (non-filterable residue) concentrations should not exceed 10 mg/L over background levels to protect fish and aquatic life. Other water uses will also be protected by these objectives. In the near-term, turbidity and suspended

solids levels should not exceed 10 NTU and 20 mg/L, respectively over background to protect wildlife and agricultural water uses.

Rationale:

Of the water uses for which water quality guidelines are available, fish and aquatic life are the most sensitive to wastewater discharges and diffuse sources that contribute fine sediment to stream systems. Both the B.C. water quality criteria (Singleton 1985) and the CCME water quality guidelines (CCREM 1987) recommend that human activities should not increase total suspended solids (TSS) levels by more than 10 mg/L when background levels are less than 100 mg/L. Similarly, turbidity should not be increased by more than 5 NTU when background levels are less than 50 NTU. Anthropogenic activities should not increase TSS or turbidity by more than 10% when background levels are > 100 mg/L and 50 NTU, respectively, for the protection of aquatic life.

Background level refers to one of the following (Nagpal *et al.* 1995):

- the level measured upstream of point or diffuse sources;
- the historical or predevelopment level; or,
- the level in an adjacent, undisturbed stream or creek with similar hydrological, geological, and climatic conditions.

The background levels of TSS and turbidity in the Salmon River are difficult to determine since the entire watershed area has been disturbed. However, it is recommended that the monitoring site located in the upper reaches of the Salmon River or one of the tributary watersheds (i.e., Bolean Creek or Silver Creek) be used to define background levels of suspended solids and turbidity in the Salmon River.

The existing levels of TSS and turbidity in the Salmon River result, to a large extent, from diffuse sources of organic and inorganic particulates. Mitigation of these inputs will require substantial watershed restoration efforts and modification of various land use practices. While important progress has been made in both of these areas, it will require considerable time to complete these tasks. For this reason, short-term objectives have also been recommended for induced TSS (20 mg/L) and turbidity (10 NTU) to provide protection for wildlife and agriculture water uses (Singleton 1985).

8.5 Streambed Substrate Composition

The quantity of fine sediment in streambed substrates (i.e., percent fines) should not exceed 10% less than 2.00 mm, 19% less than 3.00 mm, and 25% less than 6.35 mm at potential salmonid spawning sites. The geometric mean diameter and fredle number of streambed substrates at such sites should not be less than 12.0 mm and 5.0, respectively. The minimum and 30-day average criteria for intragravel dissolved oxygen levels are 8.0 and 9.0 mg/L, respectively. These objectives are considered to be provisional as streambed substrate composition in undisturbed areas in the basin have not been determined.

Rationale:

The results of numerous studies have demonstrated that elevated levels of fine sediment in streambed substrates have the potential to compromise the survival of salmonid eggs and alevins. The survival of salmonid eggs and alevins is dependent on the delivery of adequate amounts of oxygen and on the removal of toxic metabolic waste products. To meet these basic requirements, streambed substrates must permit the free flow of oxygenated water to incubating embryos (Vaux 1968). Deposition of fine sediment onto and into streambed substrates tends to reduce their permeabilities and, in so doing, decrease the interchange of water between the fluvial and intragravel environments (Wickett 1954; Wickett 1958; McNeil and Ahnell 1964; Phillips 1971). Low streambed permeability can result in depressed intragravel dissolved oxygen levels which, in turn, compromise the survival of incubating fish embryos (Shumway *et al.* 1964; McNeil 1966). In addition, surviving sac fry tend to be smaller, weaker, and have more developmental abnormalities than alevins incubated at high levels of dissolved oxygen (Garside 1959; Silver *et al.* 1963). Deposited sediments can also block the emergence of fry from the gravel (Koski 1972).

In an effort to provide tools for evaluating the effects of sedimentation on aquatic ecosystems, the B.C. Ministry of Environment recently developed water quality criteria for deposited sediments for the protection of fish and aquatic life. To minimize the potential for adverse effects on salmonid populations, these criteria were established at levels to support high egg-to-fry survival rates (i.e., ≥ 80%). The key indicators of streambed substrate quality included % < 2.00 mm, % < 3.00 mm, % < 6.35 mm, geometric mean diameter, and fredle index. The results of controlled laboratory studies were used to establish relationships between these indicators and egg-to-fry survival in various salmonid fish species. The results of these analyses indicated that egg-to-fry survival rates of 80% would generally be achieved (relative to control survival) if percent fines < 2.00 mm, < 3.00 mm, and < 6.35 mm in diameter remained below 10%, 19%, and 25%, respectively. These values were adopted directly as the water quality criteria for percent fines in streambed substrates. Similarly, the results of these studies indicated that adequate egg-to-fry survival rates (i.e., ≥ 80%) will likely be maintained when geometric mean diameter and fredle index remain above roughly 12.0 mm and 5.0, respectively. Collectively, these values were adopted directly as the provisional water quality objectives for these streambed substrate statistics.

No information was located on the particle size distribution of spawning habitats in the Salmon River or its tributaries. Therefore, it is not possible to determine if the provisional WQOs are currently being exceeded in the Salmon River. It is recommended that the monitoring activities be conducted in the basin to assess streambed substrate composition and to determine if short-term WQOs are needed to support remedial actions.

8.6 Total Phosphorus

For Tappen Bay in Shuswap Lake, the concentrations of total phosphorus should not exceed 10 µg/L to protect recreational water uses. The short-term objective for total phosphorus is 15 ug/L in Tappen Bay.

Rationale:

The B.C. water quality criteria states that the maximum level of total phosphorus is 0.01 mg/L in lakes which are used for recreation (Nagpal *et al.* 1995). The objective for phosphorus in Tappen Bay (10 ug/L) is set to protect the most sensitive water use - recreation, as this is an area used for water sports. The objective is also consistent with the water quality criteria for the protection of aquatic life (0.005-0.015 mg/L), especially for lakes with salmonids as the predominant fish species (as is the case with Shuswap Lake). Data on average concentrations of total phosphorus from the 1970's indicates that this objective was being exceeded. More recent data will need to be collected to determine contemporary levels of phosphorus in the lake.

To support remedial actions in the watershed, a short-term WQO of 15 ug/L is recommended for TP. Attainment of this objective would reduce the potential for eutrophication of Tappen Bay. It is likely that a decrease in loadings from the Salmon River and possibly the Salmon Arm Sewage Treatment Plant will be necessary to assure that this objective is met. Specifically significant reductions in phosphorus inputs could be realized by improved cattle management practices and more efficient use of fertilizers in the watershed (Gregory 1989).

8.7 Total Ammonia

The water quality objectives for total ammonia are presented in Table 8.3. Using this table, site-specific objectives can be established once the temperature and pH of the river have been determined.

Rationale:

Ammonia is toxic to freshwater organisms at fairly low concentrations. Of the species tested, salmonid fishes appear to be the most sensitive. Concentrations as low as 0.083 mg/L have been shown to be acutely toxic to mountain whitefish (CCREM 1987). Several other families of fish also exhibited high sensitivities, including walleye, shiners, and darters. In general, aquatic invertebrates were less sensitive to the effects of ammonia. While ammonia is toxic to many species, it is also used as a nutrient by aquatic plants.

In water, total ammonia is present in two forms, unionized ammonia (NH_3) and ammonium (NH_4^+). Of these, unionized ammonia accounts for most of the toxicity of total ammonia (CCREM 1987). The equilibrium concentrations of these two forms of ammonia is dependent on water temperature and pH. As such, the toxicity of total ammonia also depends on these environmental variables. The results of toxicity tests conducted on a variety of freshwater fish species indicate that the acute toxicity of unionized ammonia increases as dissolved oxygen, pH and temperature decrease. However, increases in temperature and pH cause a shift in the relative proportions of the ammonium ion and unionized ammonia, which results in increased toxicity of the total ammonia. For this reason, the water quality guidelines that have been developed for total ammonia are pH and temperature dependent (CCREM 1987). The water quality criteria for the protection of aquatic life were adopted directly as the water quality objectives for total ammonia in the Salmon River watershed (Nagpal *et al.* 1995).

8.8 Algal Growth and Biomass

Chlorophyll *a* levels in the Salmon River should not exceed 50 mg/m^2 to protect recreational water uses. This objective is considered to be provisional because no data on background levels of chlorophyll *a* were located in the Salmon River.

Rationale:

No criteria for phosphorus values in streams have been proposed by B.C. Ministry of Environment, Lands and Parks (Nagpal *et al.* 1995) because there are many factors that control nuisance algal growth in streams in addition to phosphorus. Before it can be determined that phosphorus concentration is the limiting factor controlling algal growth, other physical conditions (e.g., water velocity, substrate, light, temperature and grazing pressure) must be within the tolerance range of periphytic algae (Nordin 1985). Adverse effects associated with excess periphytic algal growth include losses of fish habitat, changes in quantity of fish food organisms, and loss of recreational and aesthetic values (Nordin 1985).

The objective set for algal biomass in the Salmon River is intended to protect the most sensitive use of the river, which is recreation. This objective will also protect aquatic life, for which Nagpal *et al.* (1995) established a maximum water quality criterion of 100 mg/m^2. No data exist on chlorophyll *a* levels in the Salmon River and so it is not possible to assess the degree to which the objective is currently being met. Monitoring activities should focus on those areas upstream of Silver Creek, as substrates are too unstable to support substantial periphyton production in downstream areas. Chlorophyll *a* levels (using periphytic algal collection and extraction techniques) should be determined as the average of at least five samples randomly collected from the river bed on one day (Nordin 1985).

8.9 Microbial Indicators

The 90th percentile concentrations of faecal coliforms and *Escherichia coli* should not exceed 10 colonies/100 mL (as measured over any 30-day period) to protect raw untreated drinking water supplies that receive minimal treatment (i.e., disinfection). The 90th percentile concentration of *Enterococcus sp.* should not exceed 3 colonies/100 mL. In the near-term, a water quality objective of 100 colonies/100 mL (90th percentile

concentration) is recommended for faecal coliforms to protect agricultural water uses.

Rationale:

Water quality guidelines and criteria for microbiological indicators have been developed for a variety of water uses, including raw drinking water, aquatic life, livestock watering, irrigation, recreation, and industrial water uses. Of these, raw water for drinking water supplies, livestock watering in feedlot operations, and food processing are the most sensitive water uses.

The B.C. Ministry of Health recommends that all drinking water supplies derived from surface water sources be disinfected prior to use, as the minimum treatment. The recommended objective is set to protect drinking water supplies that utilize disinfection prior to use (i.e., no other treatment). A recent survey of water uses by residents of the lower reaches (downstream of Falkland) of the Salmon River indicated that only one person was using river water for domestic purposes to supplement their well supply (D. Einarson. Pers. Comm.). It has been assumed that anyone using water from the river will at least disinfect it prior to usage. Given the level of bacteria in the river a more stringent standard would be extremely difficult to meet and unnecessary, as most people rely on groundwater for domestic use. The potential for bacterial contamination of groundwater water is unknown in the Salmon River watershed and requires investigation. As soils tend to act as good filters, groundwater contamination of faecal contamination is not likely except in those areas with high groundwater tables and highly permeable soils.

The B.C. water quality criteria state that the 90th percentile concentrations of faecal coliforms and *Escherichia coli* in raw drinking water receiving disinfection should be ≤ 10 colonies/100 mL (Nagpal *et al.* 1995). In addition, the 90th percentile concentration of *Enterococci* (*Enterococcus sp.*) should be ≤ 3 colonies/100mL (Nagpal *et al.* 1995). Higher concentrations of these microorganisms could necessitate additional water treatment or relocation of water supplies. The 90th percentile concentration should be calculated from data obtained from at least 10 water samples taken at equal time intervals during a 30-day period (Warrington 1988). The other water uses in the basin will also be protected through compliance with these objectives, including irrigation, recreation, and livestock watering.

The available data indicate that the faecal coliform objectives are routinely exceeded at locations throughout the river. For this reason, a short-term WQO of 100 colonies/100 mg/L (90^{th} percentile concentration) is also recommended to protect agricultural water uses, particularly livestock watering in dairy operations and feedlots. Attainment of this objective and ultimately the permanent WQO will require improvement of cattle management and, perhaps, repair or repositioning of septic tile fields. The inputs of manure and other coliform-containing wastes needs to be better identified throughout the river basin to assist in controlling problem areas.

9.0 WATER QUANTITY OBJECTIVES

Changes in the hydrological regime of riverine ecosystems can have significant and lasting impacts on the organisms that reside in the basin. These impacts are not confined to stream habitats, but extend to the biota of the deltas and the adjacent riparian areas (Fraser 1972). The nature, extent, and severity of these biological impacts are likely to be dependent on the types of hydrological changes that occur, as well as their duration and magnitude. The following discussion is not intended to provide a comprehensive review of the literature on the biological effects of developmental activities that influence stream hydrology. Instead, it is designed to illustrate the functional linkages between the biotic and abiotic environment, as they relate to hydrological variables.

9.1 Effects of Alterations of the Hydrological Regime on Aquatic Ecosystems

9.1.1 Alterations in Stream Discharge

Changes in the magnitude and duration of streamflow events are likely to be associated with a range of effects on the organisms that utilize stream and riparian habitats, including aquatic plants, benthic macroinvertebrates, fish, birds, and mammals. The nature and severity of these effects will vary between species and between taxonomic groups, because each organism has unique habitat requirements.

The relationships between discharge and the status of benthic macroinvertebrate communities are complex and difficult to quantify. Nonetheless, information from a number of studies indicates that the structure of benthic invertebrate communities is significantly affected by high flow conditions (Fisher *et al.* 1982; Sousa 1985; Resh *et al.* 1988). For example, storm-related flooding was associated with large reductions in the abundance of caddisfly larvae (late instar) in a California stream over a period of four years (Feminella and Resh 1990). The densities of late instar caddisfly larvae were not affected by moderate peak streamflow events; however, smaller adults with lower fecundities were produced under these conditions. In contrast, the densities of middle instars appeared to be independent of the magnitude of peak discharge. These data indicate that even different life stages of the same species can respond very differently to flow alterations. Hence, it is dangerous to make generalizations based on limited data.

Allen (1959) reported that high flows affected insect densities differently depending on the stability of the substrate. The most dramatic effects were observed in areas with unstable substrates, while less severe effects occurred in areas that were dominated by large diameter bed materials. In addition to the composition of bed materials, substrate stability is also dependent on the average gradient and depth of the river (Cobb *et al.* 1992).

Alterations in stream discharge have been associated with both positive and negative effects on freshwater fish. For example, increased feeding and growth rates were observed in white perch, yellow perch, and channel catfish downstream of the Conowinga Dam (Maryland) when minimum flows were maintained throughout the summer low flow period (Weisberg and Burton 1993). Likewise, increases in the number and total biomass of brown trout have been observed in the North Esk-St. Patricks River (Tasmania) when mean annual streamflow was increased by a factor of three (Davies *et al.* 1988). These investigators concluded that increased flow in the shallow headwater streams, particularly during low flow periods, resulted in increased survival of juvenile trout and improved reproductive success.

Negative effects on riverine fish communities have also been reported when natural stream discharges have been altered. While abundance of fish in reservoir tailwaters tends to be higher than it is in unregulated systems, these populations also tend to be less stable. For example, Jacobs and Swink (1983) reported that fish populations, particularly cyprinids (minnows) and catostomids (suckers), in the tailwater of the Barren River Lake Reservoir in south central Kentucky were less stable than those in an unregulated stream. These investigators concluded that altered flow, low summer water temperatures, and poor summer water quality were probably responsible for the unstable fish populations in the tailwater. Similarly, the growth of rainbow trout juveniles was compromised when discharge was reduced by 32% and 60% in experimental stream channels, presumably due to reduced habitat area and, hence, increased competition for the available food resources (Rimmer 1985).

Large-scale reductions in fish spawning habitat have also been observed in association with decreased streamflows downstream of major impoundments. In the Trinity River, California, spawning habitat was reduced by 44% in downstream areas following the construction of the Lewiston Dam, with as much as 80 - 90% of the habitat eliminated in certain stream reaches (Nelson *et al.* 1987). Accordingly, the population of fall-run chinook salmon decreased from approximately 71,000 to about 11,250. The main cause of the habitat reduction was the loss of flushing flows associates with natural flood events and high sediment production from extensive land use disturbances.

9.1.2 Water Velocity

Large short-term variations in velocity and depth can have a variety of direct effects on instream water uses. For example, Perry and Perry (1986) investigated the effects of flow regulation on stream invertebrates in the Flathead and Kootenai Rivers in Montana, and concluded that invertebrate drift was highly correlated with water velocity. Increased invertebrate drift rates were observed at high water velocities during both the ascending and descending limbs of the hydrograph. Therefore, changes in stream hydrology that result in increased water velocities could cause significant reductions in benthic invertebrate populations.

Alterations in the water velocity of river systems can also affect fish communities. For example, Bain *et al.* (1988) examined the effects of water velocity on the shallow and slow water fishes in the Connecticut River system. This group of fish, which included a total of 13 centrarchid, catostomid, and cyprinid species, was affected by artificially high variability in flow. Significantly, this fish guild was absent in river habitats with a mean current velocity of 21.5 cm/sec and present in river habitats with a mean current velocity of 8.1 cm/sec. These data emphasize the potential effects of alterations in the velocity of river systems.

Water velocity is a critical factor for a successful spawning stream (Ralph 1976). Table 9.1 identifies typical water velocity requirements for anadromous salmon species which spawn in the Salmon River.

9.1.3 Water Level and Depth

Variations in water level, and hence stream depth, can be associated with a range of adverse effects on the organisms that utilize aquatic and riparian habitats. Short-term variations in water level tends to cause dewatering of shallow shoreline areas and stranding of macroinvertebrates and fish utilizing these areas (Corrarino and Brusven 1983). In large systems, these nearshore areas tend to be the most productive, so repeated dewatering of these areas could cause severe effects on aquatic biota (Bain *et al.* 1988).

Variations in water level can also modify waterfowl habitat. Currently, migratory ducks and geese in the Slave River concentrate their nesting activities on low alluvial islands that are protected from terrestrial predators. Lowering of water levels during the spring and early summer could enlarge and coalesce some of these islands such that waterfowl no longer find them attractive for nesting (Kellerhals and Gill 1973). However, the results of a five-year study in Montana indicate that Canada goose productivity (i.e., hatching success) in the Thompson Falls reservoir (which was formed upstream of a run-of-the-river dam on the Clark Fork River) was not affected when water levels were altered by as much as 4 m during the nesting season (O'Neil 1988).

Maintenance of adequate water depth is essential for sustaining the productivity of salmonid fish populations. Specifically, salmonids are dependent on maintaining adequate water depths during upstream migrations. Knapp *et al.* (1982) also indicated that the quality of spawning habitat is affected by water depth. The typical water depth requirements for anadromous salmon species which spawn in the Salmon River are presented in Table 9.1.

9.1.4 Instream Flow Needs

Instream flow is the volume of water passing through cross sections of a natural stream channel, as measured at a given time (Arnette 1975). The maintenance of minimum instream flows is necessary to protect and maintain a variety of instream uses, such as aquatic life, wildlife, recreation, raw water supply, and aesthetics.

A number of methodologies for estimating the instream flow needs have been developed. The most widely used method is the Physical Habitat Simulation System (PHABSIM) approach of the instream flow incremental methodology (IFIM) which was developed by the U.S. Fish and Wildlife Service (Moyle and Baltz 1985). It uses multiple-transect field data from a representative river reach to construct detailed hydraulic and habitat simulation models. The models are capable of predicting parameters, such as velocity, depth, substrate, temperature, cover, and weighted usable area (WUA), with which to evaluate the suitability and availability of fish habitat for various life stages of specific species at specific locations in a stream (Loar and Sale 1981).

A study to assess the salmonid habitat in the Salmon River was conducted using the PHABSIM approach (Burt and Wallis 1997). Salmon River hydraulic data was obtained from Water Survey Canada. Four types of information were collected in the field, including transect hydrometric data, temperature and dissolved oxygen, channel profile data, and longitudinal macrohabitat inventory. The WUA for each species, as an index of available rearing and spawning habitat, was determined and the number of fish potentially supported by the available habitat was estimated (Burt and Wallis 1997). The total WUA of rearing habitat calculated using depth and velocity criteria was estimated to be 332 592 m^2, 466 823 m^2, 290 043 m^2, and 149 277 m^2 for underyearling rainbow, yearling rainbow, underyearling chinook and underyearling coho, respectively. The total WUA of spawning habitat calculated using depth, velocity and substrate criteria was estimated to be 95 456 m^2, 107 951 m^2, 61 253 m^2, and 97 054 m^2 for rainbow, sockeye, chinook and coho, respectively. The study concluded that the quality and quantity of rearing habitat and spawning habitat is being degraded mainly by high levels of fine sediments in streambed substrates, insufficient instream and riparian cover, and a shortage of pool habitat. Therefore, it was recommended that the riparian corridor along the river be restored using a combination of shoreline revetment, streambank regrading, and planting of trees.

9.2 Provisional Water Quantity Objectives

The flow regime of the Salmon River watershed should be maintained in a state that will protect and restore the structure, productivity, and health of aquatic communities.

Rationale:

The aquatic ecosystem provides a wide range of benefits to the people who reside in and visit the Salmon River watershed. Therefore, maintenance of the integrity of the aquatic ecosystem should be considered to be a local and provincial priority. Evidence from a number of sources indicates alteration of the natural hydrological regime associated with extensive water withdrawals, particularly during low flow periods, has the potential to adversely affect algae, aquatic macrophytes, benthic invertebrates, and fish in the Salmon River watershed. As such, numerical water quantity objectives are needed to define the hydrological conditions needed to support a healthy and productive aquatic ecosystem.

While a substantial quantity of information has been collected on the Salmon River watershed, these data have not yet been evaluated in a manner that would support the derivation of numerical water quantity objectives. For this reason, narrative objectives have been proposed for this system. In the near future, the relationships between valued ecosystem components (and other indicator species) and various flow-related variables should be established. These relationships will provide a basis for establishing numerical water quantity objectives that will support the designated water uses in the Salmon River and its tributaries.

10.0 AMBIENT HYDROLOGICAL AND WATER QUALITY CONDITIONS

10.1 Hydrology of the Salmon River Watershed

10.1.1 Surface Water Hydrology

Information on surface water hydrology has been collected at numerous stations over the past 85 years (Table 10.1 and 10.2). Evaluation of these and other data indicates that the hydrology of the Salmon River watershed is influenced by local climatic conditions and the underlying geology of the area. As such, peak flows occur during periods of high incident precipitation and snowmelt. In the Salmon River and Bolean Creek, peak flows occur during April, May, and June. Peak daily discharge in the order of 15 to 25 m^3/s are typical in the Salmon River at Salmon Arm (Table 10.3). However, higher flows have been reported during major floods, including one that occurred in 1948 and another in 1990.

The flood in 1948 registered as the largest on record for the Falkland gauge station, where the daily peak flows reached 49 m^3/s on May 28 (the Falkland gauge station is located 170 m downstream of the mouth of Bolean Creek). During the flood, the Highway 97 bridge was unsafe to use and residents were reportedly using dynamite to destroy the Armstrong Road bridge because of threatening log jams. Bolean Creek was also flooded and destroyed the Highway 97 bridge near Falkland.

During the flood of 1990, the maximum daily discharge recorded for Water Survey Canada (WSC) station 08LE021 (located at the junction of Salmon River and Palmer Creek - 3 km from Salmon Arm) for June 13 was 50.1 m^3/s and the maximum instantaneous discharge was 52.3 m^3/s (Crippen

Consultants Ltd. 1990). At the Falkland gauge station, the daily flow reached 41.1 m^3/s on June 15. It was reported that several farms were destroyed and up to 1500 acres of hay fields and pasture were flooded. In Falkland, at the confluence of Bolean Creek and the Salmon River, the Falkland Trailer Park was surrounded by water.

While freshet conditions are dominated by inputs from snowmelt, base flow conditions are mediated primarily through linkages with groundwater aquifers. These linkages are particularly evident in the vicinity of Westwold. At this location, the Salmon River flows below the surface for most of the year, with the water entering a large underground storage area with expansive deposits of gravel and sand (Obedkoff 1976). The dry reach of the river spans a distance of approximately 13 km, extending from 8 km upstream to 5 km downstream of Westwold. This section usually has subsurface flows for 9 to 10 months of the year (i.e., July through April); however, continuous above ground flows are known to occur in years with high precipitation.

Streamflows in the Salmon River below the dry reach are influenced by inputs from groundwater and tributaries, and by withdrawals for various uses (McPhee *et al.* 1996). Land use patterns (e.g., timber harvest) can also affect stream hydrology in the Salmon River watershed. Typically, baseflows in the Salmon River at Salmon Arm range between 1 and 3 m^3/s (Figures 10.1 and 10.2). As such, permitted water withdrawals can have significant effects on instream flows in the river. Low flow information for three hydrometric stations on the Salmon River is presented in Table 10.4.

10.1.2 Groundwater Hydrology

The distribution and abundance of groundwater depends on topography and geology of the area under study. Groundwater usage in British Columbia is common because many people live in rural communities where groundwater is readily available, reliable, and economical to obtain (BCMOELP 1993). In British Columbia, 22% of the population relies on groundwater for municipal, domestic and agricultural uses (Environment Canada 1990; BCMOELP 1993). According to statistics compiled in 1981, industrial activities account for 55% of the groundwater use, followed by 20% for agriculture, 18% for municipal use and 7% for rural domestic use (BCMOELP 1993).

According to BCMOELP (1993), groundwater management is needed in certain areas in the province where there are obvious problems of contaminated or degraded water quality, groundwater aquifer depletion, groundwater/surface water conflicts, or lack of public water supplies. Some of the issues that need to be addressed in groundwater management programs include:

- poor well construction practices, resulting in contamination of groundwater;
- excess groundwater extraction from large capacity wells, resulting in depletion of surface water flows and/or lower the yields of neighbouring wells;
- free-flowing artesian wells, which have the potential to lower the yields of neighbouring wells;
- shallow groundwater wells that are susceptible to contamination from non-point or diffuse sources; and,
- excessive groundwater withdrawal for irrigation.

The primary land surface change in the Salmon River basin is deforestation (Dorcey and Griggs 1991). This change can be classified as temporary (sustained yield forestry) or permanent (agricultural development and urbanization) deforestation. Because groundwater wells are not licensed, it is estimated that only 40% of well constructions are actually reported in the Salmon River watershed (R. Zimmerman. Pers. Comm.). Well reporting is voluntary and is usually based upon the estimates of unlicensed drillers. There are no mechanisms currently in place to monitor well drilling activity or groundwater withdrawals.

According to a 1993 summary of groundwater well withdrawal data provided by the B.C. Ministry of Environment, 2913 wells have been constructed throughout the Salmon River watershed. Location information on a portion of these wells was provided and a total of 649 wells appear in the map atlas that was prepared by Aquametrix Research Ltd. (1995). A summary of well water yield, compiled by water use, is presented in Table 5.3. These uses include domestic, irrigation, commercial, municipal, observation wells, community well sites, abandoned wells, and a large category for which usage is unknown. It should be noted that the yields reported by well-drillers tend to be somewhat subjective and should be considered as estimates of well capacity only.

Generally, aquifers are located in permeable rock (fractured aquifers) or loose material (porous media) which often trap large quantities of water in underground formations. Throughout Canada, these aquifers vary in size from a few hectares to thousands of square kilometres and range in depth from a few metres to several hundred metres thick. Groundwater in the Salmon River watershed exists mainly in fractured aquifers. The bedrock in this area consists of volcanic basaltic lava in the upper reaches of the river and metamorphic rock in the lower reaches. Neither type of bedrock is very porous or permeable, which results in relatively low yields from wells (Obedkoff 1976).

The surficial materials in the Salmon River valley consist of till, clay, silt, and gravel, which vary in permeability and porosity. Near Salmon Lake, the geology of the upper valley is dominated by glacial deposits which are rich in both argillite and schist, then changes to basaltic lava near the mouth of Adelphi Creek (Obedkoff 1976). In the Salmon River valley, sand and gravel deposits occur to depths of 50 to 100 feet, with silt and clay common at greater depths (i.e., to 300 feet). Therefore, groundwater well-yields are usually high on the valley floor and near the mouths of tributaries (Obedkoff 1976).

Topography plays a major role in the direction of groundwater movement within the basin. Groundwater flows vary with surface water flows on a seasonal basis. Through the summer months, the Salmon River dries between Westwold and Falkland, with groundwater discharge representing much of the flow downstream of Falkland.

10.2 Water Quality Conditions in the Salmon River Watershed

Data from the BCMOELP water quality sampling programs were obtained from the SEAM and EQUIS databases (now replaced by EMS - the Environmental Management System). The period of record began in 1970 and extends to 1996. Over 50 stations (locations) have been sampled during the past 26 years of in the Salmon River watershed. The period of record for each station ranges from as few as one sampling event to over 12 years.

Environment Canada has established one federal-provincial water quality sampling station on the Salmon River near the Highway 1 bridge (BC08LE0004). The period of record at this station spans an eight year period, which begins in 1988. Data from this station were obtained from the ENVIRODAT database at the Environment Canada Web Site. Summary statistics, including minima, maxima, averages and standard deviations for these data are presented in Table 10.5. The summary statistics for these data, presented on annual and monthly bases, are included in Appendix II and III. Some values that were decidedly wrong (e.g., pH value = 803) or obviously typographic errors were omitted from the analysis. This station (BC08LE0004) is at the same location as the water survey station BC08LE021 and the BCMOELP stations 050062 and E206092 (Lilley and Webber 1997).

Due to the large number of infrequently sampled stations, the discontinuous nature of sampling, and the variety of parameters measured, only a portion of the available data were summarized to support the objectives of this study (i.e., to assess the past and present water quality of the Salmon River). Based on a preliminary review of the data, five stations were selected to represent the various areas in the watershed, including (Table 10.6):

- Salmon River near Mouth (near Highway 1 bridge at Salmon Arm), Stations BC08LE0004 and E206092;
- Lower Salmon River near Silver Creek, Station E206091;
- Middle Salmon River upstream of Falkland (i.e., downstream of the dry reach), Station E206087;
- Upper Salmon River upstream of Adelphi Creek, Station E206086; and,
- Salmon River upstream of McInnis Creek, Station E206084.

In addition to routine monitoring, water quality data have also been collected during several surveys in the Salmon River watershed (B. Grace, BCMOELP, Kamloops, B.C. Unpublished data). These data provide important information on the spatial variability of water quality conditions in the basin (Appendix IV). These results are also discussed in the following sections.

The water quality variables discussed in the following section were selected in two ways. First, the variables that were likely to be affected by land and/or water use patterns were identified as the highest priority for evaluation. Second, the variables that have potential to influence the toxicity or effects of the priority variables were also examined.

10.2.1 Water Quality Assessment

Water Temperature

Water temperature is vital for maintaining instream water uses, particularly fish production. When temperature falls outside of the optimum temperature ranges, spawning success may be impaired (Ralph 1976). Increases in temperature above the optimum range may affect egg-to-fry survival rates, increase disease incidence and severity, lower tolerance to contaminants, and reduce growth rates. Few long-term measurements of water temperature have been made in the Salmon River. The most complete data set is for the Salmon River at the Highway 1 bridge (BC08LE0004), for which 212 measurements were made over an eight year period (Figure 10.3). Typical seasonal trends are apparent, with peak summer temperatures of up to 24°C and winter temperatures falling to 0°C.

The optimal temperature range for salmonid migration and spawning is considered to be 7.2 to 15.6 °C (Ralph 1976). However, temperatures in the lower reaches of the Salmon River frequently exceeded 15°C during August and September (Figure 10.4). As chinook, coho and sockeye migration generally occurs during this period, these elevated water temperatures have the potential to cause delays in migration and decreases in overall spawning success.

Dissolved Oxygen

Insufficient data currently exist to fully characterize dissolved oxygen (DO) levels in the Salmon River (i.e., only 40 DO measurements have been reported; Table 10.7). These data were collected at three sites within the basin, primarily between 1971 and 1978, and do not provide a basis for determining contemporary DO levels in the watershed. Nonetheless, these data show that DO depressions have occurred in the Salmon River, particularly during the summer months.

pH

With the exception of two pH values (8.55 and 8.60) at stations near the mouth of the river in 1988 (Table 10.5 and 10.6), the pH of the Salmon River consistently fell within the recommended range of 6.5 to 8.5 for the protection of aquatic life (Table 8.1; Figure 10.5). The monthly median values calculated for the Salmon River at Salmon Arm (BC08LE0004) show that pH remains fairly constant throughout the year, with a slight drop during freshet months (i.e., April and May; Figure 10.6). Based on data from five stations located throughout the watershed, pH seems to increase in the downstream reaches of the river (Figure 10.7).

Water Hardness

The available data show that water hardness of the Salmon River at Salmon Arm varies significantly on a seasonal basis (Figure 10.8). At this site, water hardness fluctuated between 45.7 and 270 mg/L $CaCO_3$ over the period of record. The lowest measurements of water hardness were taken during the peak of freshet (May), whereas the highest values were recorded during base flow periods (Figure 10.9). These observations suggest that there is a relationship between water hardness and discharge in this river.

To evaluate the relationship between water hardness and discharge, a regression analysis of the available data was performed (Figure 10.10). The results of this analysis show that the relationship is significant, with increased discharge diluting the levels of dissolved $CaCO_3$ in the Salmon River. Long term trends in water hardness were not apparent, however, based on a time series analysis conducted by Regnier and Shaw (1997; Figure 10.11).

Suspended Solids and Turbidity

The Salmon River and its tributaries carry high suspended sediment loads during portions of the year. The available data show that non-filterable residue (NFR; i.e., suspended solids) levels peak during spring freshet (Figure 10.12), with levels as high as nearly 650 mg/L observed near Salmon Arm. In contrast, NFR levels tend to remain fairly low during base flow periods (Figure 10.13). Turbidity measurements generally reflect NFR levels in this watershed, peaking in the spring and remaining fairly low during base flow periods (Figure 10.14 and 10.15). High discharges are often associated with increased rates of erosion, resuspension and transportation of sediment. Therefore, it is not surprising to find that both NFR and turbidity were positively correlated with stream discharge in the Salmon River (Figure 10.16).

While mean levels of NFR are similar at upstream and downstream locations, the highest levels of NFR generally occur near the mouth (Figure 10.17). Independent data collected by BCMOELP in 1989 and 1995 confirm the spatial pattern of increasing levels of NFR in the downstream portion of the basin (Appendix IV; B. Grace, BCMOELP, Kamloops, B.C. Unpublished data). These data suggest that land use patterns within the basin are contributing to streambank erosion and sediment transport. Notably, there is more plowed field acreage in the downstream portions of the basin; run-off from these fields and associated roads undoubtedly contributes to sediment loadings in the system. It is likely that ongoing bank stabilization efforts will substantially reduce erosion and sediment transport in the future.

Phosphorus

Phosphorus (P) concentrations in the Salmon River are of concern because phosphorus concentrations often limit plant growth in freshwater ecosystems. Addition of phosphorus may lead to eutrophication of a waterbody, with an associated impairment of water quality condition. Water quality changes occur as a result of increased algal growth. For example, certain algae degrade drinking water quality by altering the colour and/or taste of the water. In extreme cases, algal blooms may render the water unsuitable for recreation and the subsequent die-off of algae may depress dissolved oxygen to levels low enough to cause fish mortality. Excessive algal growth can also degrade fish habitat by blanketing spawning substrates. Inputs of phosphorus from the Salmon River, the sewage treatment plant at Salmon Arm, and several other small tributaries (i.e., White Creek and Turner Creek) are the primary sources of phosphorus to Tappen Bay in Shuswap Lake (M. Ross, Shuswap Nation Fisheries Commission. Pers. Comm.; BCMOELP unpublished data). Possible sources of phosphorus to the Salmon River include:

- agricultural activities, including inputs of manure, fertilizers and fine-grained sediment;
- runoff and contaminated groundwater seepage from fertilized fields;
- domestic and industrial effluent (septic and tile field discharges);
- natural geological materials (possibly apatite); and,
- forestry activities and linear developments (power lines, railways, roads, etc.) where soil is disturbed.

The most recent data available on phosphorus levels in the watershed were those collected at the Highway 1 bridge at Salmon Arm. These data show that total phosphorus (TP) levels vary significantly on a seasonal basis, typically peaking during spring freshet (Figure 10.18). Over the period of record, TP levels have ranged between 0.015 mg/L and 0.590 mg/L. At this site, TP levels averaged more than 0.20 mg/L during May and generally less than 0.10 mg/L between August and February (Figure 10.19).

Further analysis of these data showed that TP concentrations were positively correlated with stream discharge (Figure 10.20). Importantly, TP levels were also positively correlated with NFR levels (Figure 10.21), indicating that a portion of the phosphorus was associated with suspended particulate matter. The highest levels of TP were observed in the vicinity of Falkland, probably due to the number of livestock production operations located in that portion of the watershed (Figure 10.22; Table 10.8). This conclusion is supported by the results of monitoring activities which showed that samples taken near a cattle winter feeding area contained 16.8 mg/L total-P and 11.4 mg/L ortho-P. By comparison, the effluent from the Salmon Arm sewage treatment plant (STP; E102156) had peak values of 12.5 mg/L total-P and 5.26 mg/L ortho-P in May of 1986. Data collected more recently show that contemporary levels of TP in STP effluent are much lower, typically less than 1 mg/L.

Concentrations of orthophosphorus (OP) followed the same general trends as TP levels, with the highest levels observed upstream of Falkland (Figure 10.23). The survey by BCMOELP in 1989 and 1995 confirm that the highest levels of dissolved phosphorus occurred upstream of Falkland (Appendix IV; B. Grace, BCMOELP, Kamloops, B.C. Unpublished data). Importantly, the results of time series analysis of the OP data collected between 1987 and 1995 failed to identify long-term temporal trends for this variable (Figure 10.24; Regnier and Shaw 1997). Comparison of TP and OP concentrations suggests that much of the phosphorus in the Salmon River is bioavailable.

The B.C. Waste Management Branch has concluded that Tappen Bay is mesotrophic, based on the phosphorus levels in the Salmon Arm of Shuswap Lake (Station 0500127; BCMOELP unpublished data; Table 10.9). High densities of phytoplankton, including trophic indicator species (such as *Asterinella formosa*, *Anabaena sp.*, and *Aphanizomenon sp.),* also provide evidence of eutrophication. The high chlorophyll *a* concentrations and the predominance of blue-green algae in samples collected within the lake confirm this conclusion. The levels of these indicators decrease with distance from Tappen Bay, which indicates that the problem is localized and probably associated with phosphorus inputs from the Salmon River, the Salmon Arm STP, and diffuse loadings from shoreline development, including White, Turner, Tappen, and Canoe Creeks. The fact that phosphorus levels in the bay increase simultaneously with those of the Salmon River during freshet, points to the Salmon River as the largest source of nutrients to Shuswap Lake.

The relative contributions of phosphorus from the Salmon River and the Salmon Arm Sewage Treatment Plant (STP) are estimated in Table 10.10. Based on the available data, the Salmon River contributes between 60 and 97% of the combined total-P load to Tappen Bay, depending on discharge stage. While the Salmon River is contributing the bulk of the phosphorus load to Tappen Bay, there is some evidence that the STP contributions prior to freshet may have been sufficient to allow algae to bloom earlier at stations sampled within the bay relative to those further up Salmon Arm of Shuswap Lake (M. Ross, Shuswap Nation Fisheries Commission. Pers. Comm.). It is likely that recent decreases in TP loading from the STP have reduced the potential for pre-freshet algal blooms in the bay. Plankton blooms at stations outside Tappen Bay did not occur until after spring freshet, which indicates that phosphorus from the Salmon River is likely influencing primary production at these distant stations.

Nitrogen

The available data on the levels of various forms of nitrogen in the Salmon River at Salmon Arm are summarized in Table 10.5, including total nitrogen, dissolved nitrogen, dissolved nitrate plus nitrite, total nitrite, dissolved nitrate, and ammonia. Thirty-five measurements of total ammonia were made between 1971 and 1979. However, the corresponding measurements of temperature and pH which are needed to determine the portion of total ammonia that would occur as the un-ionized fraction (which is the form toxic to aquatic life), were made on fewer than 10% of the samples. Therefore, it was not possible to determine the frequency of exceedances of the water quality objectives in the 1970s.

A total of 251 measurements were taken more recently (i.e., 1985-1996) to determine dissolved ammonia levels in the Salmon River at Salmon Arm (Figure 10.25). Temperature and pH were also measured on each sampling date. While elevated levels of ammonia were measured on several dates (e.g., January 31, 1995 - 0.529 mg/L and March 12, 1996 - 0.399 mg/L), none of the measurements exceeded the water quality objectives, suggesting that ammonia levels are unlikely to adversely affect water uses in the Salmon River. While the existing data did show an increasing trend in peak ammonia levels (Lilly and Webber 1997), the results of a more rigorous analysis failed to detect such trends (Regnier and Shaw 1997; Figure 10.26). However, the data on levels of nitrate/nitrite, Kjeldahl nitrogen, and dissolved nitrogen showed linearly increasing trends in concentrations overtime (Figure 10.27, 10.28, 10.29; Regnier and Shaw 1997).

Ammonia levels peak during late winter and early spring in the Salmon River, possibly resulting from early snowmelt runoff from livestock areas (Figure 10.30). This hypothesis is supported by the results of spatial analysis, which showed the highest ammonia levels in middle portion of the Salmon River, where most of the cattle farms are located (Figure 10.31). Total nitrogen data collected by BCMOELP in 1989 and 1995 also show a spatial pattern of increasing levels of total nitrogen in the vicinity of Falkland (Appendix IV; B. Grace, BCMOELP, Kamloops, B.C. Unpublished data).

Microbial Indicators

Microbial indicators, such as faecal coliforms are used to determine the suitability of water quality for various uses by providing an indication of the concentrations of pathogens in water. Faecal coliforms are useful indicators of faeces-contaminated water as they are found in virtually all warm-blooded animals in numbers much greater than the pathogens themselves (CCREM 1987).

The levels of faecal coliforms have been measured at a number of sites in the Salmon River watershed since 1985. The results of this monitoring show that levels of faecal coliforms in the Salmon River at Salmon Arm frequently exceed the water quality objective of 10 colonies/100 mL for the protection of raw water supplies (Figure 10.32). The levels also frequently exceed the criterion for the protection of livestock watering (200 colonies/100 mL, maximum) and for crop irrigation and contact recreation (≤ 200 colonies/100 mL, geometric mean; Nagpal *et al.* 1995). Faecal coliforms and total coliforms were also measured at four other stations. At every location, maximum values for faecal coliforms exceeded the recommended levels for crop irrigation and contact recreation at least once during the sampling period (Table 10.6). With the exception of outliers, the maximum level of faecal coliforms in the Salmon River was observed to be 2400 colonies/100 mL.

The high levels of faecal coliforms in the Salmon River have been attributed to inputs from the livestock feedlots and winter feeding areas in the watershed, manure handling and storage, and seepage from septic fields (Lilley and Webber 1997). The highest coliform count occurred in the middle reach of the river, near Falkland, where the highest concentration of feedlots is located (Figure 10.33). This spatial pattern is supported by faecal coliform data collected by BCMOELP (Appendix IV; B. Grace, BCMOELP, Kamloops, B.C. Unpublished data). The peaks of faecal coliform levels occurred during freshet and late summer (Figure 10.34). The late summer peak was probably caused by runoff from manure rich fields where the cattle were free to graze in the summer. Unrestricted access to the river by cattle probably also contributed to the peaks.

There is a linearly increasing trend over time in the levels of faecal coliform in the Salmon River at Salmon Arm (BC08LE0004). However, the annual summary plots did not show significant temporal patterns (Figure 10.35; Regnier and Shaw 1997). Therefore, the increasing trend may be due to the increased precipitation in the 1990's.

Metals

The concentrations of more than 25 metals have been measured at various times throughout the Salmon River. For many of these metals, data collected prior to early 1991 is considered to be invalid due to possible sample contamination (Lilley and Webber 1997). Nonetheless the most recent data showed exceedances of the water quality criteria for total aluminum, total cadmium, total chromium, total cobalt, total copper, total iron, total lead, total manganese, total mercury, and total zinc (Table 8.1 and 10.5).

Total aluminum levels (Al) in the Salmon River at Salmon Arm generally exceeded the water quality criteria for the protection of aquatic life (0.1 mg/L, total Al; CCREM 1987; 0.1 mg/L, dissolved Al; Nagpal *et al.* 1995), drinking water, recreation and aesthetics (0.2 mg/L, dissolved Al; Nagpal *et al.* 1995). With three exceptions, levels were below the 5 mg/L total aluminum criterion for wildlife, livestock, and irrigation (Figure 10.36, Nagpal *et al.* 1995). The peak values were positively correlated with NFR, indicating that much of the aluminum was associated with suspended particles and probably not biologically available (Figure 10.37). Dissolved aluminum should be measured in the future to provide a more appropriate basis for comparison with the water quality criteria.

The available data are insufficient to fully evaluate the hazards posed by cadmium in the Salmon River. Specifically, the minimum detection limit for cadmium was much higher than the water quality criterion recommended for the metal (0.024 mg/L; Nagpal *et al.* 1995; Figure 10.38). The data show that total cadmium levels vary on a seasonal basis, with the highest concentrations observed during freshet. While cadmium showed a positive correlation with NFR (Figure 10.39), NFR levels explained only 10% of the variability in cadmium levels. Therefore, further investigations are needed to assess the bioavailability of cadmium in the Salmon River.

The levels of total chromium (Figure 10.40), cobalt (Figure 10.41), copper (Figure 10.42), iron (Figure 10.43), and manganese (Figure 10.44) in the Salmon River at Salmon Arm have been routinely measured between 1988 and 1996. The analyses of these data reveal that these metals commonly exceed water quality criteria or guidelines (0.001 mg Cr/L; 0.0009 mg Co/L; 0.002 mg Cu/L; 0.3 mg Fe/L; 0.1 mg Mn/L; A. Pawlisz. Pers. Comm.; Nagpal *et al.* 1995). The levels of cobalt, iron and manganese are highly positively correlated with NFR levels, suggesting that these metals are present in the particulate phase and would be unlikely to exert direct toxicological effects on aquatic organisms (Figure 10.45, 10.46, 10.47). However, the correlations between chromium and copper levels and NFR concentrations are weaker. As such, the bioavailability of these metals is uncertain (Figure 10.48, 10.49).

A total of 209 measurements of total lead levels have been made between 1988 and 1996 in the Salmon River at Salmon Arm. These results show that the levels of lead exceeded the water quality criterion only 3 times, one of which occurred prior to 1991 and may have been the result of sample contamination (Figure 10.50). The other two exceedances were above the 30 day average water quality criterion (0.0054 mg/L; Nagpal *et al.* 1995). The available data also show that lead concentrations follow a seasonal pattern, with peaks occurring during spring freshet. The levels of NFR explain only 36% of the variability in lead concentrations; therefore, it is difficult to draw conclusions about the potential bioavailability of lead in the Salmon River (Figure 10.51).

Over the past five years, mercury levels in the Salmon River at Salmon Arm have generally remained below the water quality criterion for the protection of aquatic life (0.02 mg/L; Nagpal *et al.* 1995). However, the data collected between 1988 and 1991 showed multiple exceedances of the water quality criterion (possibly due to sample contamination). As was the case for other metals, the highest levels were observed during freshet (Figure 10.52); however, there was no correlation between mercury and NFR (Figure 10.53).

Data collected between 1988 and 1996 show that total zinc concentrations in the Salmon River at Salmon Arm are generally below the maximum water quality criterion for the protection of aquatic life (0.007 mg/L; Nagpal 1997; Figure 10.54). However, seasonal peaks in zinc levels often exceed the water quality criterion by 5 to 10 times. As these peaks generally occur during spring freshet, and are positively correlated with NFR levels (Figure 10.55). However, additional information is needed to evaluate the potential bioavailability of zinc in the Salmon River.

Annual summary plots of total chromium, total cobalt, and total iron data in the Salmon River are presented in Figures 10.56, 10.57 and 10.58. No long-term temporal trends were identified for any metal, either by non-parametric analyses or by regression analysis (Regnier and Shaw 1997).

11.0 RECOMMENDATIONS

11.1 Recommended Surface Water Quality Monitoring Program

Aquatic environmental quality monitoring encompasses an array of activities that are designed to provide information on the physical, chemical, and biological characteristics of the environment. In practice, these activities include both routine monitoring (ongoing) and special survey (one time) programs that are undertaken in support of water quality management. It is now universally recognized that monitoring is indispensable for supporting rational and effective management of aquatic resources (Ward *et al.* 1986). However, a fundamental problem associated with many ongoing monitoring programs is the lack of a well-defined monitoring strategy (Whitfield 1988). To be effective, a monitoring program must have a well defined purpose and must support water quality management (Ward 1979; Schilperoot and Groot 1983).

The main reasons for conducting environmental quality monitoring programs include: i) status and trends assessment; ii) assessment of compliance with environmental quality objectives; iii) estimation of mass transport; and, iv) environmental impact assessment (Whitfield 1988). Each of these approaches provides data sets that are applicable to a specific monitoring goal. Data collected for one purpose (i.e., impact assessment) can not necessarily be used to address other monitoring goals (i.e., trend assessment). In the Salmon River watershed, an ambient environmental quality monitoring program should be designed to support assessment of compliance with environmental quality objectives and to support estimation of loadings of certain nutrients to Shuswap Lake.

The goal of compliance monitoring is to determine whether or not the objectives set for the quality of the aquatic ecosystem are being met (Whitfield 1988). Monitoring for compliance with environmental quality objectives is complicated by the inherent variability of the system in space and time and by the way in which the objectives are written. For example, specific objectives may be written as maximum, arithmetic mean, geometric mean, and/or median values over a particular period of time (to mention a few). The effectiveness of compliance monitoring programs are often expressed as the ratio of detected violations to actual violations of the objective (Schilperoot and Groot 1983). The most appropriate sampling strategies for use in compliance monitoring programs are those which have high effectiveness to cost ratios.

A recommended water quality monitoring program for the Salmon River watershed is presented in Table 11.1. In total, seven sites are identified for monitoring water quality within the study area. On the Salmon River mainstem, these sites include a reference site located upstream of most known contaminant sources (Salmon River upstream of Salmon Lake), three sites located downstream of potential non-point sources of contaminants, and one site located at the mouth of the river. Two sites were also located in Tappen Bay of Shuswap Lake to assess the trophic status and other conditions in the bay.

The recommended monitoring program includes the priority variables that were identified in this study and by the Salmon River Watershed Roundtable (Stavinga and MacDonald 1997). For each water quality variable, target sampling dates and frequencies have been identified using the available information on the frequency and timing of exceedances of the water quality objectives and on the timing of critical biological processes (e.g., salmon spawning) in the river. The rationale for the recommended monitoring program is described below:

- *Water Temperature* - This variable should be measured continuously on an hourly basis at all of the sites in the Salmon River and every two weeks in Tappen Bay. In the lake, spot sampling with calibrated thermometers is recommended for three water depths at each of the two sites. Intensive information on water temperature is needed to determine if conditions in the river are likely to meet the needs of salmonid fishes during migration, spawning, incubation, and rearing. The most efficient way to obtain accurate long-term temperature records involves the placement of a temperature probe in the river.

- *Dissolved Oxygen* - Depressions in dissolved oxygen levels are most likely to occur during the summer when water temperatures and organic matter loadings are highest. The recommended sampling program will ensure that 5 samples are collected monthly at each site between May and October to evaluate attainment of the water quality objectives. Less frequent sampling is recommended between November and April, primarily to determine if oxygen depressions occur during the winter. If such depressions are observed, more frequent monitoring will need to be conducted to determine if the water quality objectives are being attained. Sampling at every two weeks is recommended at two sites in Tappen Bay, with three water depths sampled at each site (surface, mid-depth, and near bottom).

- *Suspended Solids and Turbidity* - In stream systems, concentrations of suspended solids and turbidity measurements vary significantly over time, primarily in response to changes in streamflows. For this reason, relatively frequent sampling (weekly) is recommended at all of the riverine sites to evaluate temporal variability in these variables. More frequent sampling is recommended during freshet at three of the sites to better define short-term variability in these variables. For the purposes of assessing attainment of the water quality objectives, the site located immediately upstream of Salmon Lake is considered to represent background conditions in the watershed. Water hardness, pH, and conductivity should be measured each time that suspended solids and turbidity are measured. Further investigations should focus on determining sources and levels of suspended sediments throughout the watershed.

- *Total Ammonia* - The existing water quality data suggest that total ammonia levels are highest during the winter, early spring, and autumn. For this reason, four sampling periods were identified for measuring total ammonia levels at the five riverine sites. At each site, it is recommended that 5 samples be collected over each 30-day period (i.e., every 6 days) to evaluate compliance with the water quality objectives. Water temperature and pH should be measured each time samples are collected for analysis of total ammonia levels.

- *Total Phosphorus (TP) and Dissolved Phosphorus (DP)* - Phosphorus is an essential plant nutrient and is often a factor limiting the growth of aquatic plant communities. In the recommended monitoring program, TP and DP should be monitored bi-weekly at the Salmon Arm site to evaluate loadings from the Salmon River. In addition, TP and DP levels should be monitored at two sites in Tappen Bay (at three depths, surface, mid-depth, and near the bottom) to evaluate the trophic status of the lake.

- *Microbial Indicators* - Monitoring for microbial indicators is recommended at three sites in the Salmon River and in Tappen Bay. In the river, sampling is recommended for three periods (May, June, and September) when levels of microorganisms have been shown to be the highest. Sampling should be conducted every 3 days at these sites to assure that 10 samples are collected during each 30-day period. Less frequent sampling (every 6 days) is recommended for surface waters in Tappen Bay during the open water period.

- *Metals* - It is unlikely that dissolved metal levels represent a hazard to fish and aquatic life in the Salmon River. Nonetheless, it is recommended that the levels of dissolved metals be evaluated during two sampling periods (March and September) at two sites in the Salmon River. These two sampling periods correspond with relatively low streamflows. During each sampling period, 5 samples should be collected over a 30-day period (i.e., every 6 days) to assess attainment of the water quality objectives. Water hardness and conductivity should be measured each time samples for metals analysis are collected. The results obtained during the first year of the program should be evaluated against published water quality criteria (Nagpal *et al.* 1995; Nagpal 1997). Metals should be eliminated from the monitoring program if the results indicate that they are not currently jeopardizing water uses.

- *Pesticides and Herbicides* - Agriculture is an important land use in the Salmon River watershed. Since contemporary agricultural practices often involve the application of pesticides and/or herbicides, the potential exists for these chemicals to contaminate surface waters. Insufficient information currently exists to identify the most appropriate sampling strategy for agricultural chemicals in the Salmon River watershed. For this reason, it is recommended that a pesticide use survey be conducted to identify which chemicals are currently being used, where these chemicals are being applied, and when application rates are the highest. This information should be used to design a focussed monitoring strategy that will maximize the potential for detecting any agricultural chemicals that are released into the river.

- *Chlorophyll a* - Measurement of periphyton production on streambed substrates is needed to determine if the designated water uses in the Salmon River watershed are being maintained. It is recommended that measurements of chlorophyll *a* levels be conducted at four sites in the river basin (the fifth site at Salmon Arm was excluded because the streambed substrate is considered to be too unstable to support significant periphyton accrual) during two sampling periods, including August and October. These two periods were selected to determine if periphyton accrual could adversely affect recreational water uses (August) or salmonid spawning (October). Monthly sampling is also recommended during the open water period at the two sites in Tappen Bay to evaluate the trophic status of the lake.

- *Streambed Substrate Composition* - The composition of streambed substrates is important for assuring high egg-to-fry survival rates for salmonid fishes. However, accelerated rates of sediment transport resulting from various land use practices can lead to sedimentation of spawning habitats and associated impacts on fisheries. For this reason, it is recommended that streambed substrate composition be monitored annually at four sites in the

Salmon River watershed. The site near Salmon Arm was excluded because salmonids are not known to utilize that stream reach for spawning activities. A reconnaissance of the watershed will be needed to identify suitable sampling sites for streambed substrate composition.

The recommended water quality monitoring program is intended to provide a systematic basis for evaluating attainment of the water quality objectives and assessing potential hazards associated with several other variables (e.g., dissolved metals). However, it is not intended to satisfy all of the water quality monitoring requirements in the basin. The Salmon River Watershed Roundtable, BCMOELP, and/or Environment Canada may have additional interests in environmental monitoring that are not reflected in the recommended monitoring program. Therefore, it would be helpful to convene a workshop to help coordinate monitoring activities among the various groups. This will result in certain economies for each group, assure the compatibility of data that are collected, and avoid duplication of effort. It is recognized that certain adjustments to the recommended attainment monitoring program will be necessary to accommodate the needs of other interest groups (e.g., changes in sample site location, sampling frequency, etc.); however, the benefits of coordination will more than offset the challenges associated with the development of an integrated monitoring program.

It is recommended that the integrated monitoring program that is ultimately developed be reviewed and evaluated annually to assure that it responds to current environmental assessment priorities. It is anticipated that the Salmon River Watershed Roundtable would work cooperatively with First Nations, government agencies, stakeholder groups, and non-governmental organizations to assure that the resultant monitoring program is fully implemented each year.

11.2 Recommended Groundwater Monitoring Program

Groundwater plays a pivotal role in the Salmon River watershed, both in terms of directly supporting various water uses and in terms of recharging surface waters. However, very little information was located on the quality of groundwater within the basin or on the linkages between groundwater use and surface water hydrology. For this reason, it is recommended that several key groundwater investigations be conducted in the Salmon River watershed.

Importantly, representative groundwater supplies should be sampled to determine if existing water uses are being maintained. It is recommended that the sampling sites be located based on the proximity of the wells to known land use activities. The key variables that should be considered in this investigation include conventional variables, nitrate, nitrite, ammonia, phosphorus, metals, microbial indicators, and pesticides/herbicides. Such monitoring should provide a basis for determining if groundwaters are being contaminated by animal wastes, inorganic fertilizers, or pesticides. Groundwater observation wells should also be monitored to measure water withdrawal rates and recharge rates to provide more information on groundwater quantity in the study area.

A study should also be designed and implemented to evaluate the linkage between groundwater use and streamflows in the Salmon River and tributaries. This information is critical for making informed decisions on the allocation of surface waters and for determining if limitations on groundwater use are needed to achieve the ecosystem health goals that have been established.

11.3 Additional Monitoring Requirements

The Salmon River Watershed Roundtable has identified a number of candidate physical, chemical, and biological indicators of ecosystem health. While the chemical indicators have been included in the recommended water quality monitoring program, many of the physical and biological indicators that have been identified should also be included in the monitoring program. These include a number of flow-related variables (e.g., magnitude and duration of high and low flows, mean annual discharge, mean monthly discharge, water level, etc.), aquatic habitat structure and abundance, and riparian zone characteristics (e.g., shoreline quality, wetland area, sedimentation rates, biodiversity, etc.). Some important biological indicators were also identified, including aquatic plants, benthic macroinvertebrates, fish, reptiles, amphibians, reptiles, and birds. It is recommended that these candidate indicators of ecosystem health be reviewed and evaluated to identify additional variables that should be included in the integrated environmental monitoring program. The success of the monitoring program will necessarily depend on the degree to which the needs of each participant are addressed and on the level of involvement by the community.

11.4 Quality Assurance

The measures needed to assure data quality have not been identified in the recommended compliance monitoring program. Nonetheless, an appropriate quality assurance program will need to be implemented as part of the overall monitoring program. Considerations in the development of the quality assurance program should include:

- Establishment of protocols for field sampling, including a detailed monitoring program design, precise identification of sampling sites, sampling methods, sample handling and transport methods, and sample preparation and archiving procedures;

- Implementation of station evaluations at new sites to assess short-term temporal and spatial variability in water quality conditions (i.e., using replicate sampling, cross-sectional sampling, and time series sampling);

- Establishment of performance-based standards for analytical laboratories and minimum laboratory quality assurance programs (including analyses of standard reference materials, laboratory and field blanks, sample splits, and sample spikes); and,

- Establishment of effective and efficient data management and interpretation procedures. The format and location for storing data should be agreed upon prior to collection (i.e., Aquadat or EMS), as well as procedures for assessing the information.

11.5 Restoration of the Aquatic and Riparian Ecosystems

The Salmon River Watershed Roundtable has identified a number of major concerns with respect to protecting and restoring the Salmon River ecosystem. The five high priority issues included:

- maintenance of adequate water levels and flows in the river and groundwater aquifers;
- restoration of fish abundance;
- improved water quality;
- maintenance of land uses; and,
- restoration of the riparian zone.

One of the first steps toward restoring the abundance of anadromous and resident fish involves maintaining adequate streamflows and water levels in the Salmon River (i.e., to facilitate restoration of the aquatic ecosystem). However, little progress can be made towards this goal without first defining the minimum flow requirements for resident and anadromous fish species. For this reason, it is recommended that the instream flow incremental methodology (IFIM) and other approaches (i.e., as outlined by Platts 1990) be used to define streamflow requirements in the Salmon River and its tributaries during various times of the year.

The second step in this process involves development of an effective strategy for achieving the minimum streamflows during various periods throughout the year. As water withdrawals from the river and nearby groundwater have a significant impact on instream hydrological conditions, it is recommended that ways and means of reducing water withdrawals be identified and evaluated. One obvious option involves installation of metering devices on all large water intake systems (i.e., irrigation systems) to assess compliance with permits. Other options could include adjusting water pricing and fee structures, negotiating voluntary water use reductions with licensees, providing incentives for finding alternative water sources, improving the efficiency of waterworks, and educating the public on the benefits of water conservation.

Improvements in water quality conditions are also necessary to support ecosystem restoration initiatives. Therefore, it is recommended that ways and means of reducing sediment and nutrient loadings be identified, evaluated, and implemented, as practicable, in the Salmon River watershed. Some of the options that should be considered include continued installation of cattle exclusion fences, stabilization of streambanks, proper handling and management of manure stockpiles, and optimization of inorganic fertilizer use (Bertrand and Bulley 1985).

Restoration of riparian areas along the Salmon River and its tributaries is also needed to meet ecosystem restoration goals. As a first step, it is recommended that a riparian assessment be conducted to establish restoration priorities (i.e., which areas are most degraded). This assessment should be linked to a fish habitat assessment to assure that restoration efforts yield the greatest benefits to fish habitat. Next, a variety of options for restoring riparian area should be identified and evaluated, including installation of cattle exclusion fences, planting trees and shrubs to stabilize streambanks, planting large tree species to enhance shading of the stream channel (and reduce water temperatures), and increased instream habitat complexity. The width of the riparian management area is recommended to be 100 m along the Salmon River (Oikos Ecological Services Ltd. 1996); however, practical consideration may necessitate the establishment of narrower buffer strips in certain locations.

11.6 Cooperation and Resources

The Salmon River Watershed Roundtable is playing a leadership role in the establishment of ecosystem goals, objectives, and indicators for the Salmon River watershed. The Roundtable consists of landowners, concerned citizens, First Nations, government representatives, and others, representing a broad cross-section of the community as a whole. While the Roundtable has been successful in galvanizing public support for restoration efforts, effective public involvement in the future will require the cooperation and continued support of responsible government agencies. For this reason, it is recommended that federal and provincial agencies continue to work with the members of the Salmon River watershed Roundtable to identify opportunities for cooperation and resource sharing. Importantly, ways and means of fully implementing the environmental quality monitoring program must be found to assure that progress towards watershed sustainability can be measured and necessary modifications to the restoration strategies can be made on a timely basis.

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Tables

Table 3.1. Mean monthly air temperatures (in °C) for Westwold, Falkland and Salmon Arm (Environment Canada 1982).

	Westwold	Falkland	Salmon Arm
Elevation (m)	616	456	396
Number of years on record	30	21	30
January	-7.3	-6.0	-5.5
February	-2.5	-1.7	-1.6
March	1.2	1.9	2.1
April	6.1	7.2	7.8
May	11.1	11.8	12.8
June	14.9	16.1	16.5
July	17.5	18.9	19.3
August	16.6	18	18.5
September	11.8	12.9	13.8
October	5.9	6.8	7.8
November	-0.5	0.6	1.3
December	-4.5	-3.3	-2.8
Mean temperature (°C)	5.9	6.9	7.5

Table 3.2. **Major agricultural land uses in the Columbia-Shuswap region (Statistics Canada 1993).**

Agricultural Uses	Unit of Measure	Columbia-Shuswap Region (Subdivision C)	B.C. Total	% of B.C. Total
Land in crops	acres	20,845	1,375,873	1.5
Alfalfa/alfalfa mixtures	acres	10,680	335,763	3.2
Tame hay	acres	5,128	470,182	1.1
Total tree fruits	acres	371	27,523	1.3
Total vegetables	acres	116	20,447	0.6
Total cattle/calf producers	farms	325	8,698	3.7
Horses/pony producers	farms	182	6,303	2.9
Sheep/lamb producers	farms	28	1,870	1.5
Poultry producers	farms	204	7,014	2.9
Other livestock producers	farms	123	4,357	2.8
	Total # farms	539	19,225	2.8

Table 4.1. **Annual escapement of Salmon to the Salmon River, Salmon Arm (Burt and Wallis 1997).**

Year	Sockeye	Coho	Pink	Chum	Chinook
1953	0	400	0	0	750
1954	NI	NI	NI	NI	NI
1955	0	7500	0	0	200
1956	0	400	0	0	200
1957	0	1500	0	0	25
1958	0	3500	0	0	200
1959	0	750	0	0	200
1960	0	1500	0	0	200
1961	0	1500	0	0	25
1962	45	750	0	0	400
1963	0	1500	0	0	200
1964	0	750	0	0	75
1965	0	3500	0	0	200
1966	0	400	0	0	200
1967	0	200	0	0	200
1968	0	1000	0	0	200
1969	0	1500	0	0	200
1970	0	750	0	0	200
1971	0	1500	0	0	400
1972	0	2000	0	0	200
1973	0	600	0	0	150
1974	92	1800	0	0	250
1975	0	900	0	0	200
1976	0	900	0	0	150
1977	0	1588	0	0	300
1978	434	1500	0	0	350
1979	0	2000	0	0	300
1980	0	1300	0	0	360
1981	0	500	0	0	300
1982	1602	800	0	0	700
1983	50	1000	0	0	300
1984	0	1550	0	0	850
1985	0	3800	0	0	1670
1986	1465	2700	0	0	1000
1987	75	2476	0	0	641
1988	0	4405	0	0	1252
1989	-2	2517	0	0	1456
1990	1300	1070	0	0	1100
1991	41	308	0	0	616
1992	0	2250	NI	NI	300
1993	0	500	NI	NI	1850
1994	78	129	NI	NI	1262
Mean	130	1597	0	0	479
Maximum	1602	7500	0	0	1850
Minimum	0	129	0	0	25

Note: NI = Stream not inspected

Table 4.2. Fish species present in the Salmon River (Whelen et al. 1982).

Common Name	Scientific Name
Salmonids	
Chinook salmon	*Oncorhynchus tshawytscha*
Coho salmon	*Oncorhynchus kisutch*
Sockeye salmon	*Oncorhynchus nerka*
Rainbow trout	*Oncorhynchus mykiss*
Mountain whitefish	*Prosopium williamsoni*
Non-Salmonids	
Redside shiner	*Richardsonius balteatus*
Northern squawfish	*Ptychocheilus oregonensis*
Slimy sculpin	*Cottus cognatus*
Prickly sculpin	*Cottus asper*
Carp	*Cyprinus carpio*
Longnose dace	*Rhinichthys cataractae*
Leopard dace	*Rhinichthys falcatus*
Lake chub	*Couesius plumbeus*
Burbot	*Lota lota*
Largescale sucker	*Catostomus machrocheilus*
Peamouth chub	*Mylocheilus caurinus*

Table 4.3. Life history timing for salmon in the Salmon River (Anonymous 1990).

Species	Activity	January	February	March	April	May	June	July	August	September	October	November	December
Sockeye Salmon	Migration									x x			
	Spawning										x x	x	
	Incubation	x x	x x	x x							x x	x x	x x
	Rearing												
Coho Salmon	Migration										x		
	Spawning										x	x x	
	Incubation	x x	x x	x x								x	x x
	Rearing	x x	x x	x x	x x	x x	x x	x x	x x	x x	x x	x x	x x
Chinook Salmon	Migration							x x	x x				
	Spawning									x x			
	Incubation	x x	x x	x x						x	x x	x x	x x
	Rearing	x x	x x	x x	x x	x x	x x	x x	x x	x x	x x	x x	x x

Table 5.1. A summary of agricultural production in the Salmon River Watershed (McPhee *et al*. 1996)

Types of Farms	Number of Farms	Percent of Total	Total Gross Farm Receipts
Dairy	30	9.5	$5,284,450
Cattle	132	41.6	$4,689,014
Hog	3	0.9	$282,000
Poultry	8	2.5	$1,289,317
Small grain	0	0	$0
Other field crops	26	8.2	$929,397
Fruit	13	4.1	$162,512
Vegetable	2	0.6	
Other specialty products	84	26.5	$2,103,011
Livestock combination	12	3.8	$375,440
Other types of livestock	7	2.2	
Total	317	100	$15,119,141

Table 5.2. Summary of licensed surface water withdrawals for the Salmon River watershed (R. Zimmerman, BCMOELP. Pers. Comm.).

River Reach	Number of Licensed Withdrawals/ Reach	License Purpose			Licensed Water Consumptive Use	
		Irrigation	Domestic	Storage	Irrigation Reach Total (m3/s)	Domestic Reach Total (m3/s)
Salmon River above Salmon Lake	1	0	1	0	0	unknown
Salmon River above Douglas Lake	14	8	1	5	0.052	unknown
Salmon River above Adelphi Creek	11	7	1	3	0.072	0.00005
Salmon River near Westwold	38	29	8	1	0.166	0.00096
Salmon River at Falkland	160	97	59	4	0.608	0.00239
Salmon River near Falkland	81	48	33	0	0.120	0.00234
Salmon River at Glenemma	64	45	19	0	0.158	0.00076
Salmon River near Glenemma	12	12	0	0	0.038	0
Salmon River above Fowler Lake	19	6	12	1	0.013	0.00018
Salmon River above Silver Creek	68	36	27	5	0.079	0.00081
Salmon River below Silver Creek	80	44	36	0	0.061	0.00096
Salmon River above Kernaghan Creek	19	19	18	2	0.049	0.00075
Salmon River near Salmon Arm	144	74	69	1	0.213	0.00474
Total	731	425	284	22	1.63	0.014

Table 5.3. Well water yield summary for the Salmon River watershed (R. Zimmerman, BCMOELP. Pers. Comm.).

Water Usage	Statistics Summary (Estimated in m^3/s)				
	Number of wells	Minimum	Maximum	Mean	Total yield
Unknown	2097	0	0.062	0.002	3.63
Domestic	662	0	0.046	0.001	0.651
Irrigation	58	0	0.048	0.011	0.641
Commercial	3	0.0005	0.004	0.002	0.005
Municipal	4	0.00008	0.038	0.011	0.042
Observation	6	0	0.002	0.000	0.002
Other	66	0	0.017	0.001	0.050
Community Well Site	3	0.0005	0.004	0.002	0.006
Abandoned	14	NA	NA	NA	NA
Total	2913	0	0.062	0.002	5.03

NA = not applicable.

Table 6.1. Permitted commercial tile-field discharges in the Salmon River watershed (L. D'Andrea, B.C. Ministry of Health. Pers. Comm.).

Permittee	Type of Discharge
Petty's Meats	Abattoir effluent to tile-field
Gord's Gouda	Effluent to tile-field
Valley Mobile Park	39 individual septic tile-fields
Mega Holdings	Abattoir effluent to tile-field

Table 8.1. Recommended water quality and quantity objectives for the Salmon River watershed.

Variable	Water Quality Objective	
	Maximum	30-day Average
Temperature	15.6 °C (December 1 - September 30) 12.8 °C (October 1 - November 30)	≤14.2 °C (year round)
Dissolved Oxygen	9.0 mg/L (minimum) 5.0 mg/L (short-term minimum)	≥ 11.0 mg/L ≥ 8.0 mg/L (short-term)
pH	6.5 - 8.5 units	6.5 - 8.5 units
Total Suspended Solids	NG	≤10 mg/L over background ≤20 mg/L over background (short-term)
Streambed Substrate Composition		
% < 2.00 mm	10%	NG
% < 3.00 mm	19%	NG
% < 6.35 mm	25%	NG
Geometric Mean Diameter	12.0 mm	NG
Fredle Index	5.0 mm	NG
Intragraval Dissolved Oxygen	8.0 mg/L (minimum)	≥9.0 mg/L
Turbidity	NG	≤5 NTU over background ≤10 NTU over background (short-term)
Total Phosphorus	10 ug/L (Tappen Bay) 15 ug/L (Tappen Bay) (short-term)	NG
Total Ammonia	NG	See Table 8.3
Chlorophyll a	50 mg/m^2	NG
Microbial Indicators		
Total faecal coliforms	10 colonies/100 mL* 100 colonies/100 mL* (short-term)	NG
Escherichia coli	10 colonies/100 mL*	NG
Enterococcus sp.	3 colonies/100 mL*	NG
Water Quantity Objectives	NG	Narrative (see Section 9.2)

NG = No water quality objective is recommended.
* = 90th percentile value (rather than maximum).

Table 8.2. Optimum temperature ranges for salmonids (Ralph 1976).

Cycle	Temperature (°C)	
	Minimum	Maximum
Migration	7.2	15.6
Spawning	7.2	12.8
Rearing	12.8	15.6

Table 8.3. Average 30-day concentrations of total ammonia nitrogen (mg/L) for protection of freshwater aquatic life (Nagpal *et al*. 1995). *

	Temperature Degrees Celsius																				
pH	0.1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
6.5	2.08	2.05	2.02	1.99	1.97	1.94	1.92	1.90	1.88	1.86	1.84	1.82	1.81	1.80	1.78	1.77	1.64	1.52	1.41	1.31	1.22
7.0	2.08	2.05	2.02	1.99	1.97	1.94	1.92	1.90	1.88	1.86	1.84	1.83	1.81	1.80	1.79	1.77	1.64	1.53	1.42	1.32	1.22
7.1	2.08	2.05	2.02	1.99	1.97	1.94	1.92	1.90	1.88	1.86	1.84	1.83	1.81	1.80	1.79	1.77	1.65	1.53	1.42	1.32	1.23
7.2	2.08	2.05	2.02	1.99	1.96	1.95	1.92	1.90	1.88	1.86	1.85	1.83	1.81	1.80	1.79	1.78	1.65	1.53	1.42	1.32	1.23
7.3	2.08	2.05	2.02	1.99	1.97	1.95	1.92	1.90	1.88	1.86	1.85	1.83	1.82	1.80	1.79	1.78	1.65	1.53	1.42	1.32	1.23
7.4	2.08	2.05	2.02	2.00	1.97	1.95	1.92	1.90	1.88	1.87	1.85	1.83	1.82	1.80	1.79	1.78	1.65	1.53	1.42	1.32	1.23
7.5	2.08	2.05	2.02	2.00	1.97	1.95	1.93	1.91	1.88	1.87	1.85	1.83	1.82	1.81	1.80	1.78	1.66	1.54	1.43	1.33	1.23
7.6	2.09	2.05	2.03	2.00	1.97	1.95	1.93	1.91	1.89	1.87	1.85	1.84	1.82	1.81	1.80	1.79	1.66	1.54	1.43	1.33	1.24
7.7	2.09	2.05	2.03	2.00	1.98	1.95	1.93	1.91	1.89	1.87	1.86	1.84	1.83	1.81	1.80	1.79	1.66	1.54	1.44	1.34	1.24
7.8	1.78	1.75	1.73	1.71	1.69	1.67	1.65	1.63	1.62	1.60	1.59	1.57	1.56	1.55	1.54	1.53	1.42	1.32	1.23	1.14	1.07
7.9	1.50	1.48	1.46	1.44	1.43	1.41	1.39	1.38	1.36	1.35	1.34	1.33	1.32	1.31	1.31	1.30	1.21	1.12	1.04	0.970	0.904
8.0	1.26	1.24	1.23	1.21	1.20	1.18	1.17	1.16	1.15	1.14	1.13	1.12	1.11	1.10	1.10	1.09	1.02	0.944	0.878	0.818	0.762
8.1	1.00	0.989	0.976	0.963	0.952	0.942	0.932	0.922	0.914	0.906	0.899	0.893	0.887	0.882	0.878	0.874	0.812	0.756	0.704	0.655	0.611
8.2	0.799	0.788	0.777	0.768	0.759	0.751	0.743	0.736	0.730	0.724	0.718	0.714	0.709	0.706	0.703	0.700	0.651	0.606	0.565	0.527	0.491
8.3	0.636	0.628	0.620	0.613	0.606	0.599	0.594	0.588	0.583	0.579	0.575	0.571	0.568	0.566	0.564	0.562	0.523	0.487	0.455	0.424	0.396
8.4	0.508	0.501	0.495	0.489	0.484	0.479	0.475	0.471	0.467	0.464	0.461	0.458	0.456	0.455	0.453	0.452	0.421	0.393	0.367	0.343	0.321
8.5	0.405	0.400	0.396	0.381	0.387	0.384	0.380	0.377	0.375	0.372	0.370	0.369	0.367	0.366	0.366	0.365	0.341	0.318	0.298	0.278	0.261
8.6	0.324	0.320	0.317	0.313	0.310	0.308	0.305	0.303	0.301	0.300	0.298	0.297	0.297	0.296	0.296	0.296	0.277	0.259	0.242	0.227	0.213
8.7	0.260	0.257	0.254	0.251	0.249	0.247	0.246	0.244	0.243	0.242	0.241	0.241	0.240	0.240	0.241	0.241	0.226	0.212	0.198	0.186	0.175
8.8	0.208	0.206	0.204	0.202	0.201	0.200	0.198	0.197	0.197	0.196	0.196	0.196	0.196	0.196	0.197	0.198	0.185	0.174	0.164	0.154	0.145
8.9	0.168	0.166	0.165	0.163	0.162	0.161	0.161	0.160	0.160	0.160	0.160	0.160	0.161	0.161	0.162	0.163	0.153	0.144	0.136	0.128	0.121
9.0	0.135	0.134	0.133	0.132	0.132	0.131	0.131	0.131	0.131	0.131	0.131	0.132	0.132	0.133	0.134	0.135	0.128	0.121	0.114	0.108	0.102

*The average of the measure values must be less than the average of the corresponding individual values in this table. Also each measured value is compared to the corresponding individual values in this table. No more than one in five of the measured values can be greater than one-and-a-half times the corresponding criteria values in this table.

Table 9.1. Water velocity and depth requirements for spawning salmon (Knapp *et al*. 1982).

Species	**Water Velocity (cm/sec)**	**Water Depth (cm)**
Chinook salmon	24-68	30-45
Coho salmon	18-54	30-38
Sockeye salmon	53-54	30-45

Table 10.1. **Summary of hydrometric stations in the Salmon River watershed (Environment Canada 1992).**

Station	Location Description	Period of Record (Archived Data)	Type of Gauge	Type of Record
08LE001	Bolean Creek at Falkland	1911-1964	M	C, S, #
08LE006	Pringle Creek near Westwold	1911-1953	M, #	S, #
08LE008	Ingram Creek near the mouth	1911-1978	M, #	S, #
08LE011	Monte Creek (Diver. to Monte Lake) N	1911-1954	M	S, #
08LE012	Monte Creek near Monte Lake	1911-1980	M, #	S, #
08LE013	Monte Creek	1911-1980	M, #	S, #
08LE018	Robbins Creek near Monte Lake	1911-1929	M, #	S, #
08LE019	Salmon River above Adelphi Creek	1911-1978	M	S, #
08LE020	Salmon River at Falkland	1911-1991	R, M	C, S, #
08LE021	Salmon River near Salmon Arm	1911-1991	R, M	C, S, #
08LE038	Blair Creek near Falkland (lower Statio	1921-1921	M	S
08LE040	Blair Creek near Falkland (upper station	1921-1922	M	#
08LE042	Spa Creek above Cowpersmith Diversio	1923-1931	M	S, #
08LE043	Silver Creek near Salmon Arm	1923-1948	M	S, #
08LE044	Gordon Creek near Salmon Arm	1911-1975	M	C, S, #
08LE045	Grier Creek near Salmon Arm	1930-1931	M	S
08LE046	Kernaghan Creek near Salmon Arm	1930-1931	M	S
08LE059	Salmon River near Westwold	1946-1947	M	S, #
08LE063	Salmon River near Douglas Creek	1951-1953	M	S
08LE064	Salmon River near Falkland	1951-1978	M	C, S
08LE065	Salmon River at Glenemma	1951-1976	M	C, S
08LE067	Fowler Creek near Falkland	1927-1964	M	S, #
08LE072	Palmer Creek near Salmon Arm	1911-1979	M	C, S, #
08LE075	Salmon River above Salmon Lake	1965-1991	R	C, S
08LE088	Salmon River above Kernaghan Creek	1973-1979	M	C
08LE089	Salmon River above Fowler Creek	1974-1986	M	C, S
08LE090	Salmon River below Silver Creek	1974-1977	M	C, S
08LE091	Kernaghan Creek above diversions	1974-1988	R	C, S
08LE093	Palmer Creek above diversions	1974-1979	R	C
08LE094	Bolean Creek near the mouth	1974-1986	M	C
08LE096	Fowler Creek at 640m contour	1974-1986	M	C
08LE097	Salmon River near Glennema	1974-1976	M	C
08LE103	Monte Lake above Monte Lake diversio	1981-1991	M	S

M= Manual gauge; R= Recording gauge; C= Continuous operation; S= Seasonal operation;
# = miscellaneous measurement.

Table 10.2. A summary of hydrological information on selected stations in the Salmon River watershed (Environment Canada 1991).

Location	Station	Monthly Mean Discharge (m^3/s)												Total Mean Discharge (m3/s)	Maximum Daily Discharge (m3/s)	Minimum Daily Discharge (m3/s)
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec			
Salmon River above Salmon Lake	08LE075	0.117	0.121	0.153	0.46	2.97	2.83	0.698	0.26	0.235	0.226	0.194	0.142	0.715	13.9	0
Salmon River above Adelphi Creek	08LE019	NA	NA	NA	1.26	7.31	5.3	1.08	0.473	0.286	0.476	0.246	0.155	NA	25.6	0
Salmon River at Falkland	08LE020	0.934	0.931	1.13	2.43	10.1	7.89	2.99	1.5	1.31	1.31	1.27	1.05	2.77	49	0.28
Bolean Creek at Falkland	08LE001	0.306	0.31	0.233	0.962	4.25	3.11	1.08	0.356	0.314	0.321	0.389	0.319	1.49	13.3	0.011
Bolean Creek near mouth	08LE094	0.279	0.267	0.398	1.36	4.63	3.16	1.01	0.466	0.416	0.369	0.384	0.314	1.07	11.7	0.028
Salmon River at Glenemma	08LE065	1.12	1.03	1.37	2.71	12.1	10.8	3.55	2.24	1.87	1.9	1.77	1.36	3.31	29.4	0.609
Silver Creek near Salmon Arm	08LE043	NA	NA	NA	0.225	0.908	0.614	0.123	0.066	0.069	NA	NA	NA	NA	3.85	0.003
Salmon River below Silver Creek	08LE090	1.62	1.59	1.66	3.86	13.7	13.4	4.18	3.13	2.42	1.88	1.79	1.75	3.51	29.7	0.34
Salmon River at Salmon Arm	08LE021	1.96	2.03	2.94	5.61	17.1	12.6	4.21	2.01	1.9	2.01	2.25	1.83	4.82	48.8	0.497

Table 10.3. Daily and instantaneous peak flow estimates of the Salmon River (KPA Engineering Ltd. 1991).

Location	Cumulative Drainage Area (km^2)	Estimated Peak Flows (m^3/s)			
		Daily		Instantaneous	
		20-yr	200-yr	20-yr	200-yr
Bolean Creek at Mouth	228	16	21	18	23
Salmon River at District Boundary	742	30	46	32	49
Salmon River Upstream of Bolean Creek	812	31	48	33	51
Salmon River at Falkland	1040	35	54	37	57
Salmon River at Sweetsbridge	1109	38	59	40	62
Salmon River at Glenemma	1206	40	62	42	65
Salmon River at Spa Creek	1299	41	65	43	68

Table 10.4. Seven-day low flow return period for the Salmon River (Northwest Hydraulic Consultants Ltd. and Hamilton 1992).*

Location	7-Day Low Flow (m^3/s)	
	2-Year Return Period	10-Year Return Period
Salmon River near Salmon Arm (08LE021)	1.0	0.6
Salmon River at Falkland (08LE020)	0.65	0.45
Salmon River above Salmon Lake (08LE075)	0.06	0.025

* values were estimated from low flow frequency analysis graphs.

Table 10.5. Water quality characteristics of the Salmon River at Highway 1 bridge (Station BC08LE0004) for the period of April 1988 to November 1996 (Environment Canada unpublished data).

Variable	Units	n	Mean	Standard Deviation	Maximum	Minimum	90th Percentile
General Parameters							
pH	pH units	219	NA	NA	8.55	6.79	8.4
Non Filterable Residue	mg/L	12	63.3	69.1	227	10	148
Specific Conductance	µsie/cm	219	356	108	557	102	463
Hardness	mg/L	218	168	52.1	270	45.7	218
Alkalinity	mg/L	219	150	44	228	41.3	191
Temperature	°C	212	8.5	6.29	24	0	18
Turbidity	NTU	219	4.5	9	82	0.1	12.2
Flow	m/s^2	4383	4.26	5.86	48.8	0.489	10.6
Major Ions							
Calcium, Dissolved	mg/L	41	41	13.9	60.9	13	54.2
Chloride, Dissolved	mg/L	219	3.02	1.18	5.96	0.2	4.4
Fluoride, Dissolved	mg/L	152	0.17	0.046	0.27	0.05	0.22
Sulphate, Dissolved	mg/L	219	35.4	14.1	67.8	5.9	49.7
Sodium, Dissolved	mg/L	45	10.7	3.28	15.1	3.5	14
Major Nutrients							
Potassium, Dissolved	mg/L	40	2.83	0.723	4.1	1.4	3.62
Nitrogen, Dissolved	mg/L	206	0.261	0.166	1.4	0.055	0.392
Nitrate and Nitrite, Dissolved	mg/L	157	0.118	0.106	0.58	0.002	0.243
Nitrogen, Total	mg/L	5	0.478	0.072	0.58	0.395	0.554
Ammonia, Dissolved	mg/L	5	0.023	0.026	0.069	0.005	0.048
Nitrite, Total	mg/L	67	0.006	0.005	0.042	0.005	0.005
Nitrate, Dissolved	mg/L	67	0.119	0.260	2.11	0.002	0.229
Phosphorous, Total	mg/L	219	0.112	0.095	0.59	0.015	0.234
Metal and Metalloids							
Aluminium, Total	µg/L	169	626	1105	8090	36	1640
Arsenic, Total	µg/L	177	0.96	0.287	2.9	0.1	1.2
Barium, Total	µg/L	169	28.3	9.4	97.2	18.5	33.5
Bromide, Dissolved	µg/L	67	48.5	7.02	50	10	50
Cadmium, Total	µg/L	209	0.18	0.380	5.0	0.1	0.3
Chromium, Total	µg/L	169	1.65	2.55	16.5	0.2	3.84
Cobalt, Total	µg/L	169	0.617	0.904	6.3	0.1	1.5
Copper, Total	µg/L	209	8.05	20.7	165	0.4	14

Table 10.5. Water quality characteristics of the Salmon River at Highway 1 bridge (Station BC08LE0004) for the period of April 1988 to November 1996 (Environment Canada unpublished data).

Variable	Units	n	Mean	Standard Deviation	Maximum	Minimum	90th Percentile
Metal and Metalloids (cont.)							
Iron, Total	µg/L	209	1026	1751	13100	133	2638
Lead, Total	µg/L	209	1.04	3.60	50	0.2	2.02
Manganese, Total	µg/L	209	61.3	45.1	381	24.8	103
Mercury, Total	µg/L	144	0.033	0.170	2.04	0.005	0.05
Molybdneum, Total	µg/L	169	1.70	0.801	10	0.5	2.2
Nickel, Total	µg/L	169	1.65	2.13	14.5	0.2	4.1
Thallium, Total	µg/L	1	0.5	NA	0.5	0.5	0.5
Vanadium, Total	µg/L	169	4.16	3.6	24.6	1.4	7.92
Zinc, Total	µg/L	209	4.54	9.21	82.3	0.2	10.9

Data compiled from Environment Canada ENVIRODAT database (EC Info world wide web 1997).
NA = not applicable; n = number of stations.

Table 10.6. Summary of historic water quality data for five selected stations in the Salmon River watershed (BCMOELP unpublished data).

Site Number	Period of Record	Summary Statistics	pH (pH units)	Phosphate, Total (mg/L)	Ortho-P, Dissolved (mg/L)	Coliform, Fecal (MPN)	Coliform, Total (MPN)	Ammonia, Dissolved (mg/L)	Residue, Non-Filterable (mg/L)	Residue, Total (mg/L)
E206092	23/1/85	n	63	103	74	50	26	83	35	84
(Salmon River	30/8/89	minimum	7.3	0	0.000	2	2	0.005	154	1
near Mouth)		maximum	8.6	0.07	0.52	2400	3300	0.061	719	617
		mean	NA	0.036	0.095	250	906	0.015	268	36
		standard deviation	0.245	0.011	0.072	402	1000	0.015	94.4	79.7
		median	8.1	0.035	0.073	79.5	445	0.008	274	8
		90th percentile	8.3	0.05	0.156	540	2400	0.043	312	93
E206091	23/1/85	n	23	23	23	9	9	23	12	23
(Salmon River	30/8/89	minimum	7.5	0.020	0.04	14	49	0.005	180	2
near Silver Creek)		maximum	8.4	0.079	0.250	350	2400	0.039	346	236
		mean	NA	0.042	0.099	177	795	0.013	263	52
		standard deviation	0.247	0.013	0.058	155	920	0.010	55.3	69.8
		median	8.2	0.042	0.073	220	350	0.008	274	26
		90th percentile	8.4	0.057	0.171	350	2320	0.032	316	162
E206087	23/1/85	n	23	23	23	9	9	23	12	23
(Salmon River	30/8/89	minimum	7.1	0.041	0.081	26	130	0.005	192	2
upstream of		maximum	8.5	0.72	1.06	2400	2400	1.32	330	228
Falkland)		mean	NA	0.098	0.189	443	1239	0.074	239	45
		standard deviation	0.363	0.136	0.21	762	866	0.272	39	53.2
		median	7.9	0.067	0.116	79	1600	0.010	237	34
		90th percentile	8.4	0.093	0.276	912	2320	0.047	273	76.8

Table 10.6. Summary of historic water quality data for five selected stations in the Salmon River watershed (BCMOELP unpublished data).

Site Number	Period of Record	Summary Statistics	pH (pH units)	Phosphate, Total (mg/L)	Ortho-P, Dissolved (mg/L)	Coliform, Fecal (MPN)	Coliform, Total (MPN)	Ammonia, Dissolved (mg/L)	Residue, Non-Filterable (mg/L)	Residue, Total (mg/L)
E206086	23/1/85	n	24	24	24	8	8	24	13	24
(Salmon River	30/8/89	minimum	7.6	0.02	0.07	2	13	0.005	118	1
upstream of		maximum	8.3	0.215	0.279	240	920	0.163	404	312
Adelphi Creek)		mean	NA	0.063	0.113	59.5	209	0.014	177	32
		standard deviation	0.241	0.039	0.056	86.7	313	0.032	74.3	66.2
		median	8	0.05	0.095	10.5	56	0.007	164	10
		90th percentile	8.2	0.091	0.188	163	521	0.013	215	55.1
E206084	23/1/85	n	24	24	24	9	9	24	15	24
(Salmon River	30/8/89	minimum	7.1	0.029	0.062	2	2	0.005	80	1
upstream of		maximum	7.9	0.081	0.219	350	790	0.02	206	97
McInnis Creek)		mean	NA	0.058	0.088	74.1	203	0.007	116.8	16
		standard deviation	0.208	0.014	0.035	120	263	0.004	30.3	26.6
		median	7.7	0.059	0.074	2	79	0.005	116	3
		90th percentile	7.8	0.076	0.11	206	438	0.011	136	55

Note: An outlier (71,600 MPN) was removed from the total coliform data set prior to calculating summary statistics.
n = number of stations; MPN = most probable number.

Table 10.7. Dissolved oxygen at three stations along the Salmon River (BCMOELP unpublished data).

Station (0500062)		Station (0500063)		Station (0500127)	
Date	**Dissolved Oxygen (mg/L)**	**Date**	**Dissolved Oxygen (mg/L)**	**Date**	**Dissolved Oxygen (mg/L)**
06-May-71	12.3	19-Feb-72	13.8	09-May-73	10
06-Jul-71	10.8	16-May-72	6.9	12-Aug-74	7.9
09-Aug-71	9.6	15-Nov-72	10.3	12-Aug-74	8.2
20-Sep-71	11.8	08-May-73	11.2	05-Aug-75	9.1
16-Nov-71	13.5	05-Sep-73	11.2	05-Aug-75	9.6
08-Dec-71	14.3	11-Feb-74	12.2	09-Aug-76	9.3
24-Apr-72	11.3	08-May-74	10.3	09-Aug-76	9.3
15-Nov-72	11.6	26-Aug-74	11.3	09-Aug-76	6.9
19-Feb-73	14	05-Feb-76	12.2	09-Aug-76	9.2
08-May-73	11.6	05-Feb-76	12.2	17-Apr-78	12.9
05-Sep-73	11.6	25-Nov-76	11.2	17-Apr-78	13
11-Feb-74	14.1			17-Apr-78	12.9
08-May-74	10.8			17-Apr-78	13
26-Aug-74	10				
05-Feb-76	12.8				
05-Feb-76	12.8				
n	16		11		13
Mean	12.1		11.2		10.1
Maximum	14.3		13.8		13
Minimum	9.6		6.9		6.9
Standard deviation	1.44		1.73		2.13

n = number of samples.

Station Description

0500062	Salmon River at Highway # 1 bridge, west of Salmon Arm; Latitude: 50.6914; Longitude: 119.3289
0500063	Salmon River at Falkland Highway 97 bridge, approximately 2 miles upstream of confluence with Bolean Creek; Latitude: 50.4892; Longitude: 119.6000
0500127	Shuswap Lake opposite of Salmon Arm; Latitude: 50.7292; Longitude: 119.2778

Table 10.8. Salmon River phosphorus loading as measured in the lower Salmon River near Shuswap Lake (BCMOELP unpublished data).

Date	Discharge (m^3/s)	Total Phosphorus Concentration (µg/L)	Average Daily Loading of TP (kg/d)	Ortho-Phosphorus Concentration (µg/L)	Average Daily Loading of OP (kg/d)
84/09/13	1.94	53	8.87	41	6.86
84/11/22	1.96	57	9.63	43	7.26
85/01/23	1.60	69	9.54	50	6.91
85/02/26	1.71	98	14.5	60	8.86
85/03/18	2.31	72	14.4	50	9.99
85/04/29	7.46	93	60	21	13.5
85/05/15	12.6	50	54.4	25	27.2
85/05/22	22.1	317	605	58	111
85/06/11	10.4	63	56.7	37	33.3
85/06/25	2.83	38	9.28	26	6.35
85/07/24	0.77	62	4.12	46	3.06
85/08/19	0.85	58	4.24	46	3.36

Table 10.9. The general trophic classification of lakes and reservoirs compared to Tappen Bay, Salmon Arm at station 0500127 (Wetzel 1983).

Variable	Statistics	Oligotrophic	Mesotrophic	Eutrophic	Shuswap Lake near Salmon Arm
Total Phosphorus (mg/L)	Mean	8	26	84	24
	Range	3-17	11-96	16-386	10-56
	n	21	19	71	NA
Total Nitrogen (mg/L)	Mean	661	753	1875	283
	Range	307-1630	361-1387	393-6100	150-450
	n	11	8	37	NA
Chlorophyll a (mg/m^2)	Mean	1.7	4.7	14.3	7
	Range	03.-4.5	3-11	3-78	3-12
	n	22	16	70	7

NA = not available; n = number of samples.

Table 10.10. Relative phosphorus loadings from the Salmon River and the Salmon Arm Sewage Treatment Plant (STP) at three discharges (BCMOELP unpublished data).

Phosphorus Source	Discharge (m^3/s)	Total-Phosphorus Loading (kg/d)	Ortho-Phosphorus Loading (kg/d)
Salmon River	15.4 (Freshet)	310 (97%)	50.6 (88%)
Salmon Arm STP		9.4 (3%)	7.0 (12%)
Salmon River	4.4 (Intermediate)	35.0 (79%)	24.0 (77%)
Salmon Arm STP		9.4 (21%)	7.0 (23%)
Salmon River	2.43 (Non-Freshet)	13.9 (60%)	10.3 (59%)
Salmon Arm STP		9.4 (40%)	7.0 (41%)

Table 11.1. Recommended water quality monitoring program in the Salmon River watershed.

Sampling Location	Site Number	Variables to be Measured	Sampling Date	Sampling Frequency	Number of Samples
Salmon River about 2 km east of Falkland	E207855	Pesticides and Herbicides	TBD	Once	TBD
		Chlorophyll *a*	Aug., & Oct.	Once	TBD
		Streambed Substrate Composition	Sept.	Once	TBD
Salmon River 10 m upstream of highway 97 bridge above Glenemma Latitude: 50.4561 Longitude: 119.3728	E206089	Water Temperature	Jan. - Dec.	Daily	Continuous
		Dissolved Oxygen	May - Oct.	Weekly	30
		Dissolved Oxygen	Nov. - Apr.	Monthly	6
		Total Suspended Solids, Turbidity, Water Hardness, pH, and Conductivity	Jan. - Dec.	Weekly	52
		Total Ammonia	Mar., June, Sept., & Dec.	Weekly	20
		Chlorophyll *a*	Aug., & Oct.	Once	TBD
		Streambed Substrate Composition	Sept.	Once	TBD
Salmon River 10 m upstream of road bridge below the community of Silver Creek (approximately 1.7 km downstream of Silver Creek) Latitude: 50.6083 Longitude: 119.3642	E206091	Water Temperature	Jan. - Dec.	Daily	Continuous
		Dissolved Oxygen	May - Oct.	Weekly	30
		Dissolved Oxygen	Nov. - Apr.	Monthly	6
		Total Suspended Solids, Turbidity, Water Hardness, pH, and Conductivity	Jan. - Dec.	Weekly	52
		Total Ammonia	Mar., June, Sept., & Dec.	Weekly	20
		Chlorophyll *a*	Aug., & Oct.	Once	TBD
		Streambed Substrate Composition	Sept.	Once	TBD
Salmon River 5 m upstream of Salmon Valley Road bridge near Highway #1	BC08LE0004	Water Temperature	Jan. - Dec.	Daily	Continuous
	E206092	Dissolved Oxygen	May - Oct.	Weekly	30
		Dissolved Oxygen	Nov. - Apr.	Monthly	6

Table 11.1. Recommended water quality monitoring program in the Salmon River watershed.

Sampling Location	Site Number	Variables to be Measured	Sampling Date	Sampling Frequency	Number of Samples
Salmon River at first farm bridge (approximately 400m) upstream of confluence with McInnis Creek Latitude: 50.2844 Longitude: 119.9850	E206084	Water Temperature	Jan. - Dec.	Daily	Continuous
		Dissolved Oxygen	May - Oct.	Every 6 days*	30
		Dissolved Oxygen	Nov. - Apr.	Monthly	6
		Total Suspended Solids, Turbidity, Water Hardness, pH, and Conductivity	Jan. - Dec.	Weekly	52
		Total Suspended Solids and Turbidity	Freshet	Every 3 days	20
		Total Ammonia	Mar., June, Sept., & Dec.	Every 6 days*	20
		Microbial Indicators (total faecal coliforms, *Escherichia coli, Enterococcus spp.)*	May, July, & Sept.	Every 3 days	30
		Pesticides and Herbicides	TBD	Once	TBD
		Chlorophyll a	Aug., & Oct.	Once	TBD
		Streambed Substrate Composition	Sept.	Once	TBD
		Metals (arsenic, cadmium, copper, chromium, lead, mercury, and zinc), Water Hardness, and Conductivity	Mar. & Sept.	Every 6 days*	10
Salmon River about 2 km east of Falkland Latitude: 50.4861 Longitude: 119.5381	E207855	Water Temperature	Jan. - Dec.	Daily	Continuous
		Dissolved Oxygen	May - Oct.	Every 6 days*	30
		Dissolved Oxygen	Nov. - Apr.	Monthly	6
		Total Suspended Solids, Turbidity, Water Hardness, pH, and Conductivity	Jan. - Dec.	Weekly	52
		Total Suspended Solids and Turbidity	Freshet	Every 3 days	20
		Total Ammonia	Mar., June, Sept., & Dec.	Every 6 days*	20
		Microbial Indicators (total faecal coliforms, *Escherichia coli, Enterococcus spp.)*	May, July, & Sept.	Every 3 days	30

Table 11.1. Recommended water quality monitoring program in the Salmon River watershed.

Sampling Location	Site Number	Variables to be Measured	Sampling Date	Sampling Frequency	Number of Samples
Salmon River at first farm bridge (approximately 400m) upstream of confluence with McInnis Creek Latitude: 50.2844 Longitude: 119.9850	E206084	Water Temperature	Jan. - Dec.	Daily	Continuous
		Dissolved Oxygen	May - Oct.	Weekly	30
		Dissolved Oxygen	Nov. - Apr.	Monthly	6
		Total Suspended Solids, Turbidity, Water Hardness, pH, and Conductivity	Jan. - Dec.	Weekly	52
		Total Suspended Solids and Turbidity	Freshet	Every 3 days	20
		Total Ammonia	Mar., June, Sept., & Dec.	Weekly	20
		Microbial Indicators (total faecal coliforms, *Escherichia coli, Enterococcus spp.)*	May, July, & Sept.	Every 3 days	30
		Pesticides and Herbicides	TBD	Once	TBD
		Chlorophyll *a*	Aug., & Oct.	Once	TBD
		Streambed Substrate Composition	Sept.	Once	TBD
		Metals (arsenic, cadmium, copper, chromium, lead, mercury, and zinc), Water Hardness, and Conductivity	Mar. & Sept.	Weekly	10
Salmon River about 2 km east of Falkland Latitude: 50.4861 Longitude: 119.5381	E207855	Water Temperature	Jan. - Dec.	Daily	Continuous
		Dissolved Oxygen	May - Oct.	Weekly	30
		Dissolved Oxygen	Nov. - Apr.	Monthly	6
		Total Suspended Solids, Turbidity, Water Hardness, pH, and Conductivity	Jan. - Dec.	Weekly	52
		Total Suspended Solids and Turbidity	Freshet	Every 3 days	20
		Total Ammonia	Mar., June, Sept., & Dec.	Weekly	20
		Microbial Indicators (total faecal coliforms, *Escherichia coli, Enterococcus spp.)*	May, July, & Sept.	Every 3 days	30

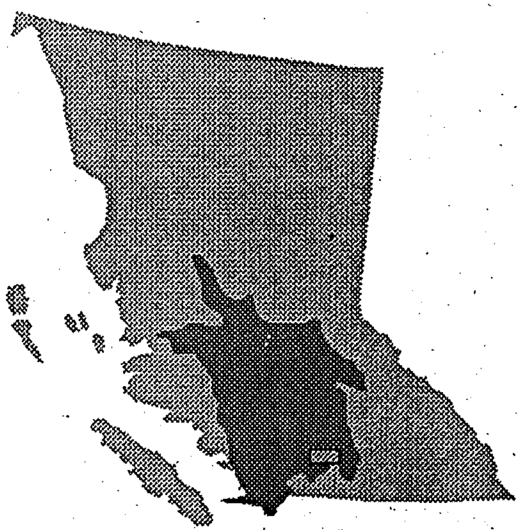
Table 11.1. Recommended water quality monitoring program in the Salmon River watershed.

Sampling Location	Site Number	Variables to be Measured	Sampling Date	Sampling Frequency	Number of Samples
Salmon River 5 m upstream of Salmon Valley Road bridge near Highway #1 Latitude: 50.6929 Longitude: 119.3298	BC08LE0004 E206092	Total Suspended Solids, Turbidity, Water Hardness, pH, and Conductivity	Jan. - Dec.	Weekly	52
		Total Suspended Solids and Turbidity	Freshet	Every 3 days	20
		Total Ammonia	Mar., June, Sept., & Dec.	Weekly	20
		Total and Ortho-Phosphorus	Jan. - Dec.	Bi-weekly	26
		Microbial Indicators (total faecal coliforms, *Escherichia coli, Enterococcus spp.)*	May, July, & Sept.	Every 3 days	30
		Pesticides and Herbicides	TBD	Once	TBD
		Metals (arsenic, cadmium, copper, chromium, lead, mercury, and zinc), Water Hardness, and Conductivity	Mar. & Sept.	Weekly	10
Shuswap Lake in southeast end of Tappen Bay shallows opposite downtown Salmon Arm Latitude: 50.7144 Longitude: 119.2789	E206770	Total and Ortho-Phosphorus	Open Water	Bi-Weekly	60
		Water Temperature, Hardness, and pH	Open Water	Bi-Weekly	60
		Dissolved Oxygen	Open Water	Bi-Weekly	60
		Chlorophyll *a*	Open Water	Monthly	30
		Microbial Indicators (total faecal coliforms, *Escherichia coli, Enterococcus spp.)*	Open Water	Every 3 days	50
Shuswap Lake in southwest end of Tappen Bay in deep hole opposite Sandy Point, in 30 m of water Latitude: 50.7239 Longitude: 119.3014	E206771	Total and Ortho-Phosphorus	Open Water	Bi-Weekly	60
		Water Temperature, Hardness, and pH	Open Water	Bi-Weekly	60
		Dissolved Oxygen	Open Water	Bi-Weekly	60
		Chlorophyll *a*	Open Water	Monthly	30
		Microbial Indicators (total faecal coliforms, *Escherichia coli, Enterococcus spp.)*	Open Water	Every 3 days	50

TBD = to be determined.

Figures

Figure 1.1. Map of the Salmon River Watershed



Salmon River Watershed within the
Fraser Basin in British Columbia

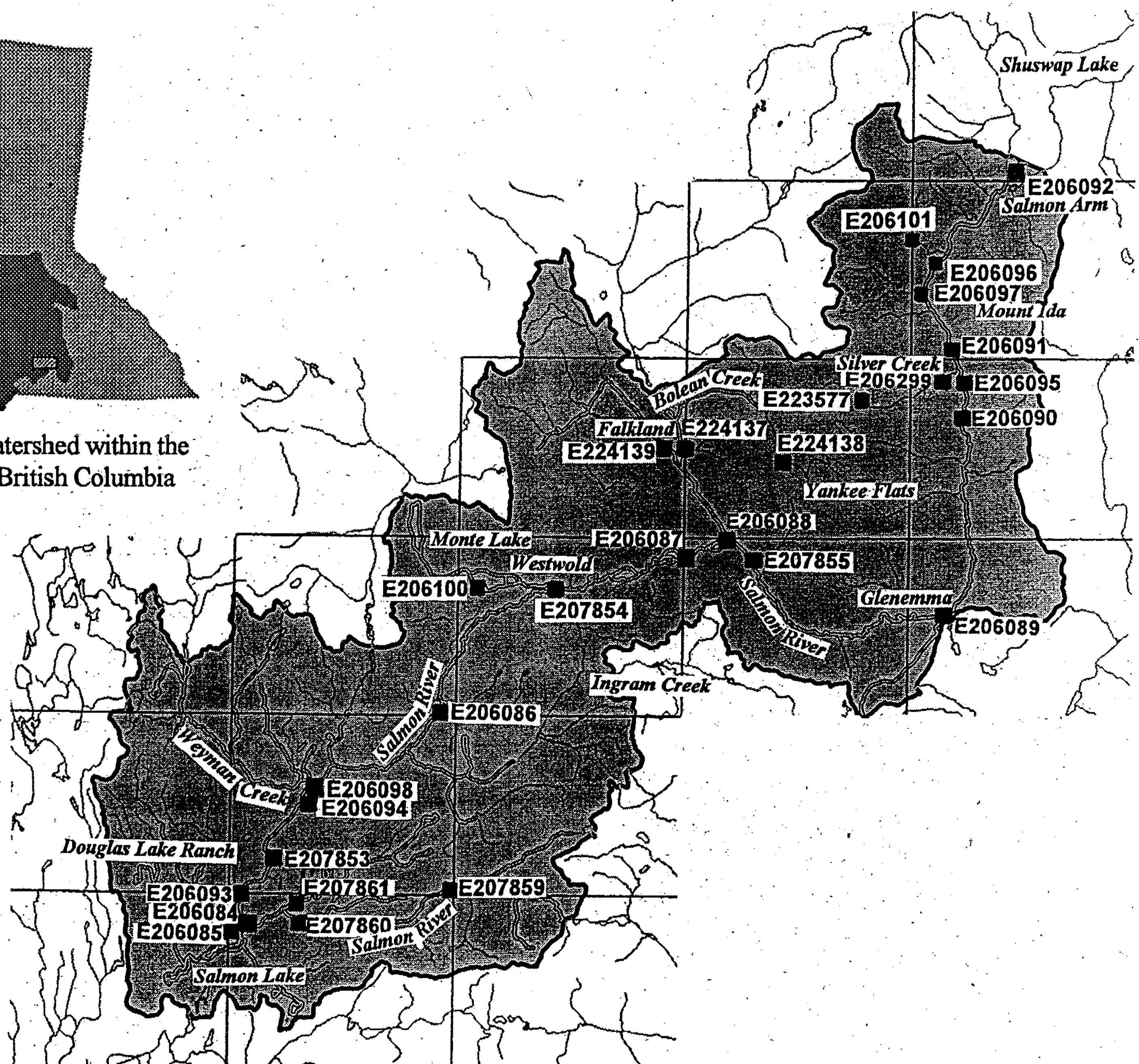
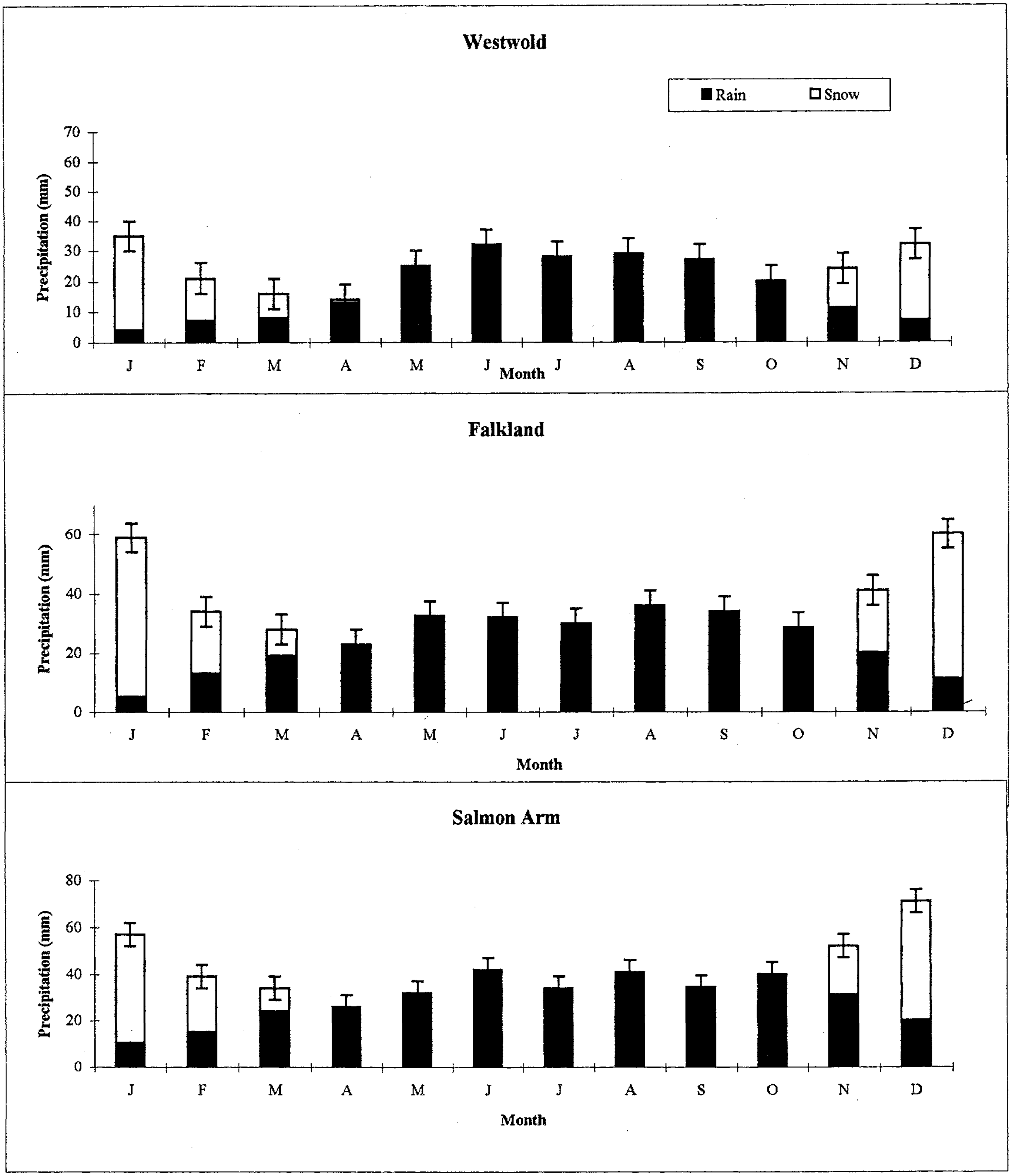


Figure 3.1. Monthly mean precipitation of Westwold, Falkland, and Salmon Arm (Environment Canada 1982).



Note: Error bars represent sample standard errors.

Figure 3.2. Mean monthly air temperatures for Westwold, Falkland, and Salmon Arm (Environment Canada 1982).

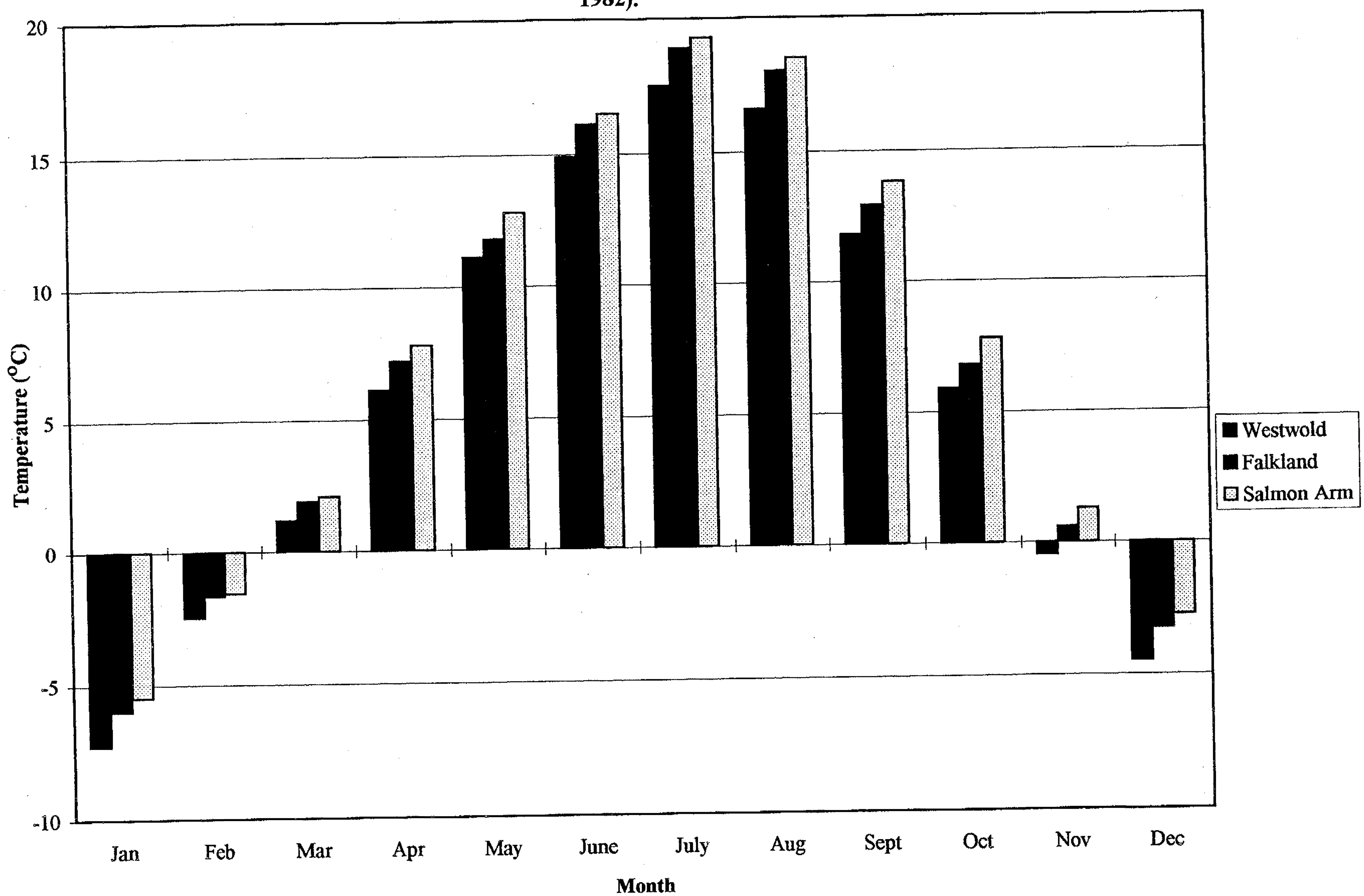


Figure 4.1. Annual escapement of anadromous salmonids from the Salmon River (Burt and Wallis 1997).

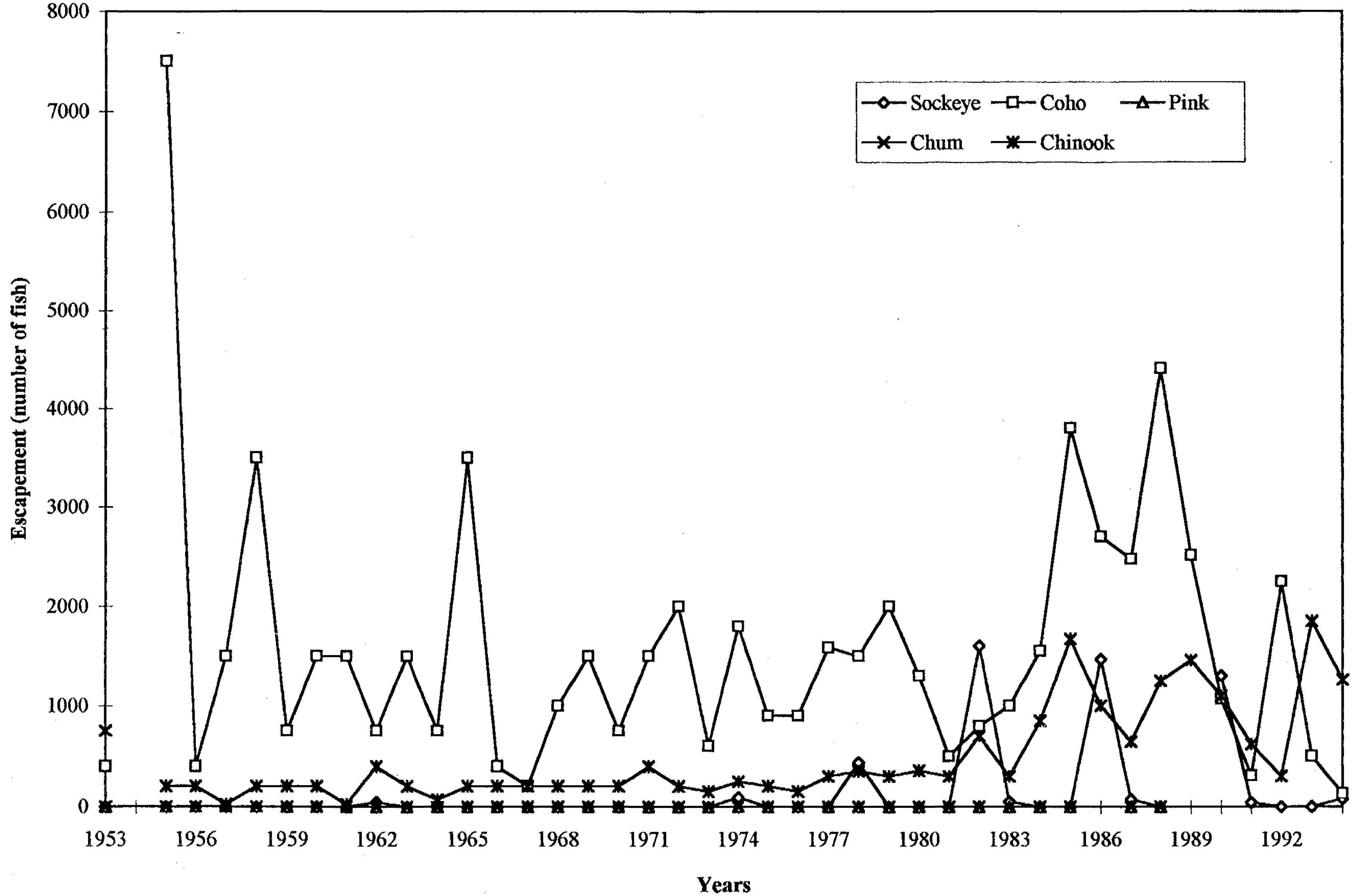


Figure 10.1. Mean monthly discharge of the Salmon River at Salmon Arm, Falkland, and above Salmon Lake (Environment Canada 1991).

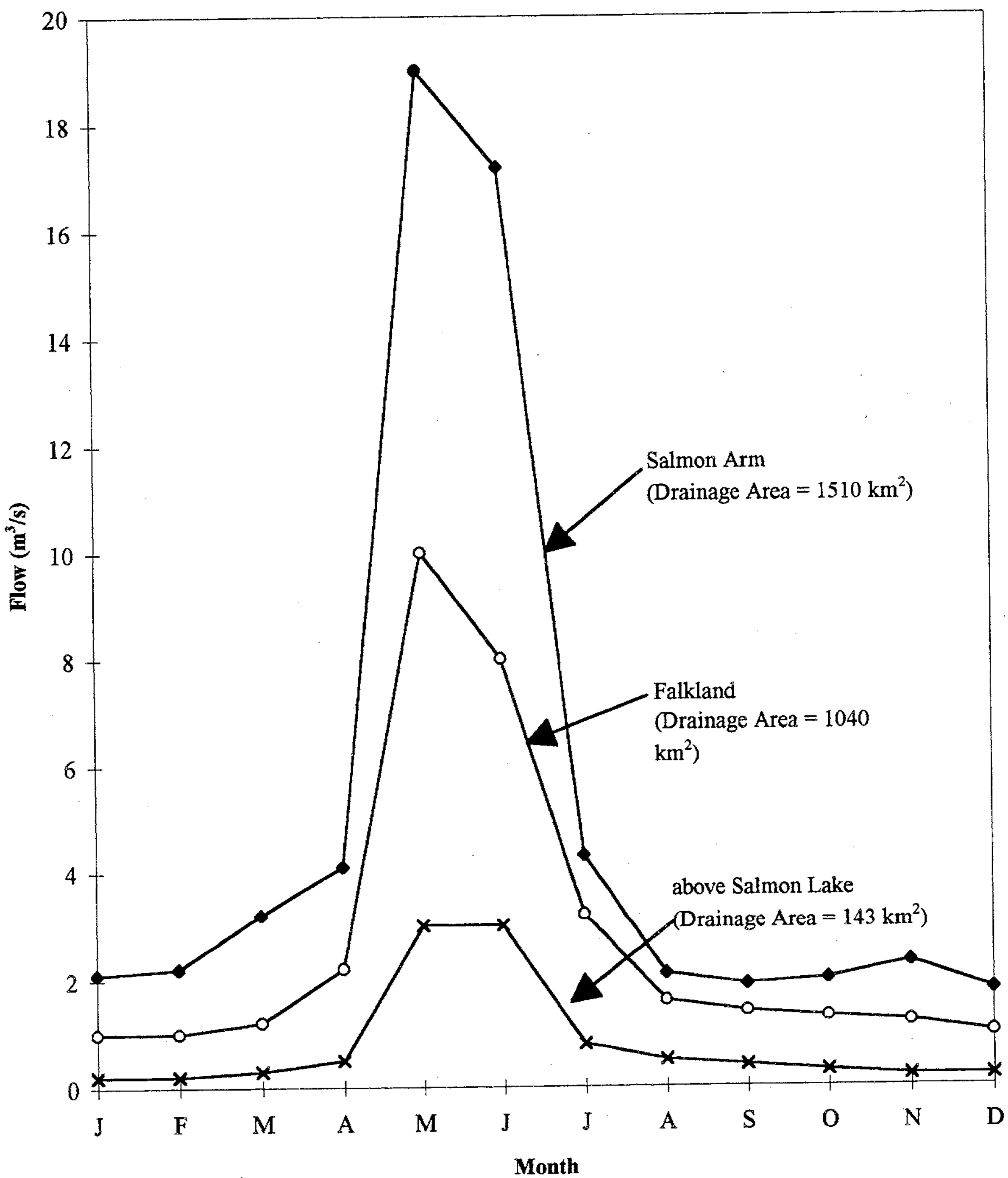


Figure 10.2. Discharge of the Salmon River at Salmon Arm between 1984-1995 (Environment Canada unpublished data).

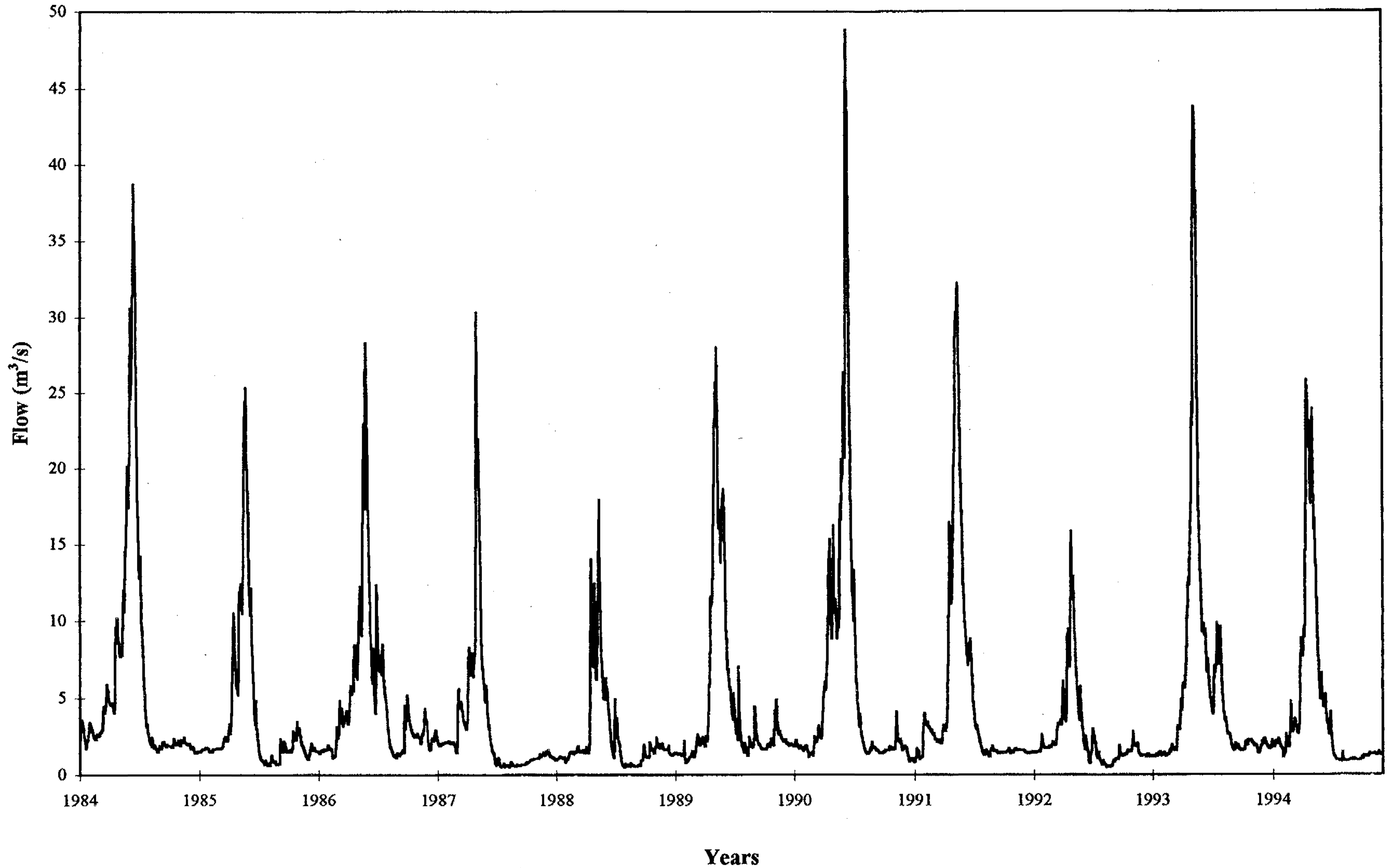


Figure 10.3. A summary of available water temperature data for the Salmon River at Salmon Arm (Environment Canada unpublished data).

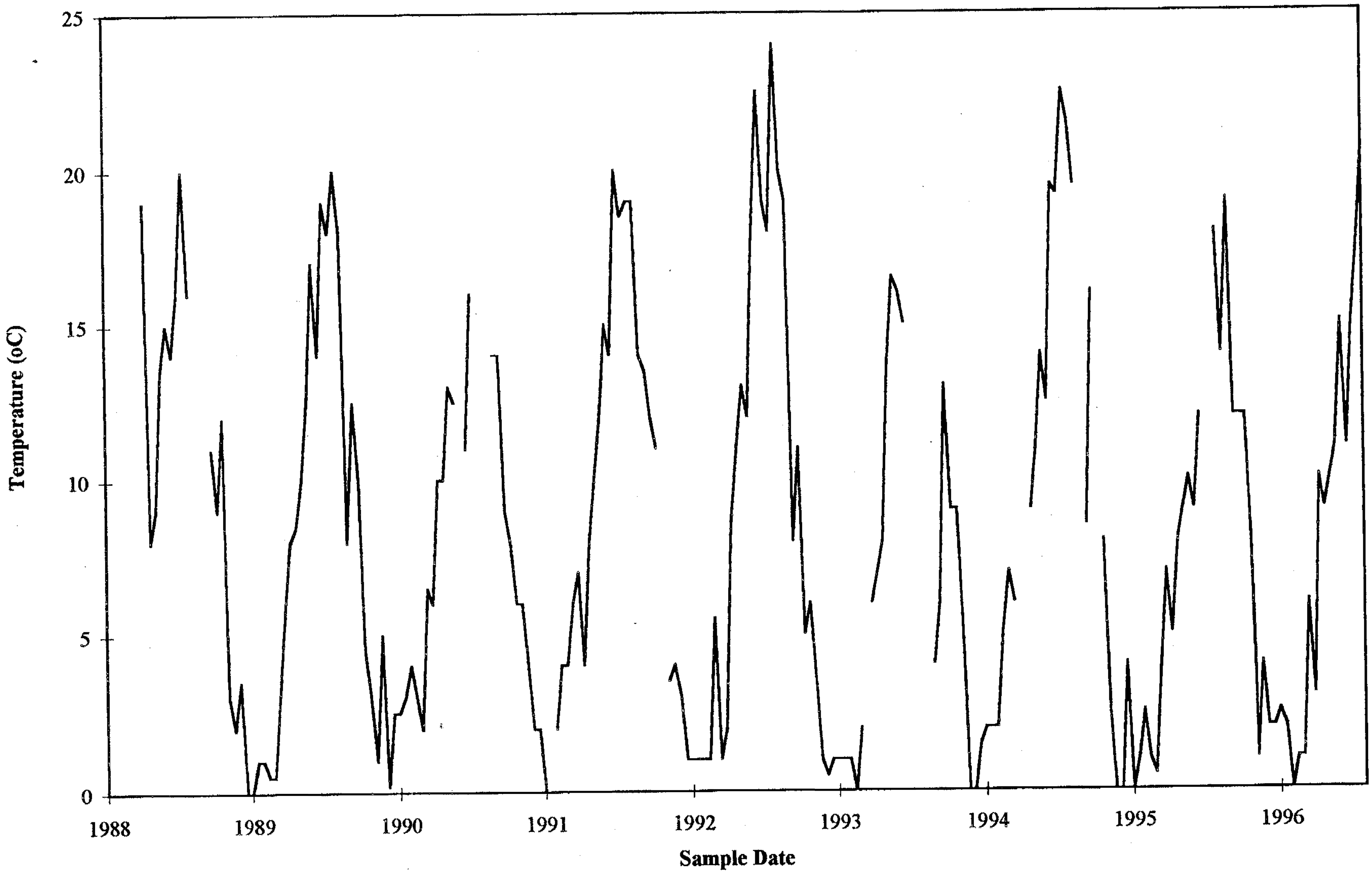


Figure 10.4. Mean monthly temperature of the Salmon River at Salmon Arm (Environment Canada unpublished data).

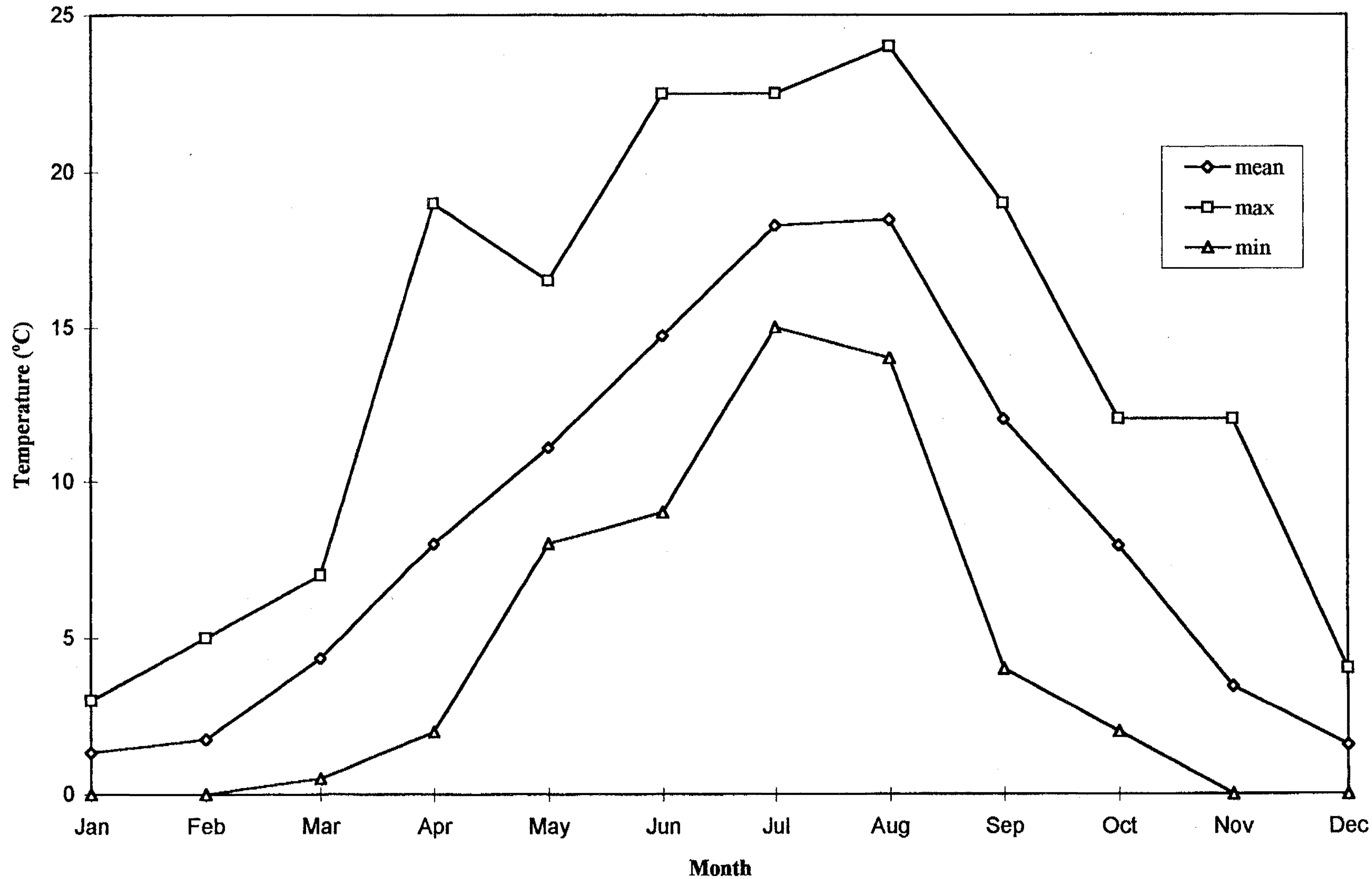


Figure 10.5. A summary of available pH data for the Salmon River at Salmon Arm (Environment Canada unpublished data).

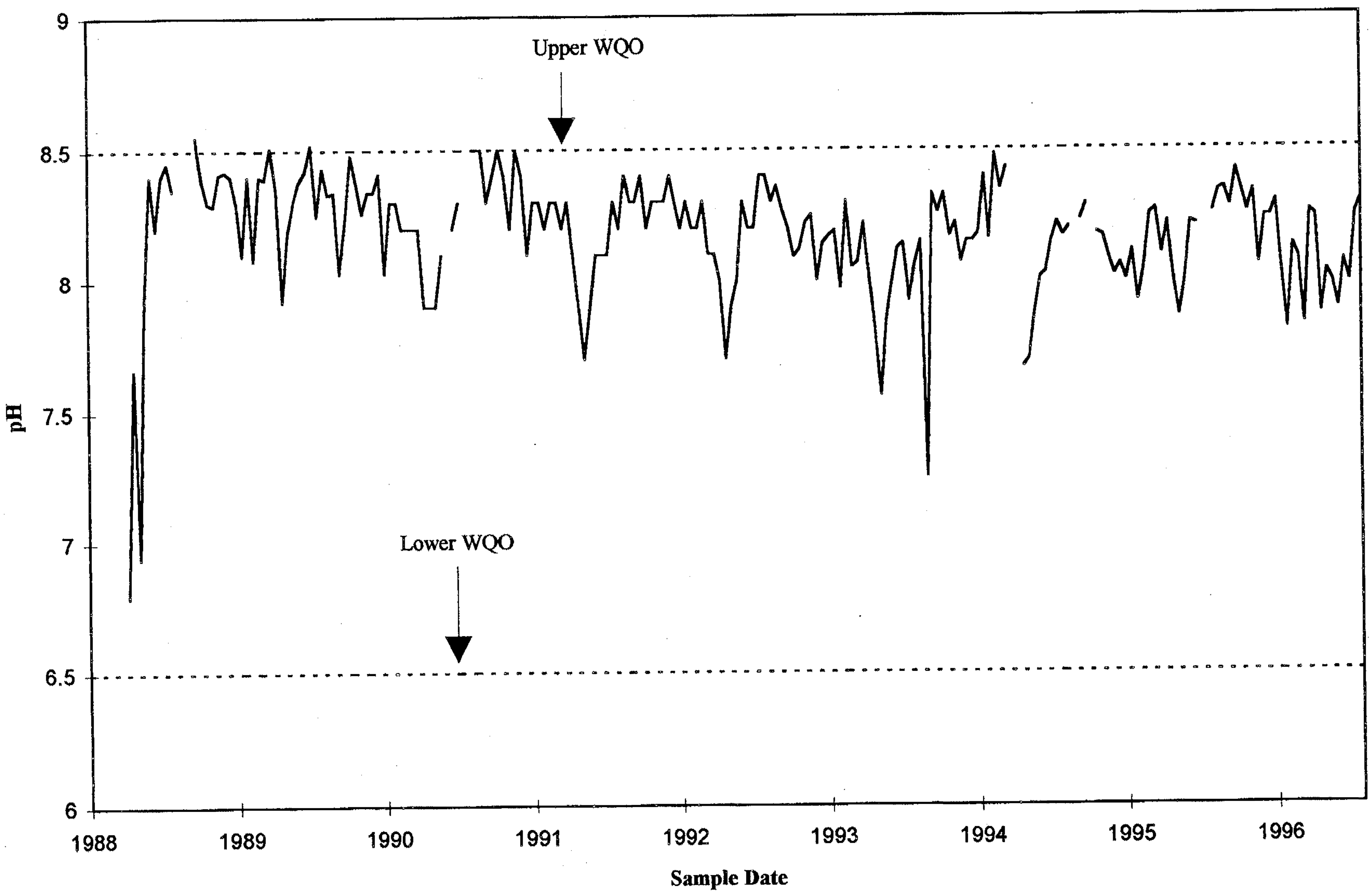


Figure 10.6. Median monthly pH of the Salmon River at Salmon Arm (Environment Canada unpublished data).

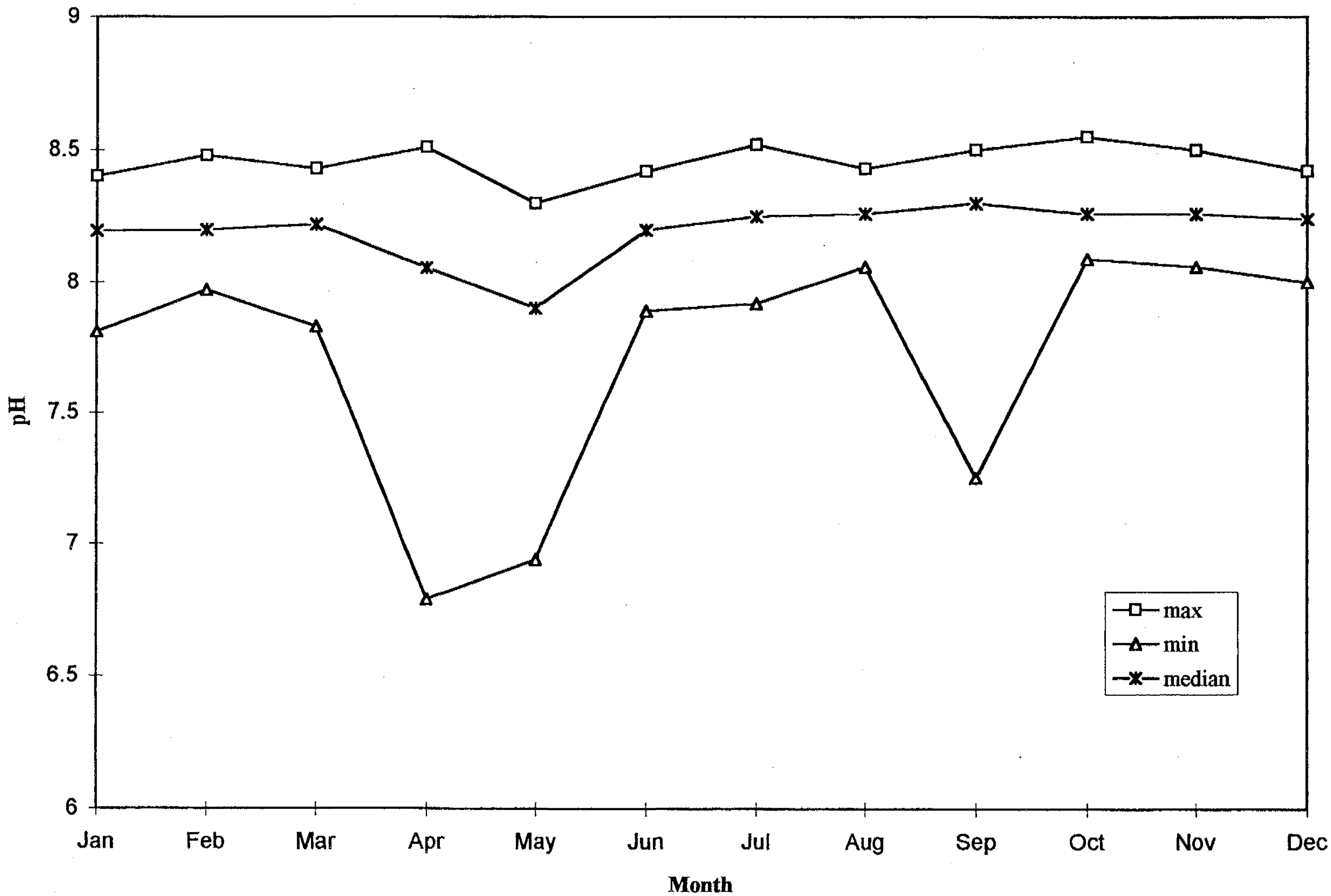


Figure 10.7. Longitudinal variability of pH in the Salmon River watershed (BCMOELP unpublished data)

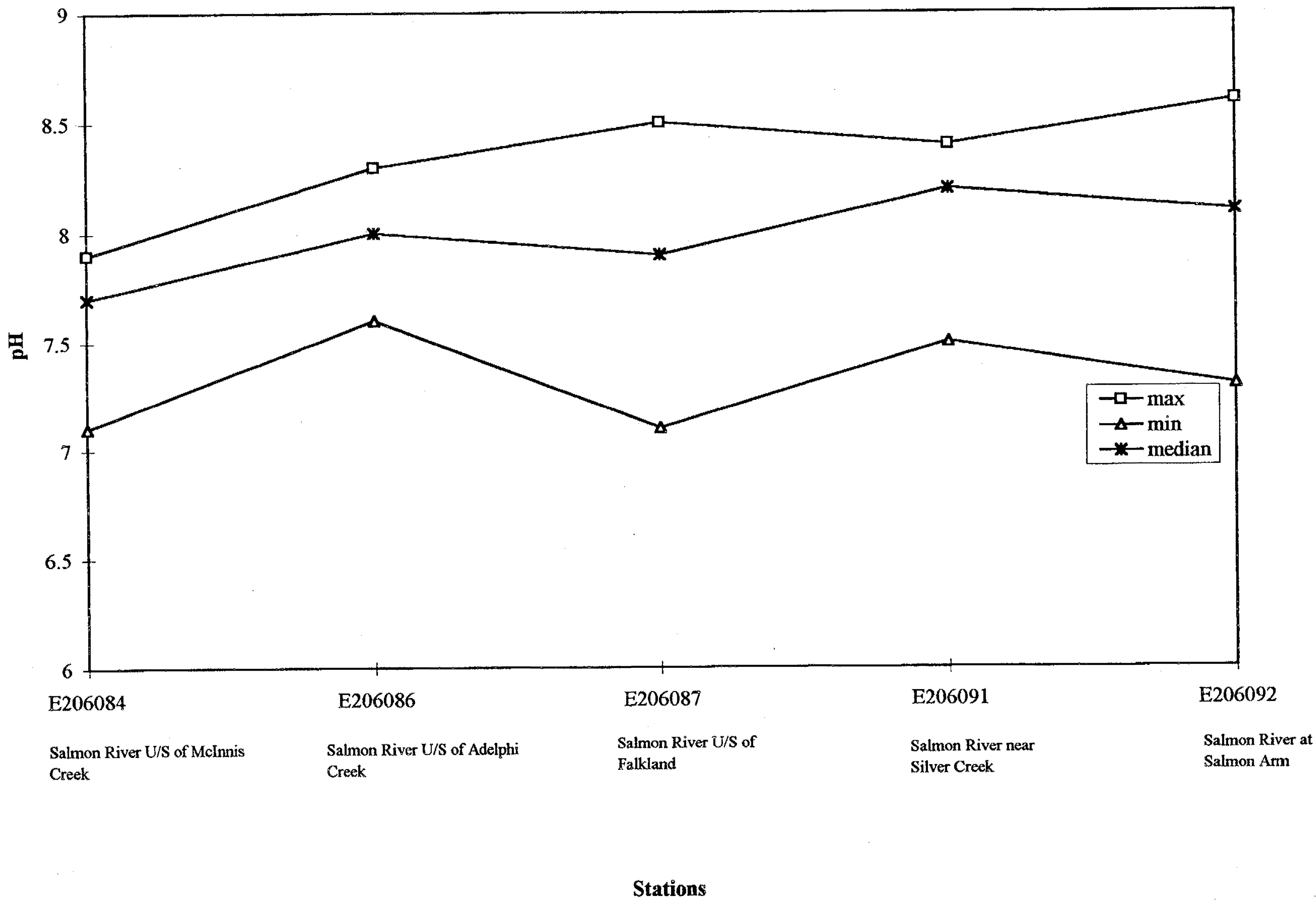


Figure 10.8. A summary of the available water hardness data for the Salmon River at Salmon Arm (Environment Canada unpublished data).

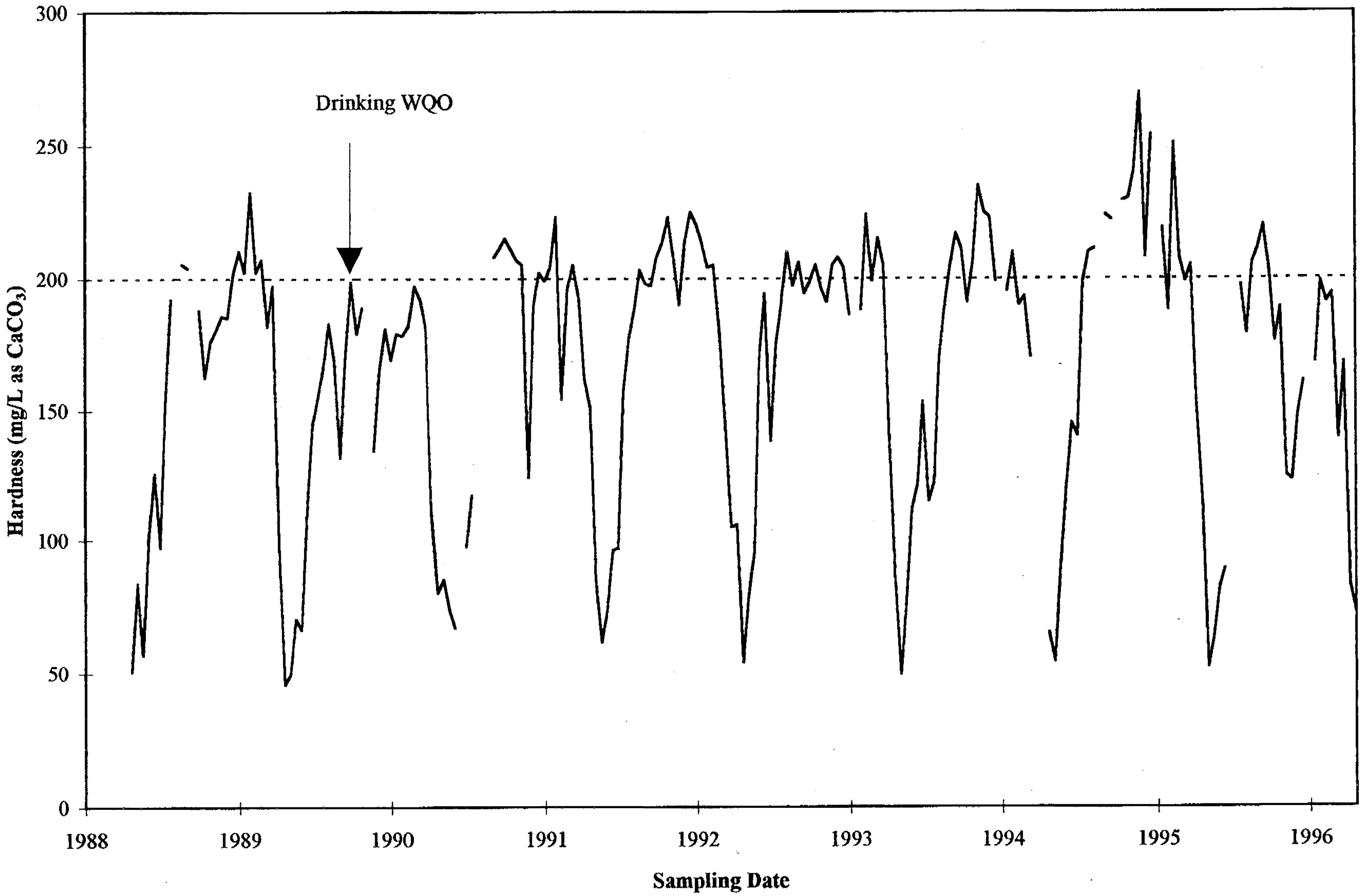


Figure 10.9. Mean monthly water hardness in the Salmon River at Salmon Arm (Environment Canada unpublished data).

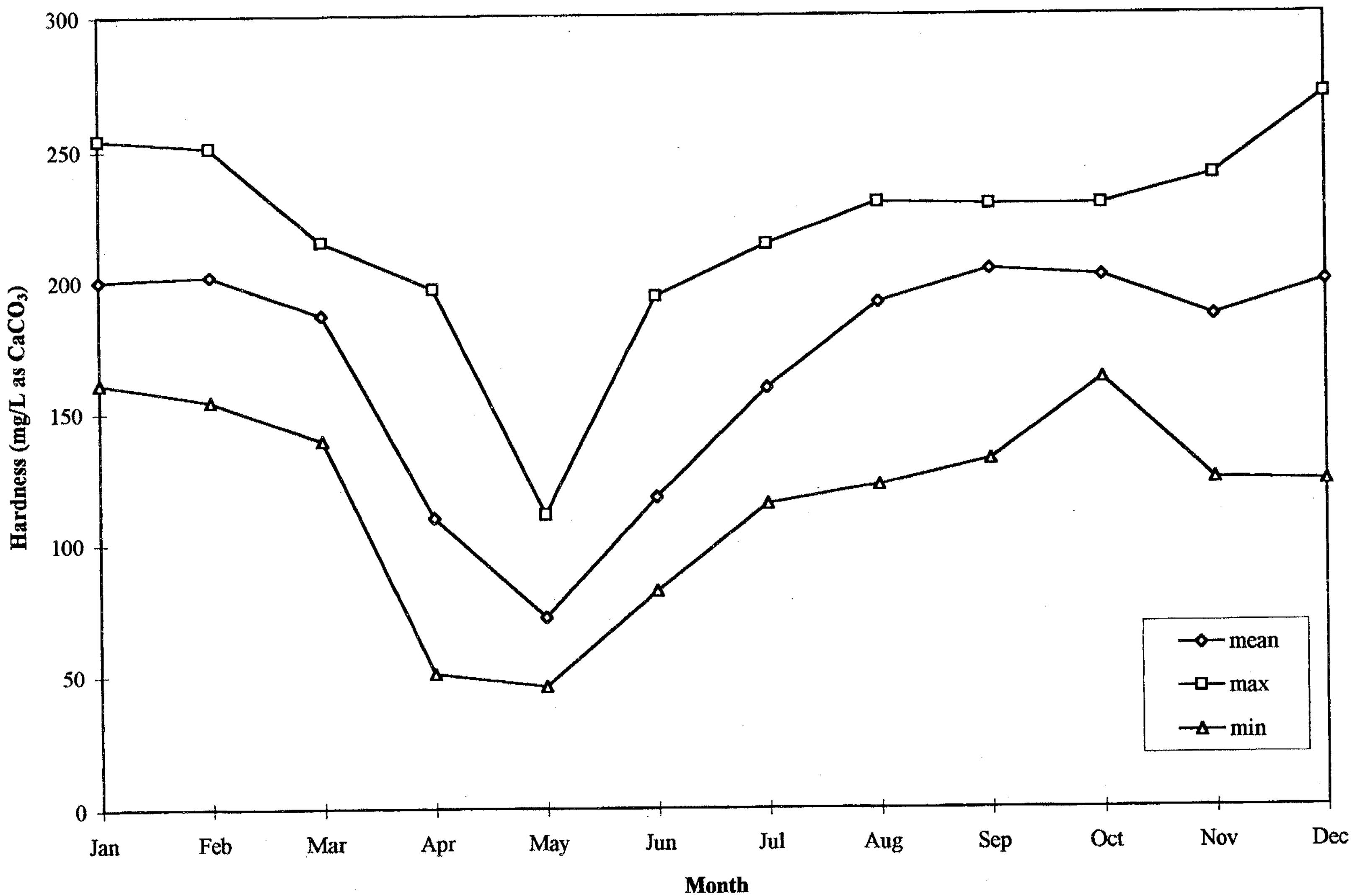


Figure 10.10. Relationship between water hardness and discharge (Q) in the Salmon River at Salmon Arm (Station BC08LE0004).

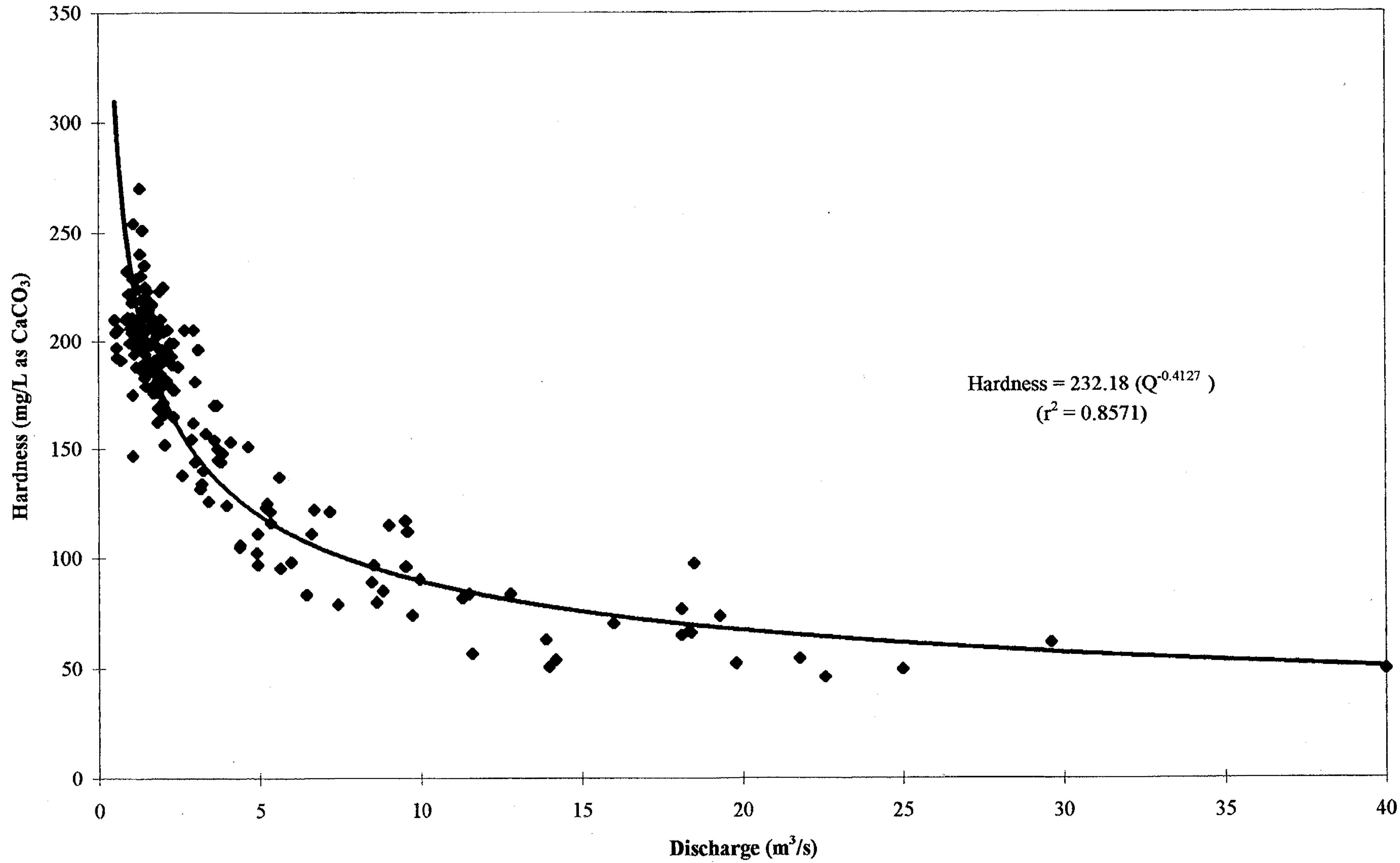
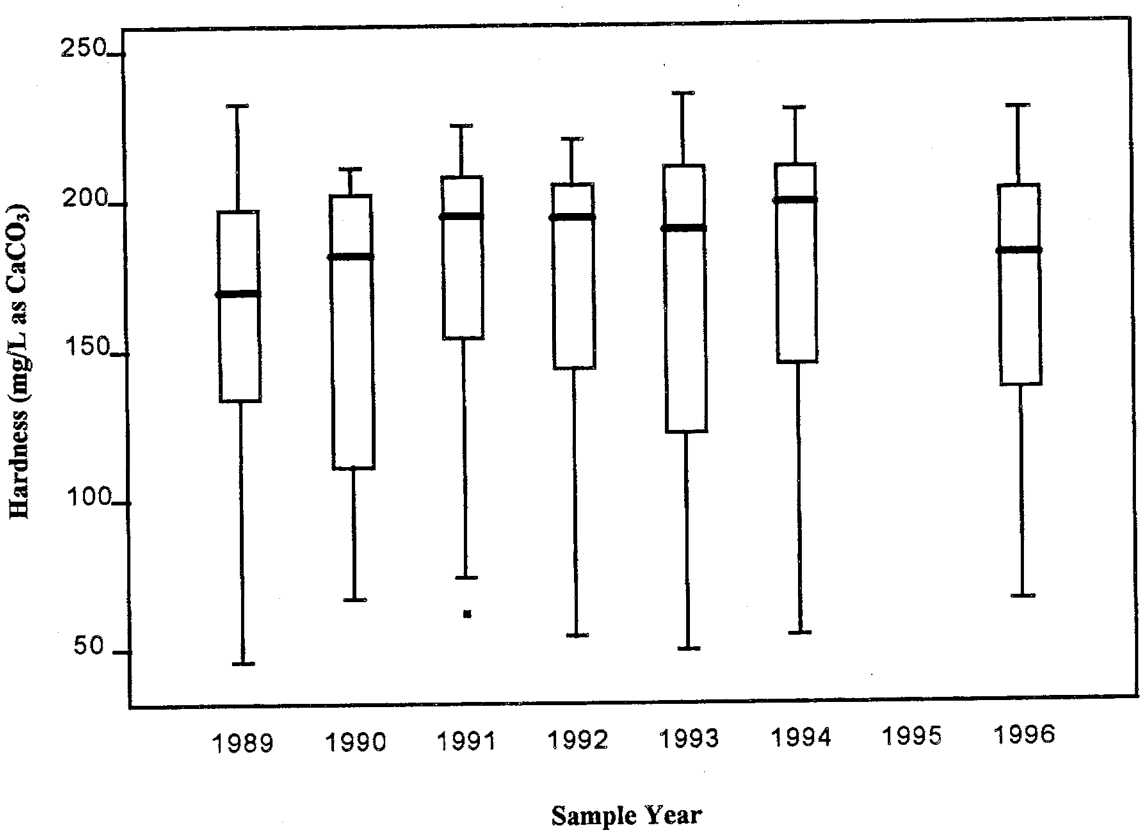


Figure 10.11. Annual summary of water hardness data in the Salmon River at Salmon Arm, 1989-1996 (from Regnier and Shaw 1997).



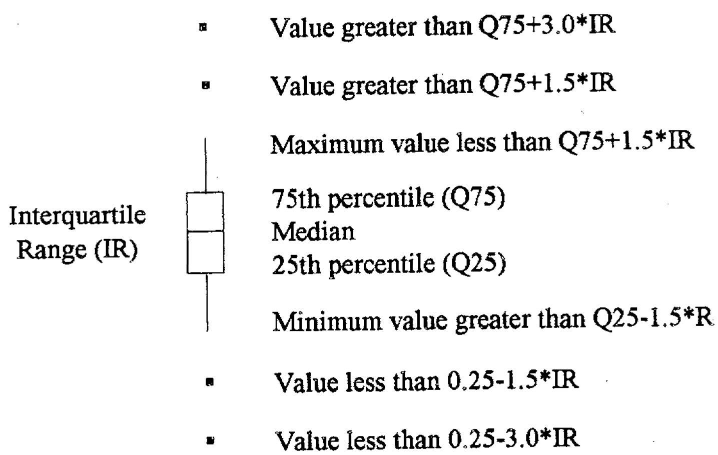


Figure 10.12. A summary of available non-filterable residue (NFR) data for the Salmon River at Salmon Arm (BCMOELP unpublished data).

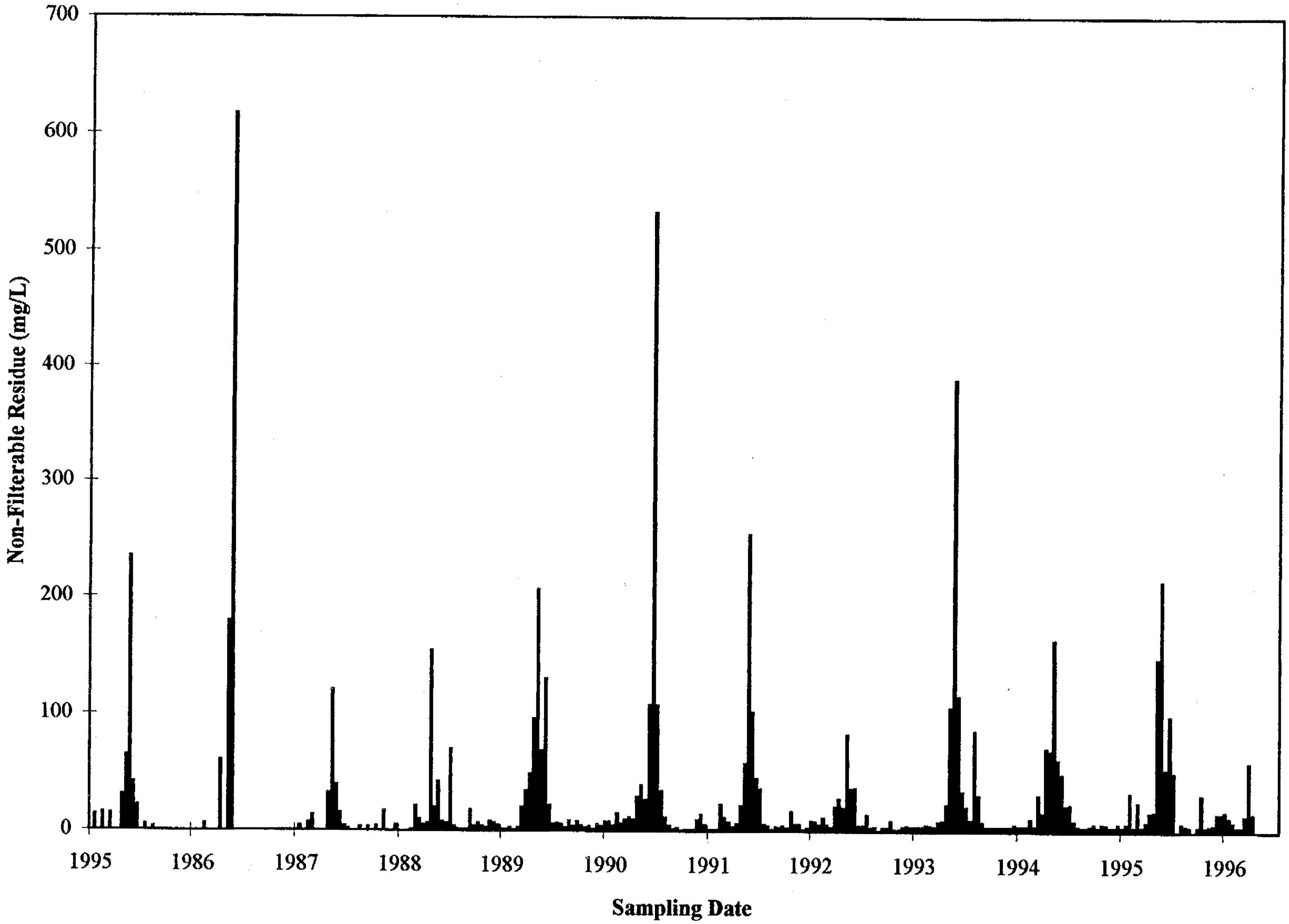


Figure 10.13. Mean monthly non-filterable residue (NFR) in the Salmon River at Salmon Arm (BCMOELP unpublished data).

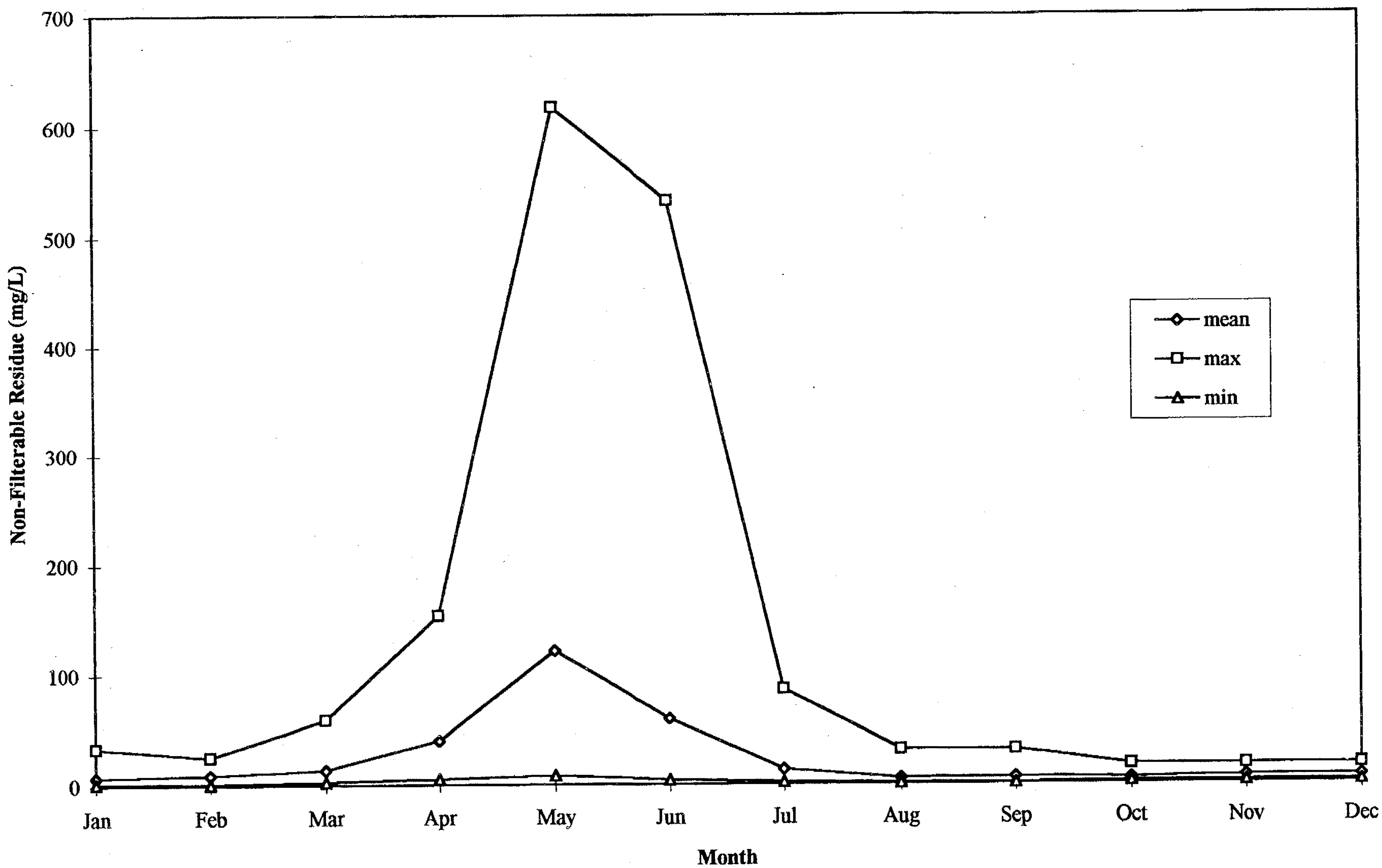


Figure 10.14. A summary of the available turbidity data for the Salmon River at Salmon Arm (Environment Canada unpublished data).

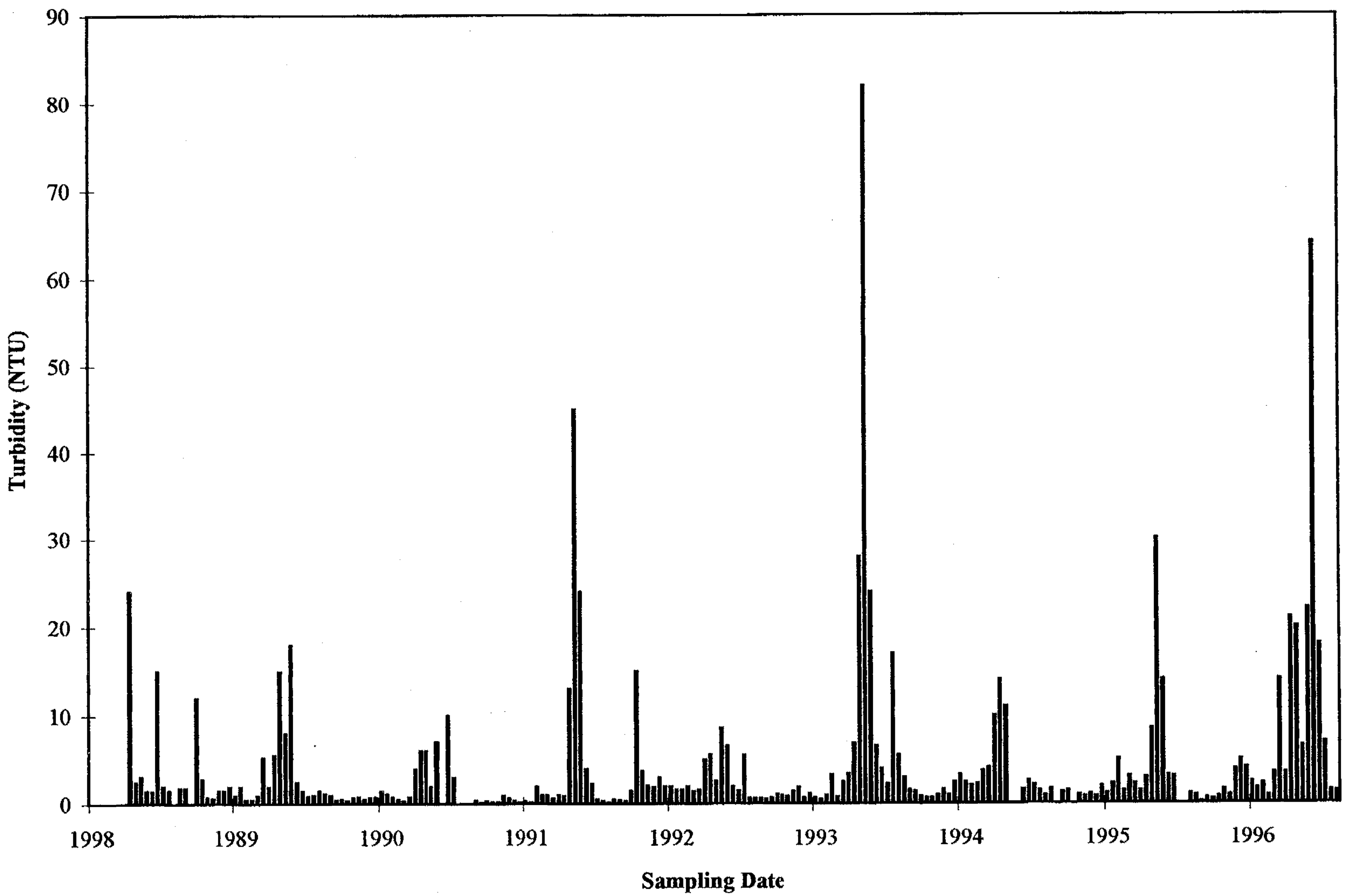


Figure 10.15. Mean monthly turbidity in the Salmon River at Salmon Arm (Environment Canada unpublished data).

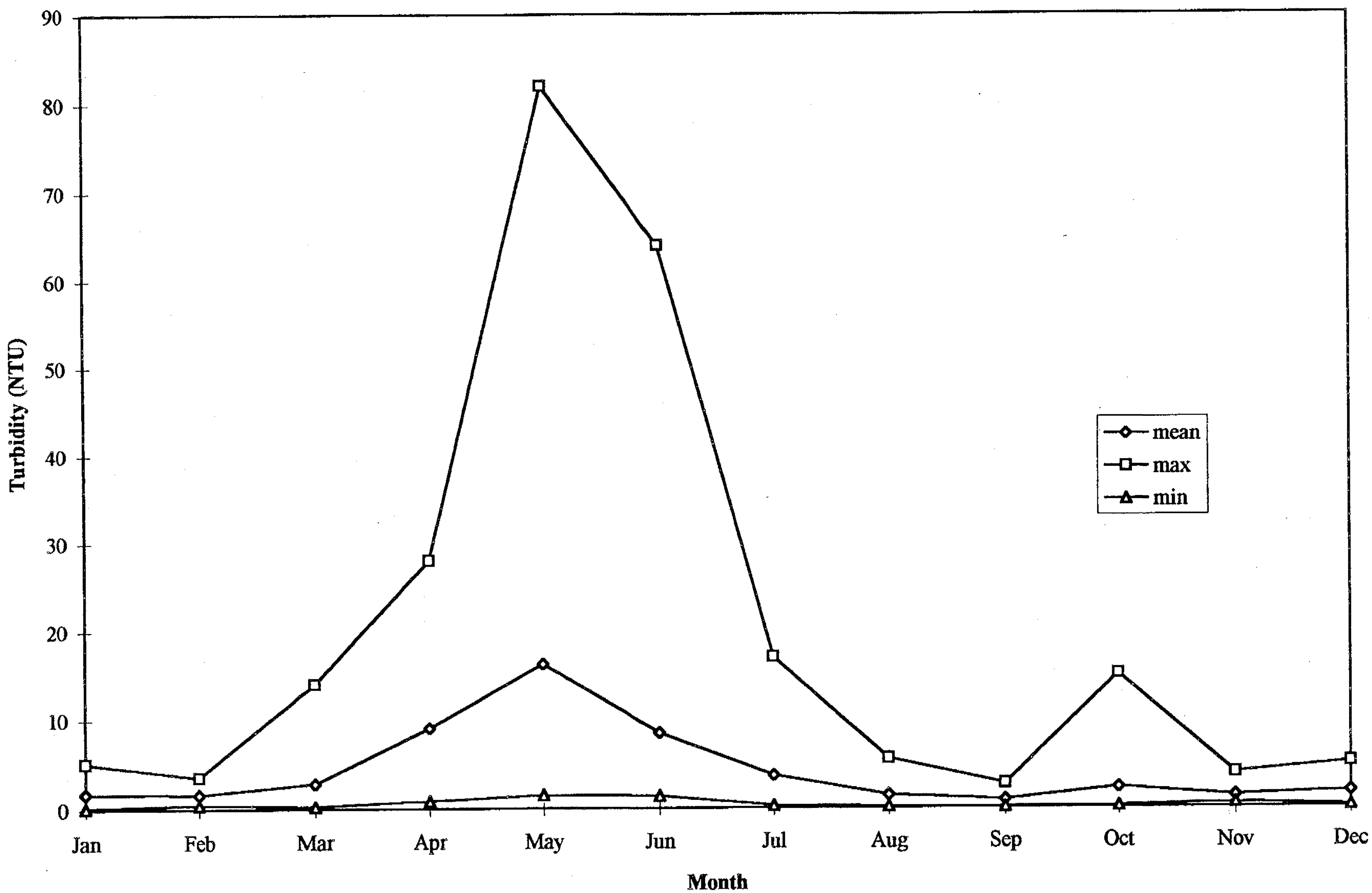


Figure 10.16. Relationship between turbidity and discharge (Q) in the Salmon River at Salmon Arm.

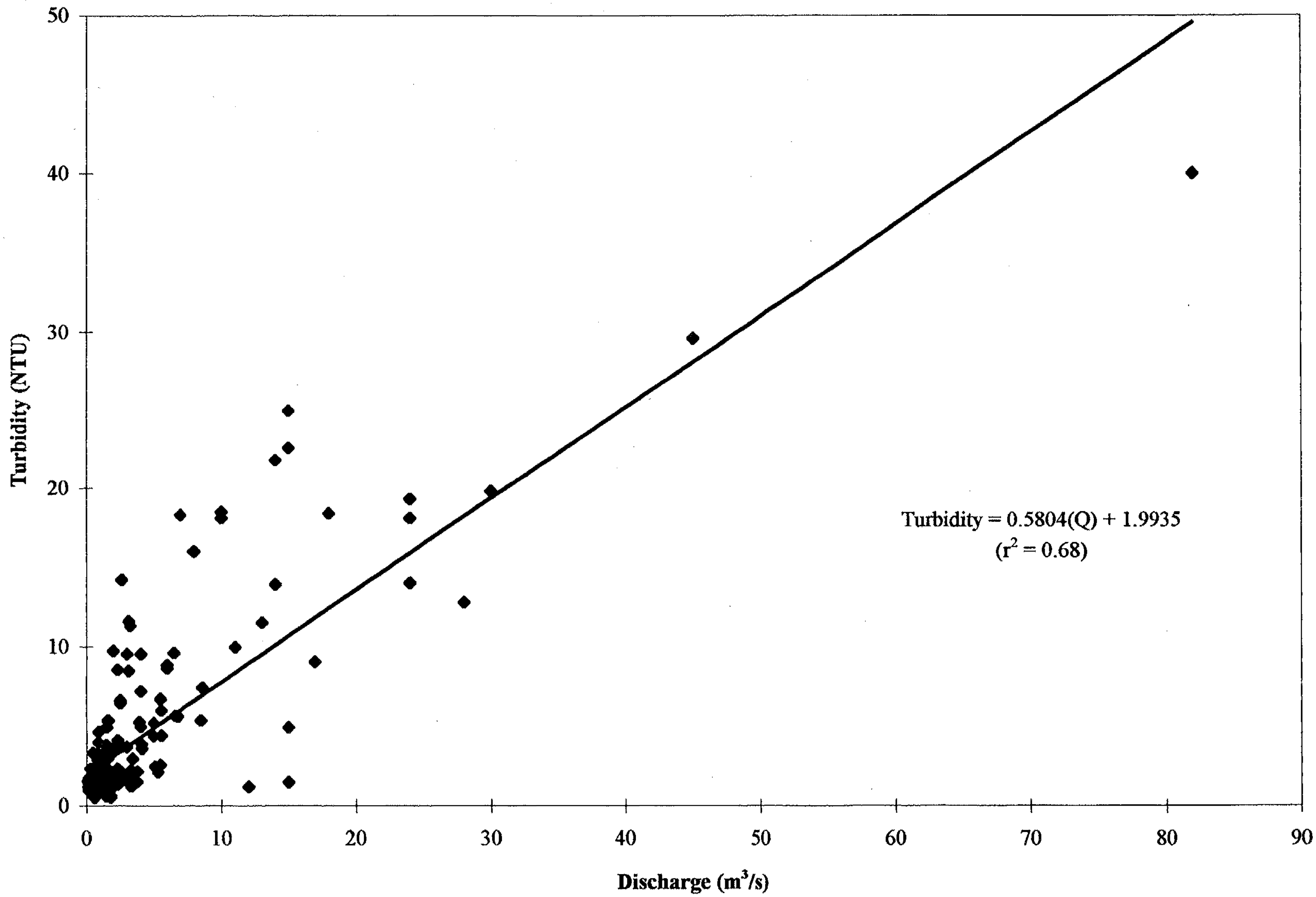


Figure 10.17. Longitudinal variability in non-filterable residue (NFR) levels in the Salmon River watershed (BCMOELP unpublished data).

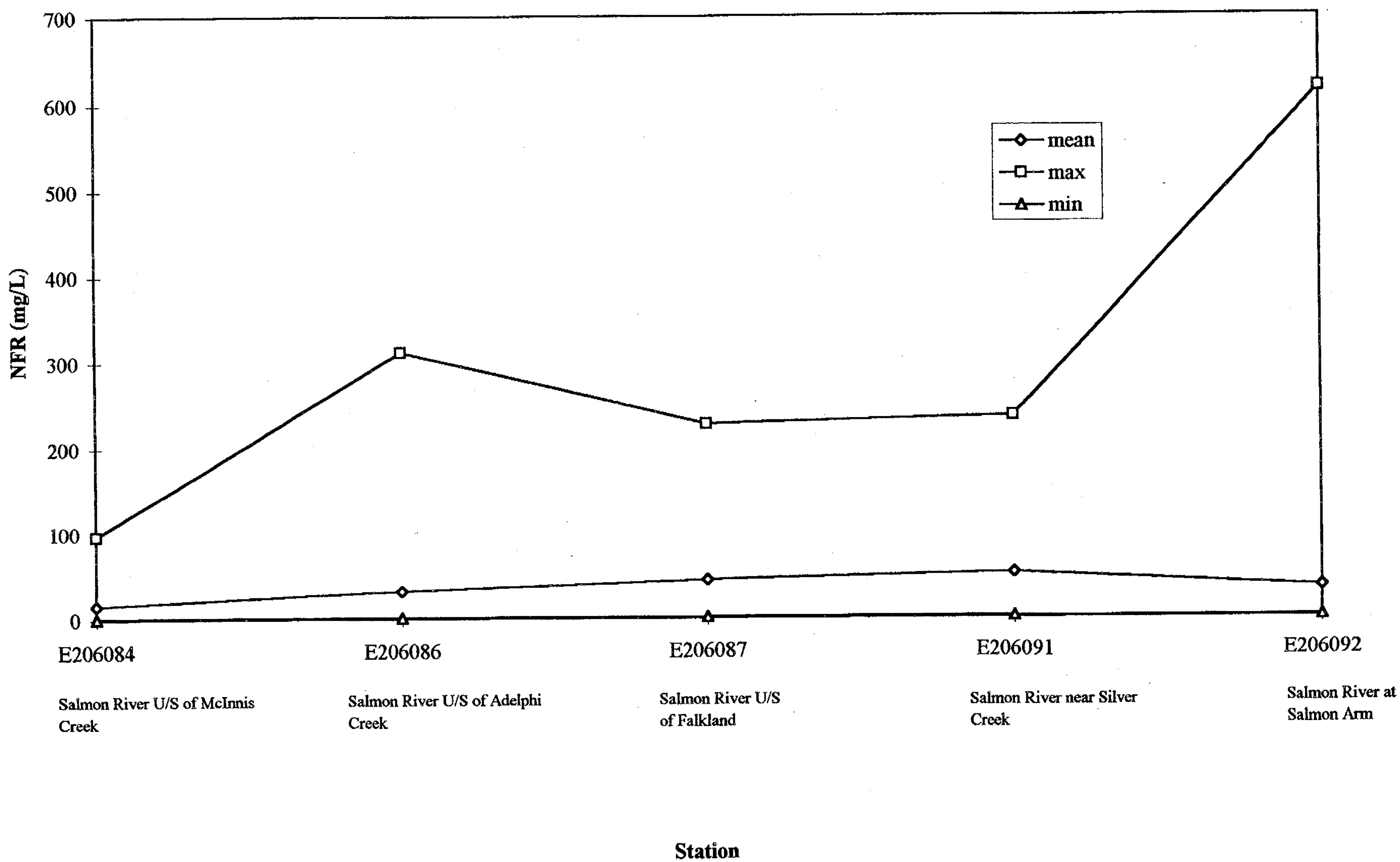


Figure 10.18. A summary of the available total phosphorus data for the Salmon River at Salmon Arm (Environment Canada unpublished data).

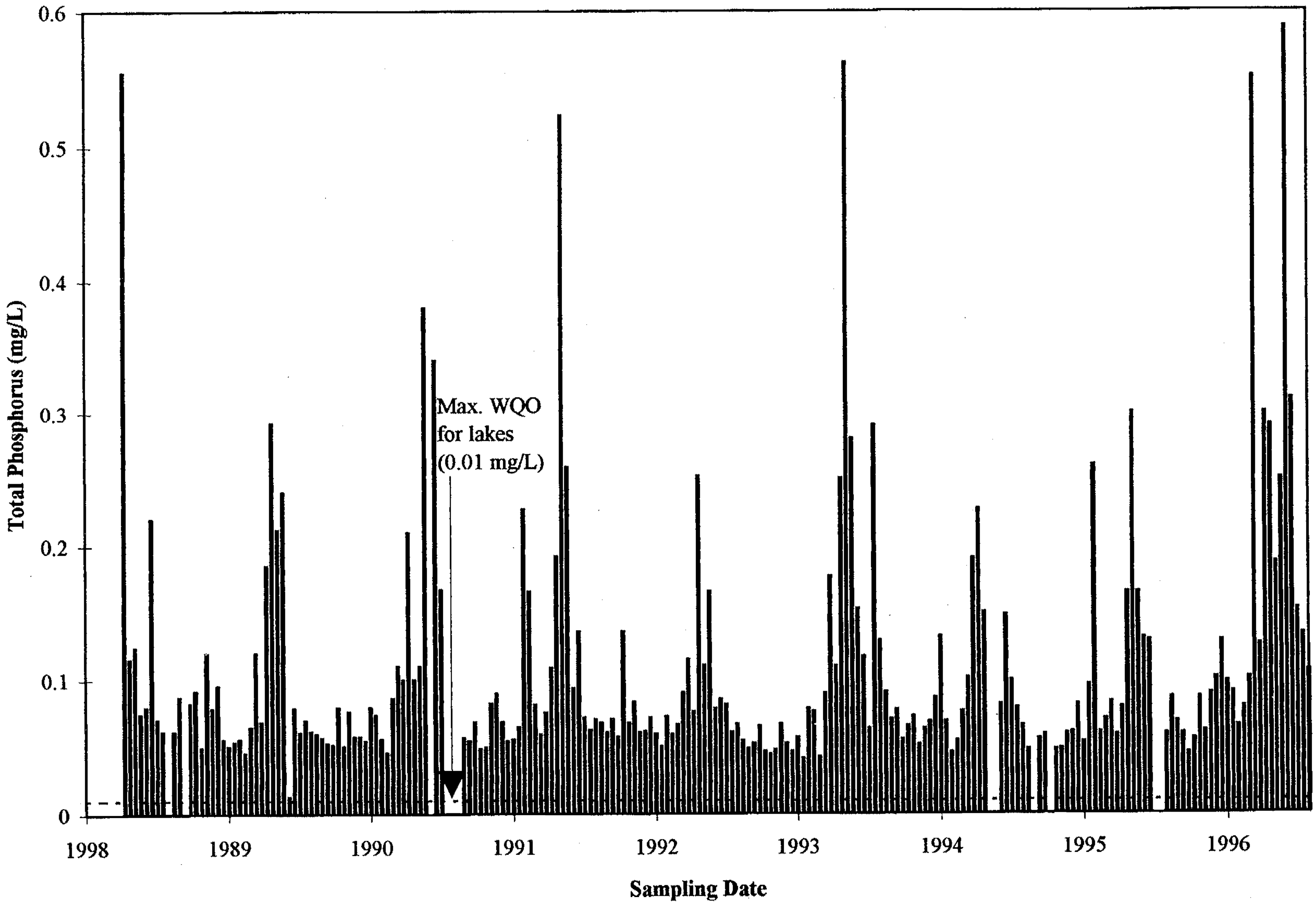


Figure 10.19. Mean monthly total phosphorus in the Salmon River at Salmon Arm (Environment Canada unpublished data).

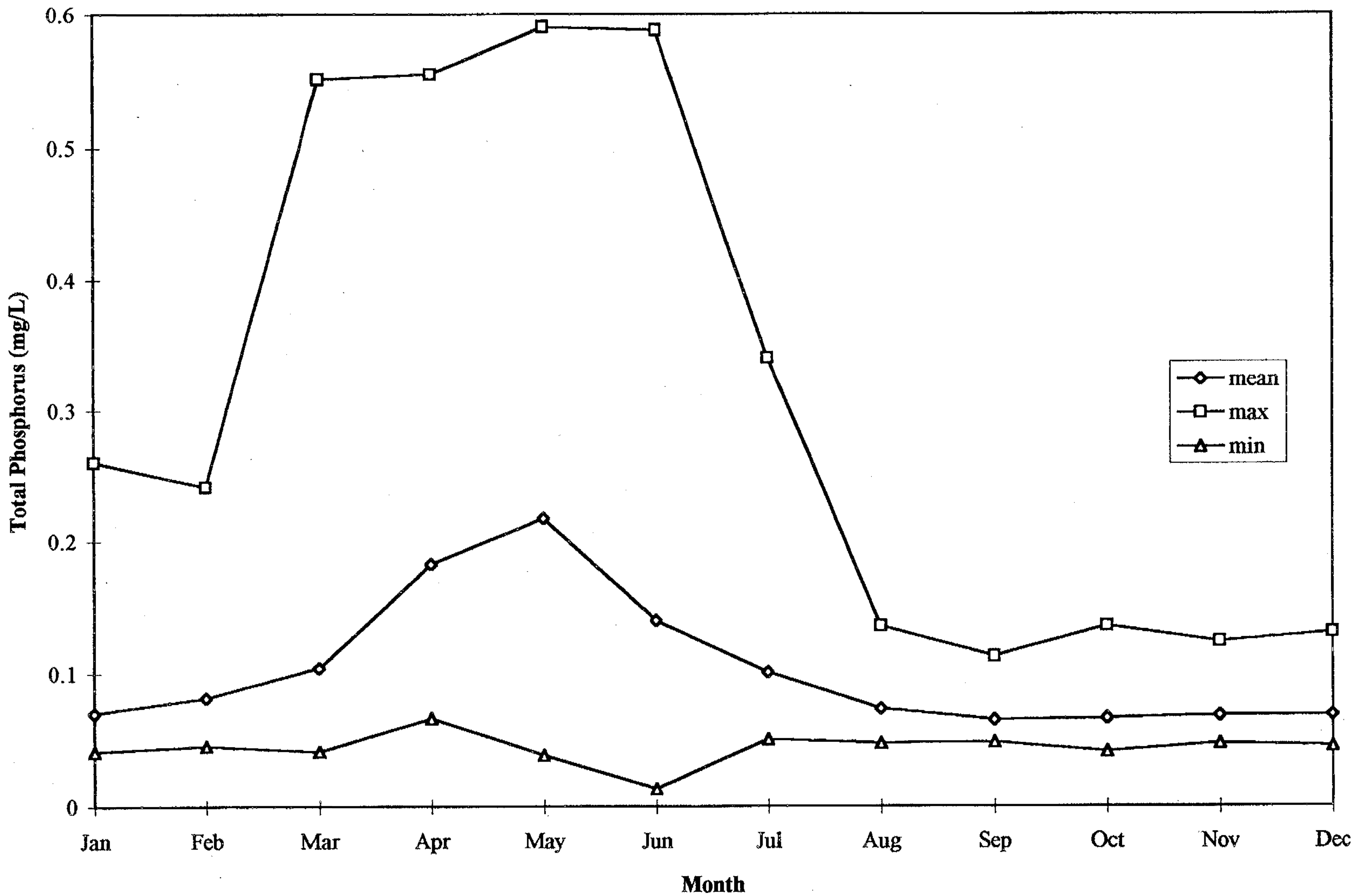


Figure 10.20. Relationship between total phosphorus (TP) and discharge (Q) in the Salmon River at Salmon Arm.

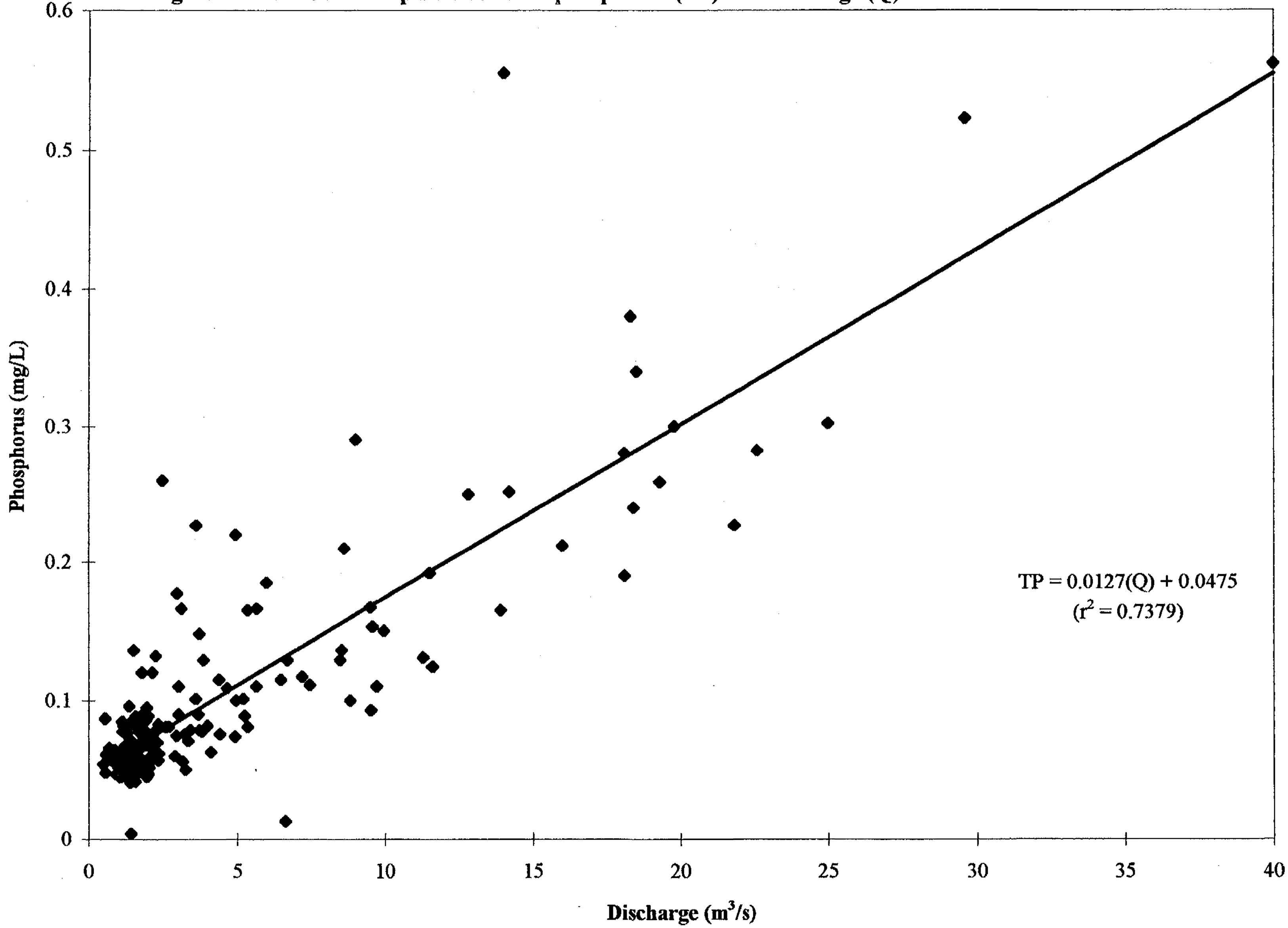


Figure 10.21. Relationship between total phosphate (PO_4) and non-filterable residue (NFR) in the Salmon River at Salmon Arm.

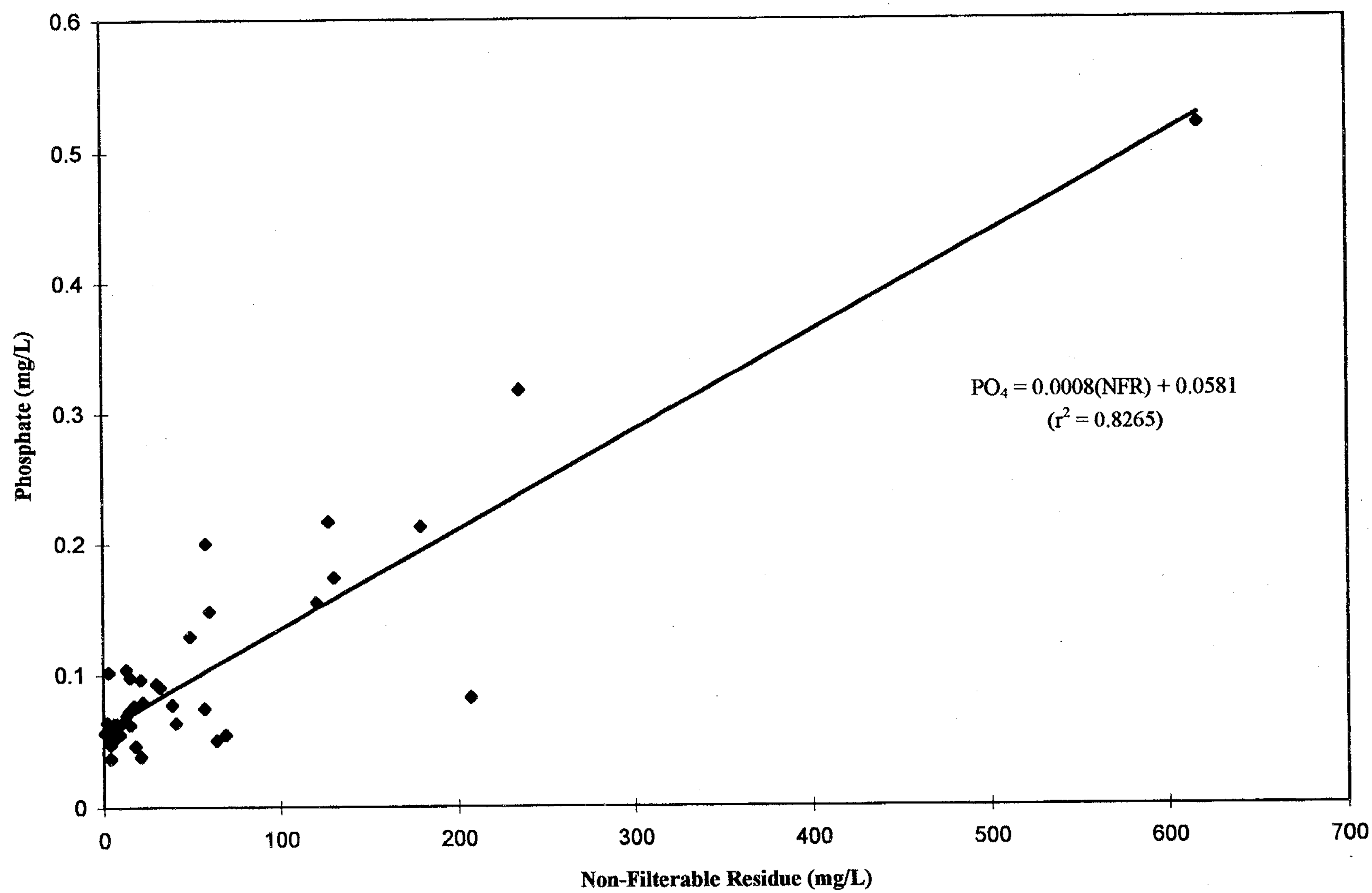


Figure 10.22. Longitudinal variability of total phosphate levels in the Salmon River watershed (BCMOELP unpublished data).

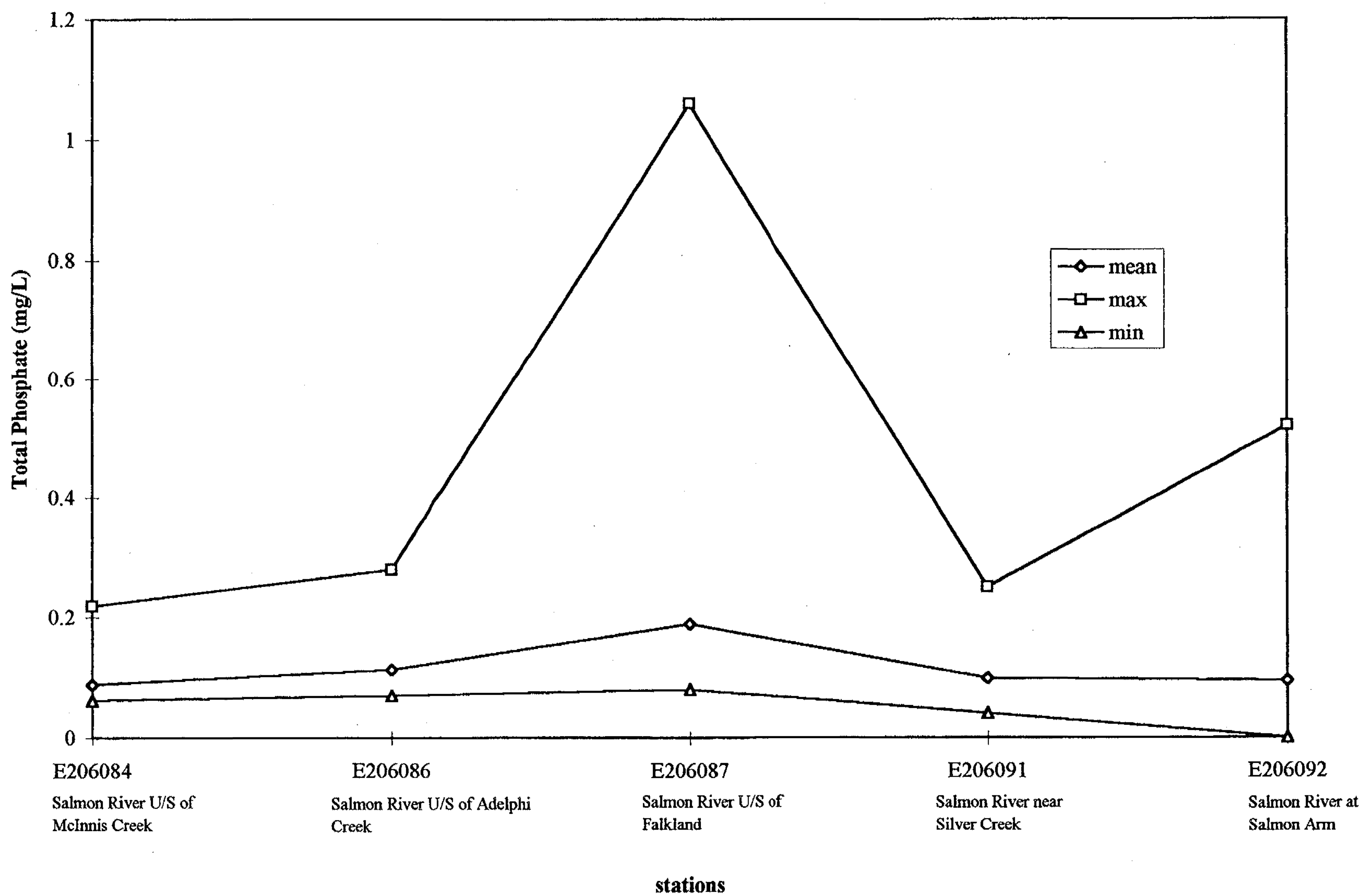


Figure 10.23. Longitudinal variability of ortho-phosphate levels in the Salmon River watershed (BCMOELP unpublished data).

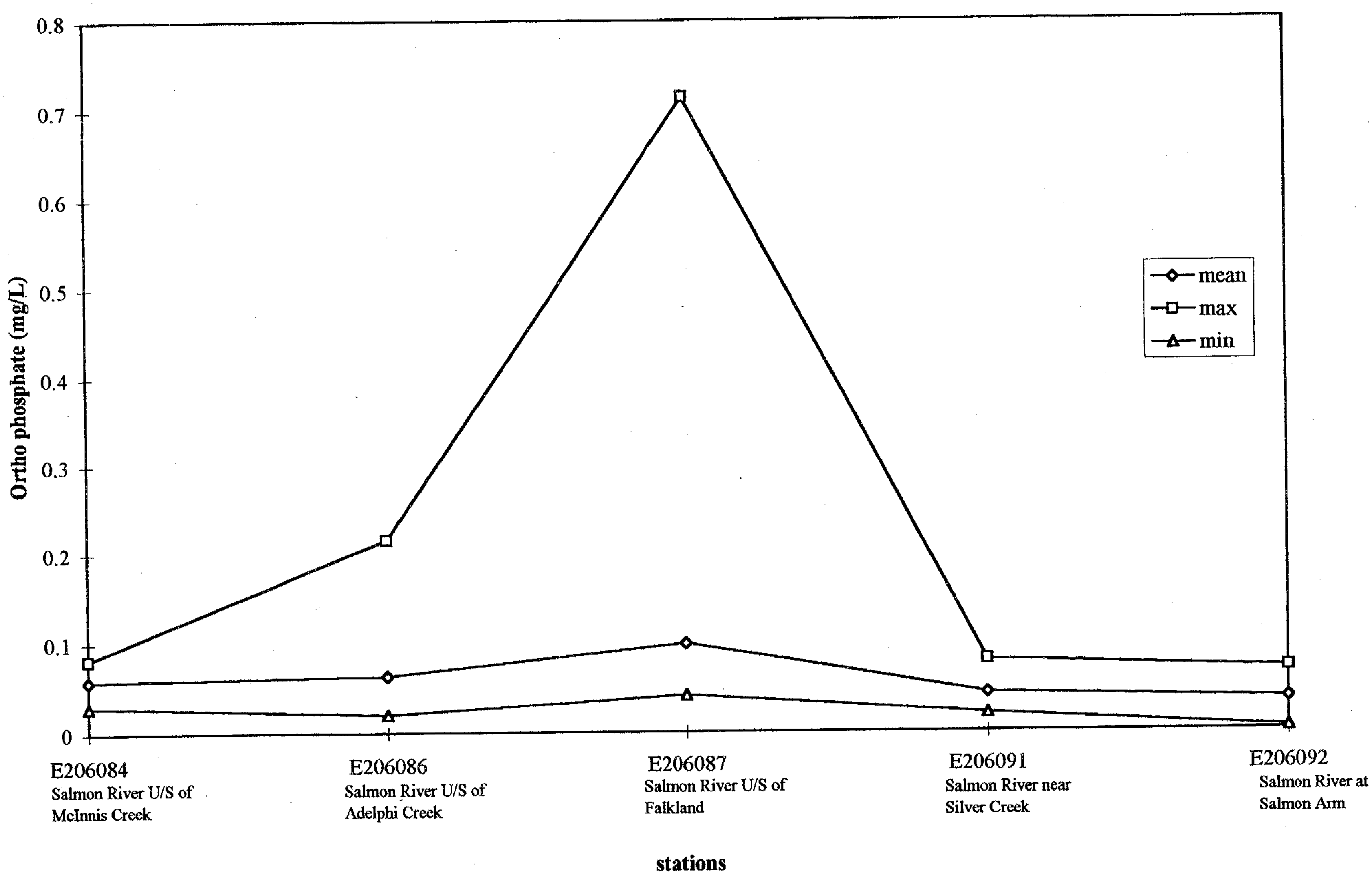


Figure 10.24. Annual summary of ortho-phosphorus data in the Salmon River at Salmon Arm, 1987-1995 (from Regnier and Shaw 1997).

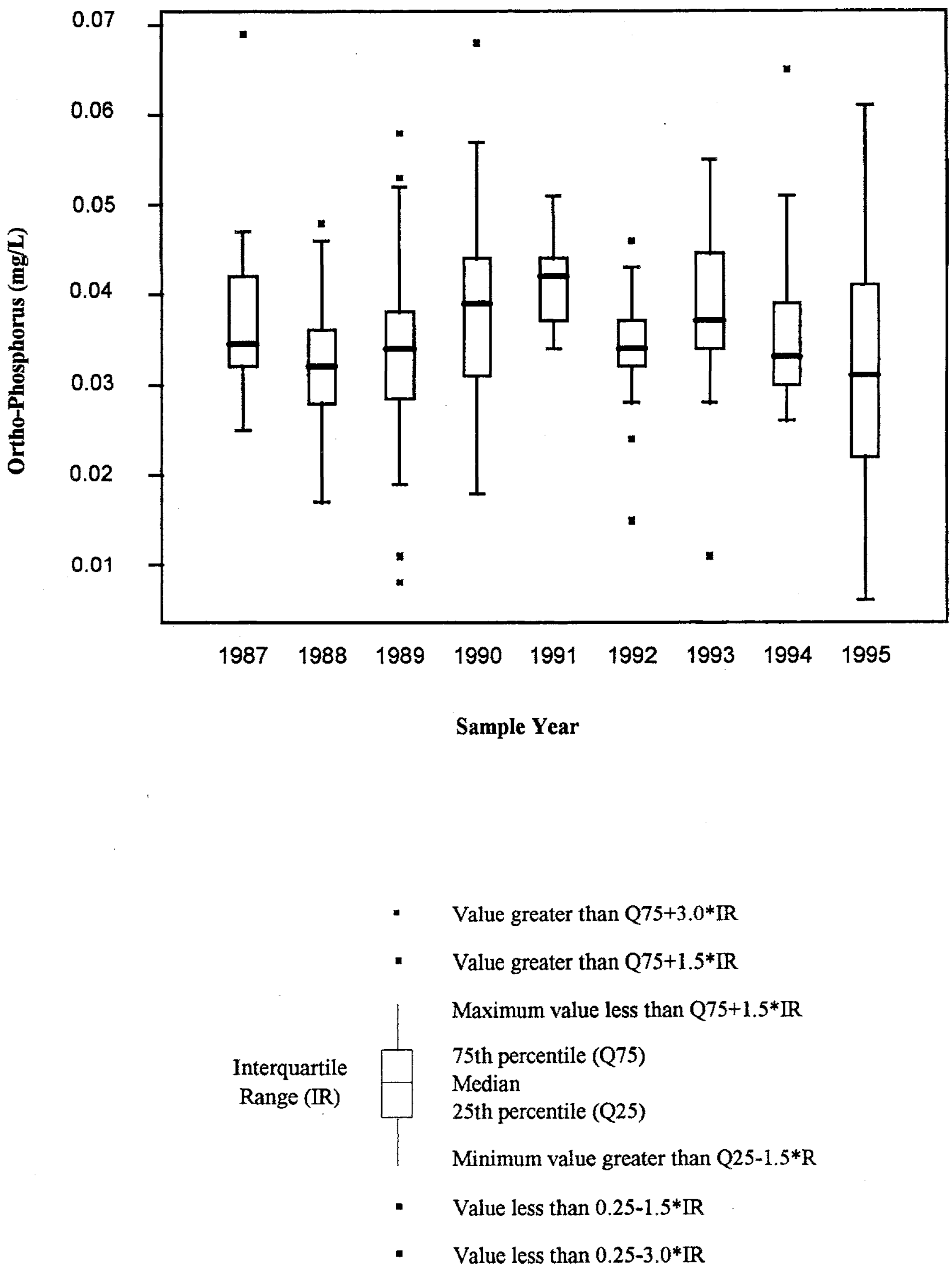


Figure 10.25. A summary of available total dissolved ammonia data for the Salmon River at Salmon Arm (BCMOELP unpublished data).

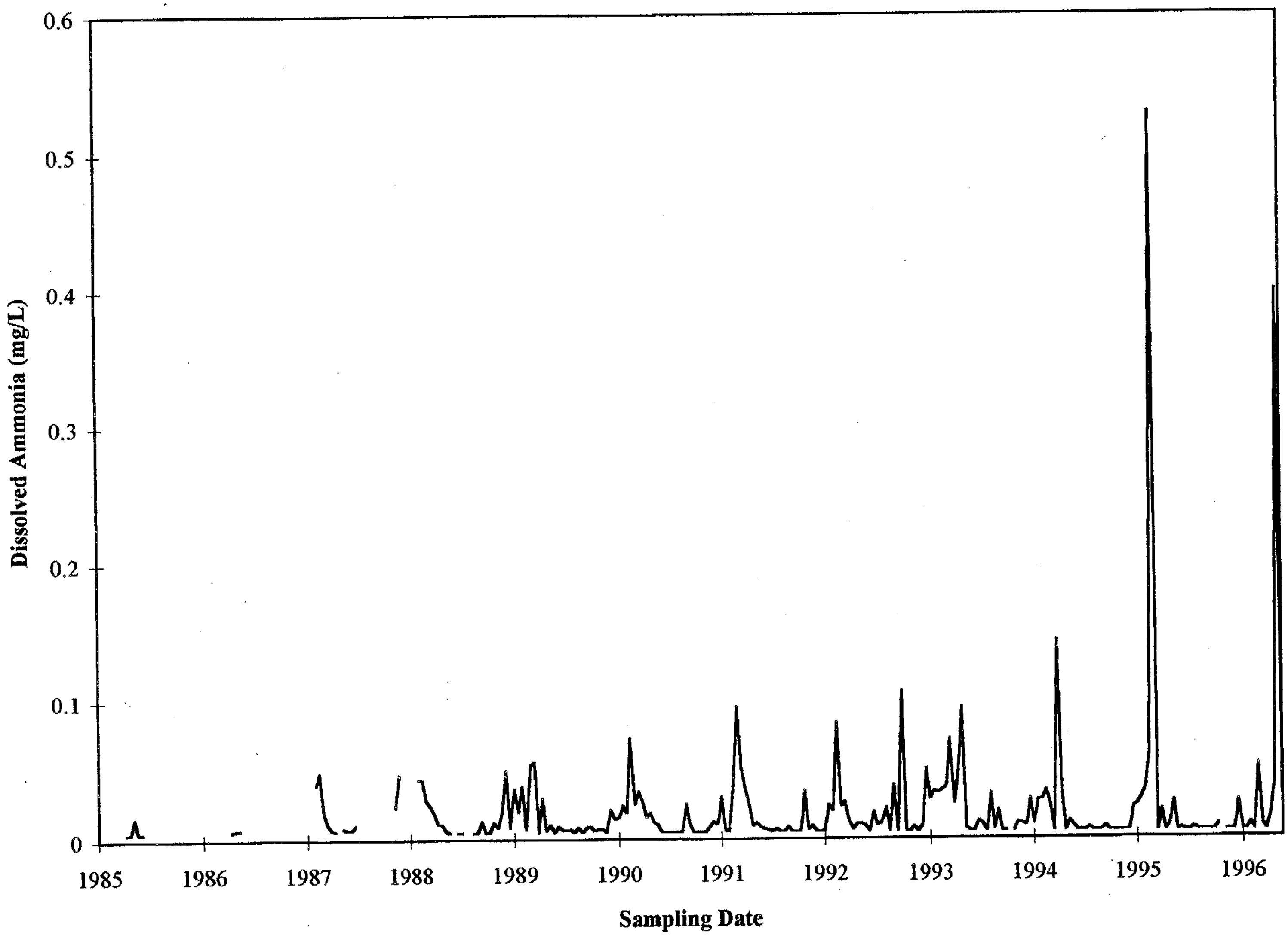


Figure 10.26. Annual summary of ammonia data in the Salmon River at Salmon Arm, 1987-1995 (from Regnier and Shaw 1997).

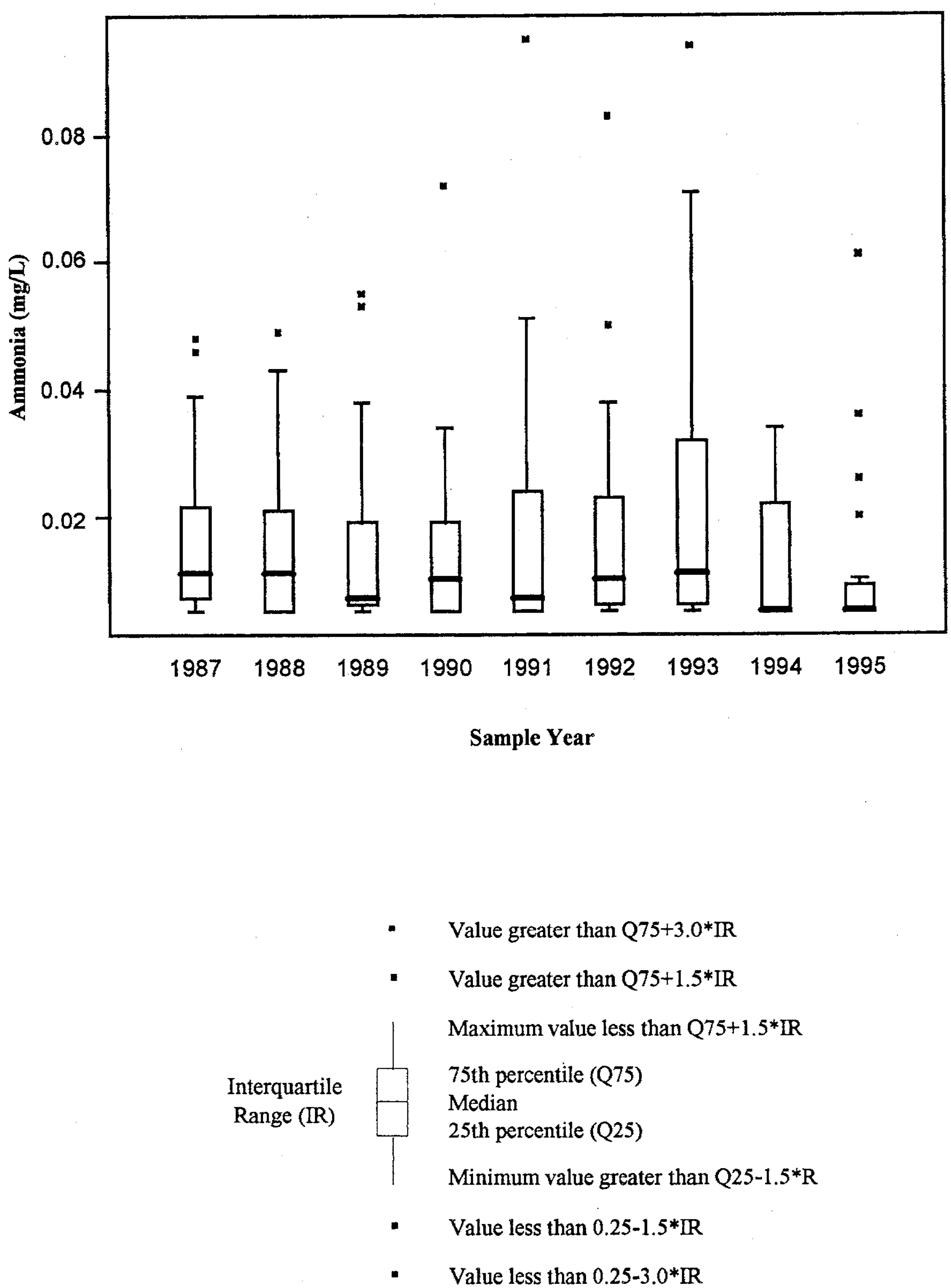
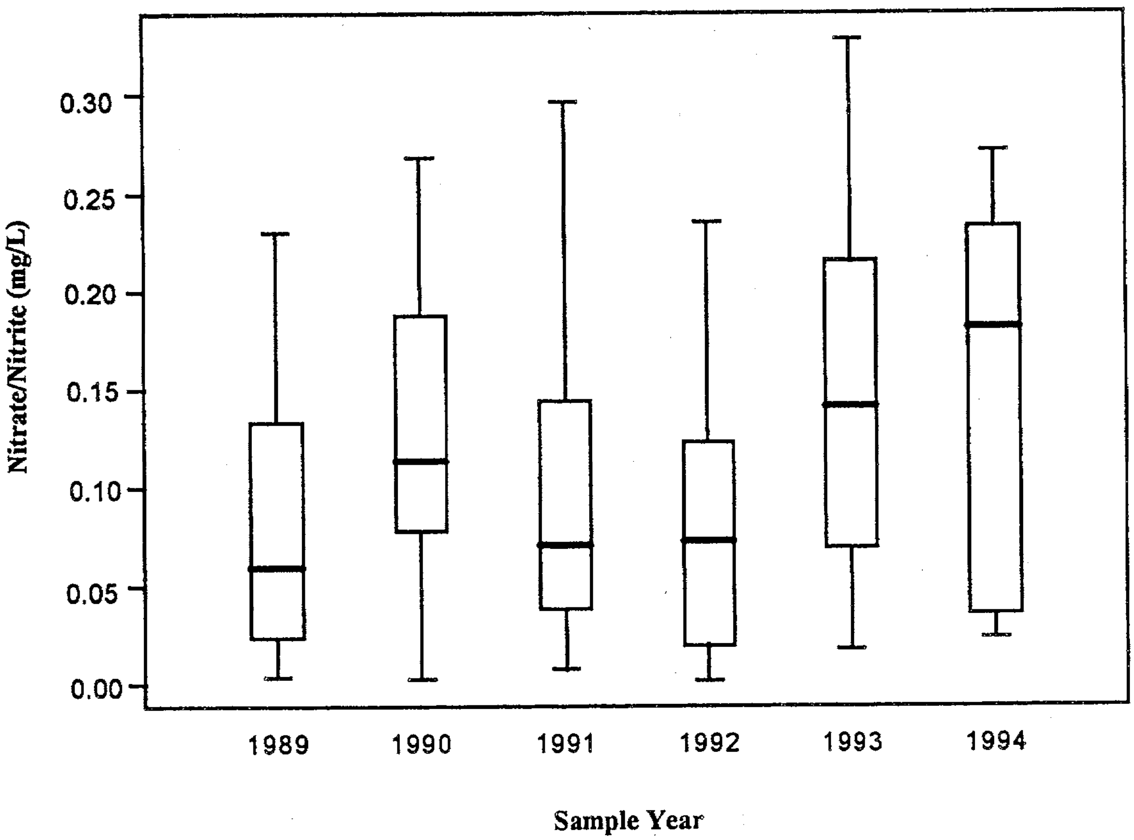


Figure 10.27. Annual summary of nitrate/nitrite data in the Salmon River at Salmon Arm, 1989-1994 (from Regnier and Shaw 1997).



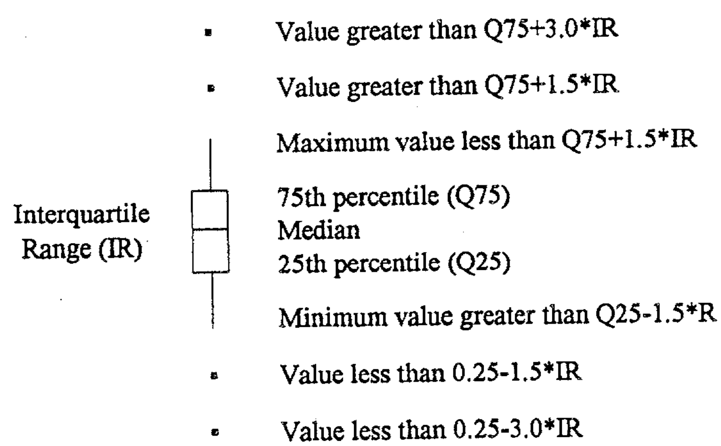


Figure 10.28. Annual summary of Kjeldahl nitrogen data in the Salmon River at Salmon Arm, 1987-1996 (from Regnier and Shaw 1997).

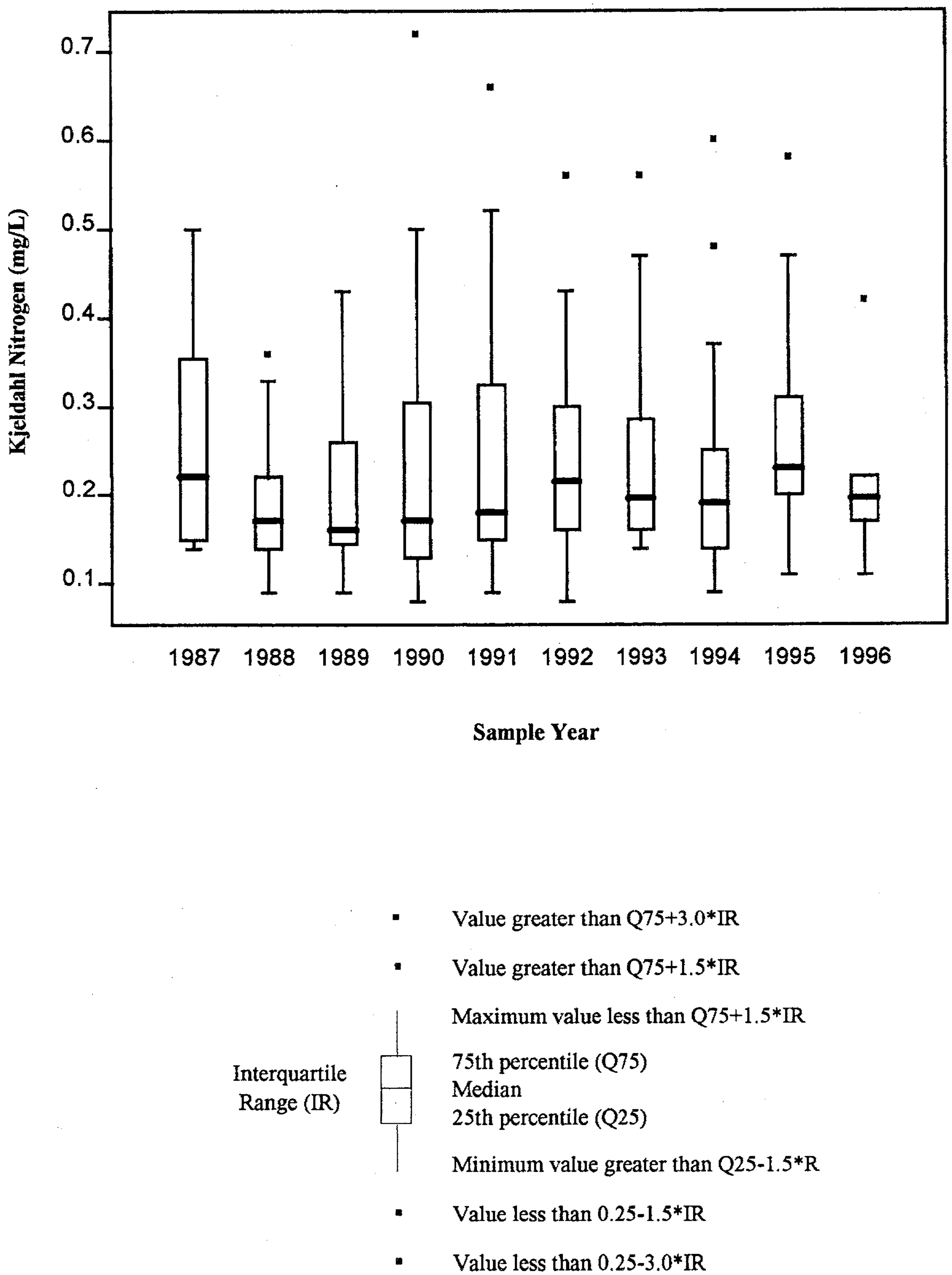


Figure 10.29. Annual summary of dissolved nitrogen data in the Salmon River at Salmon Arm, 1989-1994 (from Regnier and Shaw 1997).

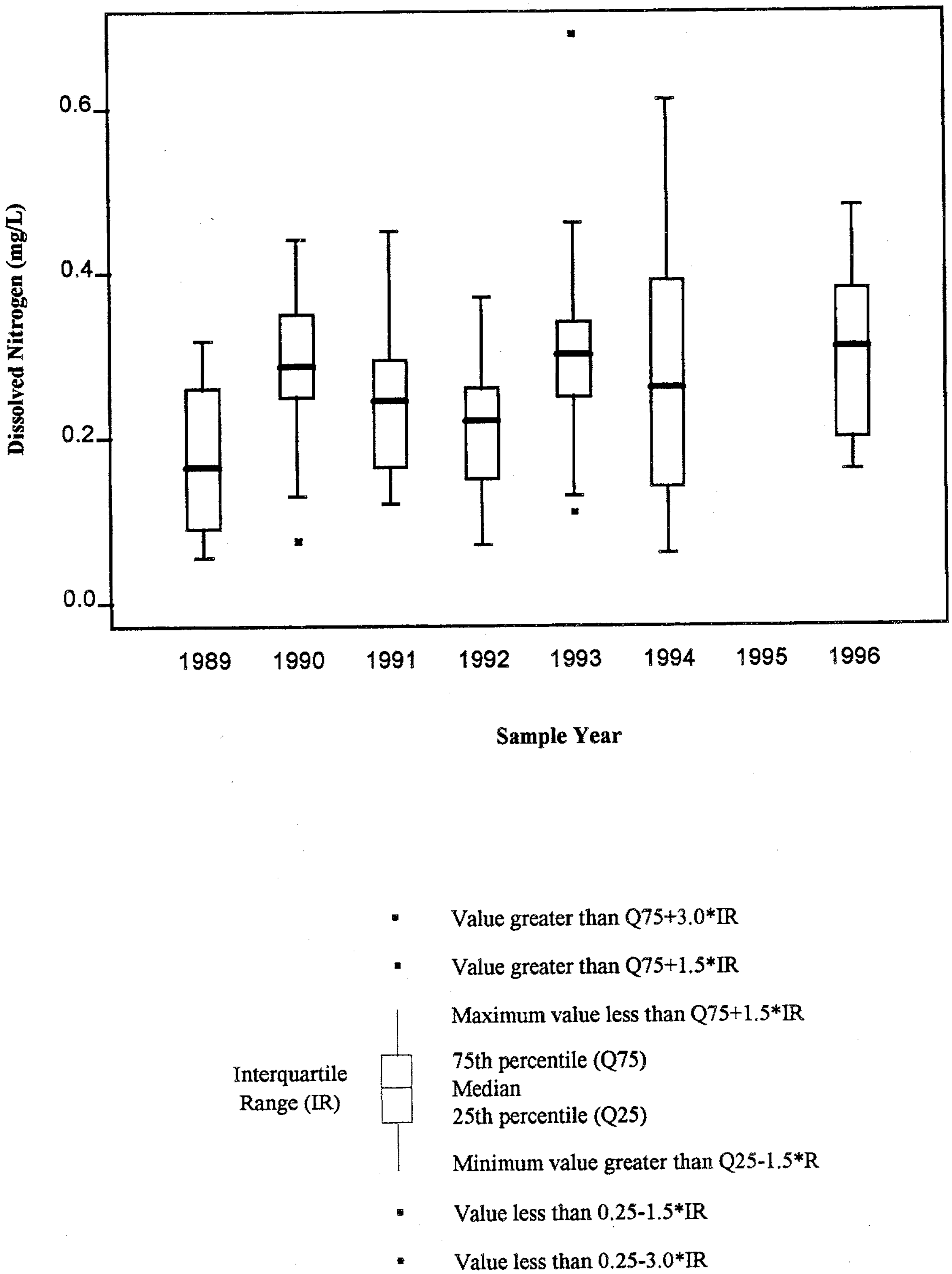


Figure 10.30. Monthly dissolved ammonia levels in the Salmon River at Salmon Arm (BCMOELP unpublished data).

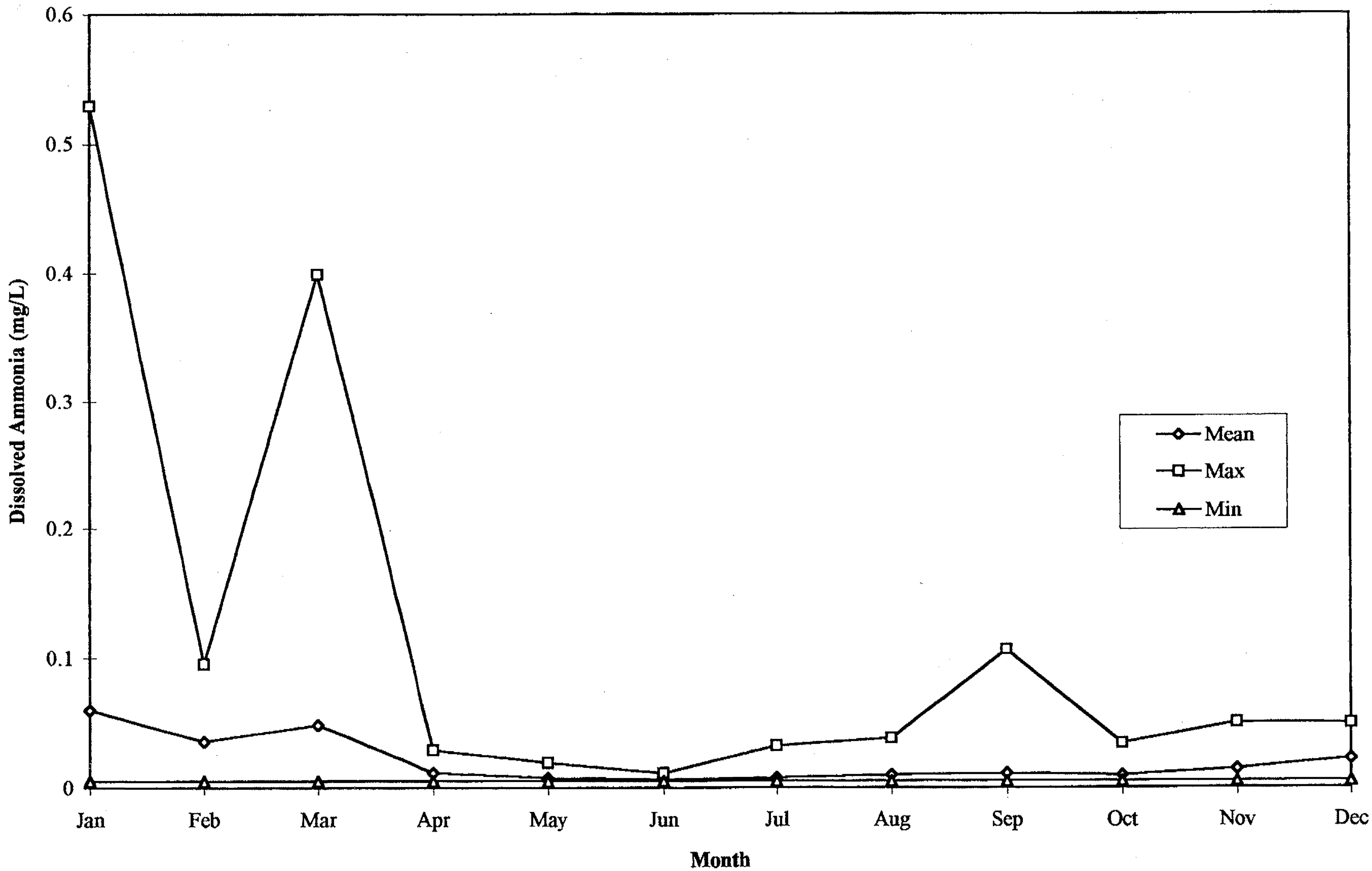


Figure 10.31. Longitudinal variability of dissolved ammonia in the Salmon River watershed (BCMOELP unpublished data).

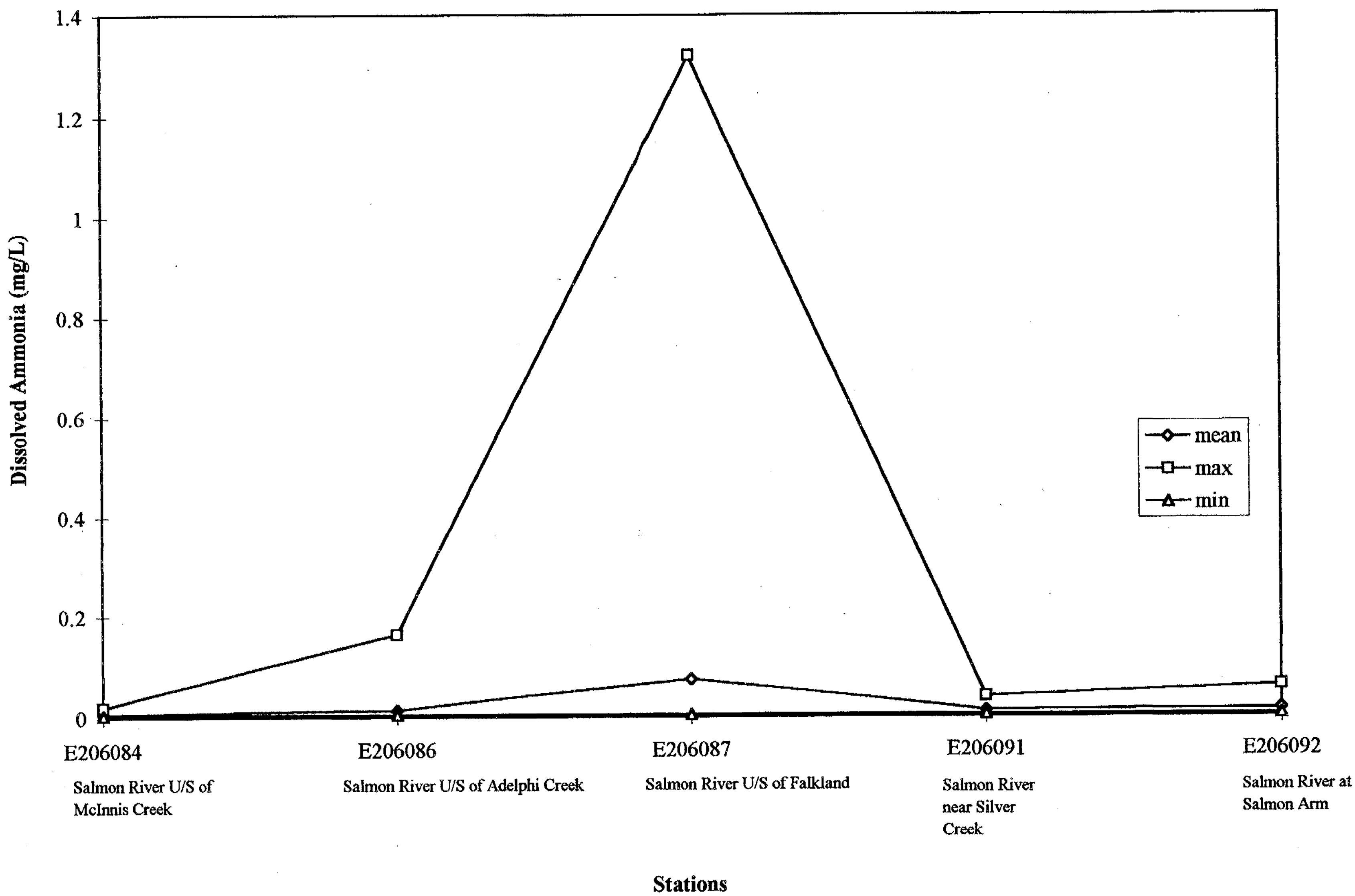


Figure 10.32. A summary of available faecal coliform data for the Salmon River at Salmon Arm (BCMOELP unpublished data).

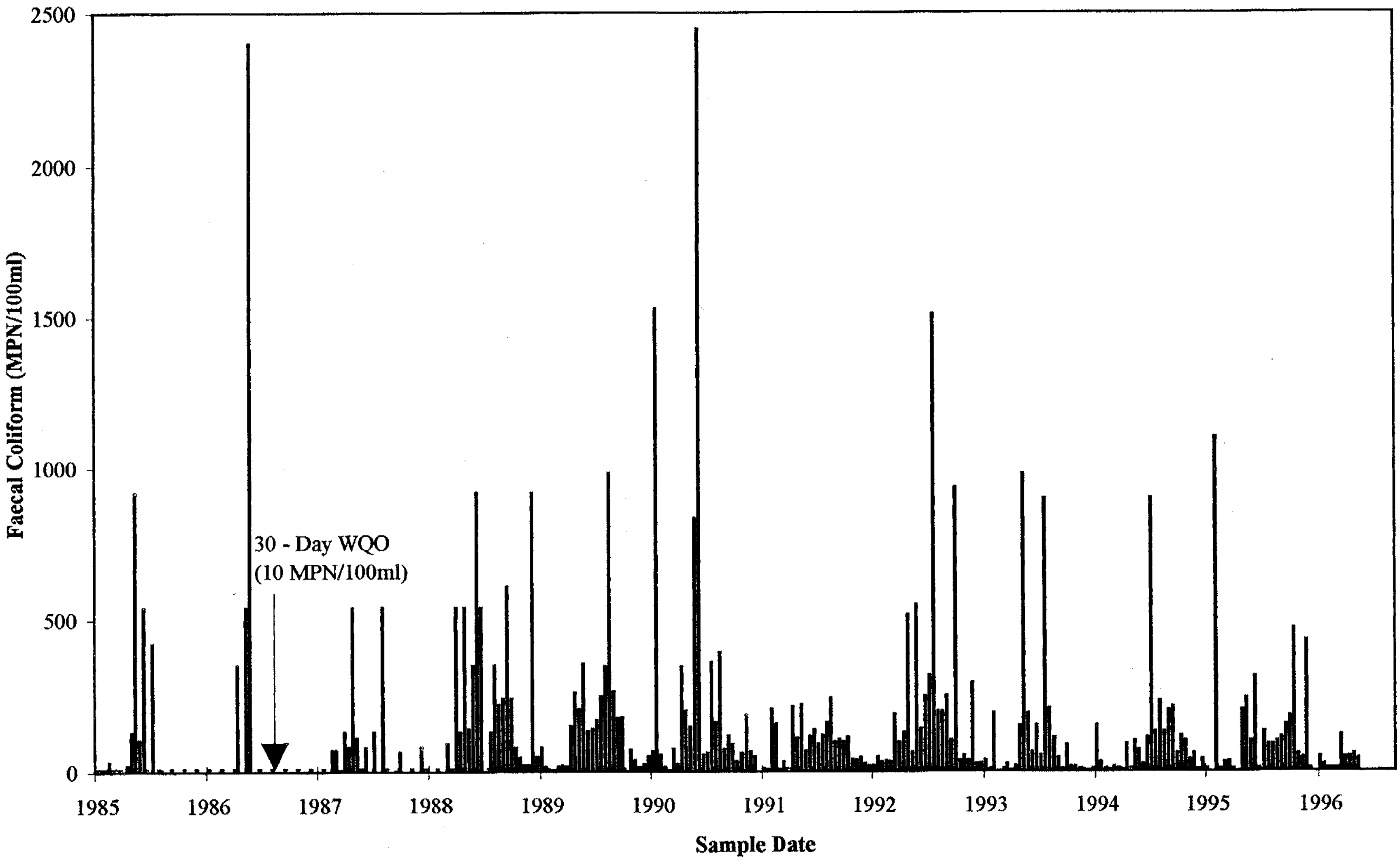


Figure 10.33. Longitudinal variability of faecal coliform in the Salmon River watershed (BCMOELP unpublished data).

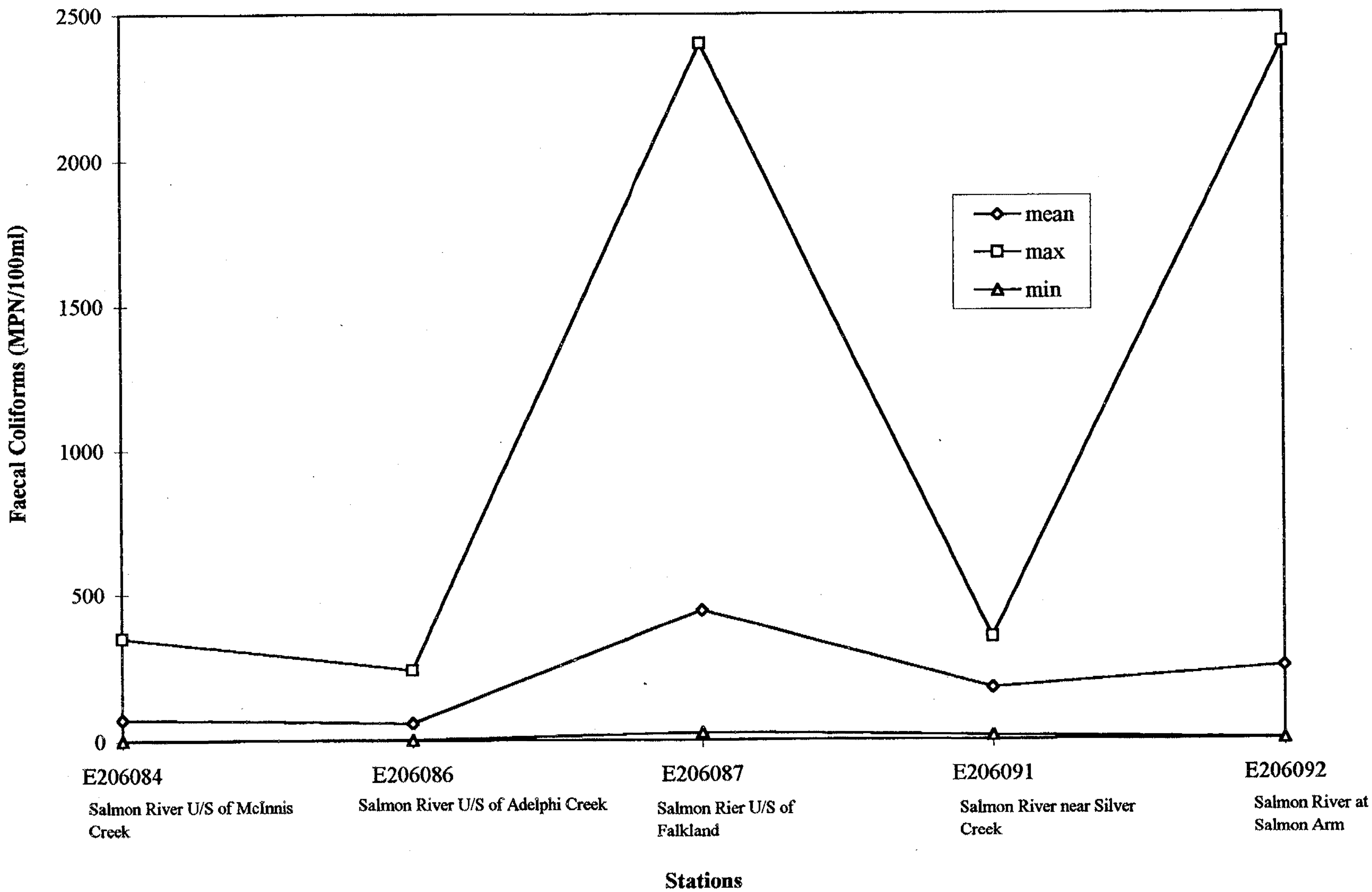


Figure 10.34. Mean monthly faecal coliform levels in the Salmon River at Salmon Arm (BCMOELP unpublished data).

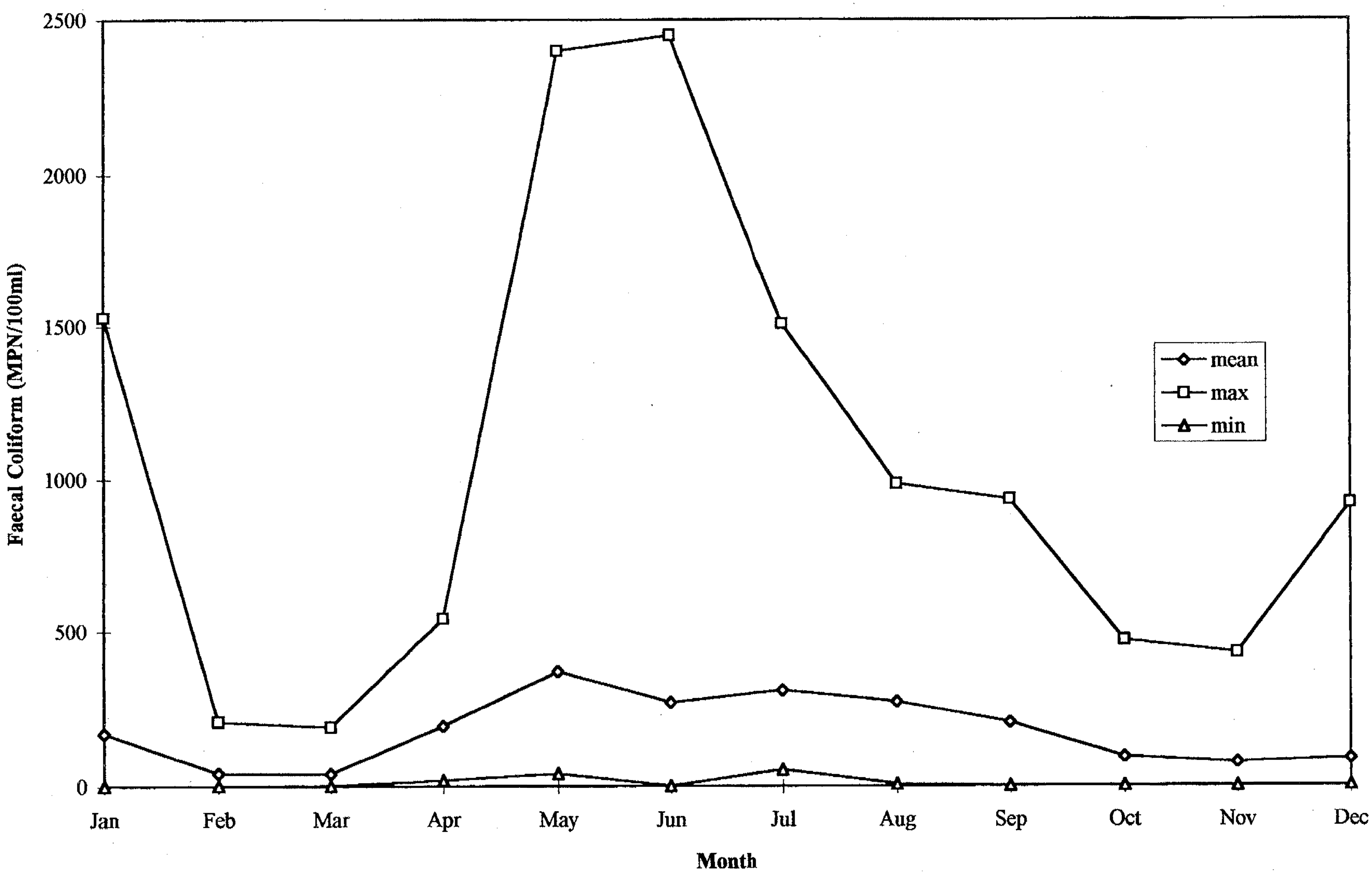


Figure 10.35. Annual summary of faecal coliform data in the Salmon Riverat Salmon Arm, 1988-1995 (from Regnier and Shaw 1997).

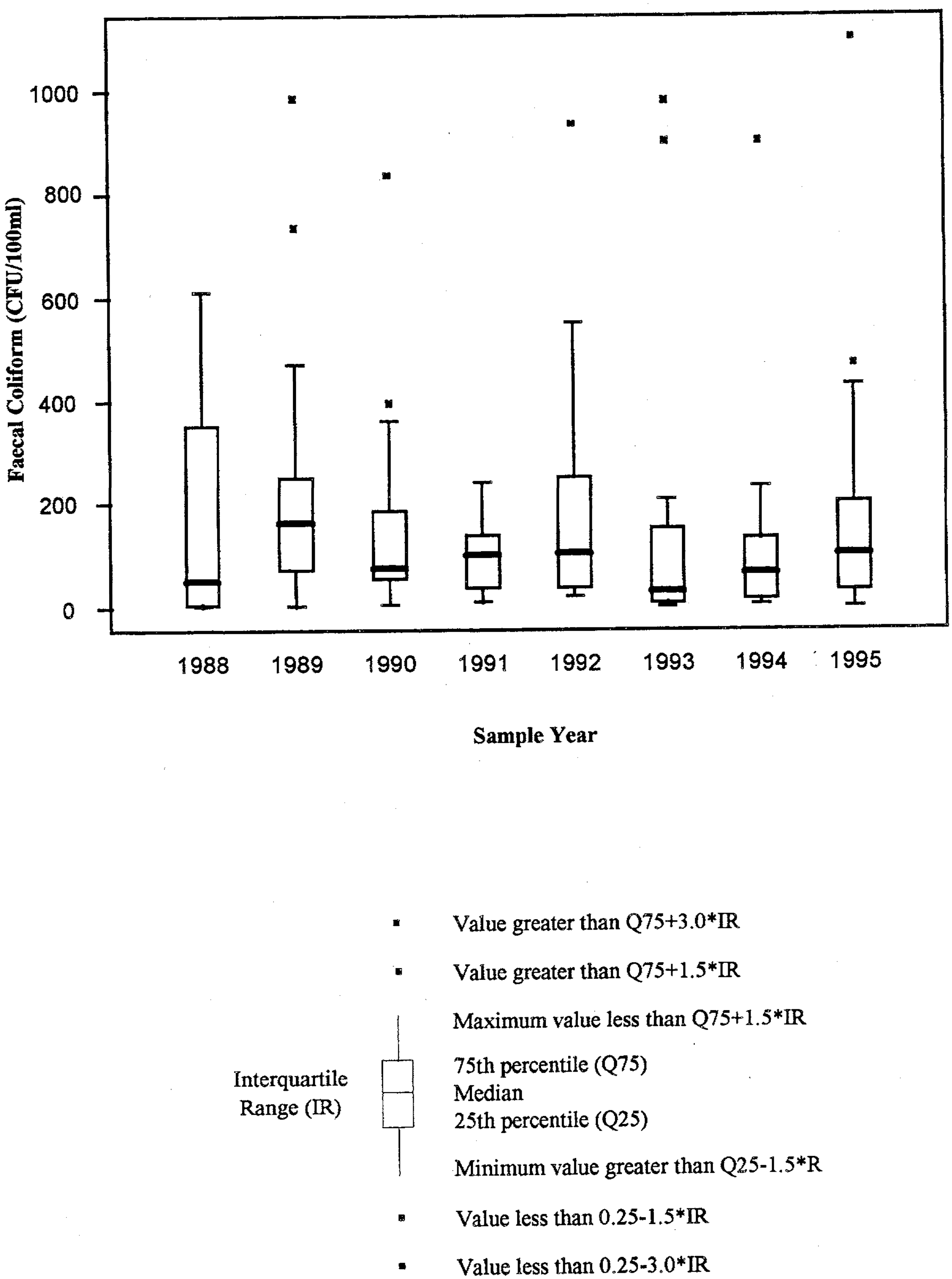


Figure 10.36. A summary of available total aluminum data for the Salmon River at Salmon Arm (Environment Canada unpublished data).

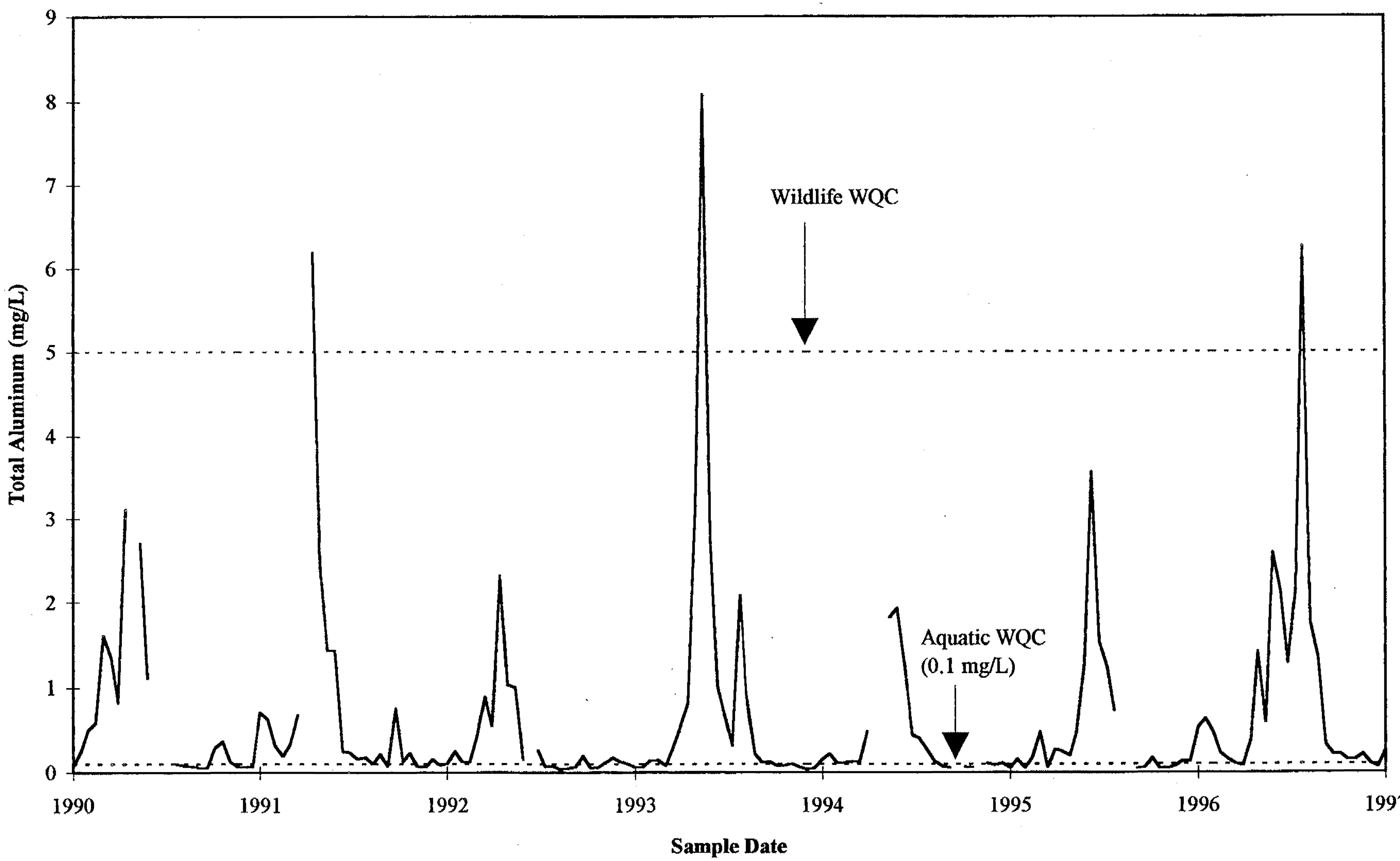


Figure 10.37. Relationship between total aluminum and non-filterable residue (NFR) in the Salmon River at Salmon Arm.

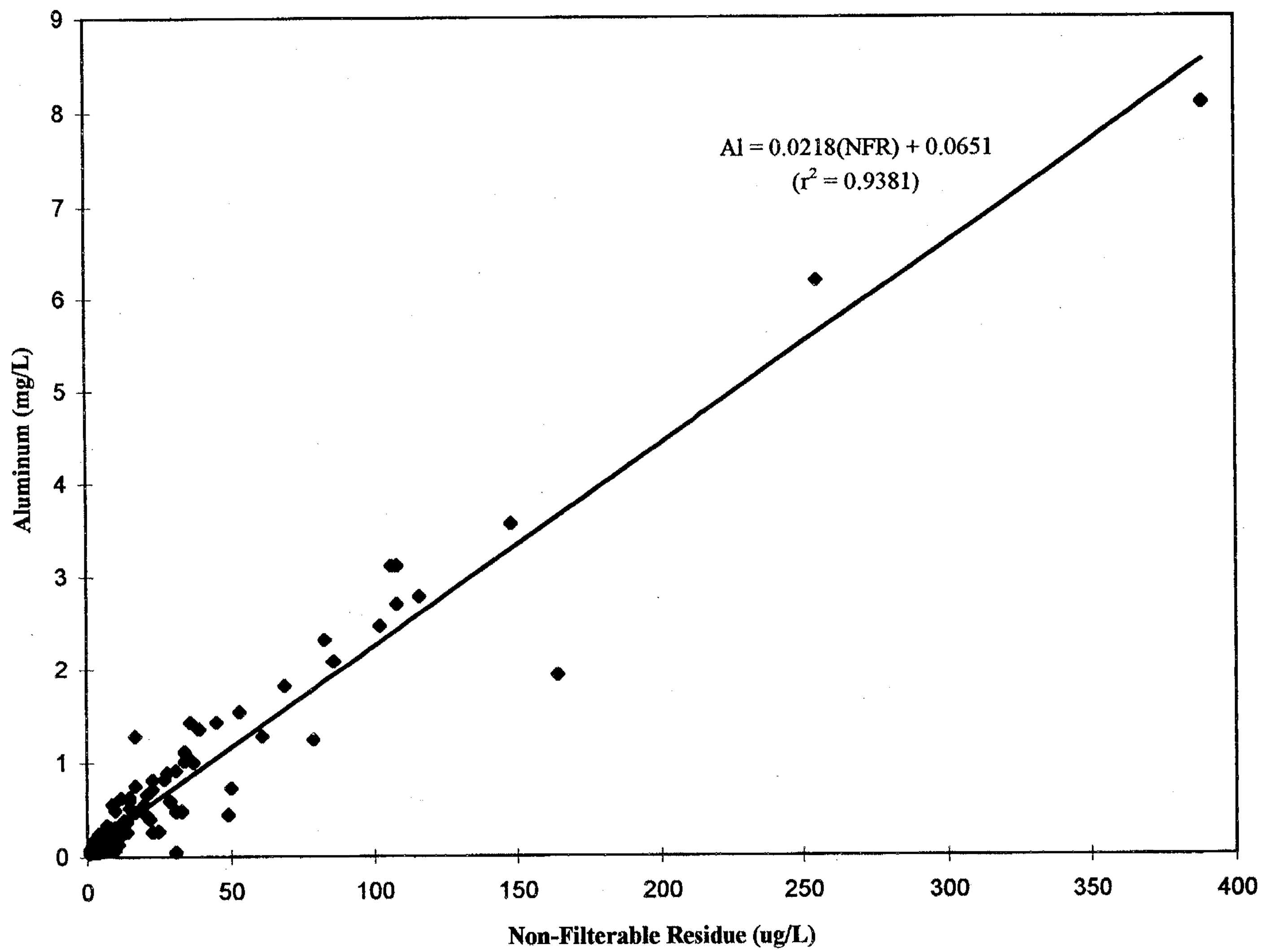


Figure 10.38. A summary of the available total cadmium data for the Salmon River at Salmon Arm (Environment Canada unpublished data).

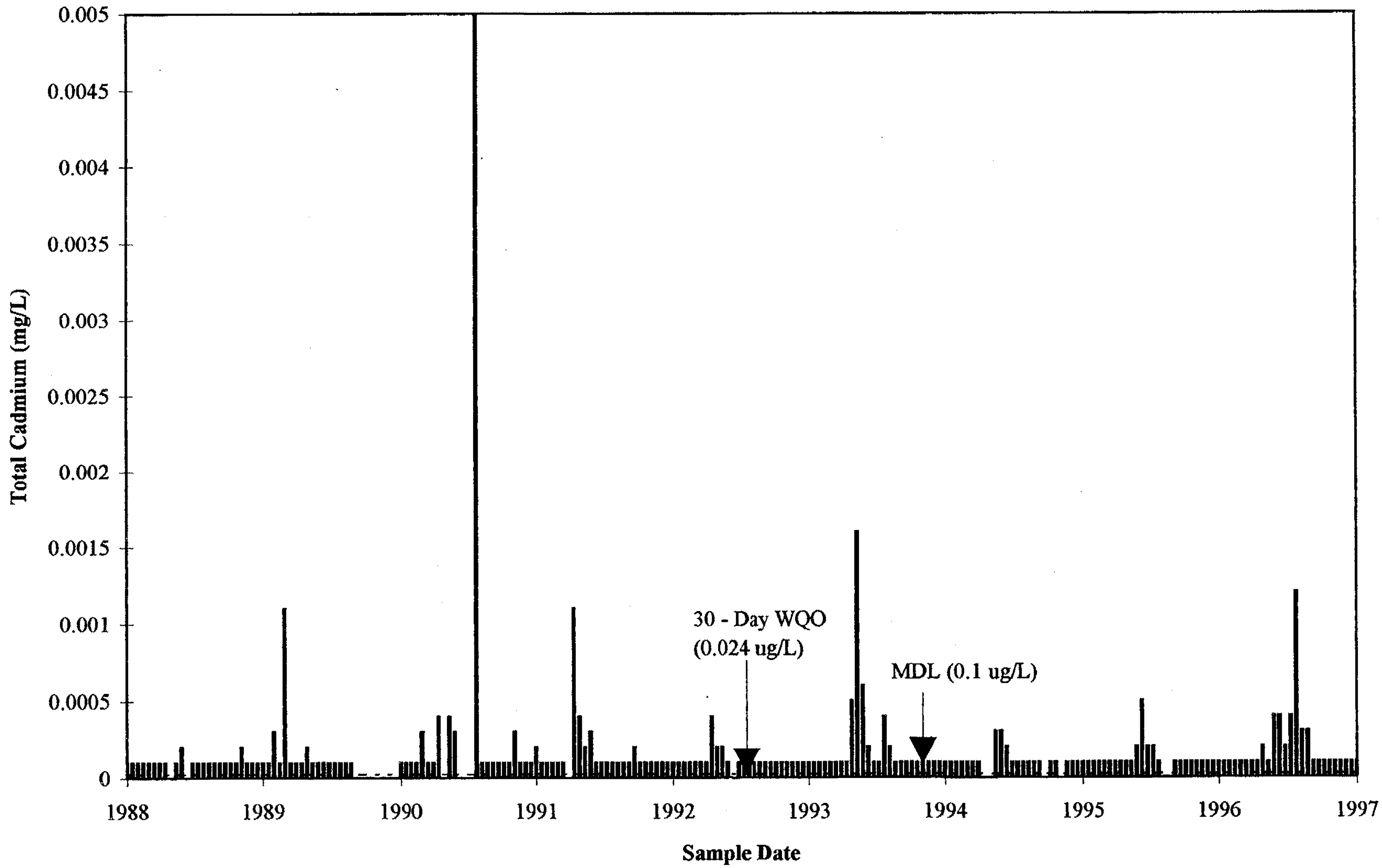


Figure 10.39. Relationship between total cadmium and non-filterable residue (NFR) in the Salmon River at Salmon Arm.

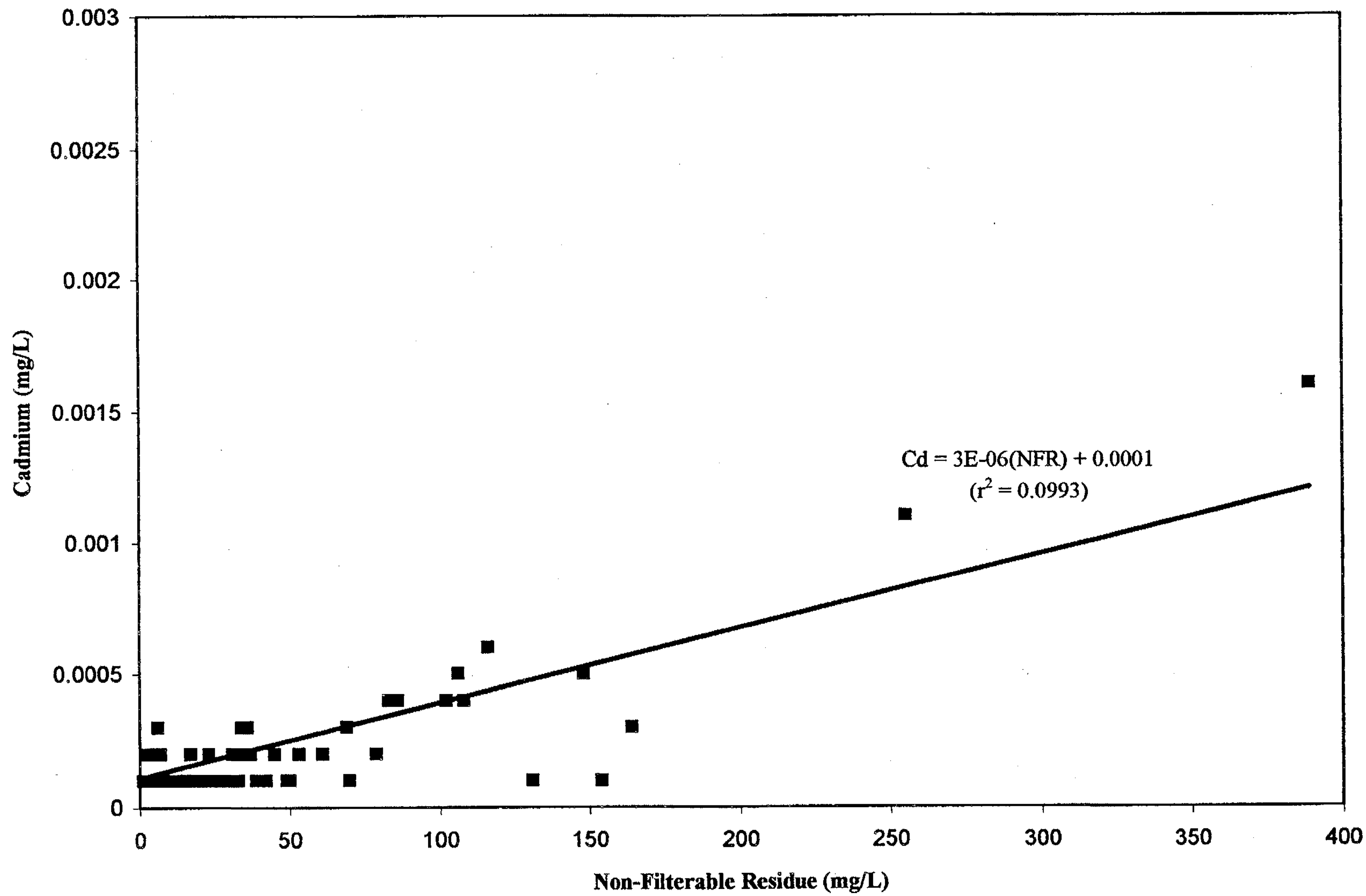


Figure 10.40. A summary of the available total chromium data for the Salmon River at Salmon Arm (Environment Canada unpublished data).

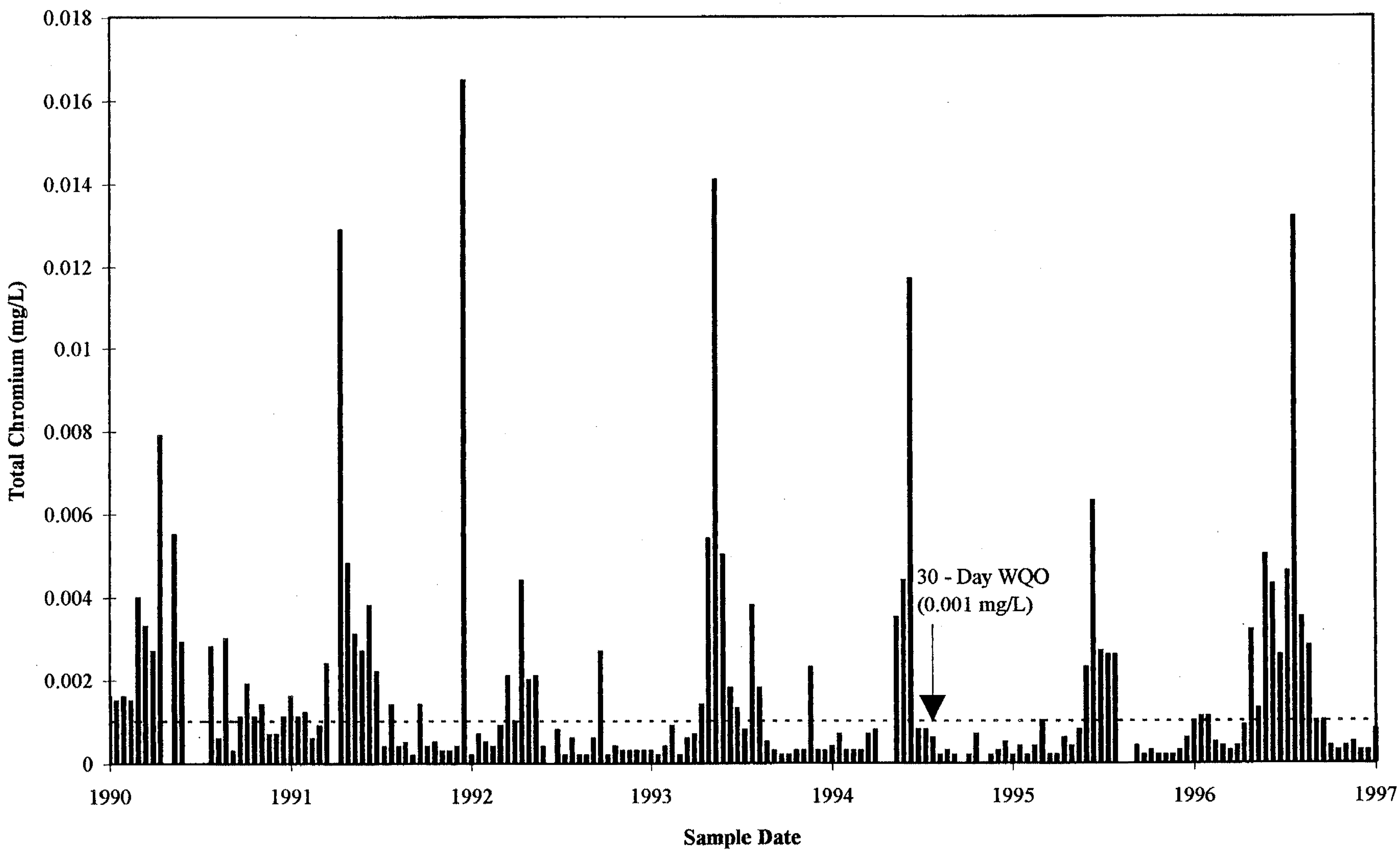


Figure 10.41. A summary of the available total cobalt data for the Salmon River at Salmon Arm (Environment Canada unpublished data).

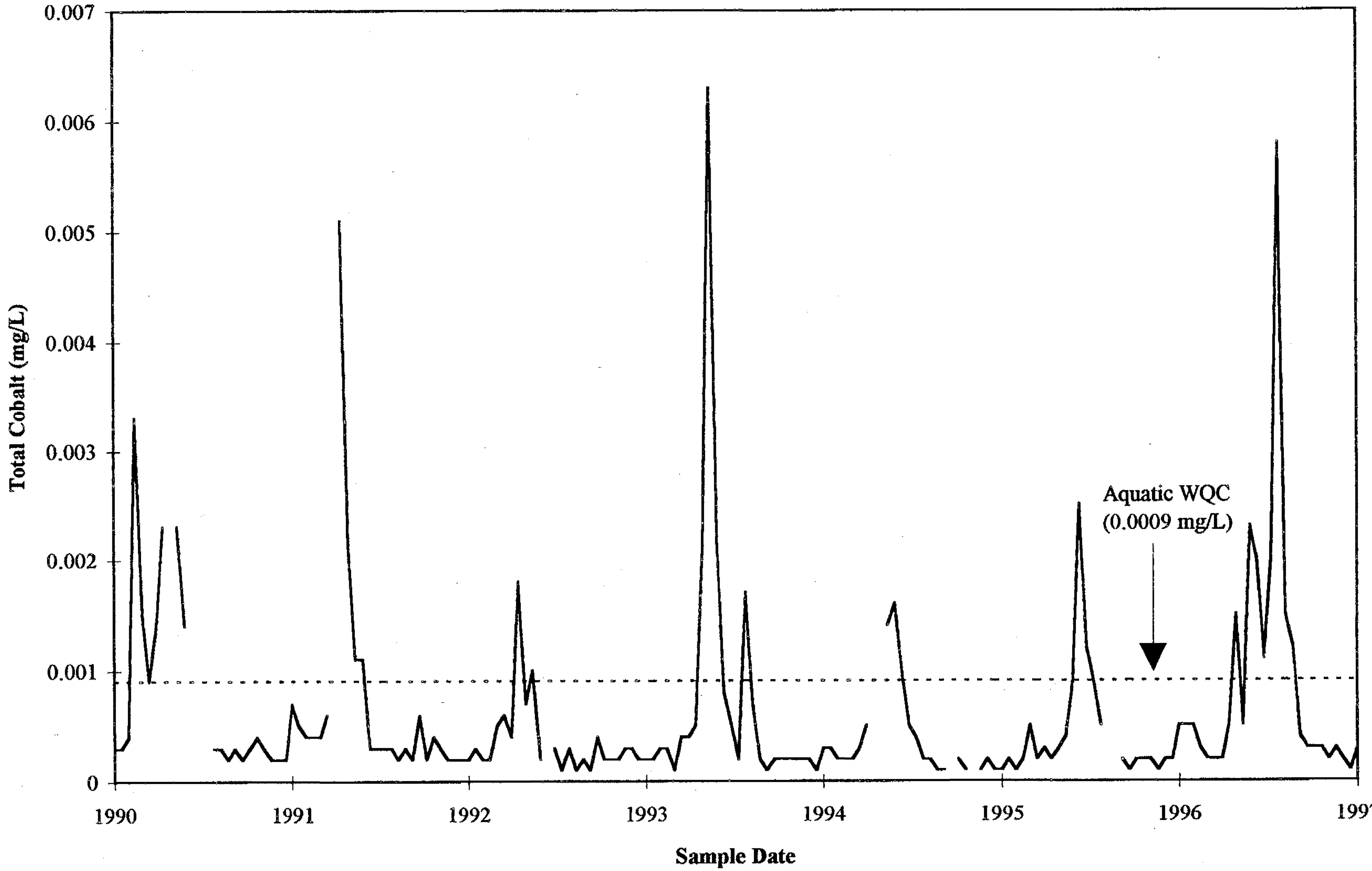


Figure 10.42. A summary of the available total copper data for the Salmon River at Salmon Arm (Environment Canada unpublished data).

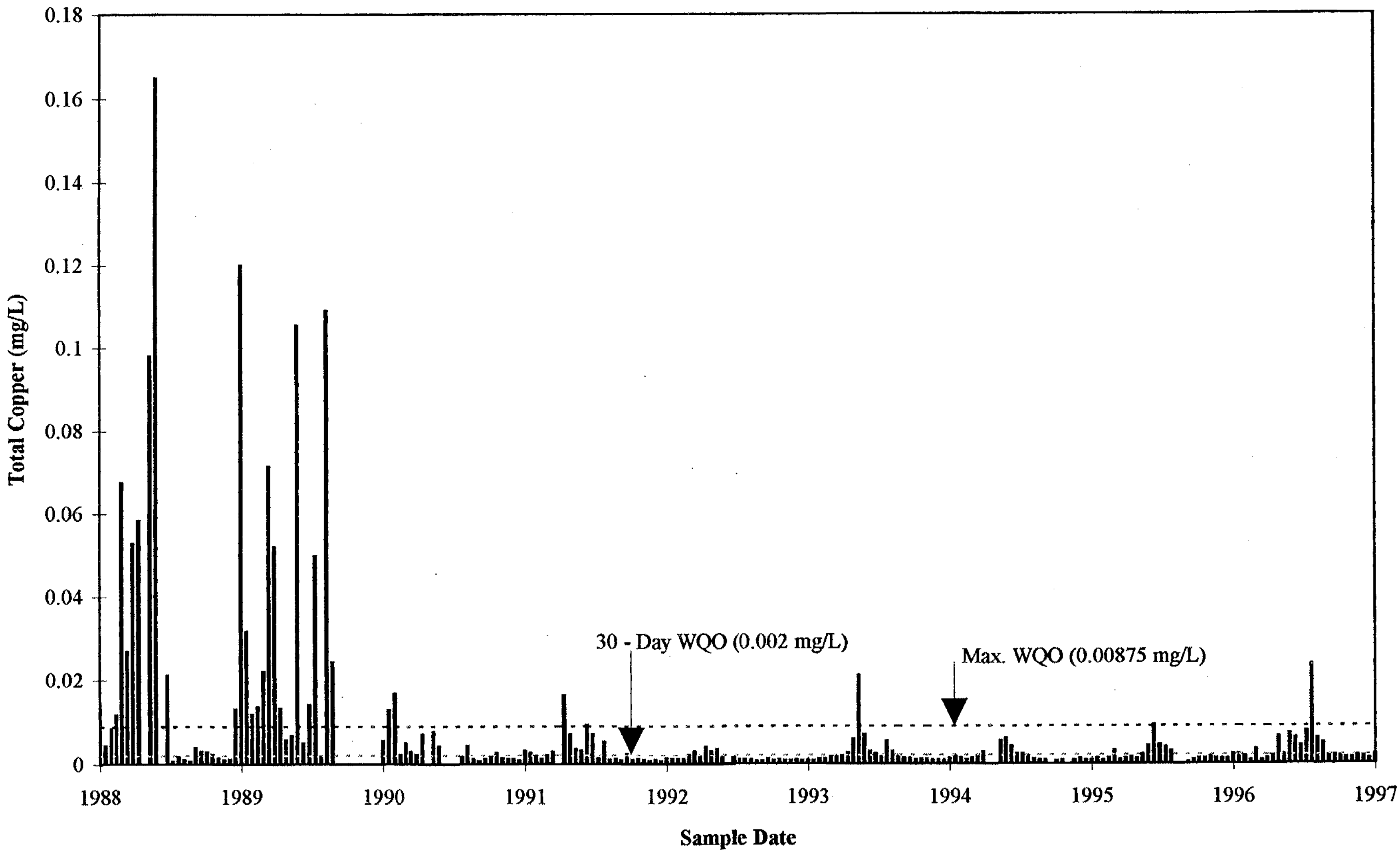


Figure 10.43. A summary of the available total iron data for the Salmon River at Salmon Arm (Environment Canada unpublished data).

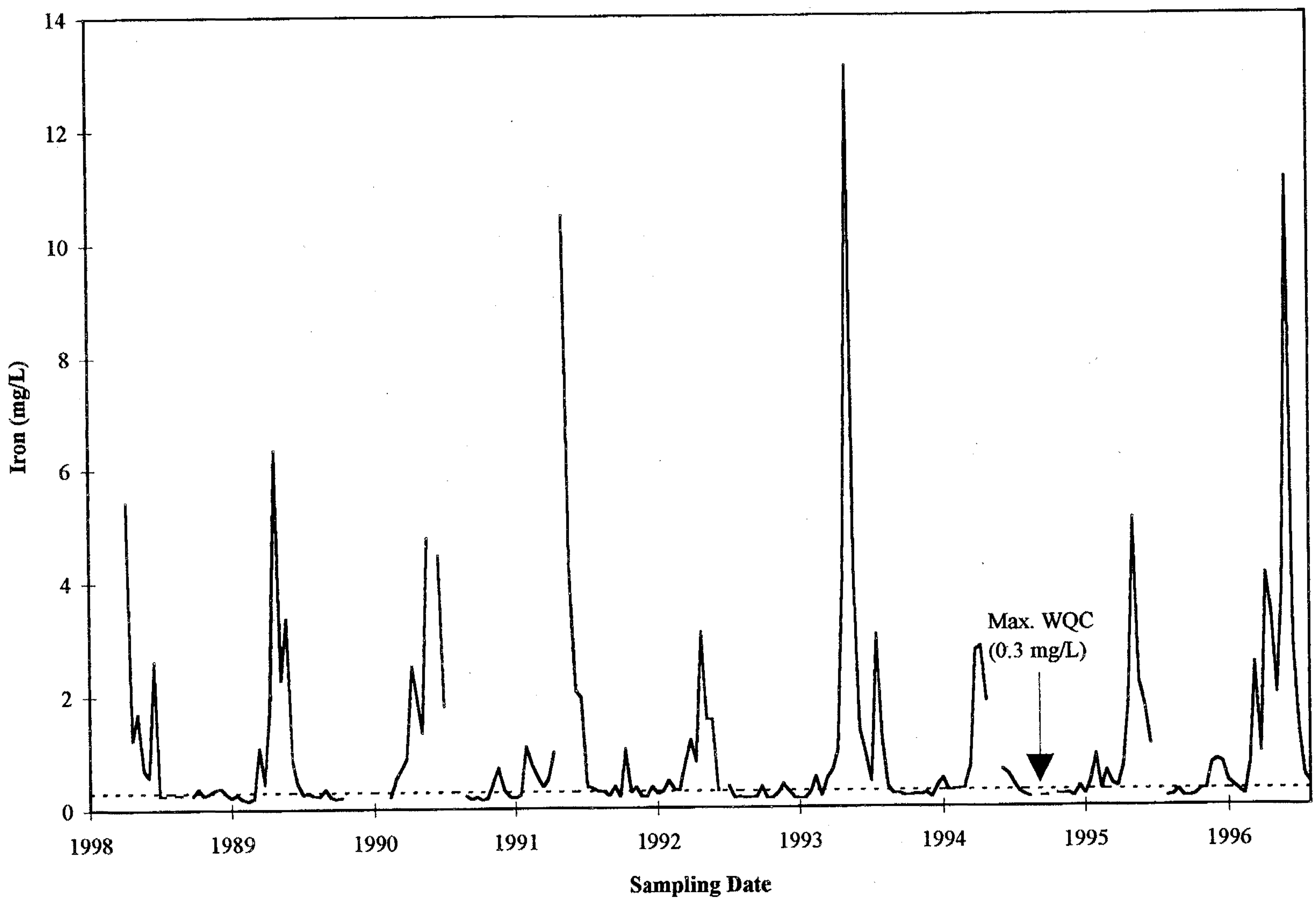


Figure 10.44. A summary of the available total manganese data for the Salmon River at Salmon Arm (Environment Canada unpublished data).

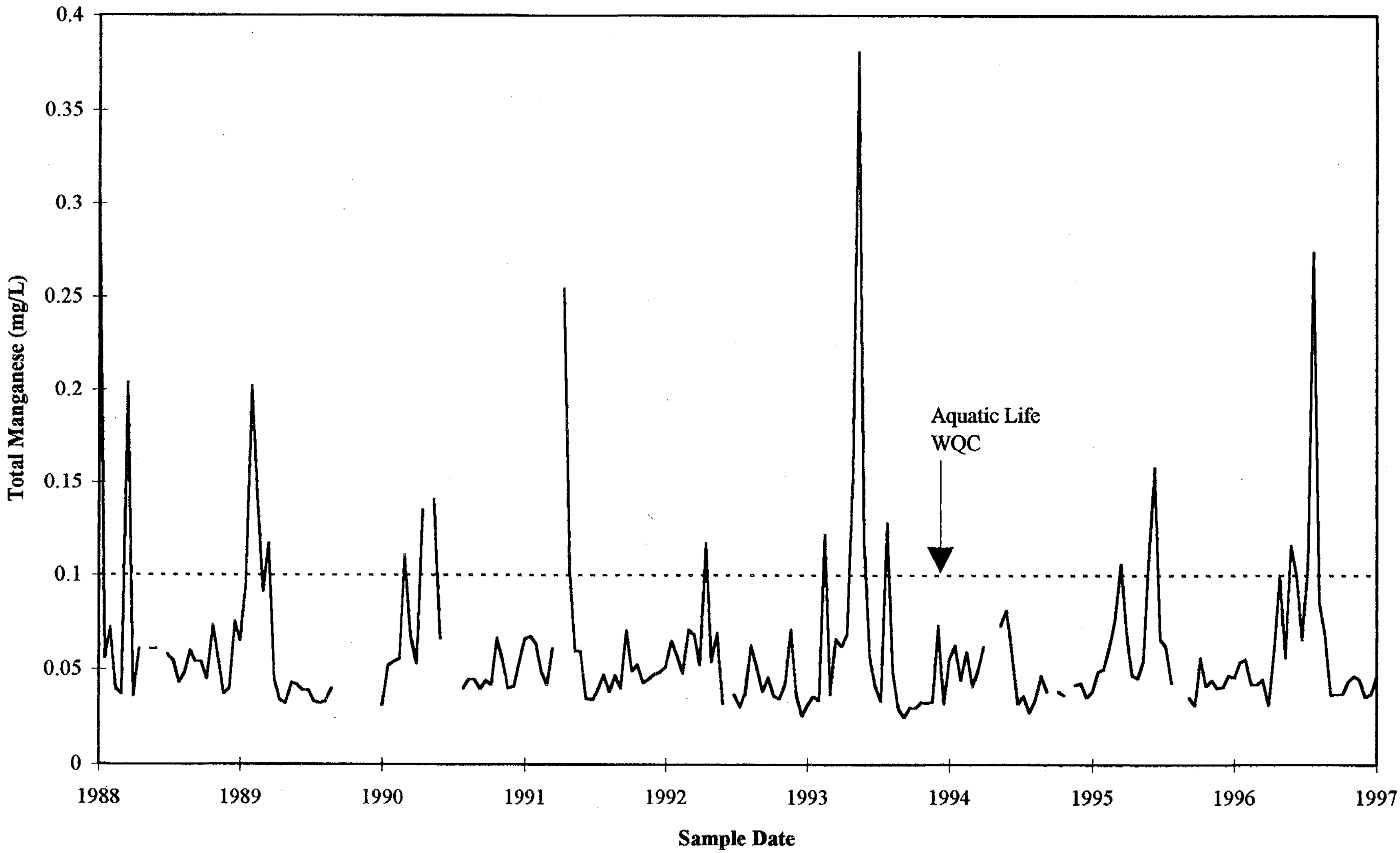


Figure 10.45. Relationship between total cobalt and non-filterable residue (NFR) in the Salmon River at Salmon Arm.

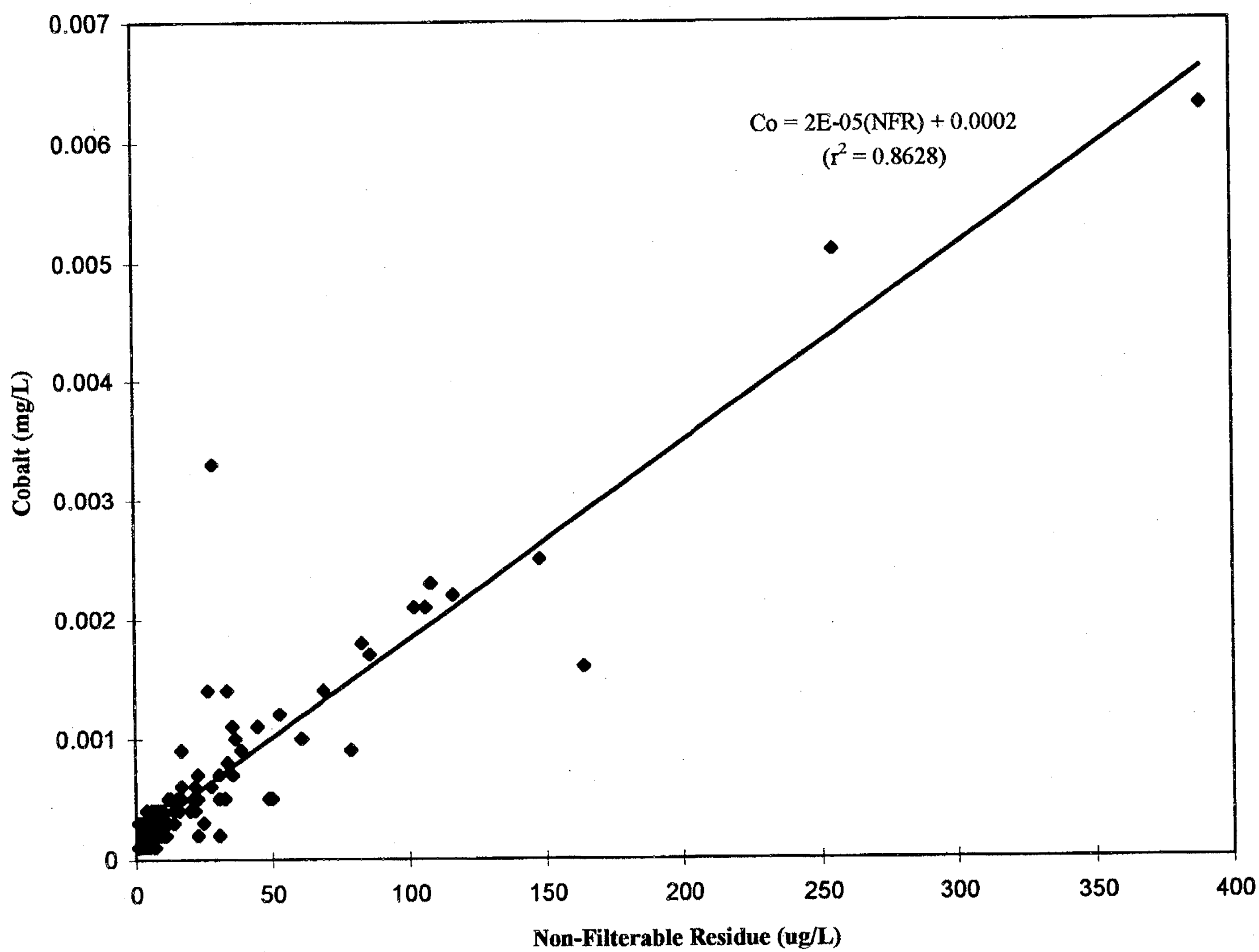


Figure 10.46. Relationship between total iron and non-filterable residue (NFR) in the Salmon River at Salmon Arm.

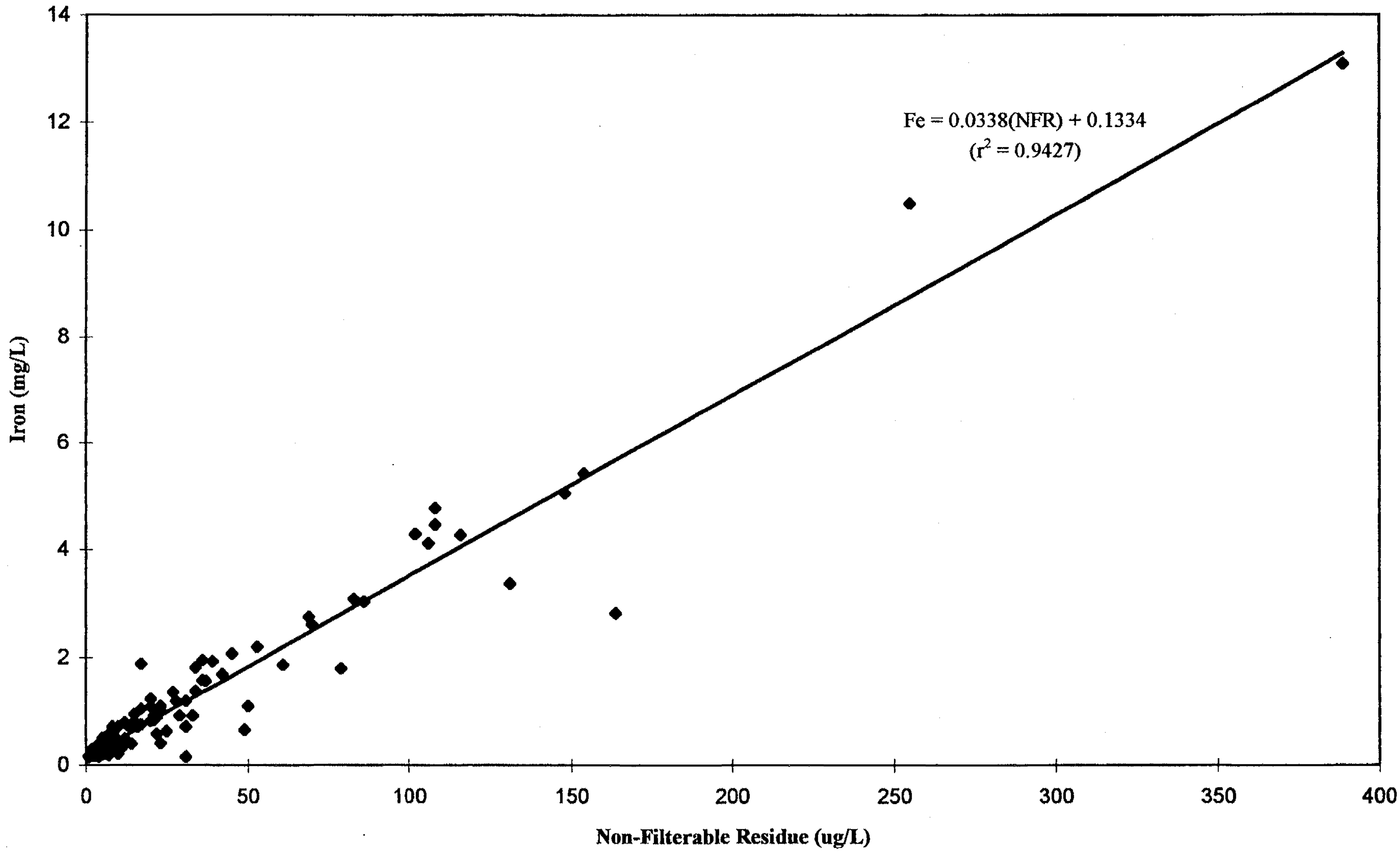


Figure 10.47. Relationship between total manganese and non-filterable residue (NFR) in the Salmon River at Salmon Arm.

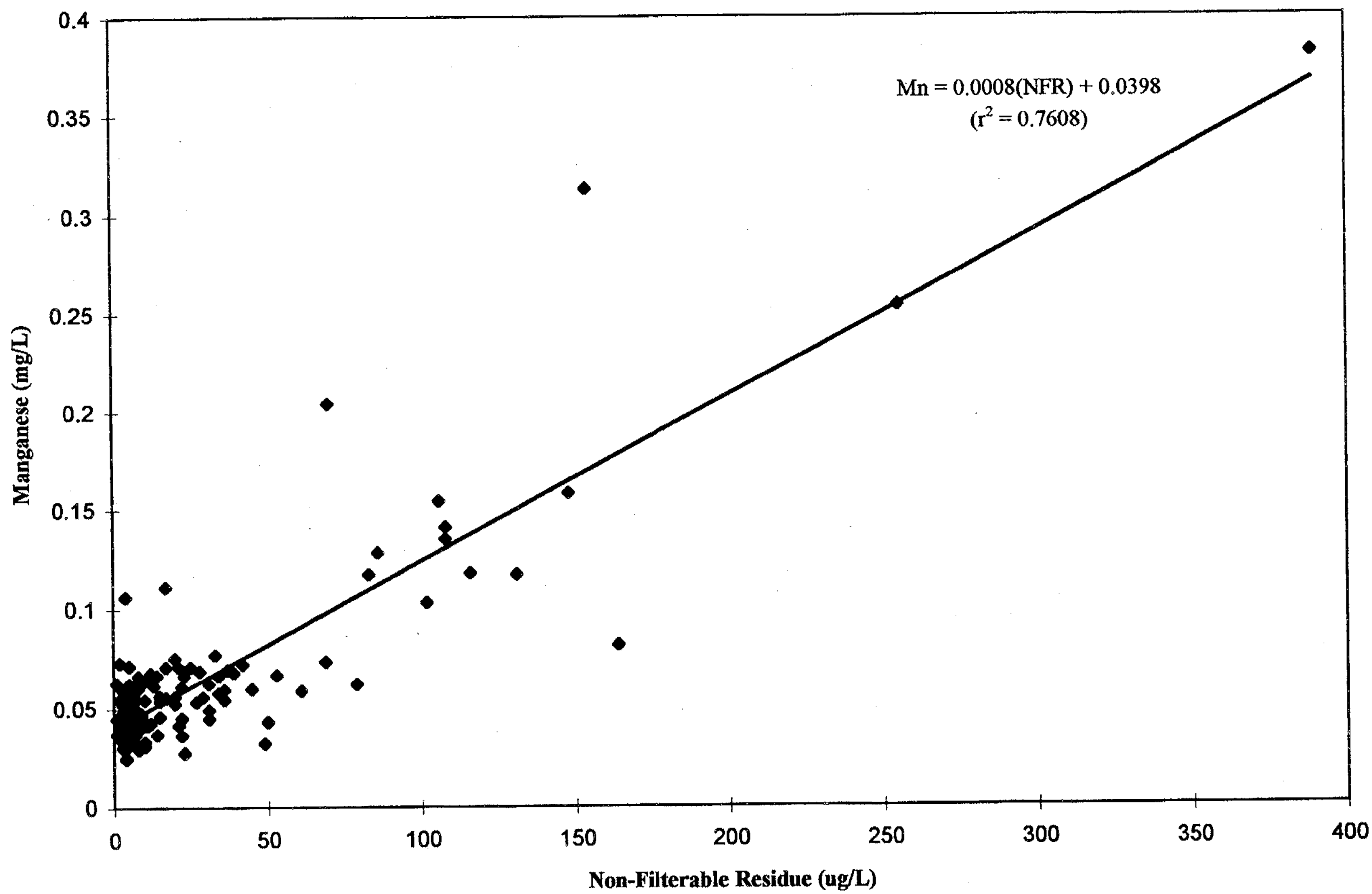


Figure 10.48. Relationship between total chromium and non-filterable residue (NFR) in the Salmon River at Salmon Arm.

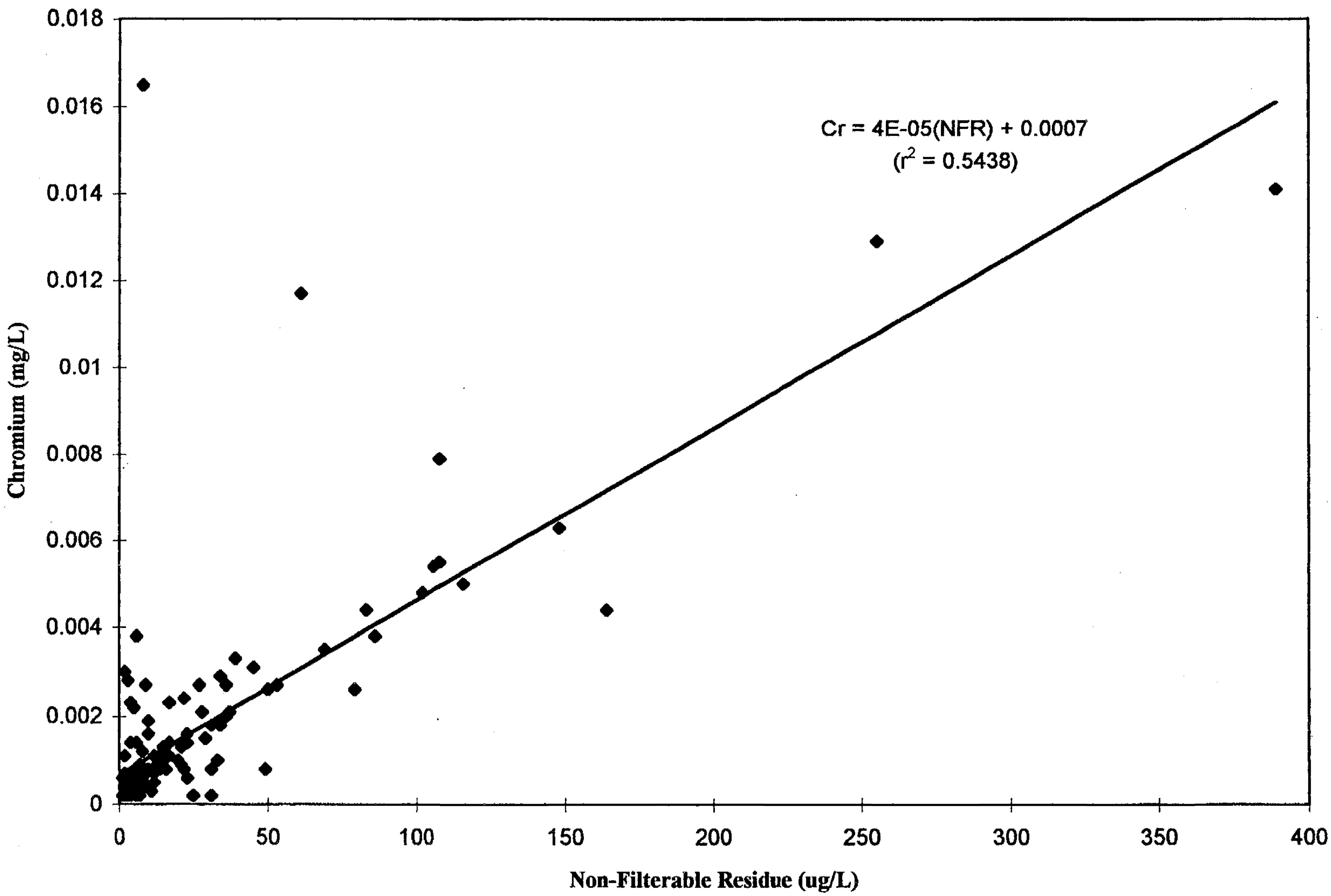


Figure 10.49. Relationship between total copper and non-filterable residue (NFR) in the Salmon River at Salmon Arm.

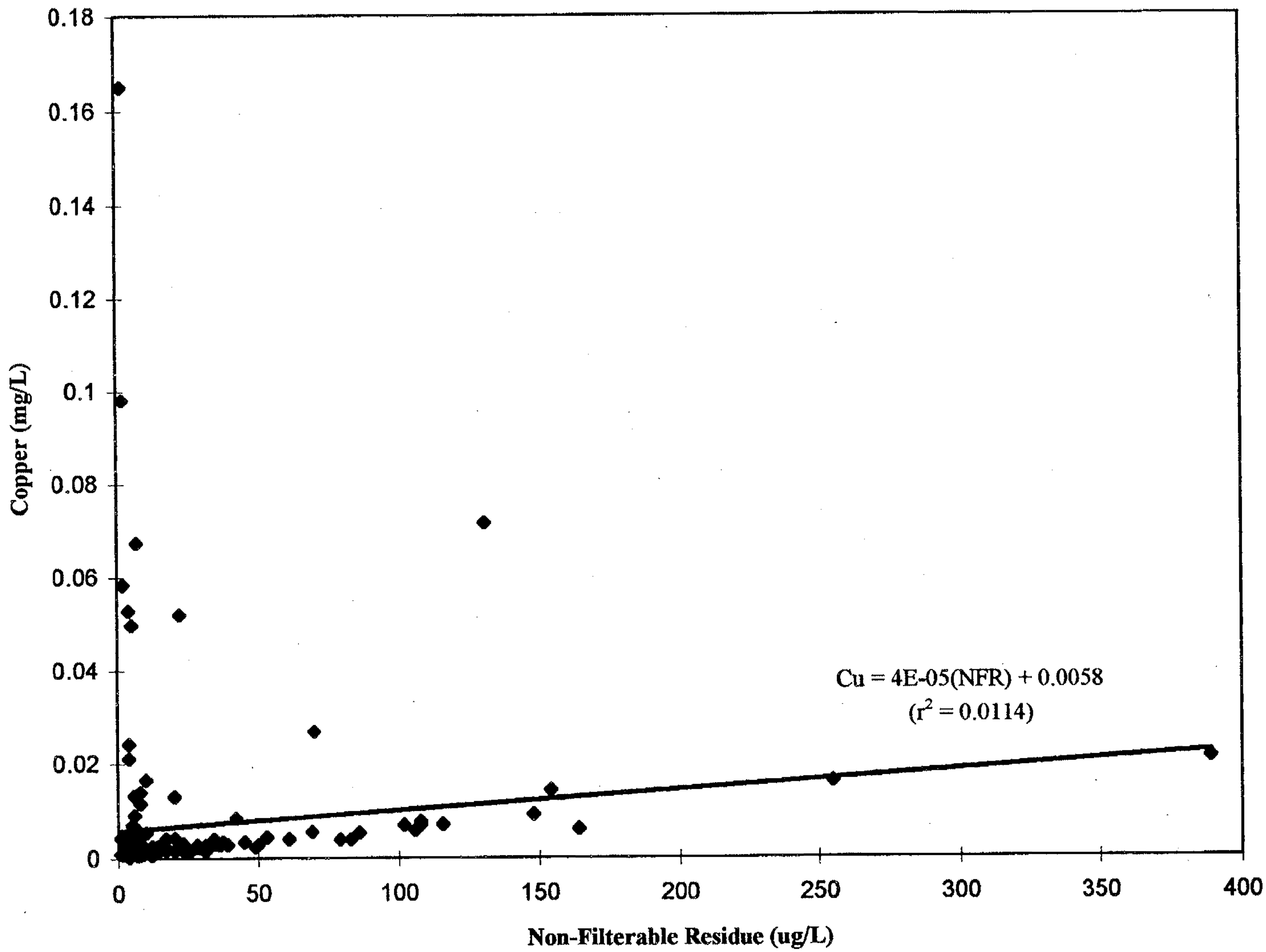


Figure 10.50. A summary of the available total lead data for the Salmon River at Salmon Arm (Environment Canada unpublished data).

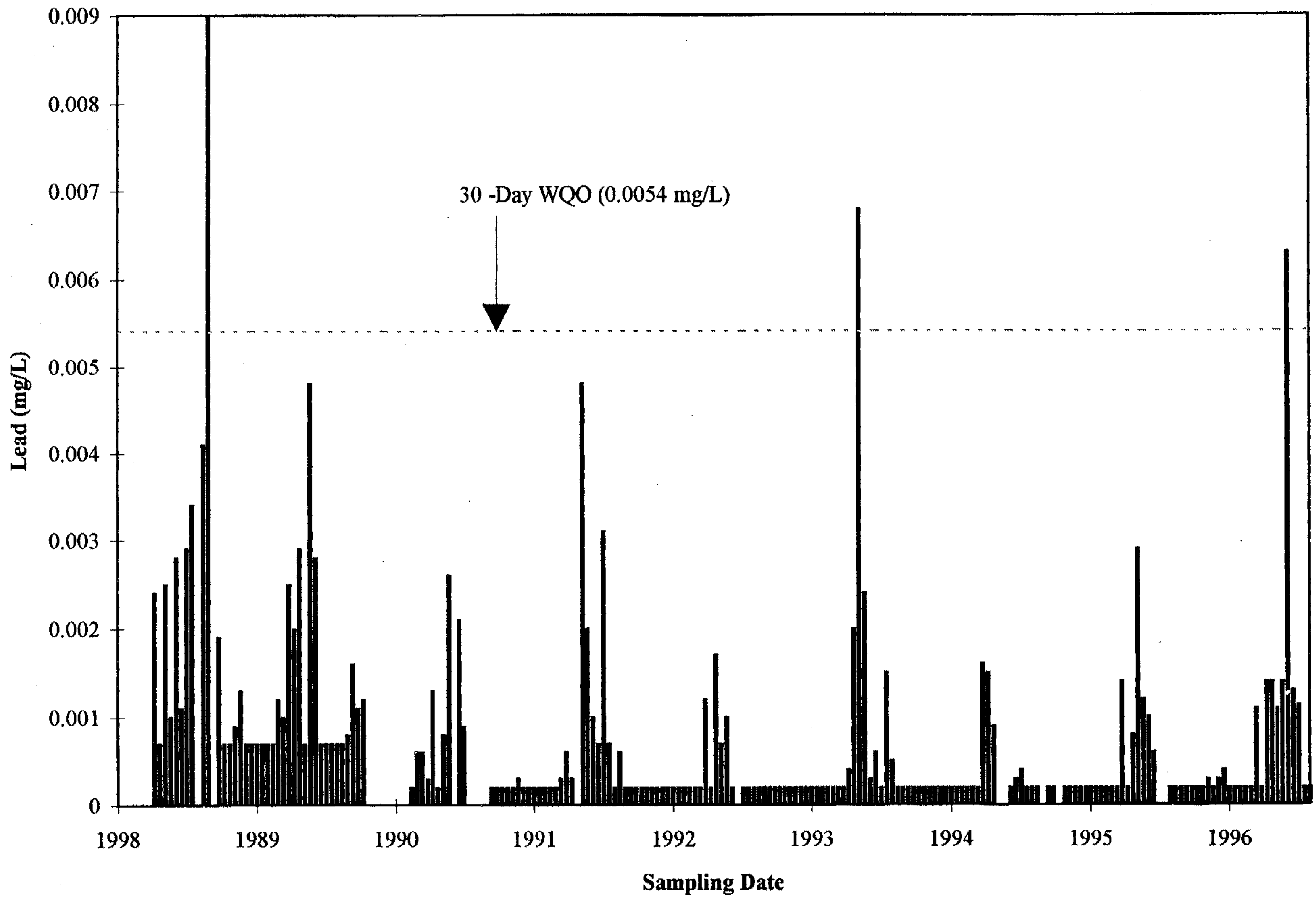


Figure 10.51. Relationship between total lead and non-filterable residue (NFR) in the Salmon River at Salmon Arm.

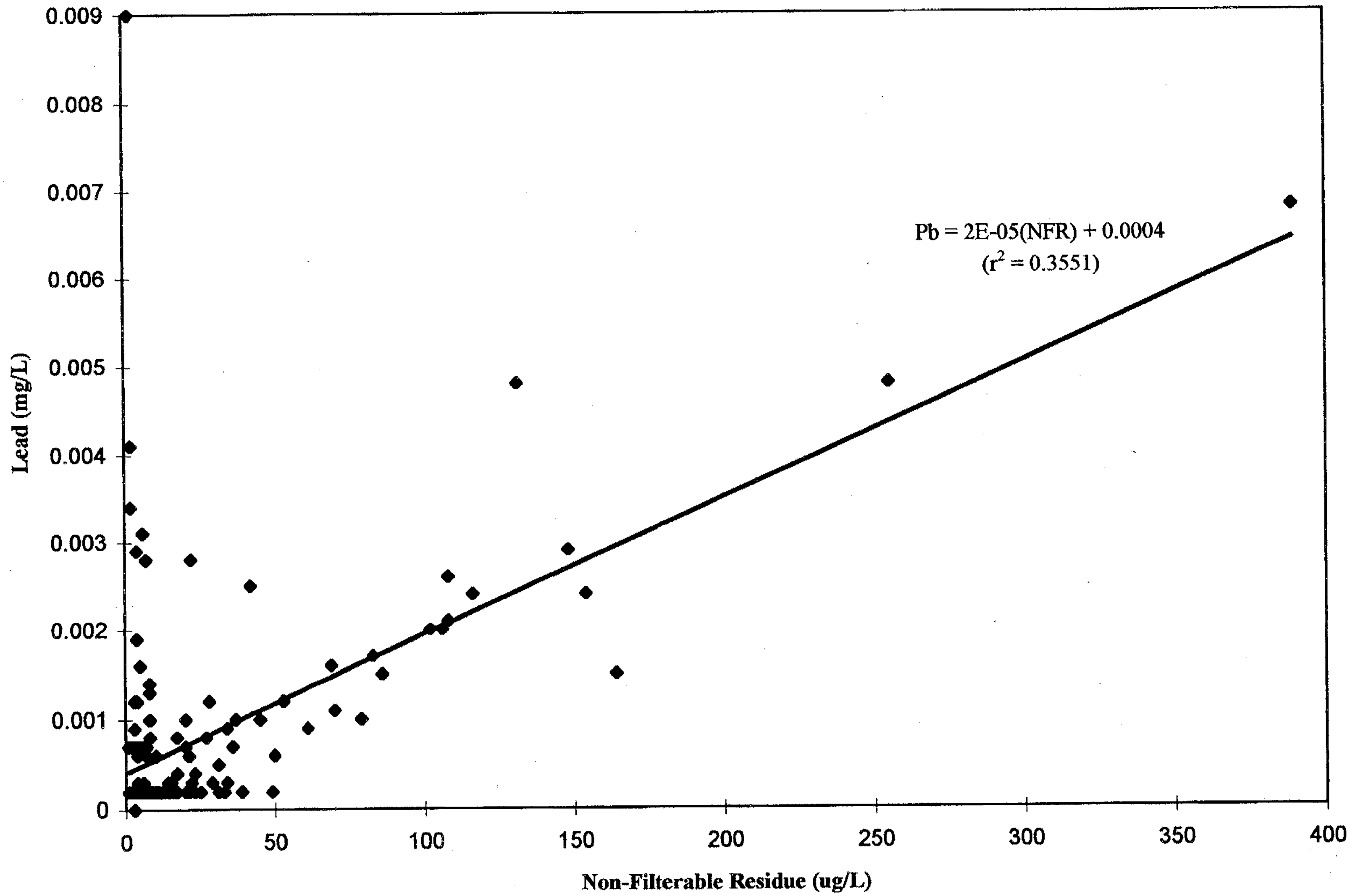


Figure 10.52. A summary of the available total mercury data for the Salmon River at Salmon Arm (Environment Canada unpublished data).

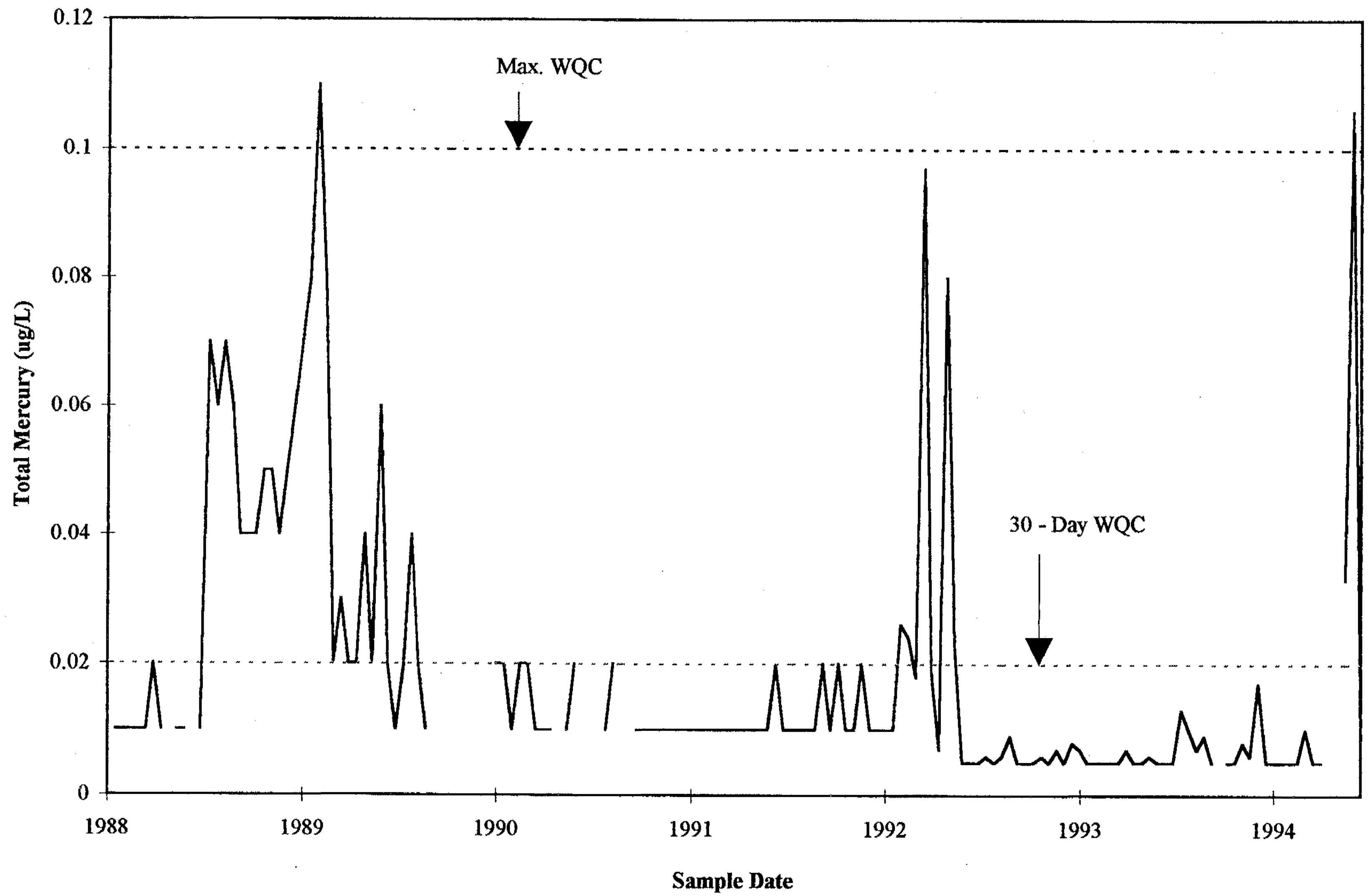


Figure 10.53. Relationship between total mercury and non-filterable residue (NFR) in the Salmon River at Salmon Arm.

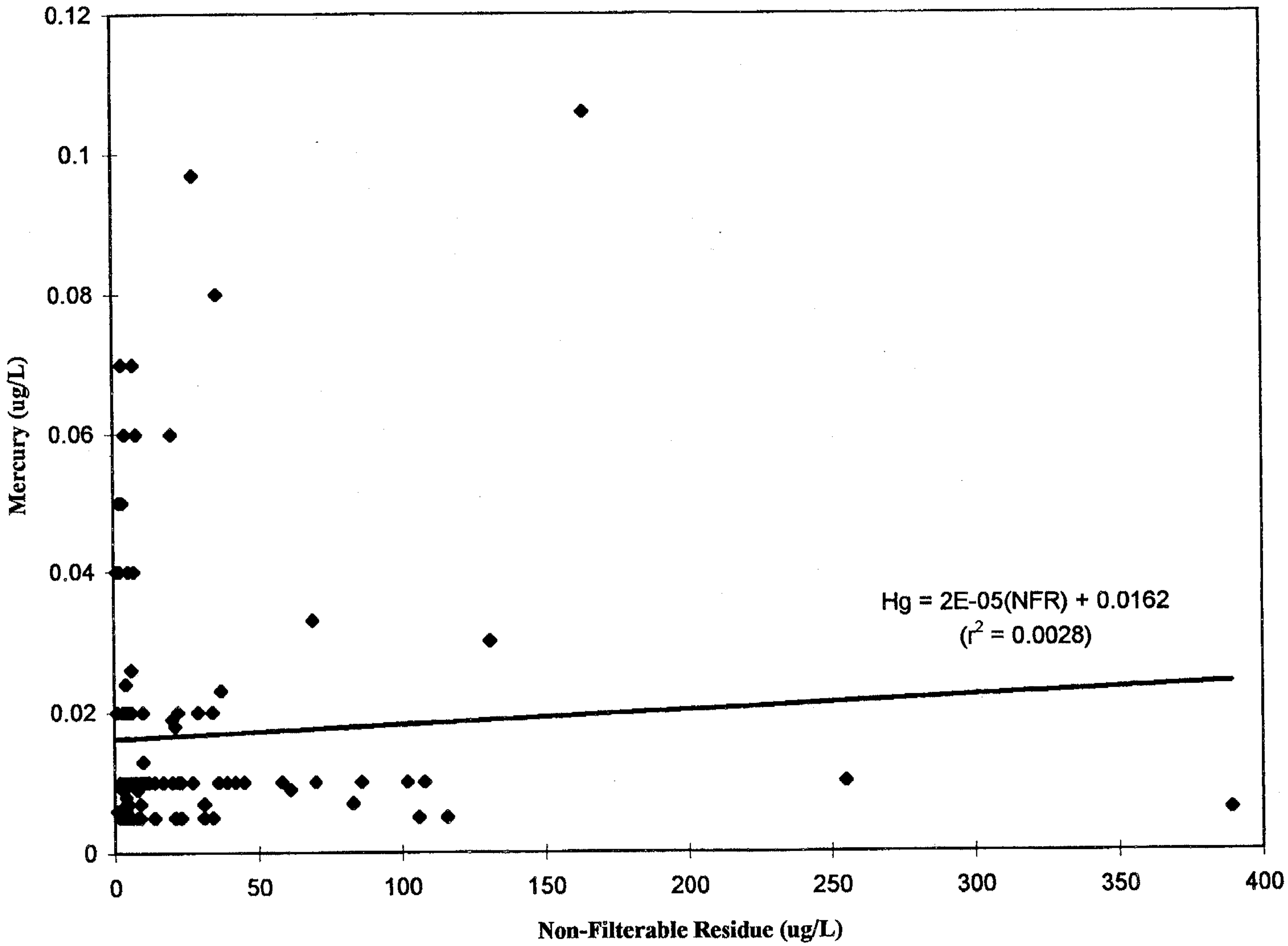


Figure 10.54. A summary of the available total zinc data for the Salmon River at Salmon Arm (Environment Canada unpublished data).

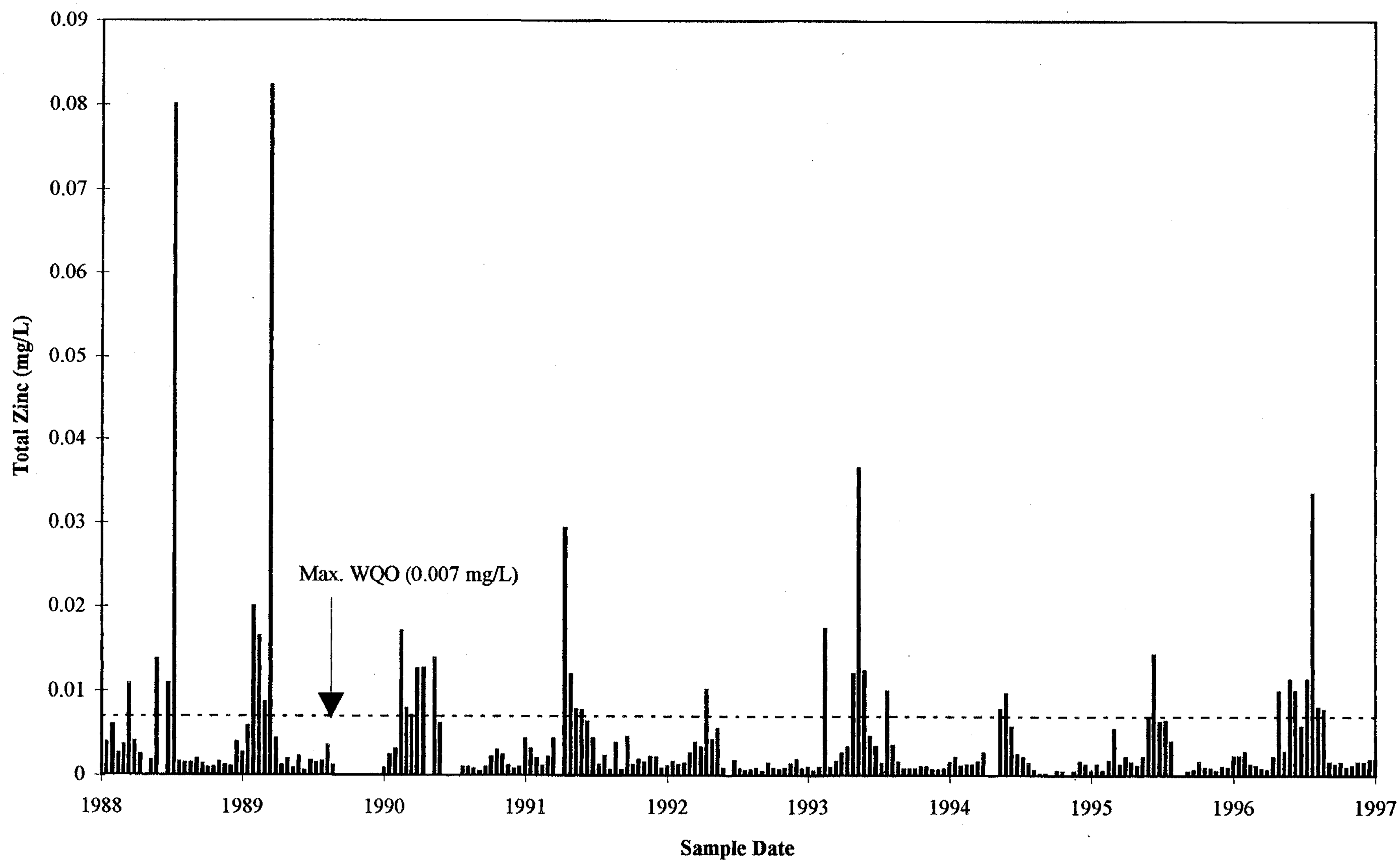


Figure 10.55 Relationship between total zinc and non-filterable residue (NFR) in the Salmon River at Salmon Arm.

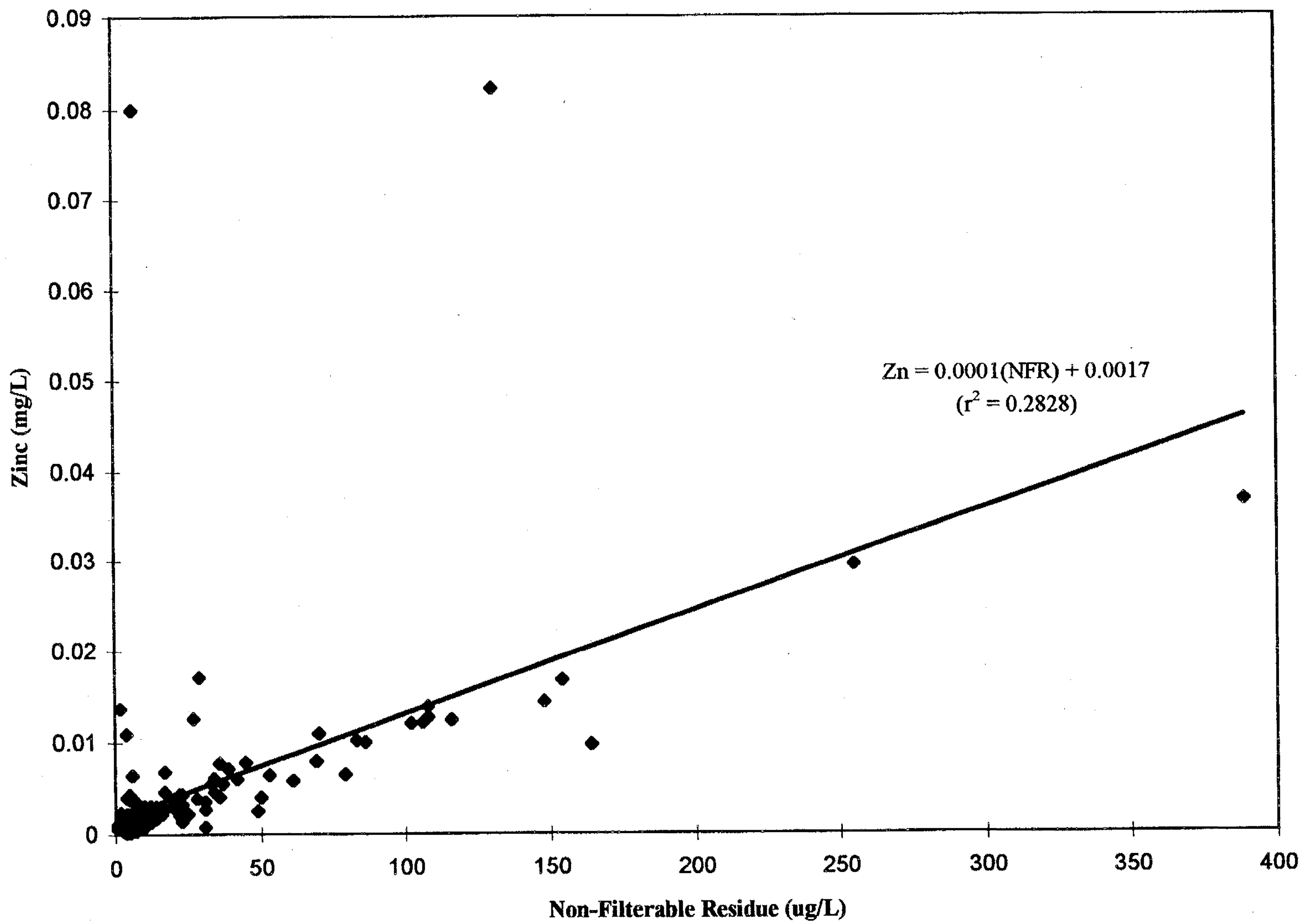


Figure 10.56. Annual summary of total chromium data in the Salmon River at Salmon Arm, 1990-1996 (from Regnier and Shaw 1997).

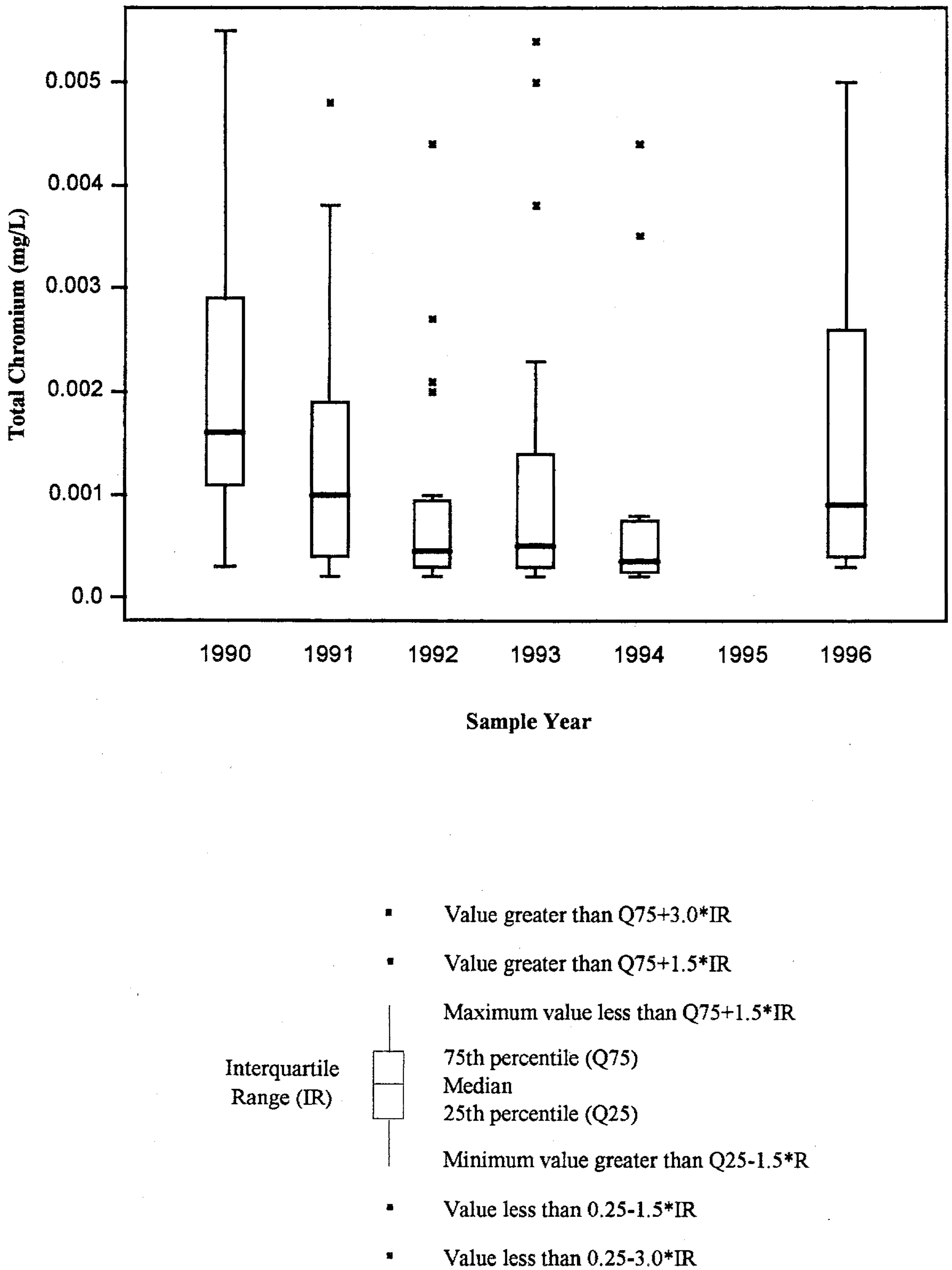
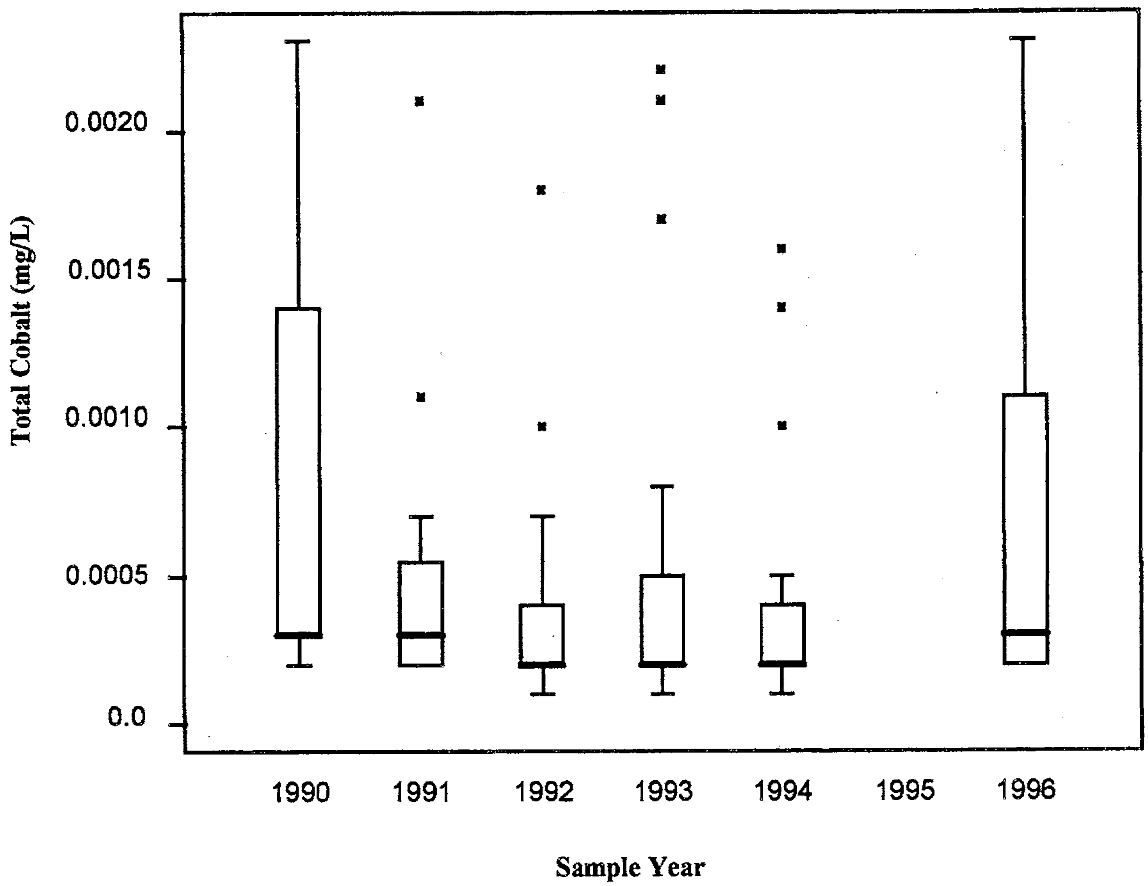


Figure 10.57. Annual summary of total cobalt data in the Salmon River at Salmon Arm, 1990-1996 (from Regnier and Shaw 1997).



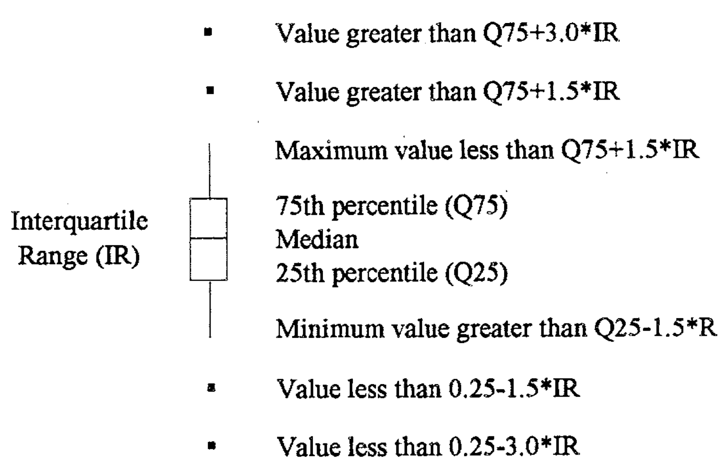


Figure 10.58. Annual summary of total iron data in the Salmon River at Salmon Arm, 1989-1996 (from Regnier and Shaw 1997).