WATER QUALITY BRANCH
ENVIRONMENTAL PROTECTION
DEPARTMENT
MINISTRY OF ENVIRONMENT, LANDS AND
PARKS

Water Quality Assessment and Objectives for Tsolum River Basin Vancouver Island

OVERVIEW

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SUMMARY

THIS DOCUMENT is one in a series that presents water quality objectives for British Columbia. It has two parts: an overview and the report. The overview provides general information about water quality in the Tsolum River basin, and water quality objectives and monitoring tables for those readers requiring this information. It is intended for both technical readers and for readers who may not be familiar with the process of setting water quality objectives. The report presents the details of the water quality assessment in the Tsolum River basin, and forms the basis of the recommendations and objectives presented in the overview.

In 1984, BC Environment became aware of water quality problems created by acid drainage from an abandoned mine on Mount Washington. Several studies were done to assess the impact of the mine on water quality during 1984-89, and the Ministry of Energy, Mines and Petroleum Resources began reclamation of the mine in 1988.

This overview summarizes the results of the water quality assessment of the Tsolum River and its tributaries. Objectives for copper in the Tsolum River basin are proposed to protect water quality, and to guide the reclamation work at the Mt. Washington mine. All available data and current water quality criteria were used to derive the water quality objectives.

PREFACE

Purpose of Water Quality Objectives

WATER QUALITY OBJECTIVES are prepared for specific bodies of fresh, estuarine and coastal marine surface waters of British Columbia as part of the Ministry of Environment, Lands and Parks' mandate to manage water quality. Objectives are prepared only for those waterbodies and water quality characteristics that may be affected by human activity now or in the future.

How Objectives Are Determined

WATER QUALITY OBJECTIVES are based on scientific guidelines called water quality criteria*. Water quality criteria relate the physical, chemical or biological characteristics of water, biota (plant and animal life) or sediment to their effects on water use. Objectives are established in British Columbia for waterbodies on a site-specific basis. They are derived from the criteria by considering local water quality, water uses, water movement, waste discharges and socio-economic factors.

Water quality objectives are set to protect the most sensitive designated water use at a specific site or location. A designated water use is one that is protected in a specific location and is one of the following:

- raw drinking water, public water supply and food processing
- aquatic life and wildlife
- agriculture (livestock watering and irrigation)
- recreation and aesthetics
- industrial water supplies

* The process for establishing water quality objectives is outlined more fully in *Principles for Preparing Water Quality Objectives in British Columbia*. Copies of this document are available from the Water Quality Branch, Environmental Protection Department.

Each objective for a location may be based on the protection of a different water use, depending on the uses that are most sensitive to the physical, chemical or biological characteristics affecting that waterbody.

How Objectives Are Used

WATER QUALITY OBJECTIVES have no legal standing at this time and are not directly enforced. However, they do provide policy direction for resource managers for the protection of water uses in specific waterbodies. Objectives guide the evaluation of water quality, the issuing of permits, licenses and orders, and the management of fisheries and the province's land base. They also provide a reference against which the state of water quality in a particular waterbody can be checked, and help to determine whether basin-wide water quality studies should be initiated. Water quality objectives are also a bench mark for assessing the Ministry's performance in protecting water uses.

Objectives and Monitoring

WATER QUALITY OBJECTIVES are established to protect all uses that may take place in a given waterbody. Monitoring, which is sometimes called sampling, is undertaken to determine if the designated water uses are being protected. Monitoring usually takes place at a critical time, as determined by a water quality specialist, when water quality objectives may not be met. It is assumed that if all designated water uses are protected at the critical time, then they also will be protected at other times when the threat to water quality is less. Monitoring usually takes place during a five-week period, which allows specialists to measure the worst, as well as the average, condition of the water. For some waterbodies, the monitoring period and frequency of sampling may vary, depending upon the nature of the problem, severity of threats to designated water uses, and the way the objectives are expressed; for example, objectives may be expressed as 30-day averages and maximums as in this document.

INTRODUCTION

THIS REPORT assesses water quality in the Tsolum River basin. Water quality objectives for copper and steelhead egg survival in the Tsolum River and its tributaries are set to protect aquatic life (especially salmonid fish), which is the most sensitive water use in the basin for copper. Copper is the predominant toxic substance from the mine on Mt. Washington, and its control is the key to protecting aquatic life in the river. An analysis of the available data suggested that objectives for other substances are not needed at this time.

The Tsolum River originates on Mount Washington and flows southeast about 30 km before joining the Puntledge River just before it enters Comox Harbour and the Strait of Georgia. Murex, McKay, and Pyrrhotite creeks are the tributaries that drain the Mt. Washington mine to the Tsolum River.

The river is licensed for domestic and irrigation water supply. In the past, the river supported large populations of steelhead and resident rainbow trout, sea-run cutthroat trout, and coho, pink, and to a lesser extent, chum salmon. The fisheries resource is believed to have declined in the basin predominantly because of the acid mine drainage from Mt. Washington. However, other factors such as the reduction of summer low flows by irrigation withdrawals, overfishing, logging and gravel extraction may have also played a role for certain species. The neighbouring Puntledge River has continued to support strong salmonid populations, despite similar human disturbances. In any case, the Tsolum River has the potential to support an extensive fishery, with or without an enhancement program.

TSOLUM RIVER BASIN PROFILE

Hydrology

The Tsolum River is approximately 30 km long, from its origin on Mt. Washington to the point where it joins the Puntledge River in Courtenay, just upstream from Comox Harbour (Figure 1). The drainage area of the Tsolum River near its mouth at Courtenay is 258 km^2. Murex Creek drains 41 km^2 on the eastern flank of Mt. Washington, including the acid drainage from the abandoned mine. The drainage area of the Tsolum just downstream from Murex Creek is 78 km^2.

A hydrological analysis of the basin downstream from the abandoned mine was conducted to assist in the assessment of the water quality. The majority of the runoff from the mine at 1300 m near the Mt. Washington ski area flows into the headwaters of Pyrrhotite Creek, through Murex Creek, the Tsolum River, and the Puntledge River, and discharges into Comox Harbour and the Strait of Georgia near Courtenay.

The patterns of runoff in the Tsolum watershed are influenced greatly by the mountain topography. The entire Tsolum watershed has a median elevation of 230 m and an average runoff of 1250 mm (10.2 m^3/s), with 71% of this occurring in winter due to rainfall. In contrast, the high-elevation Pyrrhotite Creek watershed (median elevation of 1300 m) has an average runoff of 2030 mm, with 50% occurring in spring due to snowmelt. The Murex Creek watershed is intermediate in elevation (670 m median), and exhibits characteristics of both the spring snowmelt and winter rain regimes. All three watersheds experience very low flows during the summer.

Water Uses

Licences

The Tsolum River is licensed for domestic and irrigation water supply. There are 9 domestic water licenses and 23 irrigation licenses on the river, all downstream from Murex Creek.

Recreation

Water-based recreation in the Tsolum River, including fishing and swimming, occurs mainly downstream from Headquarters Creek.

Fisheries

In the past, the Tsolum River supported large populations of steelhead and resident rainbow trout, sea-run cutthroat trout, and coho, pink, and to a lesser extent, chum salmon. Peak escapement (spawning returns) were: pink salmon - 100,000, coho salmon - 15,000, chum salmon - 11,000, and steelhead - 3500, but there are virtually no escapements at present. The fisheries resource is believed to have declined in the basin predominantly because of the acid mine drainage from Mt. Washington, but other factors such as the reduction of summer low flows by irrigation withdrawals, overfishing, logging and gravel extraction may have also played a role for certain species. With the exception of Murex Creek, tributaries of the Tsolum have good water quality and are suitable for fish. However, the mainstem of the Tsolum exposes fish to high copper levels at various stages of their life cycle.

The Tsolum River hatchery on Headquarters Creek was built by the Department of Fisheries and Oceans to maintain and enhance fish stocks in the Tsolum River. It was originally designed as an adult capture and egg-take facility to produce 3 million pink salmon fry. But in spite of its output, returns have been extremely poor.

In 1987, the 50-year values of the Tsolum River fishery were estimated to be $1.6 million with the current harvest, $9.5 million at the natural capability harvest, and $12.1 million with enhancement. Similarly, the 1987 number of annual angler-days was 188, with 3000 and 6000 possible at the natural capability and enhanced capability, respectively.

Waste Discharges

Several human activities influence water quality in the Tsolum River basin to varying degrees. They include residential development in and around Courtenay, logging in the headwaters of the tributaries, road development and agriculture. However, the primary concern is the impact of acid drainage from the abandoned copper mine on Mt. Washington on water quality in the Tsolum River.

Mining

A small open pit copper mine was operated near the summit of Mt. Washington during 1964-67. The area disturbed was about 13 ha, with 940,000 t of waste rock and 360,000 t of ore excavated. The ore body is an iron-copper-sulphide deposit, which produces sulphuric acid when oxidized by bacteria in the presence of water and atmospheric oxygen. The acid dissolves the metals in the ore and waste rock remaining at the mine, resulting in acid drainage with very low pH and very high dissolved metals concentrations. The acid drainage flows into Pyrrhotite and McKay creeks, which flow into Murex Creek and the Tsolum River. Several metals are present at elevated concentrations in the acid mine drainage, but copper is the most toxic (to fish) by a factor of 10 or more.

The Ministry of Energy, Mines and Petroleum Resources began to reclaim the mine in 1988 to reduce the impacts on water quality, and work is anticipated to continue at least through 1994. Reclamation has focused on diversion of water around the mine, covering waste rock to shed precipitation, and other measures to minimize water contact with acid-producing materials.

WATER QUALITY ASSESSMENT AND OBJECTIVES

Water Quality Assessment

During the assessment of the data, several observations were made regarding water quality in the Tsolum River basin:

- The background water quality in the Tsolum basin indicates soft water, with near-neutral pH, and relatively little buffering capacity for acid inputs. Background metal levels are low, generally meeting water quality criteria for aquatic life. A few metals, including copper, slightly exceed these criteria, but the high organic binding capacity of the water renders the metals non-toxic to aquatic life.

- Immediately downstream from the mine in Pyrrhotite Creek, the water is acidic (pH 3.6 - 4.7), and copper, cadmium, aluminum, manganese, zinc, chromium, iron, nickel, and cobalt exceed water quality criteria for aquatic life or drinking water. Copper is the most toxic metal to aquatic life by a factor of 10 or more.

- Water quality improved with distance downstream from the mine as the acid drainage was diluted, neutralizing the pH and precipitating the metals. By the time the water reached the Tsolum River, where fish reside and the water is used for drinking and irrigation, copper was the only substance that was still at toxic levels. Copper exceeded criteria for aquatic life and was toxic in long-term fish bioassays, particularly during spring when the majority of the runoff was snowmelt.

- Predicted copper levels in the Tsolum River just downstream from Murex Creek exceeded the proposed average copper objective 85% of the time during 1987-90. Peak concentrations during spring snowmelt and fall rains were up to 6 times greater than the objective.

Water Quality Objectives

Water quality objectives have been set for the dissolved copper in the Tsolum River basin to protect water quality for aquatic life, the most sensitive water use for copper (Table 1). The objectives consider the organic complexing capacity and background copper levels in the basin. An objective has also been set for steelhead egg survival as a direct measure of aquatic ecosystem health. Aquatic ecosystem health will also be assessed by monitoring benthic invertebrate populations, but we are unable to recommend an objective for these populations at this time.

The objectives apply to the entire Tsolum basin, excluding the Murex Creek basin and a 500-m reach of the Tsolum River immediately downstream from Murex Creek. The proposed water quality objectives for copper were exceeded in the Tsolum River 500 m downstream from Murex Creek during 1987-90, indicating that additional reclamation of the Mt. Washington mine is required.

Monitoring Recommendations

There has been substantial water quality monitoring in the Tsolum basin since 1985. Monitoring should now focus on the most critical substance - dissolved copper, at the most critical location - just downstream from Murex Creek, during the most critical periods - spring and fall (Table 2). If the copper objectives can be attained during these times at this location, the rest of the basin will be protected. Monitoring is also recommended for free copper, humic acid, and dissolved organic carbon to further develop the copper - organic complexing capacity relationship used to derive the objectives. A quality assurance program including field blanks, field replicates, and reference samples is recommended to ensure that high quality data are collected.

To monitor the health of the aquatic ecosystem, we recommend triannual in-situ steelhead egg bioassays and measurement of benthic invertebrate abundance and diversity in the Tsolum River upstream and 500 m downstream from Murex Creek.

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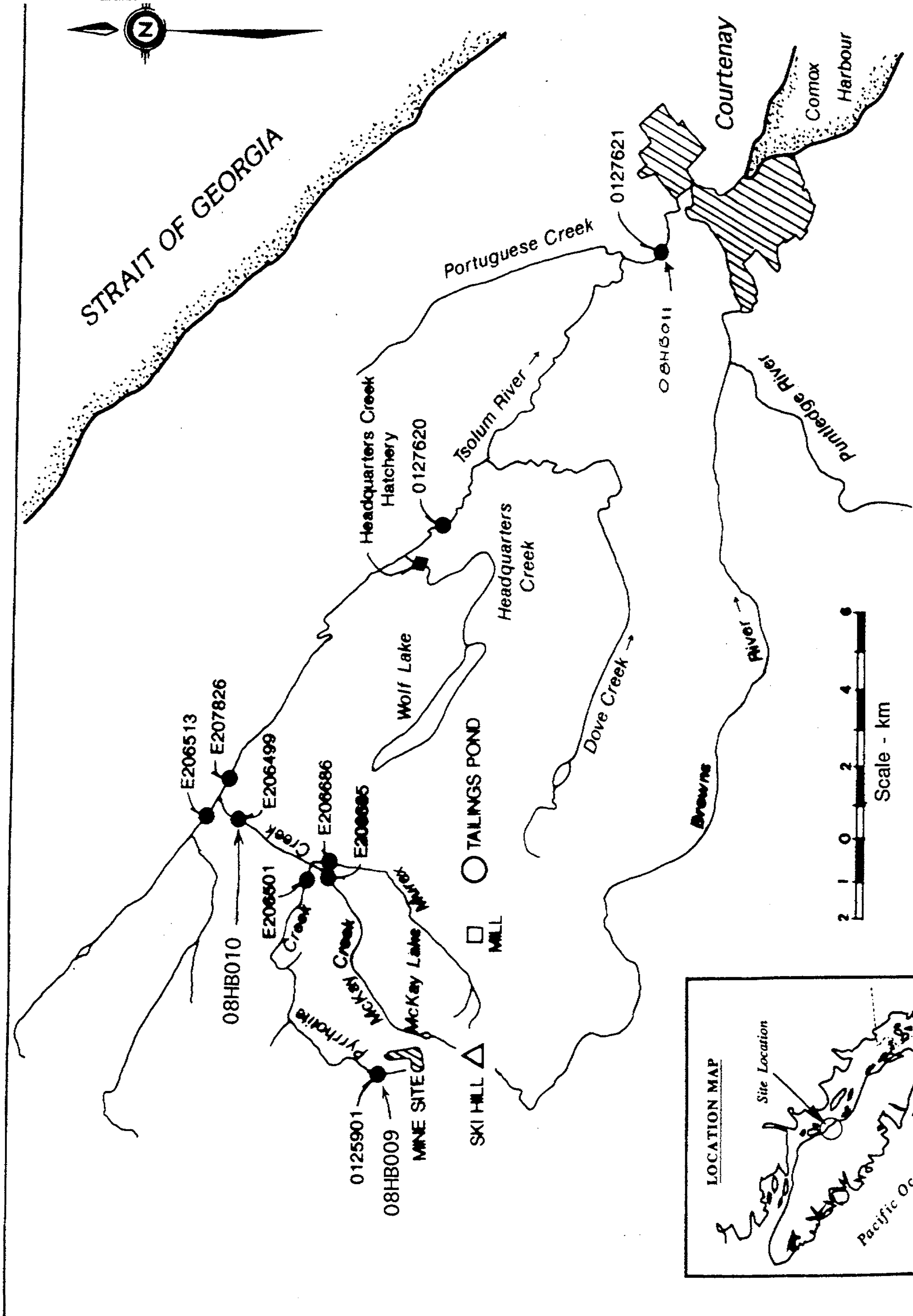

FIGURE 1

TSOLUM RIVER BASIN AND SELECTED WATER QUALITY MONITORING SITES

TABLE 1

TSOLUM RIVER BASIN WATER QUALITY OBJECTIVES

Designated Water Uses	Aquatic life and wildlife, drinking water, primary-contact recreation, irrigation, livestock watering
Characteristic	**Objective**[1]
Dissolved Copper	0.007 mg/L (30-day average)[2] 0.011 mg/L (maximum)
% Egg Survival (for in situ steelhead egg bioassays)	No significant difference in egg survival between test & control sites at a 95% confidence level

1 These objectives apply to the entire Tsolum River basin with the exception of the Murex Creek basin, the 500-m reach of the Tsolum River downstream from Murex Creek, and the initial dilution zones of effluents. These latter excluded zones extend up to 100 m downstream from the point of discharge, from the surface to the bottom, but not exceeding 50% of the width of the waterbody.

2 The average is calculated from at least 5 weekly samples taken in a period of 30 days. For values below the detection limit, use the detection limit to calculate the statistic.

TABLE 2
RECOMMENDED WATER QUALITY MONITORING FOR TSOLUM RIVER

Characteristics	Frequency and Timing	Proposed Sites
Dissolved copper	Weekly, April 15 - June 30 and Sep 15 - Nov 30	Tsolum River 500 m downstream from Murex Creek (SEAM # E207826)
Humic acids Dissolved organic carbon Copper speciation (free, organic & dissolved)	Monthly, April - June and Sep - Nov	"
In-situ steelhead egg bioassays (modified Whitlock-Vibert boxes)	Triannual, April 15 - June 30 (2-week exposure)	Tsolum River: i) upstream Murex Cr. (SEAM # E206513) ii) 500 m downstream Murex Cr. (SEAM # E207826)
Benthic invertebrate abundance & diversity (Surber sampler)	Triannual, April 15 - June 30	"

MINISTRY OF ENVIRONMENT, LANDS AND PARKS
PROVINCE OF BRITISH COLUMBIA

TSOLUM RIVER WATERSHED WATER QUALITY ASSESSMENT AND OBJECTIVES

TECHNICAL APPENDIX

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1. INTRODUCTION

1.1 Background

Mt. Washington Milling Co. Ltd. operated an open pit copper mine located near the summit of Mount Washington from 1964 to 1967. The minesite is situated at high elevation (1310 m) on a ridge straddling the Oyster and Tsolum river watersheds (Figure 1).

The ore body located on Mt. Washington is a copper-rich sulphide deposit, which, when oxidized in the presence of water and oxygen (with/without the mediation of iron-oxidizing bacteria), produces sulphuric acid. In addition to the direct release of heavy metals during sulphide oxidation, the production of sulphuric acid solubilizes the heavy metals in the ore and waste rock remaining on site. The result is runoff (acid mine drainage) from the mine that has very low pH and very high heavy metal concentrations.

B.C. Environment became aware of the water quality problems created by the acid mine drainage from the Mt. Washington mine site in 1984. Several reports dealing with the impact on water quality have been completed to date (Kangasniemi and Erickson, 1986; Erickson and Deniseger, 1987; Deniseger and Erickson, 1989a, and Deniseger and Erickson, 1989b).

The purpose of this report is to summarize the water quality data collected to date, with emphasis on the data collected since the last Ministry Report (Deniseger and Erickson, 1989a), and set water quality objectives for the Tsolum River watershed. Water quality objectives are designed to protect all designated water uses, and can be used to determine the degree of reclamation required to reduce acid mine drainage. Water quality objectives already exist for the Oyster River (Nagpal, 1990).

1.2 Water Quality Objectives - Basic Philosophy

Water quality objectives are established in British Columbia for water-bodies on a site-specific basis. The objective can be a physical, chemical, or biological characteristic of water, biota, or sediment, which will protect the most sensitive designated water use at a specific location with an adequate degree of safety. The objectives are aimed at protecting the most sensitive designated water use with due regard to ambient water quality, aquatic life, waste discharges and socio-ecomomic factors (Water Management Branch, 1986).

Water quality objectives are based upon approved or working water quality criteria which are characteristics of water, biota, or sediment that should not be exceeded to prevent specified detrimental effects from occurring to a water use (Water Management Branch, 1986). The working criteria come from the literature, and are referenced in the following chapters. B. C. Environment is working in conjunction with CCME (Canadian Council of Ministers of the Environment) to develop water quality guidelines for Canada that would also apply to the province. These would form part of the basis for objectives.

As a general rule, objectives will only be set in reaches where man-made influences threaten a designated water use, either now or in the future. Objectives proposed in this report are to be reviewed as monitoring information becomes available and as the Ministry establishes approved water quality criteria.

2. WASTE DISCHARGES

Mt. Washington Milling Co. Ltd. operated an open pit copper mine located near the summit of Mount Washington from 1964 to 1967. The minesite is situated at high elevation, at approximately 1,310 m on a ridge straddling two watersheds (Figure 1). Two working areas are apparent, a north block comprising approximately 7.4 ha and a south block covering about 5.7 ha. During the operation of the mine, 940,000 t of overburden and waste rock were moved. The total ore mined during the life of the operation was 360,000 t, and the mill produced 17,762 t of copper concentrate.

The mill serving the mine was located approximately 4 km east of the minesite, within the upper Murex Creek watershed. The tailings pond area, approximately 7.8 ha, is located 2.6 km east of the mill and has impoundments on the northwest and north sides.

Drainage from the mine site flows toward both the Oyster River via Piggott Creek,and the Tsolum River via Pyrrhotite Creek and to a lesser degree McKay Creek (Figure 1). Drainage from the abandoned tailings pond flows though a swamp to Wolf Lake, and then via Headquarters Creek to the Tsolum River (Figure 1).

Esso Resources Limited held the mineral rights to the abandoned Mt. Washington mine from October 1978 to July 1983. During 1979 and 1980, Esso conducted leaching experiments on a portion of the waste rock draining into Pyrrhotite Creek to determine the potential for recovery of copper. The company attempted to enhance copper leaching from the waste rock through techniques such as sulphuric acid injection and innoculation with bacteria. Upon completion of the project, Esso added lime to neutralize the acidification. At present, Better Resources Limited has leased the base mineral rights from Fording Coal Limited, while Better Resources owns the rights to precious minerals and has conducted gold exploration.

Acid mine drainage is produced from the oxidation of metallic sulphide minerals, particularly those containing iron. Thiobacillus ferrooxidans is a unique bacterium in that it has the ability to oxidize sulphides from which it obtains its energy for growth. The oxidation process yields substantial quantities of sulphuric acid, which leaches out the associated metals such as copper. The bacterium exponentially increases the rate of the oxidation process, producing an environment extremely low in pH (<3) and very high in metals such as iron and copper.

As a result of the water quality investigations by the Ministry of Environment, Lands and Parks, an Order-in-Council directed the British Columbia Ministry of Energy, Mines and Petroleum Resources to reclaim the site to reduce impacts on water quality. The original objective was to create a long-term passive closure plan which would minimize the need for maintenance, while eliminating downstream water quality problems. The first phase of minesite reclamation began in 1988 and was completed in 1989. Further work continued through 1992. To date the reclamation activity has focused upon the following activities: a) the diversion of water around the mine site; b) contouring, capping and covering highly mineralized waste rock in an effort to shed the majority of precipitation; c) cleaning areas down to bedrock and sealing to minimize water contact with bedrock; d) installation of piezometers to examine groundwater influence; e) monitoring of water quality both at mine site and downstream waters. The work carried out thus far is presently being reviewed and additional reclamation activity is anticipated.

3. HYDROLOGY

A hydrological analysis of the drainage downstream from the abandoned copper mine on Mount Washington was conducted to facilitate the development of ambient water quality objectives for Murex Creek and the Tsolum River. Specifically to determine the dilution of acid mine drainage in Murex Creek and the Tsolum River (Section 6.5), and to determine a mass balance model for copper for the Tsolum River watershed (Section 5.4). Runoff from the abandoned mine, located at an elevation of about 1,300 m near the Mount Washington ski area, flows into the headwaters of Pyrrhotite Creek, through Murex Creek and the Tsolum River, and discharges into Comox Harbour and the Strait of Georgia near Courtenay (Figure 1).

The information presented here is abstracted from a memorandum report entitled "Mt. Washington Hydrology Pyrrhotite Creek, Murex Creek, and the Tsolum River", from A. Chapman to C.H. Coulson (Head, Hydrology Section), dated October 16, 1991, (File Number S2102, Study 344).

3.1 Data And Methods

Water level data were collected at a 90 degree sharp-crested v-notch weir on Pyrrhotite Creek near Branch 126 (08HB009) during the May 1986 - June 1990 period. Daily discharge was estimated using the theoretical weir formula. There were a number of periods, mostly of short duration, when the water level recorder system failed to operate adequately, requiring that discharge be estimated by other means. The watershed area upstream from this location was determined from a 1:20,000 map to be 0.309 km^2.

Continuous water level data were collected on Murex Creek at Duncan Bay Mainline (08HB010) during the May 1986 - June 1990 period. A total of about 31 stream-discharge measurements had been made at 08HB010, for the purpose of estimating a stage-discharge rating curve. However, the creek channel at the gauge location, comprised of small cobbles and gravel, was quite unstable and appeared to have shifted a number of times during the period of record. After examination of the discharge measurements, the data for 1986 and part of 1987 were deemed to be unusable, and three rating curves were estimated by curvilinear regression for the remainder of the period of record. There were a substantial number of periods of missing data for which, where possible, it was necessary to estimate discharge by other means. The watershed area upstream from 08HB010 is determined from 1:20,000 map sheets to be 40.9 km^2.

Discharge from the Tsolum River near Courtenay (08HB011) has been monitored by the Water Survey of Canada during 1914-1917, 1955-1957 and 1964-present. The watershed area upstream from 08HB011 is 258 km^2.

Discharge was also estimated for the Tsolum River below Murex Creek, at which there were no water level or discharge records. The watershed area is 77.8 km^2. Daily discharge at this location was estimated by prorating flows for Murex Creek at Duncan Bay Mainline and the Tsolum River near Courtenay by drainage area, adjusting the values for seasonally-varying unit discharge resulting from median elevation differences.

The area-elevation characteristics of the study watersheds are displayed in Figure 2 and Table 1. Included are the characteristics of the Tsolum River above Murex Creek, which is similar in drainage area to the Murex Creek watershed, but is substantially lower in elevation.

There were a number of gaps of various duration in the discharge record for Pyrrhotite Creek and Murex Creek, caused mostly by level recorder failure, making it necessary to estimate some discharge values. Missing values for Pyrrhotite Creek were estimated by linear interpolation if there had been no precipitation during the period or if precipitation occurred as snow, or by regression with daily precipitation if precipitation occurred as rain. Daily precipitation and temperature data collected at the Mount Washington mine site (station number 102007) by B.C. Environment (Environmental Protection) were used for this purpose. Missing discharge values for Murex Creek were estimated by linear interpolation if no precipitation had occurred during the period, or by regression with Tsolum River daily discharge (with a lag of one day for the Tsolum River) if precipitation had occurred (precipitation at the Mount Washington mine site and at Courtenay Puntledge were used). In addition, Murex Creek and Tsolum River daily discharge hydrographs for concurrent periods were plotted and compared to ensure that the estimated flows were reasonable.

3.2 Results

Daily discharge values for Pyrrhotite Creek near Branch 126 (08HBB09), Murex Creek at Duncan Bay Mainline (08HB0100), the Tsolum River below Murex Creek, and the Tsolum River near Courtenay (08HB011), for the 1986 - 1990 period are presented in Tables 2a-2r. Mean monthly and annual discharges for the measured data during the 1986 - 1990 period, along with the adjustment values, are given in Table 3.

The discharge values presented in Table 3 were compared with the 34 years of flow data for the Tsolum River near Courtenay to determine how closely the monthly and annual discharge measured during the 1986-1990 period correspond with the long-term flow characteristics. Mean monthly and annual discharge measured on the Tsolum River during the 1914-1917, 1955-1957 and 1964-1990 periods are presented in Table 4. These values were compared with the 1986-1990 discharges in Table 5 and Figure 3. Although the 1986-90 mean annual discharge was approximately 90 percent of the long-term average, discharge during the summer months was considerably smaller than the long-term values. August, September, and October of 1986-90 averaged only 36 percent, 11 percent and 39 percent, respectively, of the long-term discharge. The ratios between short-term and long-term flows on the Tsolum River are used to estimate the long-term characteristics of monthly and annual flows on Pyrrhotite Creek and Murex Creek. The estimated long-term discharges are given in Table 5.

3.3 Discussion

In general, the patterns of runoff from the Tsolum River watershed are influenced greatly by the mountain topography. The entire Tsolum River watershed, with a median elevation of 230 m, has, on average, about 1,250 mm (10.2 m^3/s) of runoff annually. The largest portion of this runoff occurs during the winter period, as a result of rain (greater than 71 percent of the annual runoff occurs during the five-month period of November to March).

The high-elevation Pyrrhotite Creek watershed (median elevation = 1,300 m), on the other hand, has a mean annual runoff of about 2,030 mm (0.021 m^3/s), more than 60 percent greater than the Tsolum River watershed, resulting from the orographic influence of the mountains. In addition, also as a result of its elevation, runoff from the Pyrrhotite Creek watershed is largely snowmelt dominated. Snow accumulation during the winter and subsequent melt in the spring result in approximately half the annual runoff occurring during the three-month period of April to June. In addition, high elevation areas such as Pyrrhotite Creek are also subject to large runoff events during autumn and winter rain, as shown by the period of record for Pyrrhotite Creek.

The Murex Creek watershed, intermediate in elevation between Pyrrhotite Creek and the Tsolum River (median elevation = 670 m), exhibits characteristics of both spring snowmelt and winter rain runoff regimes. It has a mean annual runoff of about 1,660 mm (2.15 m^3/s), greater than the Tsolum River, but less than Pyrrhotite Creek. Also, while the largest portion of its runoff occurs during the winter period of November to March, it also experiences increased runoff during the spring snowmelt period.

All three watersheds experience very low discharge during the summer. Less than four percent of the annual runoff from the Tsolum River watershed occurs during July to September, while less than seven percent of the annual runoff from Murex Creek occurs during that time. Because the snowmelt period runoff for Pyrrhotite Creek extends into July it has slightly greater proportional summer runoff, with about 10 percent of its annual runoff occurring during the three-month period. In all watersheds, August and September are months of typically very low discharge.

The monthly discharge ratios for the three streams are given in Table 6 and Figure 4. Annual discharge from the Pyrrhotite Creek watershed, including the abandoned copper mine, comprises about one percent of the annual discharge on Murex Creek at Duncan Bay Mainline. On a monthly basis this ratio varies from a low of 0.4 percent in February, when discharge from Pyrrhotite Creek is very low due to snow storage, to a high of about 2.7 percent during the snowmelt runoff period in May and June. During some periods, however, depending on local precipitation patterns and antecedent flow conditions, discharge from Pyrrhotite Creek can comprise a very large portion of the flow in Murex Creek at Duncan Bay Mainline. During a one-week period in October, 1989, Pyrrhotite Creek discharge comprised as much as 28 percent of the Murex Creek flow, and earlier in the same year the ratio was between 5 and 15 percent for extended periods.

The discharge from Murex Creek comprises between 50 and 70 percent of the discharge in the Tsolum River below Murex Creek. During the winter period of December to March, the flow ratio is generally about 50 percent. During the spring snowmelt period, when the Murex Creek watershed is contributing relatively larger amounts of runoff, and during the summer, when the upper Tsolum River watershed has very low runoff, the ratio varies between 60 and 70 percent. This seasonal difference is even more pronounced in the flow ratios between Murex Creek and the Tsolum River near Courtenay. Despite being only 16 percent of its area, Murex Creek contributes close to 50 percent of the discharge of the Tsolum River near Courtenay during July and August. During winter months, when the low elevation portions of the Tsolum River watershed experience high runoff as a result of rain, the effect of the higher elevation Murex Creek is lessened.

In conclusion, the daily discharge data, and the analysis of these data as expressed in the appending tables and figures, describe flow relationships among streams draining an abandoned mine site on Mount Washington. This information is used in conjunction with the water chemistry data to determine a mass-balance model for copper for the Tsolum River watershed in section 5.4.

4. W ATER USES

4.1 Water Licences

There are 34 water licences on the Tsolum River registered with the British Columbia Water Management Division. All of the licences are located below the confluence of Murex Creek (Figure 5). Twenty-three of the water licences are for irrigation, and the remaining nine are for domestic water supply. The volume of water withdrawn by the irrigation and domestic water licences totals 520 dam^3/y and 38 m^3/d, respectively (Water Licencing and Utilities Branch, 1991)

4.2 Fisheries

The Tsolum River has, in the past, supported large populations of steelhead and resident rainbow trout (Oncorhynchus mykiss), sea-run cutthroat (O. clarki), coho (O. kisutch), pink (O. gorbushca), and to a lesser extent chum (O. keta) salmon. The annual escapement records (spawning returns) for pinks, chum, and coho are summarized in Figures 6, 7, and 8 (Genoe,H., pers. comm).

When examining the escapement records for the Tsolum, the Puntledge Hatchery's influence upon the estimates cannot be ignored. For example, during years when the hatchery cannot handle the returning salmon, large numbers of fish may be diverted into the Tsolum River, artificially inflating escapement estimates from time to time. Peak escapement for pinks (100,000) occurred in 1951 and 1952, for coho (15,000) in 1952, 1959, 1964, and 1966, and chum (11,000)in 1981 and 1983. Escapements for pink, chum, and coho have all declined to a point where there are virtually no escapements at present.

Steelhead populations have also declined from a maximum escapement of 3500 in 1953 to 0 in 1991 (Wightman, pers. comm.). The annual steelhead catch has declined from a mean annual catch of 101 fish (1971 to 1984) to 0 in 1990. Similarly, annual angler-day values have declined from a mean of 519 days (1971 to 1984), to 0 in 1990.

The Tsolum River Hatchery, presently operated by Project Watershed (formerly a D.F.O. site), uses water from Headquarters Creek, which is unaffected by acid drainage from the mine site. The hatchery was originally designed as an adult capture and egg take facility to produce 3,000,000 pink fry annually. In 1980 and 1984, D.F.0. began efforts to restore pink and coho stocks with adult and juvenile releases to the Tsolum watershed (Table 7a). However, very poor returns lead to the virtual closure of the facility from 1984 through 1992. In 1993, the hatchery resumed operation and released 100,000 pinks to the Tsolum in an effort to maintain and enhance the stocks in the Tsolum River.

Section 5.6 details the impacts of the elevated copper levels throughout the watershed. The bioassay data illustrate the chronic toxicity present, through much of the Tsolum River. While the decline in the coho, pinks, steelhead/resident rainbow, and cutthroat trout is thought to be largely attributable to the mining activity on Mt. Washington, other factors also play varying roles. Man's activities throughout the watershed have influenced the survival of the fisheries resource: irrigation withdrawals exacerbate summer low flow conditions; logging practices may increase erosion as well as altering hydrology; gravel removal for runway construction in the 1950's may have affected spawning (C. Beggs, pers. comm.).

By comparison, the Puntledge River has historically supported large populations of steelhead and resident rainbow trout (Oncorhynchus mykiss), coho (O. kisutch), pink (O. gorbushca), chum (O. keta) and to a lesser extent sockeye (O. nerka) and chinook salmon (O. tshawytscha). Man's activities within the watershed such as logging, agriculture, and urban development have followed similar patterns to that of the Tsolum. Hydroelectric generation involving construction of a storage dam at the outlet of Comox Lake and a downstream diversion dam has further impacted the Puntledge. Nevertheless, the Puntledge continues to support strong returns of coho, pinks, and chum salmon (Figures 9 - 11).

The Tsolum coho escapement fluctuated between 7,500 and 15,000 from 1950 through to 1966 (Figure 8). After 1966, escapement has declined steadily to a low of 14 in 1987, and 100 in 1990. The decline of the coho escapement has occurred through the 1980's despite efforts to enhance the smolt production through the release of juveniles (Table 7a). The coho are particularly vulnerable to toxicity caused by acid mine drainage as they reside in the system for up to 14 months after hatching. Although the escapement data for cutthroat, steelhead, and rainbow trout are not as complete as the coho data, trout are thought to be as vulnerable to the changes in water quality because of their long residence time in freshwater systems.

In contrast, chum and pink salmon fry emerge in the spring and migrate directly to the marine environment. They are not as vulnerable as coho to the acid mine drainage because they do not reside long in the Tsolum River, and they may migrate prior to the peak copper loadings associated with snowmelt (Sections 5.3 and 5.4). Thus, impacts upon the pink and chum population may vary from year to year. The initial decline in the pink escapement occurred prior to the operation of the mine (Figure 6), indicating other factors, such as overfishing, and summer low flows, were impacting the escapement. Enhancement efforts have maintained levels of pink returns to some extent (5,000 in 1989) so that pinks have not reached the low levels of the coho (100 in 1989). However, enhancement of the pink stocks in the 1980's has not resulted in the return to the pink escapement of the 1950's.

The chum escapement has traditionally been low in the Tsolum River, with maximum escapement occurring in the late 1970's and early 1980's (Figure 7). A high of 11,000 fish were recorded in 1981 and 1983, but this has gradually decreased to an essentially nonexistent run at present. It is possible that chum are not traditionally found in high numbers in the Tsolum River except for those years when heavy runs to the Puntledge River cannot be accommodated (H. Genoe, Puntledge Hatchery, pers. comm.).

Robertson and Malick, (1987) attempted to establish dollar values for the fisheries resources on the Tsolum River. The study calculated the current harvest value (CHV), the natural capability harvest value (NCHV), and a natural capability plus enhancement harvest value (NCEHV). The values were based on an angler's willingness to pay $25/day, and the profits made in the commercial fishing industry. Projected over a 50-year time frame, they (1987) estimated the value of the CHV at $1,600,000 the NCHV at $9,500,000 and the NCHEV at $12,100,000 (Table 8).

Robertson and Malick, (1987) estimated the 1987 steelhead and cutthroat fishery in the Tsolum River at 188 angler days. Assuming suitable water quality, the potential unenhanced trout fishery was estimated at 3000 angler days, and the potential enhanced trout fishery at 6000 angler days (Table 8).

4.3 Designated Water Uses

The Tsolum River is an important source of water for irrigation\livestock watering and domestic water use. Water-based recreational activities include fishing and swimming. These are largely centered on the Tsolum River downstream of Headquarters Creek. In addition, the Tsolum River had an important in-stream fishery for steelhead and cutthroat, and supports a sports and commercial fishery for coho, pink, and to a lesser degree, chum salmon. The major tributary to the Tsolum River is Murex Creek, which, largely due to its steep gradient, highly unstable stream bed, lack of cover and extreme summer low flow has insignificant fisheries values (Wightman,C.

pers.comm.). In fact, the portion of Murex Creek from McKay to the Tsolum is subject to prolonged periods of no visible surface flow during drier years. Pyrrhotite Creek, which drains the mine site, has no fisheries values due to its extreme gradient, extreme summer low flow and highly unstable stream bed (Wightman, pers. comm). In addition, there are no water withdrawls in Murex Creek, Pyrrhotite Creek, nor in the Tsolum River above Murex Creek. For the purposes of objectives establishment, Pyrrhotite Creek, Murex Creek below McKay Creek, and the first 500 m of the Tsolum River below Murex Creek, is to represent the initial dilution zone. It is not felt that this will form a barrier to anadromous fish migration to the Tsolum above Murex Creek as the "plume" from Murex Creek will not extend across the entire width of the Tsolum River, and dilution and organic complexing will be rapid. In addition, as discussed in section 5, the peak copper concentrations are highly seasonal in nature, so that in fact, in order for the Tsolum to meet the objectives outlined here, Murex Creek will meet the copper objective for much of the year, with the exception of up to 4 to 6 weeks during the spring and brief periods during the initial fall rains.

At present, Murex Creek easily meets the copper water quality criteria for drinking water (500 ug/L), wildlife (300 ug/L), livestock (300 ug/L), irrigation (200 ug/L) and recreation and aesthetics (1000 ug/L). As can be seen in section 6.5, in order to meet the objectives in the Tsolum River, copper levels in Murex must improve substantially, thus ensuring that these criteria continue to be met.

Ambient water quality objectives designed to protect the designated water uses will apply to the Tsolum River watershed, excluding Pyrrhotite Creek, Murex Creek below the McKay Creek confluence, and the first 500 meters of the Tsolum downstream of Murex Creek. The designated water uses of the Tsolum River are domestic, livestock and irrigation water supply, primary and secondary contact recreational use and aquatic life and wildlife. The most sensitive use of the river is by aquatic life, that is, the plant and animal communities (e.g. benthic invertebrates) which support a healthy fisheries resource, as well as the various salmonid life stages.

5. WATER QUALITY

5.1 General Water Quality

5.1.1 Tsolum River Above Murex Creek (Background - E206513)

The Tsolum River at Duncan Bay Mainline (E206513) represents background water quality for the Tsolum River (Table 9). The geometric mean pH from 1985 to 1991 was 6.9 (n=44), with a low of 6.4 and a high of 7.5. The total alkalinity of the Tsolum River averaged 16 ± 2.9 mg/L (n=3). The major cations in the system are primarily calcium and magnesium, while the major anions are bicarbonate and sulphate. Sulphate concentration averaged 1.32 ± 0.39 mg/L. Dissolved hardness averaged 15.8 mg/L, ranging as high as 27.9 mg/L and as low as 6.77 mg/L.

5.1.2 McKay and Murex Creeks Upstream of Pyrrhotite Creek (background - E206685 and E206686)

The general water chemistry of McKay and Murex Creeks upstream of Pyrrhotite Creek was similar to the background station for the Tsolum River (Tables 10 and 11). The geometric mean pHs were 6.8 and 6.7 respectively, with minimum pHs recorded as low as 6.3 and 6.2. The average total alkalinity of McKay and Murex Creeks was 6.1 ± 1.7 mg/L (n=12) and 7.4 ± 2.6 mg/L (n=13), which were lower than the Tsolum River. The average hardness was 9.96 ± 3.1 mg/L (n=31) and 7.89 ± 2.41 mg/L (n=47),respectively, both lower than that of the Tsolum River background site. Dissolved sulphate averaged 5.8 mg/L ± 2.5 mg/l (n=26) and 3.5 mg/L ± 1.3 mg/L (n=47), respectively.

5.1.3 Pyrrhotite Creek Below Mine Site (0125901)

The general water chemistry of Pyrrhotite Creek downstream of the mine site was very different from the background water quality. The geometric mean pH in Pyrrhotite Creek at Branch 126 (Table 12) was 4.1 (n=124). The maximum and minimum pHs were 4.7 and 3.6, respectively. Because the pH was < 4.5, there is no total alkalinity by definition. The acidity of the water (measured to pH 4.5) averaged 9.9 ± 7.8 mg/L.

The major cations are calcium, aluminum, magnesium, copper, and iron, while the anions are primarily sulphate resulting from the acid mine drainage. Dissolved hardness averaged 85.9 mg/L ± 51.6 mg/L (n=96), while dissolved sulphate averaged 134 mg/L ± 66 mg/L (n=123).

5.1.4 Pyrrhotite Creek Above Murex Creek (E206501)

The general water chemistry in Pyrrhotite Creek above Murex Creek is similar to McKay and Murex Creeks (Table 13). The geometric mean pH and average alkalinity at site E206501 increased to 6.7 and 7.4 ± 5.2 mg/L from 4.1 pH units and 0 total alkalinity at the upstream site (0125901; Table 12). In addition, the sulphate concentrations decreased from a high of 134 ± 66 mg/L at site 0125901, to 7.0 ± 5.3 mg/L at site E206501. Dissolved hardness averaged 12.2 mg/L ± 5.4 mg/L (n=77)

The change in general water chemistry is due to a combination of dilution, and the production of alkalinity through sulphate reduction by bacteria ($SO_4 + 2\ CH_20 = H_2S + 2HCO_3$) (Kelly et al., 1982) in the anaerobic sediments of lakes and wetlands within the Pyrrhotite Creek watershed. It is difficult to determine the relative importance of dilution and sulphate reduction because the flows at site E206501 could not be recorded. Consequently, the increase in stream flow, and the sulphate losses between the sites could not be calculated.

5.1.5 Murex Creek Above The Tsolum River (E206499)

The general water quality of Murex Creek above the Tsolum River (Table 14) was similar to that of McKay Creek and Murex Creek above Pyrrhotite Creek. Based on the general chemistry at this site, the effects of the acid mine drainage from the mine were not detectable.

5.2 HEAVY METALS

5.2.1 Field Blanks

To verify that the samples were not contaminated as a result of field filtration and preservation, a number of dissolved metals blanks were incorporated in the sampling process. These were done in the field, using lab distilled water and the filtration equipment and nitric acid preservatives, same as for the regular samples. With a few exceptions, metals were generally undetectable. In the 28 field blanks, calcium was detected in 3 samples, ranging from 0.02 to 0.03

mg/L, while iron was detected at 0.02 mg/L in 2 blanks and copper was detected at 0.001 mg/L in 8 blanks. In each case, when detectable in the blanks, each parameter was at or very near the detection limit.

5.2.2 Tsolum River above Murex Creek (Background - E216513)

Background metal concentrations were generally below their respective detection levels (e.g., cadmium, lead, molybdenum, and zinc; Table 9). Detectable concentrations of aluminum, copper, iron, and manganese were present in the system on the majority of the sampling occasions.

Background dissolved aluminum concentrations (0.057 ± 0.037; Table 9) exceeded the maximum (0.1 mg Al/L) and average (0.05 mg Al/L) dissolved aluminum criteria (Butcher, 1988). Although there are no aluminum speciation data to date, the high organic complexing capacity of the Tsolum River (Section 5.5) is thought to be sufficient to bind the dissolved inorganic aluminum to a less toxic organo-aluminum complex (Butcher, pers. comm.).

The dissolved and total copper concentrations in the Tsolum River (Table 9) were at or above the maximum (0.004 mg Cu/L) and average (0.002 mg Cu/L) copper criteria for aquatic life (hardness ≤ 50 mg/L, Singleton, 1987). Over a five-year period (1986 to 1990), the dissolved copper concentrations averaged 0.002 mg Cu/L (n=74), and ranged from <0.001 to 0.010 mg Cu/L. Total copper concentrations were higher and averaged 0.004 mg Cu/L (n=97) (Table 9). Overall, 10 of the 97 total copper results were above 0.010 mg Cu/L. The higher total copper concentrations were generally associated with high flows during storm events, indicating that the copper was associated with suspended sediment and may not be bio-available.

The dissolved iron concentrations in the Tsolum River (Table 9) were periodically above the 0.3 mg Fe/L working water quality criteria for aquatic life and domestic water supplies (Pommen, 1991). Average dissolved iron concentrations at site E206513 from 1987 to 1990 were 0.23 mg Fe/L, while concentrations above 0.3 mg Fe/L occurred about 33% of the time.

Total and dissolved manganese concentrations in the Tsolum River (Table 9) were periodically above the B.C. Environment's Approved and Working Criteria for drinking water (0.050 mg Mn/L) and aquatic life (0.100 mg Mn/L) (Pommen, 1991). The average total manganese concentrations were 0.030 ± 0.030 mg Mn/L, while drinking and aquatic life water quality criteria were exceeded 20 and 3 % of the time, respectively.

Other metals (e.g., lead, molybdenum, and zinc) were periodically present in the Tsolum River (Table 9). However, the metals were usually present in the total fraction, while the dissolved concentrations were lower, rarely exceeding the water quality criteria.

5.2.3 McKay and Murex Creeks upstream of Pyrrhotite Creek (E206685 and E206686)

McKay (Table 10) and Murex (Table 11) creeks upstream of Pyrrhotite were not considered true background stations as McKay Creek receives small amounts of copper from the south block of the minesite, and Murex Creek receives small quantities of runoff from the old tailings pond, as well as the mill site. However, most of the heavy metals present in McKay and Murex creeks were similar to the Tsolum River background station (Tables 9 and 10).

Average dissolved aluminum concentrations (McKay: 0.080 ± 0.30 Table 10; Murex: 0.070 ± 0.04, Table 11) exceeded the average (0.05 mg Al/L), and frequently exceeded the maximum dissolved aluminum criteria (0.1 mg Al/L) (Butcher, 1988).

Dissolved cadmium concentrations at both sites were below the 0.010 mg Cd/L detection level, while total cadmium was detectable only on one occasion at each station. It is difficult to determine if the single detectable total cadmium result was due to contamination of the sample, or representative of contamination in the creeks. The relatively high minimum detectable concentration, however, resulted in data which cannot be compared to the provincial criteria for the protection of aquatic life of 0.0002 mg/L.

Total and dissolved copper concentrations at both sites (Tables 10 and 11) were higher than the Tsolum River background site (Table 9). Average dissolved copper concentrations at McKay and Murex creeks were 0.006 ± 0.004 and 0.006 ± 0.003 mg Cu/L, respectively. The dissolved copper results from both sites were well above the maximum (0.004 mg Cu/L) and average (0.002 mg Cu/L) copper criteria for aquatic life (Singleton, 1987).

Other heavy metals in McKay and Murex creeks were periodically detectable; however, the average concentrations were not above the Provincial Approved or Working Criteria for aquatic life (Pommen, 1991).

5.2.4 Pyrrhotite Creek Below Mine Site (0125901)

Heavy metal concentrations in Pyrrhotite Creek below the mine site were greatly elevated above background concentrations (Table 12). For example, dissolved aluminum and copper concentrations averaged 6.8 ± 3.6 mg Al/L, and 6.6 ± 2.6 mg Cu/L, exceeding water quality criteria for aquatic life by 2 to 3 orders of magnitude.

Based on data from 1986 to 1991, the range and periodicity of aluminum and copper concentrations are highly variable from year to year, the general trend is for a decrease in metal concentration through the fall.

Other metals present in the acid mine drainage in excess of the water quality criteria include cadmium, cobalt, chromium, iron, manganese, nickel, and zinc (Table 12). Table 16 compares the average concentration for these metals to the provincial aquatic life criterion, indicating that dissolved copper averages 3300 times the criterion, while the next highest exceedance is cadmium, at 400 times. Although these metals are present in the acid mine drainage, with the exception of copper, their concentrations are sufficiently low that they were not of consequence in the Tsolum River below Murex Creek.

5.2.5 Pyrrhotite Creek above Murex Creek (E206501)

The concentrations of aluminum, copper, iron, manganese, and zinc in Pyrrhotite Creek above Murex Creek (E206501) decreased between 92 to 99 % compared to the upstream site nearest the mine site (0125901). Dilution and precipitation of the heavy metals in lakes and wetlands are the primary reasons for the decrease in metal concentrations (Deniseger and Erickson, 1989a).

Compared to the upstream site, the average dissolved aluminum concentrations at site E206501 (Table 13) decreased by 98.5%. Precipitation of aluminum has been observed in a small lake mid-way between the two sites (Deniseger, unpublished.). The precipitation is probably due to increased pH, and a decreased solubility of aluminum hydroxide (Butcher, 1988).

Dissolved aluminum exceeded the maximum criteria of 0.100 mg/L in 50% of samples taken, while the average concentration of aluminum exceeded the average criteria of 0.050 mg/L (Butcher, 1988). All samples for dissolved copper at site E206501 exceeded the maximum criteria for the protection of aquatic life (0.003 mg/L at hardness 12.2 mg $CaCO_3$; Singleton, 1987). In fact, 50% of the samples taken exceeded 0.07 mg/L. The average dissolved copper concentration of 0.20 mg/L also exceeds the average copper criteria of 0.002 mg/L for the protection of aquatic life (Singleton, 1987) by 2 orders of magnitude. In contrast, dissolved iron, manganese, nickel and zinc were generally within the aquatic life maximum criteria, except in no more than 2% of all samples (0.3 mg Fe/L; 0.100 mg Mn/L; 0.025 mg Ni/L; 0.03 mg Zn/L; Pommen,1991).

Results for cobalt, cadmium, lead, etc., at site E206501 could not be compared to the upstream site because the detection levels were higher at E206501.

5.2.6 Murex Creek above the Tsolum River (E206499)

Changes in the concentrations of heavy metals in Murex Creek just above the confluence of the Tsolum River (E206499; Table 14) compared to Pyrrhotite Creek upstream of Murex Creek (E206501; Table 13) were inconsistent. Average dissolved aluminum concentrations between the two sites did not change; average dissolved iron concentrations increased by 10 %; and average dissolved manganese, zinc, and copper concentrations decreased by 12, 53, and 88 %, respectively.

Dissolved aluminum exceeded the maximum criterion in 35% of samples, while the average value (0.10 mg/L) exceeded the criteria of 0.05 mg/L (Butcher, 1988). Dissolved copper concentrations at site E206499 were at or above the maximum criterion of 0.003 mg/L for the protection of aquatic life in 99% of all samples taken, while the average value (0.036 mg/L) greatly exceeded (18 times) the average criterion of 0.002 mg Cu/L (Singleton, 1987). Dissolved iron concentrations were above the levels for the protection of aquatic life and domestic water use in <1% of the samples taken (0.3 mg Fe/L; Pommen, 1991). The other heavy metals (e.g., manganese, zinc, etc.,) were below the working criteria for the protection of aquatic life and domestic water supplies (Pommen, 1991).

5.2.7 Tsolum River 500 meters downstream Murex Creek (E207826)

The dissolved copper concentrations in the Tsolum River just below Murex Creek (Table 15), remained above the maximum working criterion for the protection of aquatic life (0.003 mg Cu/L, Singleton, 1987) in all samples. The other heavy metals such as manganese, iron, and zinc were below the working criteria for the protection of aquatic life for all water uses (Pommen, 1991). Aluminum was not measured, while the detection limits for cadmium, cobalt, chromium, lead and nickel were too high to evaluate the data with respect to the criteria.

5.3 Mass Balance For Copper

5.3.1 Pyrrhotite Creek below mine site (0125901)

The mass of copper transported from the mine site via Pyrrhotite and Murex creeks was determined by multiplying the daily stream flow values by the ambient dissolved copper concentrations. Typically, the dissolved copper data at Pyrrhotite Creek downstream of the mine site (site 0125901) and Murex Creek above the Tsolum River (site E206499) were collected monthly in the winter, and biweekly in the summer.

Daily copper results were required for the calculation of the mass balance model; consequently, dissolved copper concentrations were estimated for the days when data were not available. Copper concentrations were estimated by interpolating the change between two sample concentrations over the time period between the two sample dates. Although this is a weakness in the model, the error caused by estimating daily dissolved copper concentrations is thought to be minimal because the dissolved copper concentrations in the acid mine drainage were not highly variable.

Copper loading estimates for Pyrrhotite Creek below the mine (Table 17a) were almost continuous for the period May 1986 to July, 1990. Copper loadings for November and December, 1988 were excluded because of problems with the stream flow measurements. The maximum copper loadings were recorded during the freshet period (e.g., May), and ranged between 434 kg Cu/month in 1990 to 1076 kg Cu/month in 1986 (Table 17a). The loadings decreased during the summer months to less than 15 kg Cu/month in September, and then increased in the fall and winter.

The variation in monthly copper loading was significantly correlated with the runoff from the mine site (r=0.94, n=49;). The strong linear relationship between runoff and copper loading indicates that reduction of runoff from the mine site should be an effective restoration technique.

5.3.2 Murex Creek above the Tsolum River (E206499)

Copper loading estimates for Murex Creek above the Tsolum River were continuous between July 1987 and June, 1990 (Table 17a). The copper loadings were typically less than at Pyrrhotite Creek below the mine site for the 34 months of comparable data. Erickson and Deniseger (1987) noted that the wetlands within the Pyrrhotite Creek watershed retained a significant proportion of the copper from the mine site through bacterial sulfate reduction followed by metal sulfide precipitation.

The percent of copper retained within the Pyrrhotite Creek watershed varied from +93% to -238% (Table 16), indicating high seasonal variability. The negative copper retention implies that the wetlands below the mine site were a source of copper. The release of copper from the wetlands typically occurred during the winter months. Presumably, decreased biological activity in the wetlands in conjunction with high stream flows, resulted in the release of dissolved copper.

On an annual basis, total loadings were calculated for two time periods: 1) September 1987-88; 2) January 1989-90. Total loadings for Pyrrhotite Creek below the mine site were calculated at 2798.7 kg for period one, and 3203.7 kg for period two. By comparison, total loadings for Murex Creek above the Tsolum were calculated at 1153.5 kg for period one, and 1042.2 kg for period two, a 59% and 67% reduction, respectively, over Pyrrhotite Creek.

Copper mass balance calculations were done to examine the relationship between copper concentration and potential percent retention of copper in the Pyrrhotite Creek wetlands. The calculations used the copper concentration in Pyrrhotite Creek downstream of the mine site, the percent copper retention, and the dilution ratio based on the stream flows between the two stations. Percent copper retention was calculated based upon the monthly loadings estimates used in table 17a as follows:

$$\frac{\text{Pyrrhotite Ck (kg/mo)} - \text{Murex Ck (kg/mo)}}{\text{Pyrrhotite Creek loadings (kg/mo)}} \times 100 = \text{\% retention}$$

The results of the mass balance calculations are summarized in Table 17b. The calculated copper concentrations for Murex Creek were very close to the measured copper concentrations. This was not unexpected because the flow and copper concentrations measured on Murex Creek were used to determine the percent copper retention and the dilution ratios, which are the primary components of the model. However, the results are key in determining which components are important in reducing the copper concentrations in Murex Creek.

To use the mass balance calcultions to confirm Murex Creek copper concentration, the following equation is used:

$$\frac{\text{Pyrrhotite Ck (mg Cu/L)} - (\%\text{retention X Pyrrhotite Ck (mg Cu/L)})}{\text{dilution factor}}$$

The seasonal patterns described by the calculations are:

Summer: Acid mine drainage: >6 mg Cu/L.
Low dilution by Murex Cr.: <50:1
High copper retention in wetlands: >60%

Result is dissolved copper concentrations in Murex Creek between 10 to 20 ug/L.

Fall: Acid mine drainage : 7 to 12 mg Cu/L.
Increased dilution by Murex Cr.: 50:1 to 200:1
Lower copper retention in wetlands: about 50%
Result is dissolved copper concentrations in Murex Creek between 10 to 30 ug Cu/L.

Winter: Acid mine drainage: < 6 mg Cu/L
High dilution by Murex Cr.: 200:1 to 1330:1
Low copper retention in wetlands: <50% to -235%

Result is dissolved copper concentrations in Murex Creek between 10 to 20 ug Cu/L.

Spring: Acid mine drainage: <6 mg Cu/L
Low dilution by Murex Cr.: 20:1 to 100:1
Lower copper retention in wetlands: >50%

Result is dissolved copper concentration in Murex Creek between 20 to 60 ug Cu/L.

Based on these results, the highest copper concentrations in Murex Creek occur in the spring and, to a lesser degree, in the fall. The conditions that cause high ambient copper concentrations were low dilution by Murex Creek (<50:1) and low percent copper retention in the wetlands (<50%). The low dilution ratios occurred in the spring because of the difference in median basin elevation between Pyrrhotite and Murex Creeks. The majority of runoff in Murex Creek occurs prior to May. Consequently, the peak runoff of acid mine drainage via Pyrrhotite Creek in May and June is not adequately diluted by Murex Creek.

The fall copper concentrations (10 - 30 ug Cu/L) were usually lower than in the spring primarily because of higher dilution by Murex Creek. Summer copper concentrations were lower (<20 ug Cu/L) because of the high copper retention within the wetlands along Pyrrhotite Creek. Winter concentrations were also lower (<20 ug Cu/L) because of high dilution by Murex Creek.

5.4 Organic Complexing Capacity

Metal speciation in rivers such as the Tsolum determines the free or biologically available portion of the total metal concentration. One of the principal variables controlling metal speciation in natural waters is the concentration of organic ligands that bind specific metals. The degree to which a given metal will be bound or complexed will depend on competition reactions with other ligands and each metal's affinity for those ligands. Copper has the highest affinity for binding sites in humic materials. In the relatively organic-rich watershed of the Tsolum River, a considerable portion of the humic material is involved in complexing with copper. It has been shown by Imber (1992) that once the organic ligand assemblage (humic acid) is saturated with copper, the amount of organic ligand binding is reduced to only a few percent. This has obvious implications in the determination of biologically active copper.

Organic complexing capacity data for the Tsolum watershed are essentially limited to two sites: Tsolum River above Murex Creek (E206513) representative of the lower elevation portions of the watershed; and Murex Creek upstream of Pyrrhotite Creek (E206686), which is representative of the upper portions of the watershed (Table 18). Data for both sites illustrate the variability of complexing capacity depending upon the season. At both sites, complexing "cycled" through the year, so that values were lowest during the winter months, when flows were high, temperatures low and biological activity low. This was followed by a gradual increase through the spring to higher summer values. The period of highest complexing coincides with the period of highest copper retention in the Pyrrhotite wetlands, which also suggests that the organics settle or are filtered out in the wetlands. The lower portion of the watershed is characterized by large areas of wetland while the upper portions are dominated by relatively steep rocky slopes with few wetland areas. As such, it is not surprising that the Tsolum River background site had a substantially higher copper complexing capacity than that of the Murex site. The seasonal nature of complexing capacity is of particular note given that the period of highest complexing (summer) does not match the period of greatest copper levels in the lower Tsolum (spring).

5.4.1 ORGANIC COMPLEXING CAPACITY AND TOXICITY

To verify the effects of complexing capacity upon toxicity, a series of acute toxicity bioassays (rainbow trout 96-h LC50) were run using three different sources of dilution water representing three different ranges of organic complexing capacity. Samples from Pyrrhotite Creek below the mine site (site 0125901) were taken for acute toxicity testing and submitted to the Aquatic Toxicity Laboratory in North Vancouver. However, rather than simply using the laboratory's water supply (Capilano River), dilution water from the Tsolum River background station (E216513) and from Murex Creek upstream of Pyrrhotite (E206686) were submitted. Thus, three sets of bioassays were run simultaneously, each representing a different copper complexing capacity: Aquatic Toxicity Laboratory - very low complexing; Murex Creek upstream Tsolum - moderate complexing; and Tsolum River background - relatively high complexing. The experiment was run on four occasions, April, August, November, and December 1991, representative of the seasonal changes in the watershed.

It was found that acute toxicity varied widely depending upon the organic complexing capacity of the dilution water used (Table 19). The relatively low complexing associated with the laboratorys' water supply resulted in a far more toxic sample than did the other two sets of dilution water. It also tended to be less variable from season to season, as toxicity varied only slightly through the year.

Using Murex Creek dilution water, toxicity was approximately 25 to 50% lower (than lab water) due to higher complexing capacity. However, seasonal variability was limited to less than 25%. Tsolum River dilution water resulted in an LC50 value averaging 410% less toxic than the lab water and 290% less toxic than the Murex water. Tsolum dilution water results showed more variability (April toxicity approximately twice that of November) due to the seasonal variability in organic complexing capacity.

5.5 Bioassay Studies

Three studies have been completed on the Tsolum River to determine the levels of acute and chronic toxicity. The first study was designed to determine the degree of chronic toxicity in the Tsolum River. The study was conducted in 1989 with coho salmon caged at various locations within the Tsolum River watershed.

The in-situ study was repeated in 1990 with both coho salmon and steelhead at four sites on the Tsolum River, and one site each on Murex and McKay Creeks. Coho mortality was used to determine the 21-day LC50, coho gills were analyzed to determine the effects of copper on gill histology, and steelhead livers were used to determine the biochemical response to acid mine drainage.

The third study was conducted in 1991 at the Ministry of Environment's Bioassay Laboratory in Vancouver. Rainbow trout were used to determine the 21-day LC50 and hepatic biochemical response to acid mine drainage under controlled conditions.

5.5.1 Study Design and Toxicity Results

1989 Study

Coho underyearlings (O. kisutch: 100 - 120 grams) were carefully transported from the Puntledge River Salmonid Enhancement Facility to six sites within the Tsolum River Watershed (Figure 1; Tsolum River upstream Murex Creek (E206513), McKay (E206685) and Murex Creeks (E206686) upstream of Pyrrhotite Creek, Tsolum River 500 m downstream of Murex Creek (E207826), Tsolum River upstream Headquarters Creek (no site number), Tsolum River at Farnham Road (0127620).

Ten coho were deployed in cages at each of the sites for 21 days (May 17 to June 7, 1989) to determine long-term survival. Sites were visited a total of 9 times over this period, a mimimum of twice per week. During each visit, water samples for total metals were taken, and the fish were fed and checked for mortality and general condition.

The 21-day LC50 based on the coho mortality data in 1989 was calculated to be 32 ug Cu/L (95% confidence limits 16 - 48 ug Cu/L). The 21-day coho mortality results in 1989 (Table 20) were strongly correlated with the average total copper concentration in the Tsolum River (r^2=0.90). It is also important to note that none of the sites utilized in 1989 were acutely toxic using the 96-h LC50 criteria, i.e. no fish died within the first 96 hours. However, long term mortality (chronic toxicity) was clearly evident at each of the Tsolum River sites impacted by the acid mine drainage.

1990 Study

Steelhead smolts (O. mykiss: 150 - 180 grams) and coho underyearlings (O. kisutch: 110 - 130 grams) were carefully transported from the Puntledge River Salmonid Enhancement Facility located in Courtenay to six sites in the Tsolum River watershed (Figure 1; Tsolum River upstream Murex Creek (E206513), Murex Creek above Tsolum River (E206499), McKay Creek above Pyrrhotite (E206685), Tsolum River 500 meters downstream Murex (E207826), Tsolum River at Farnham Road (0127620), Tsolum River upstream Puntledge (0127621).

Ten coho were deployed in cages at each site for 28 days (May 1 to May 29, 1990) to determine long-term survival. Sites were visited a minimum of twice per week. During each visit, water samples were taken and the fish were fed and checked for mortality and general health. At the end of the experiment, five surviving coho from each cage were sampled for histological examination of gill tissues.

To minimize handling stress during the extraction of gills for histology, coho were removed from the cages and immediately anaesthetized in MS222 (75 mg/L), followed by transfer to a lethal MS222 solution (150 mg/L). The gills were removed and fixed in Davidson's solution prior to shipment to the B.C. fish health laboratory in Nanaimo, where they were examined for stress response.

Five steelhead trout were placed in cages at 4 of the 6 sites. The sites at Murex Creek upstream of the Tsolum and Tsolum River 500 meters downstream of Murex Creek were not used because of the high copper concentrations and an anticipated high mortality rate. After 28 days, all surviving steelhead were sacrificed, weighed, and the extracted liver placed immediately on dry ice, and shipped to C.B.R. International (Sidney, B.C.) for biochemical analysis.

After two weeks, the steelhead and coho cages at McKay Creek in 1990 were damaged by a flood event. Unfortunately, the experiment had to be aborted at this site. No mortalities had been recorded over two weeks at this site.

The 21-day LC50 based on the coho mortality data, was calculated to be 14.7 ug Cu/L (95% confidence limits: 8.0-21.1 ug Cu/L). The 21-day coho mortality results from the Tsolum River in 1990 (Table 21) were strongly correlated with the average total copper concentration in the Tsolum River (r^2=0.97). Although this relationship would only apply to the Tsolum River, because of its specific water quality, it is important to note that with the exception of Murex Creek upstream of the Tsolum River, none of the sites tested were acutely toxic using the 96 hour LC50 criterion, i.e. none of the fish died within first 96 hours. However, long-term mortality was clearly demonstrated at each of the Tsolum River study sites impacted by the acid mine drainage.

1991 Study

The 1991 bioassays were designed to determine (under controlled conditions) the 96-hour and 21-day LC50, and the hepatic biochemical response to dissolved copper in the Tsolum River. Acid mine drainage from Pyrrhotite Creek downstream of the mine site (site 0125901) and water from the Tsolum River upsteam of Murex Creek was shipped, in bulk, to the Ministry of Environment bioassay laboratory for the test. An acute bioassay with rainbow trout was performed using Tsolum River dilution water to determine the 96-h LC50 of the acid mine drainage. A chronic rainbow bioassay was then run for 21 days at five dissolved copper concentrations that were 0%, 15%, 30%, 45%, and 60% of the 96 hour LC50. These percentages were intended to correspond to theoretical total copper concentrations of <0.001, 0.045, 0.090, 0.135 and 0.180 mg/L, respectively. However, as indicated in Table 22, the actual copper concentrations were measured as 0.025, 0.085, 0.125, 0.130 and 0.160 mg/L, respectively. The reasons for the discrepancies between theoretical and actual concentrations are unclear.

The results of the 21 day chronic bioassay were somewhat different than anticipated in that mortalities were limited to only 20% in the 30% LC50 concentration and 10% in the 60% LC50 concentration bioassays (Table 22). This means that in a copper concentration as high as 0.160 mg/L, only 10% of the test fish died. However, it must be noted that this lab bioassay was run using only Tsolum River water as dilution water, rather than the water normally used at the Aquatic Toxicity Laboratory. Organic complexing capacity was measured to be 0.100 mg/L in the dilution water. While the complexing capacity of Pyrrhotite Creek below the mine site was not measured, it would also contribute slightly to the overall binding of copper in the bioassays. An LC50 could not be calculated for this experiment as there were insufficient mortalities at each concentration used.

5.5.2 FISH GILL HISTOLOGY

As stated previously, fish gill histology was limited to a portion of the 1990 in-situ bioassay. All of the surviving coho in the Tsolum River upstream of Murex Creek (E206513) had some mild gill damage. It is thought that this may be a consequence of the caging of these fish. Gills from caged fish located at the Tsolum River just upstream of the Puntledge River (0127621) ranged from mild to moderate/severe, while those from the Tsolum River at Farnham site (0127620) ranged from mild to severe. Although no clear pattern exists between gill histology, it is apparent that the stations with higher copper concentrations (Puntledge and Farnham) had increased gill damage.

5.5.3 HEPATIC BIOCHEMICAL ANALYSIS

The protein, metallothionein, has been identified in the livers (as well as other organs) of a wide variety of vertebrates and invertebrates. Metallothionein serves a regulatory function for the essential metals copper and zinc, and also serves as a detoxification function for mercury and cadmium, as well as excess copper and zinc (Kagi and Nordberg, 1979). Metallothionein (MT) concentrations increase with exposure to these metals (McCarter et al, 1982). Other evidence shows that metallothionein provides some protection against the toxic effects of these metals by sequestering (binding) and reducing the amounts of free metals in the tissues (Brown and Parsons, 1978; Pruell and Engelhardt, 1980). Olafson et al., (1979) suggested that metallothionein concentrations may be good measures of the extent of recent exposure of aquatic organisms to specific metals.

Closely associated with the detoxification function of metallothionein is the "spillover" hypothesis initially proposed by Winge et al (1974). This hypothesis has been used to explain pathological effects in animals that have metals in protein fractions of tissues other than the protein fraction containing MT. Once the capacity of MT to sequester metals was surpassed, the metals spilled over into other protein fractions, resulting in pathological effects.

It has been shown that metallothionein binds metals in the sequence copper > cadmium >> zinc (Rupp and Weser, 1978; Furey et al., 1986). This can make interpretation difficult as all naturally occurring MT contains zinc, and both copper and cadmium are incorporated into MT by displacing zinc (Cousins,1985). However, cadmium cannot displace copper from MT. Thus, during copper exposure when the ratio of copper to zinc in MT increases, the cadmium-binding capacity of metallothionein decreases. It was shown by Hamilton and Mehrle (1986) that competition from copper for binding sites displaces quantities of cadmium, i.e., free cadmium, to other cellular components resulting in increased toxic effects. It was found that in cases such as this, MT may not be a sound indicator of early, mild exposure to a metal where a dose-dependent response is an important factor. However, MT concentrations may continue to be a good indicator of long-term, severe exposure in fish populations. If MT were significantly elevated, mortality would likely be occurring in the population as a result of the metal stress (Hamilton and Mehrle (1986). They further postulate that an additional, and at times more useful, biological indicator of metal toxicity might be the determination of free metal (i.e., non metallothionein bound) in the liver. A strong dose-dependent response was shown by free cadmium as well as a strong relation with important whole-animal responses such as mortality and whole-body residues. The concept of molecular indices of metal stress (MIMS) was developed to further address this relationship (Imber, 1988).

Although much of the existing research has been focused upon metallothionein and other similar very low molecular weight proteins (i.e., cytosolic pools), non-cytosolic pools such as lysosomal vesicles and membrane-bound granules are also important in metal metabolism and toxicity (George, 1982; Simkiss and Mason, 1983). These protein pools have been included in the MIMS process. As an organism undergoes an increasing challenge from bioavailable metal ions, the distribution of metals between the cytosolic and non-cytosolic pools is altered. To determine the MIMS ratio, concentrations of metal species bound to cytosolic proteins and the total concentration of metals in all protein fractions are compared. Changes in the ratio indicate a change in the cellular distribution of the metal and this occurs in response to environmental changes in metal concentrations.

In a study on the effects of a mixture of metals upon rainbow trout in the Campbell River watershed, Roch and McCarter (1984) proposed a metallothionein concentration of 100 nmol/g as a safe level for salmonids which correlated to 0.05 mg Zn/L, 0.0025 mg Cu/L, and less than 0.0005 mg Cd/L. Hepatic metallothionein levels in Buttle Lake rainbow trout have decreased by 76% from a high of 269 $\pm$ 23 nmol/g wet liver in 1981 to a low of 64 $\pm$ 22 nmol/g wet liver by 1985. Since 1985 MT levels have remained remarkably consistent, ranging from 64 to 71 nmol/g (Deniseger and Erickson, 1991). The relative health of the fish population is further confirmed by the dramatic improvement in angler success and catch statistics, as well as field observations.

1990 STUDY

In 1990, the hepatic metallothionein concentrations of caged steelhead in the Tsolum River increased with ambient copper concentrations (Table 21). The metallothionein concentrations at the Tsolum River at Farnham site (0127620) were significantly higher than the control site (Tsolum River upstream Murex - E206513). Metallothionein concentrations at the Tsolum River upstream of Puntledge site (0127621) were intermediate between the control and Farnham sites and thus not significantly different from either site.

In 1990, the ratio of cytosol copper to total copper increased with increasing exposure to copper. The cytosol/total copper ratio was highest at the Tsolum River at Farnham site (0127260), which was significantly different from the control site, Tsolum River upstream Murex (E206513). The Tsolum River upstream of Puntledge (0127621) cytosol/total copper ratio was intermediate between the control and Farnham site and as such was not significantly different from either site. It is difficult to directly compare the Buttle Lake metallothionein data for native fish with the Tsolum data for caged fish due to different exposure times.

1991 STUDY

The results of the 1991 laboratory study were inconclusive in terms of metallothionein and cytosol/total copper ratios (Table 22). While exposure to elevated levels of copper resulted in metallothionein and cytosol/total ratios significantly higher than in the control, levels of MT and the cytosol/total ratios did not continue to increase with increasing exposure to copper. It would appear that the high copper complexing capacity of the dilution water used resulted in lower than anticipated actual free copper concentrations in the bioassay. The overall lack of mortalities in the laboratory study further supports this argument. The study may have been further complicated by the fish feed used by the laboratory, as it may have been contaminated with heavy metals (Van Aggelen, pers.comm.).

6. WATER QUALITY OBJECTIVES

As outlined in earlier sections of this report, the primary purpose of the establishment of objectives for the Tsolum River is in response to the intensive reclamation activity presently ongoing at the abandoned minesite on Mt. Washington. For the purposes of this report the principal variable of concern in the watershed is copper. The objectives recommended here for the Tsolum River are designed to protect the most sensitive use of the river, i.e., the fisheries resource. The fisheries resource in the Tsolum watershed is limited to the lower elevation portions of the watershed, including the entire mainstem Tsolum and the lower elevation tributaries downstream of Murex Creek, such as Headquarters Creek. The objectives recommended here will apply to the entire length of the Tsolum River, with the exception of a 500 m mixing zone below Murex Creek.

To establish an objective for copper in the Tsolum River watershed, a number of factors need to be integrated: dilution of Murex Creek by the upper Tsolum; organic complexing capacity in the upper Tsolum and Murex Creek; naturally occurring background levels in the watershed; toxicity studies in upper Murex and McKay Creeks. In addition, further studies within the watershed have indicated that the toxicity associated with acid mine drainage from the mine site is highly seasonal in nature (Erickson and Kangasniemi, 1986; Erickson and Deniseger, 1987). A four to six week period during May and June has the highest levels of copper found in the lower Tsolum River. It is this period which is critical to salmonid survival, as is, although to a lesser extent, short-term pulses of copper associated with early fall storm events. Thus, the objectives will be based upon the springtime levels of complexing and the minimal dilution associated with this period.

6.1 PROVINCIAL CRITERIA AND TRUE BACKGROUND

Murex and McKay Creeks above Pyrrhotite (sites E206686 and E206685) do not represent true background in the watershed as these streams receive small amounts of copper from the south block of the minesite or the old tailings pond/mill site. Thus, the determination of true background copper levels in the watershed must consider the upper Tsolum above Murex (E205513, Table 9). This site is characterized by concentrations of copper, averaging 0.002 mg/L dissolved copper and 0.004 mg/L total copper.

The 30 day average criterion, approved by the B.C. Ministry of Environment, to protect fish from long-term effects of copper in soft waters (hardness ≤50 mg/L $CaCO_3$) is 0.002 mg/L total copper, while the maximum criterion is 0.004 mg/L total copper (Singleton, 1987). The Tsolum River watershed is characterized by wide spread occurrence of mineralization, which results in slightly higher background copper levels. In fact, given that background concentrations averaged 0.004 mg/L total copper, the provincial criteria for copper do not appear directly applicable to this watershed. In addition, it is thought that a more reliable measure of copper concentration in the Tsolum watershed would be dissolved copper. From 1986 through 1990, 10 of 97 total copper results for Tsolum River at Duncan Main were above 0.010 mg/L, largely in association with high flows during storm events, while dissolved copper values were less erratic, ranging as high as only 0.010 mg/L. During storm events high levels of suspended solids may produce high total copper concentrations, which are not bioavailable.

Further evidence supporting a copper objective higher than the provincial criteria is given at two sites within the watershed. Murex Creek upstream Pyrrhotite (E206686) and McKay Creek upstream Pyrrhotite (E206685), are both characterized by slightly elevated levels of dissolved copper, averaging 0.006 mg/L, with occasional values exceeding 0.01 mg/L. In spring 1989, at each of these sites, an in-situ bioassay (section 5.5.1) found no mortalities, indicating no acute toxicity and no toxicity over the 21 day exposure period. In addition, both sites support healthy diverse benthic invertebrate populations, and resident cutthroat trout (Erickson and Deniseger, 1987).

6.2 DILUTION OF MUREX CREEK BY THE TSOLUM

It was shown in section 3.3 that during the critical spring snowmelt period, Murex Creek contributes relatively larger amounts of runoff to the Tsolum River, typically as much as 70% of the Tsolum's discharge below Murex Creek, i.e., Murex Creek discharge is 2.33 times the Tsolum River upstream Murex discharge. This represents a "worst-case" dilution, which will be used for the purposes of objectives establishment.

6.3. ORGANIC COMPLEXING CAPACITY

The relatively high copper complexing capacity of the upper Tsolum River has been shown to protect fish from the effects of elevated levels of heavy metals. As such, copper complexing capacity must be incorporated into the copper objective for the Tsolum.

It was shown in section 5.5.1 that organic copper complexing capacity in the lower Tsolum is characterized by seasonal variability, with highest complexing occurring during the summer/fall, and moderate levels in the spring. However, given that the most critical period for water quality has been found to be the spring (and to a lesser extent the fall), organic complexing values for the spring period will be used as part of the objectives determination.

A number of mathematical models have been developed to determine the chemical speciation of anions and cations in the environment. The B.C. Acid Mine Drainage Task Force recently contracted C.B.Research to evaluate one of these models, the MINE1.2 model. The methodology for this model was first introduced by Francois Morel of M.I.T. in 1979. It was found that the model would accurately project metal speciation at any given point in time at a given location, provided that sufficient anion/cation, pH, pE and humic acid content information is available (Imber, 1992). For the Tsolum watershed it was determined that the overriding factor determining binding or complexing was humic acid content (Imber, 1992). Humic acid content was measured in the Tsolum River 500 meters downstream of Murex Creek (E207826) on three occasions in 1992 (Table 18b). Humic acid content varied seasonally. Humic acid content during spring snow melt (May 12, 1992) was measured at 1.8 mg/L. This is thought to represent humic acid content during the critical 4 to 6 week spring snow melt period.

Using the MINE 1.2 model, a humic acid content of 1.8 mg/L, and typical water quality data for the Tsolum River downstream of Murex Creek, predictions of organic binding were made in response to a number of concentrations of dissolved copper. These values are shown in Table 23. It is readily apparent that, at relatively low concentrations of copper, the majority of the copper present is organically bound. For example, at 0.010 mg/L dissolved copper, 65.7% of the copper is organically bound, i.e. only 0.0034 mg/L is "free copper".

The provincial criteria for copper are based on provincial water quality trends and characteristics, such as undetectable background levels (i.e. <0.001 mg/L total copper) and negligible copper complexing capacity (i.e negligible binding). Thus, the provincial criteria could be interpreted as approaching an average of 0.002 mg/L (total copper) above background or more specifically approaching 0.002 mg/L free copper above background, and a maximum of 0.004 mg/L free copper above background. As discussed in section 6.1, total copper concentrations in the Tsolum watershed can be misleading, particularly during storm events. Thus, it is recommended that the objective for the Tsolum be based upon dissolved copper. Using the MINE 1.2 model as specified above, background dissolved copper values of 0.002 mg/L, would result in "free copper" of 0.0004 mg/L, at Tsolum River downstream of Murex Creek. As can be seen in Table 22, a "free copper" concentration of 0.0020 mg/L, essentially 0.002 mg/L above background, would be produced by a dissolved copper concentration of 0.007 mg/L.

6.4 PROPOSED OBJECTIVES FOR COPPER

Based upon the information presented here, in order to protect aquatic life in the Tsolum River, the following copper objectives will apply for the entire length of the Tsolum River, with the exception of a 500 meter mixing zone downstream of Murex Creek:

1. 30 day average objective for copper throughout the Tsolum River of 0.007 mg/L dissolved copper.
2. maximum concentration of 0.011 mg/L dissolved copper.

6.5 ECOSYSTEM OBJECTIVES

Given that the copper objectives recommended here are somewhat higher than the provincial criteria for copper, it is important to monitor the health of the aquatic community within the watershed. Community composition and diversity are extremely sensitive indices of environmental change. While water chemistry grab samples reflect the water quality at the time of sampling, biological sampling integrates the range of conditions that the organisms have been exposed to. In this way, long-term chronic effects as well as short-term acute toxicity can be assessed.

It is recommended that the aquatic community be assessed as follows:

1. As a direct indication of the health of the fisheries resource, the most sensitive salmonid life stage (eyed egg/alevin) will be assessed through the use of in-situ egg bioassays, carried out over a two-week period. Every three years, during spring freshet two sites within the Tsolum River (E206513 and E207826) would be assessed. The objective would be no significant difference in survival, between the two sites, with a 95% confidence level.

2. The highly sensitive benthic invertebrate community has been severely impacted by the copper levels in the Tsolum River. To ensure the recovery and health of the fisheries resource, benthic invertebrates should be sampled and assessed for abundance and diversity, at two sites (E206513 and E207826), every 3 years. The qualitative objective

is to restore a healthy, diverse abundant benthic invertebrate population to the Tsolum River downstream from Murex Creek. However, no quantifiable objective will be recommended at this time due to the inherent variability of benthic invertebrate populations and our inability to define defensible quantifiable objectives.

6.6 REDUCTION IN ACID MINE DRAINAGE REQUIRED IN ORDER TO MEET THE COPPER OBJECTIVES IN THE TSOLUM RIVER

In order for the ongoing reclamation at the abandoned Mt. Washington minesite to be considered successful, copper objectives for the Tsolum River will have to be met. The most critical time period has been shown to be the spring. Thus, these calculations are based upon spring dilutions. The dilutions used here, occurred during the spring of 1987, and are thought to represent a "worst-case" scenario. As will be shown by the following table, considerable reduction in acid mine drainage will be required. The calculations here are based on the following:

a) dilution ratios (spring)

Murex/Tsolum = 2.33:1

Murex/Pyrrhotite = based upon existing copper data dilution may be as low as 7:1 for short periods through the spring

b) background dissolved copper concentrations

Tsolum River = 0.002 mg/L

Murex Creek above Pyrrhotite = 0.006 mg/L

LOCATION	30 DAY AVERAGE	PRESENT 30 DAY AVERAGE	% REDUCTION REQUIRED
Tsolum	0.007 mg/L	N/A	
Murex u\s Tsolum	0.009 mg/L	N/A	
Pyrrhotite above Murex	0.027 mg/L	0.640**	96%

** occurred in spring 1987 - heavy snow pack, warm weather

The predicted copper concentrations for the Tsolum River 500 m downstream of Murex Creek exceeded the monthly average of 0.007 mg/L for 29 of 34 months between July 1989 and June 1990 (Table 17b). The highest predicted copper levels were about 6 times higher than the recommended 30-day average objective of 0.007 mg/L

7. MONITORING RECOMMENDATIONS

7.1 WATER CHEMISTRY

The copper objective for the protection of aquatic life applies to the entire length of the Tsolum River. Given that Murex Creek is the major source of copper contamination to the Tsolum, a monitoring site 500 meters downstream of Murex Creek has been selected (SEAM site E207826). It is assumed that if the objective can be met at this site, the entire river will meet the objective, (with the exception of a small mixing zone below Murex Creek).

Monitoring of the objectives outlined in section 6.4 requires a minimum of 5 samples in 30 days. The critical periods for copper within the Tsolum have been identified as the spring and fall. To meet the 5 in 30 day requirements as well as cover the spring and fall periods, the following monitoring is recommended:

1. April 15 to June 30 - weekly monitoring for dissolved copper at Tsolum River 500 meters downstream of Murex Creek

2. September 15 to November 30 - weekly monitoring for dissolved copper at Tsolum River 500 meters downstream of Murex Creek

Samples will be analyzed for humic acid, dissolved organic carbon and "free copper", to further develop the relationship between these parameters. To achieve this, a set of 3 samples must be taken, as follows: a) sample analyzed for dissolved metals; b) sample passed through cation column to remove inorganic copper, then digested to allow analysis of organically bound copper (difference between dissolved copper and bound copper equals "free" copper; c) sample analyzed for humic acid and dissolved organic carbon. Thus, the following additional program is recommended:

Monthly monitoring (April to June and September to December) of humic acids, dissolved organic carbon, "free copper" and dissolved copper at Tsolum River 500 meters downstream of Murex Creek.

The recommended sampling program will include a quality assurance program to include field blanks, field replicates and possibly occasional field reference samples.

7.2 ECOSYSTEM MONITORING

1. In-situ egg bioassay - Every 3 years, during spring freshet (April 15 - June 30), an in-situ egg bioassay should be carried out at the following sites: Tsolum River 500 meters d/s Murex (E207826); Tsolum River upstream Murex (E206513). The bioassay would be done utilizing eyed-stage steelhead eggs, set out in modified Whitlock-Vibert boxes. Details of the method are available from the provincial Aquatic Toxicity Laboratory.

2. Benthic invertebrates - Every three years, during spring freshet, benthic invertebrates should be sampled and assessed for abundance and diversity. Utilizing a surber sampler, two sites will be assessed: Tsolum River upstream of Murex Creek (E206513); Tsolum River 500 meters downstream of Murex Creek (E207826).

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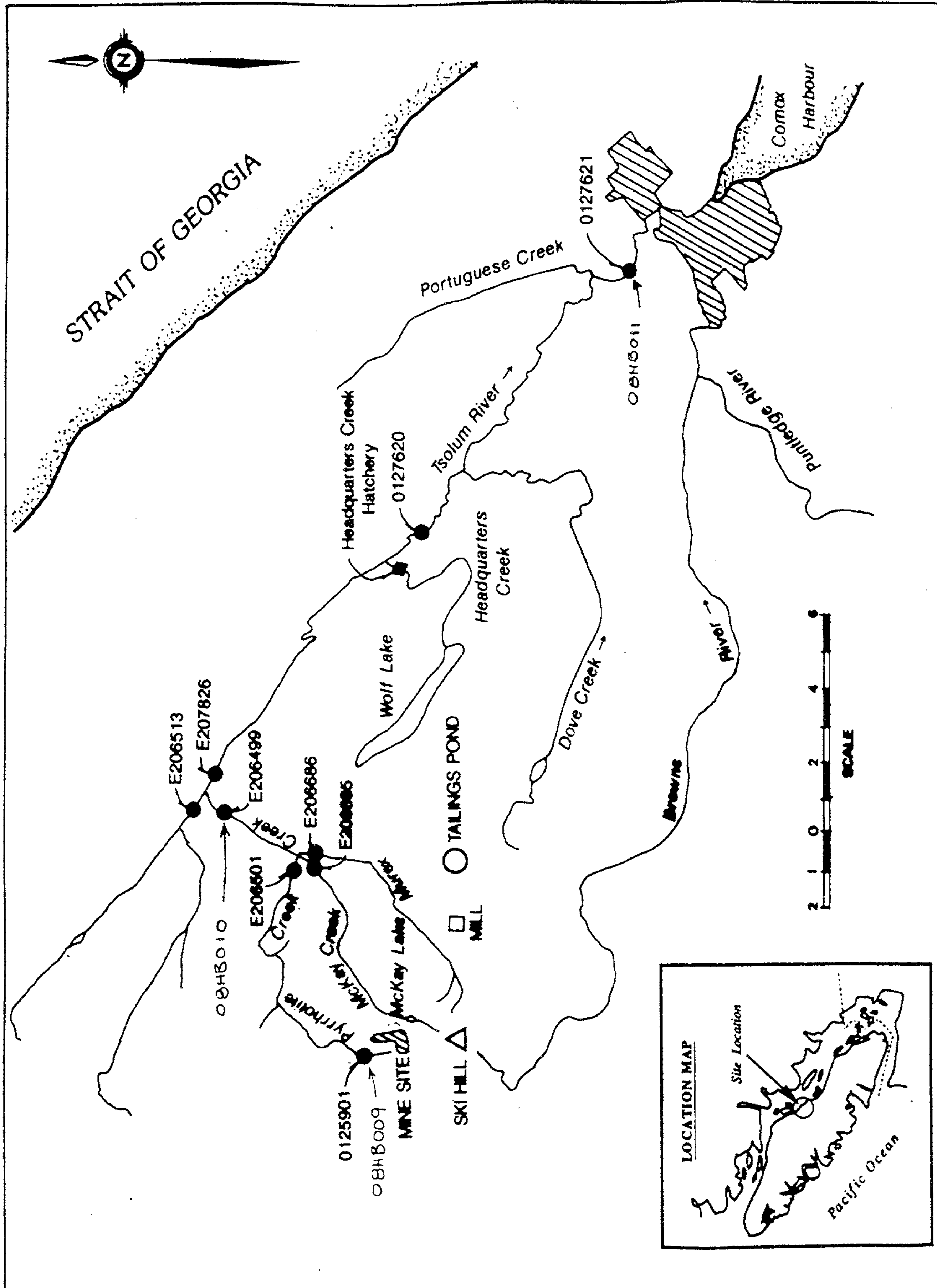

Figure 1. **Tsolum River drainage indicating sampling sites**

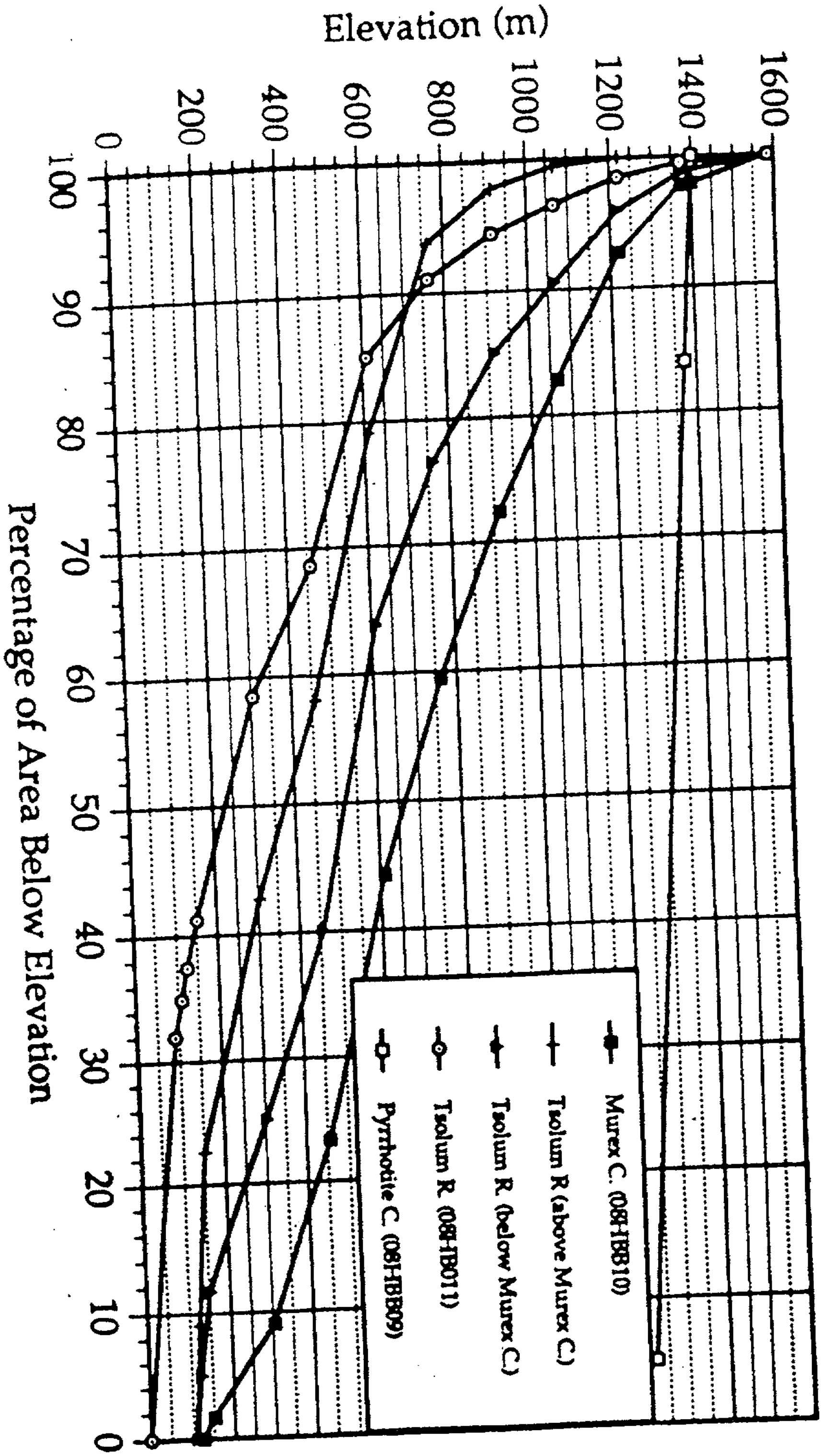

Figure 2. Area-Elevation Curves for Pyrrhotite Creek, Murex Creek, and the Tsolum River

FIGURE 3. Tsolum River Discharge-ratio of short term (1986-90) to long term discharge (data since 1914)

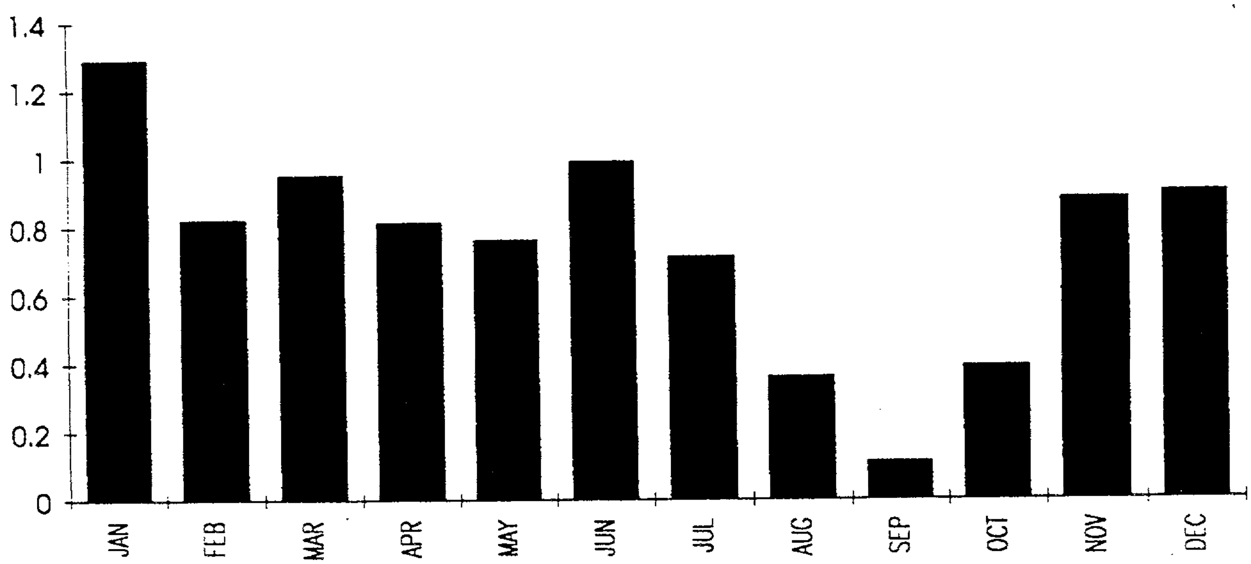

FIGURE 4. Monthly discharge ratios in the Tsolum watershed

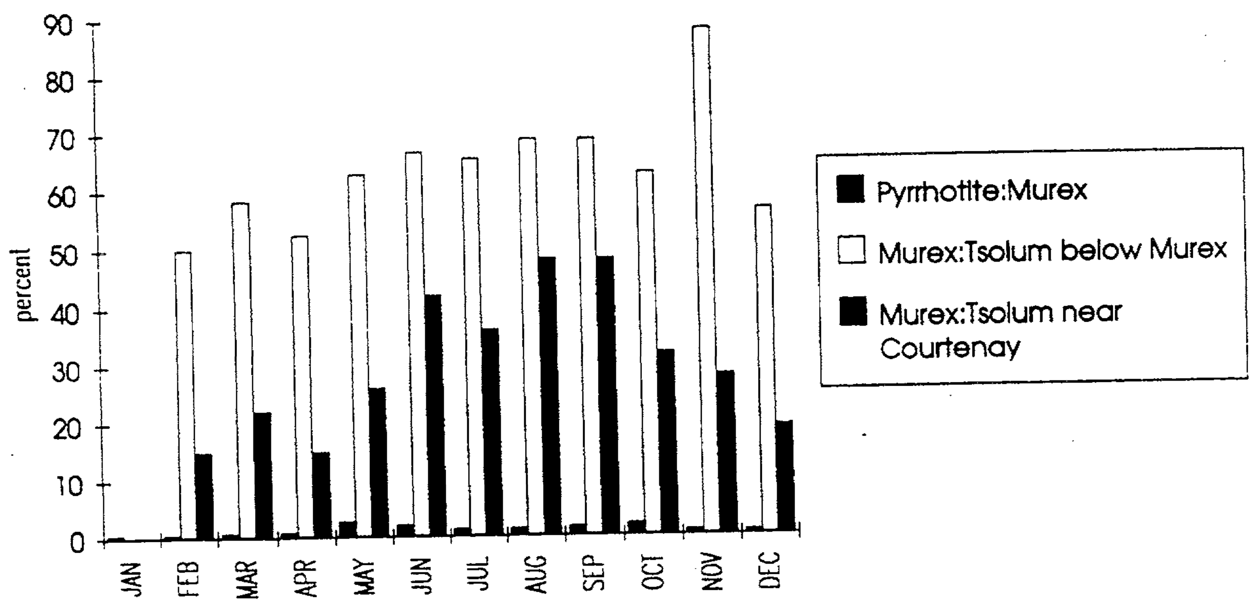

figure 5. Tsolum River Watershed Water Licences

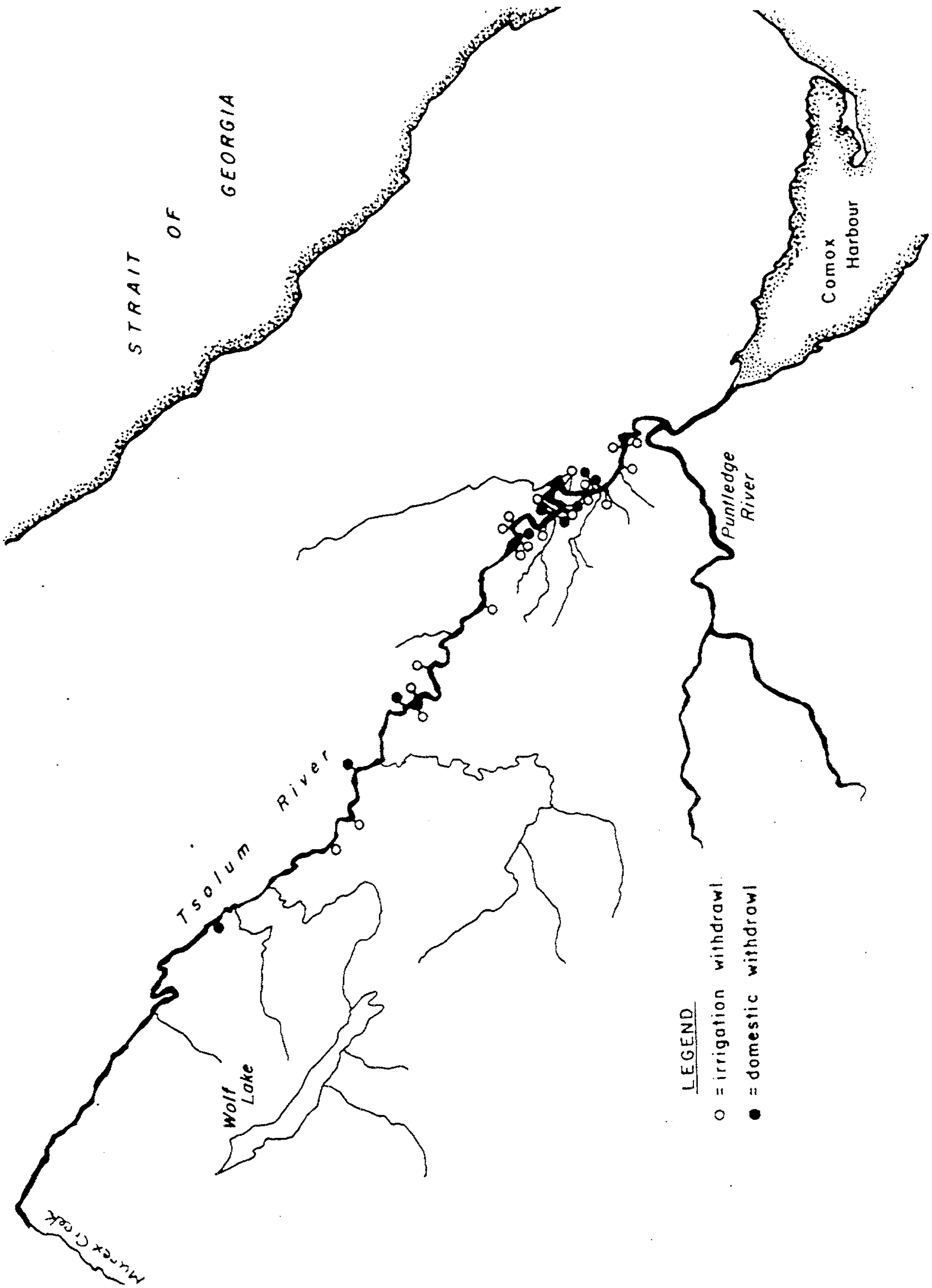

FIGURE 6. TSOLUM RIVER PINK ESCAPEMENT

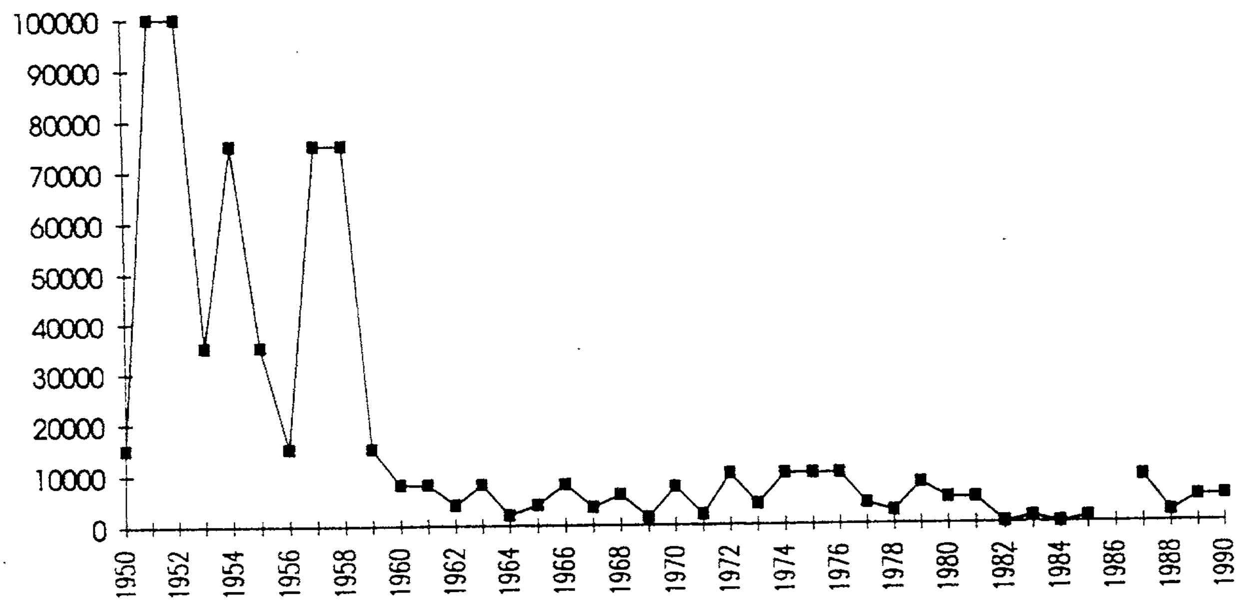

FIGURE 7. TSOLUM RIVER CHUM ESCAPEMENT

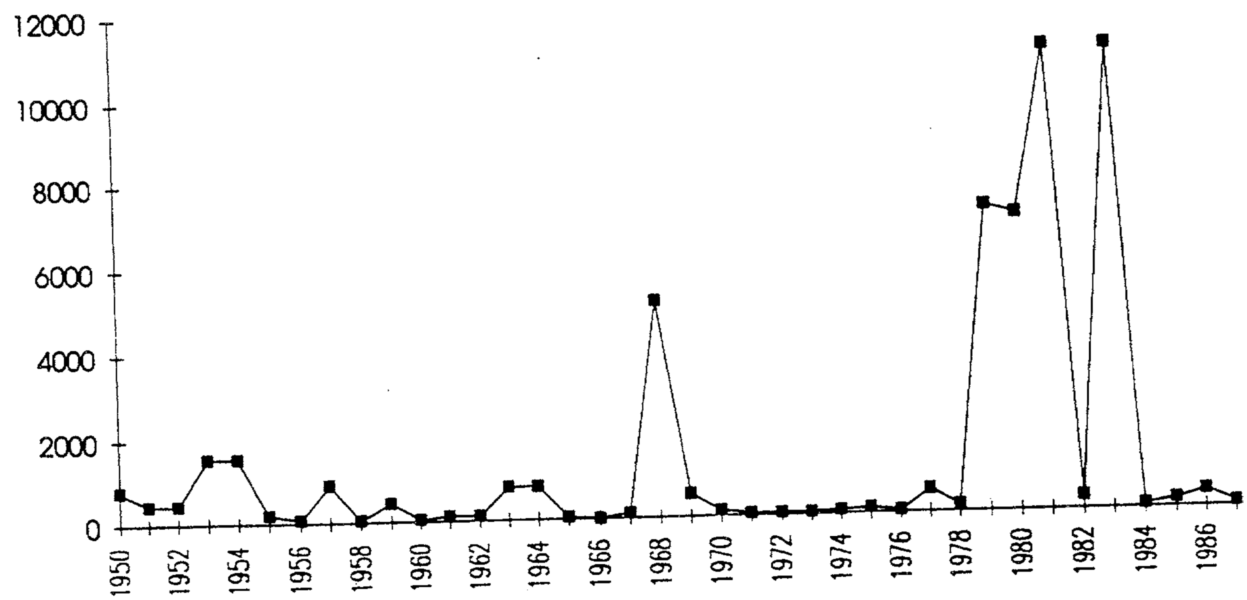

FIGURE 8. TSOLUM RIVER COHO ESCAPEMENT

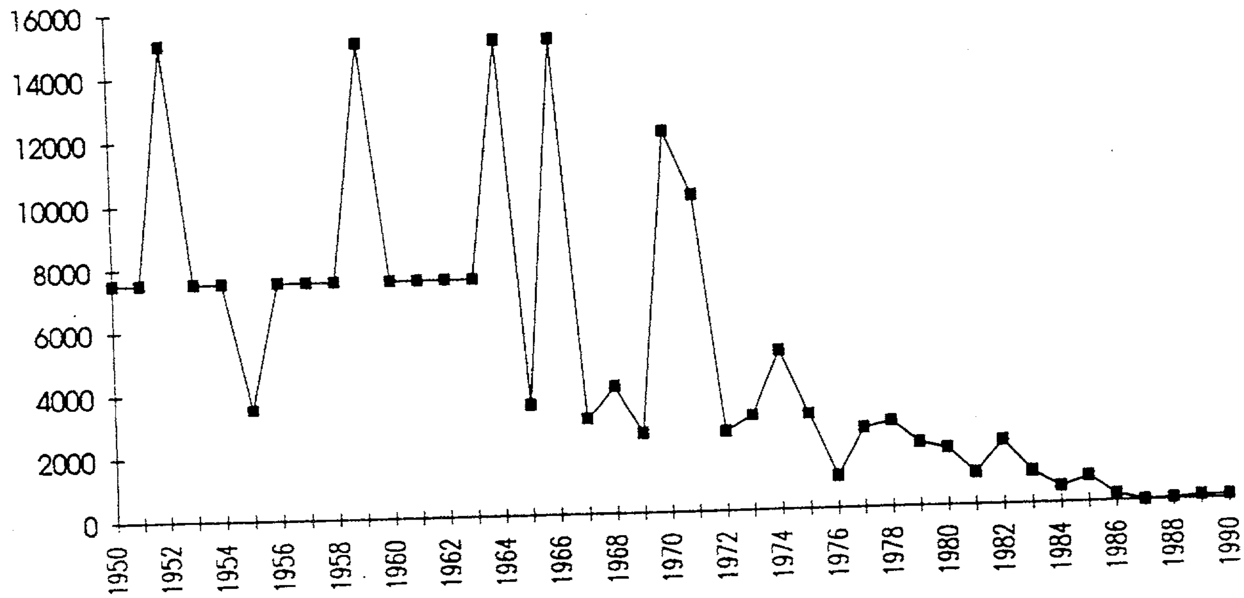

FIGURE 9. PUNTLEDGE RIVER PINK ESCAPEMENT

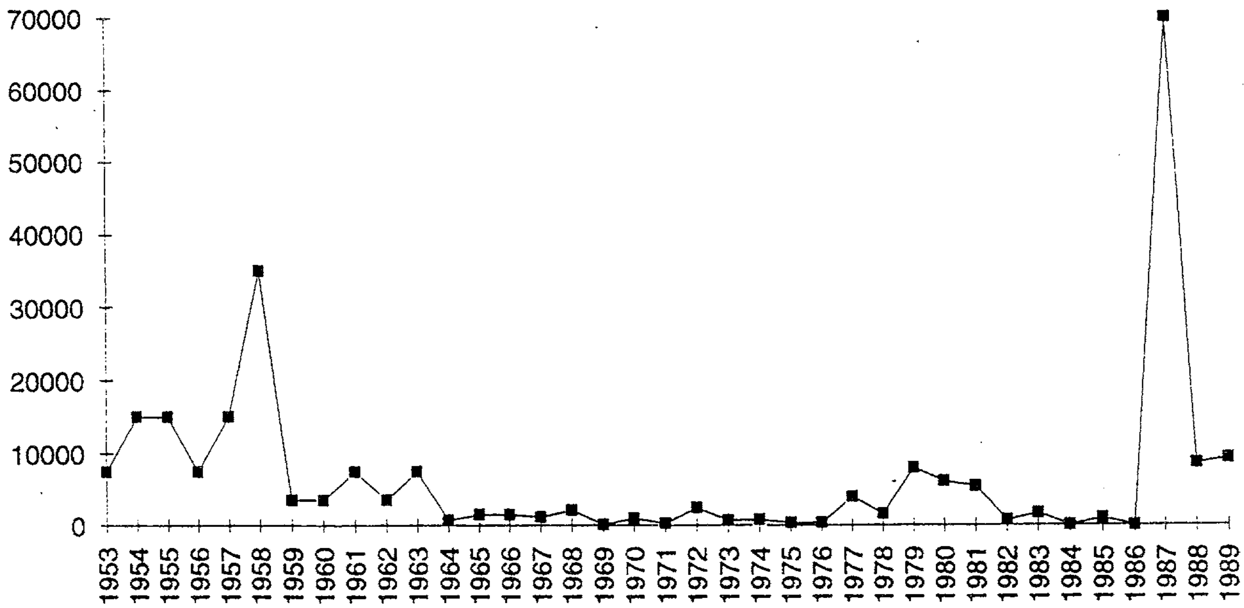

FIGURE 10. PUNTLEDGE RIVER CHUM ESCAPEMENT

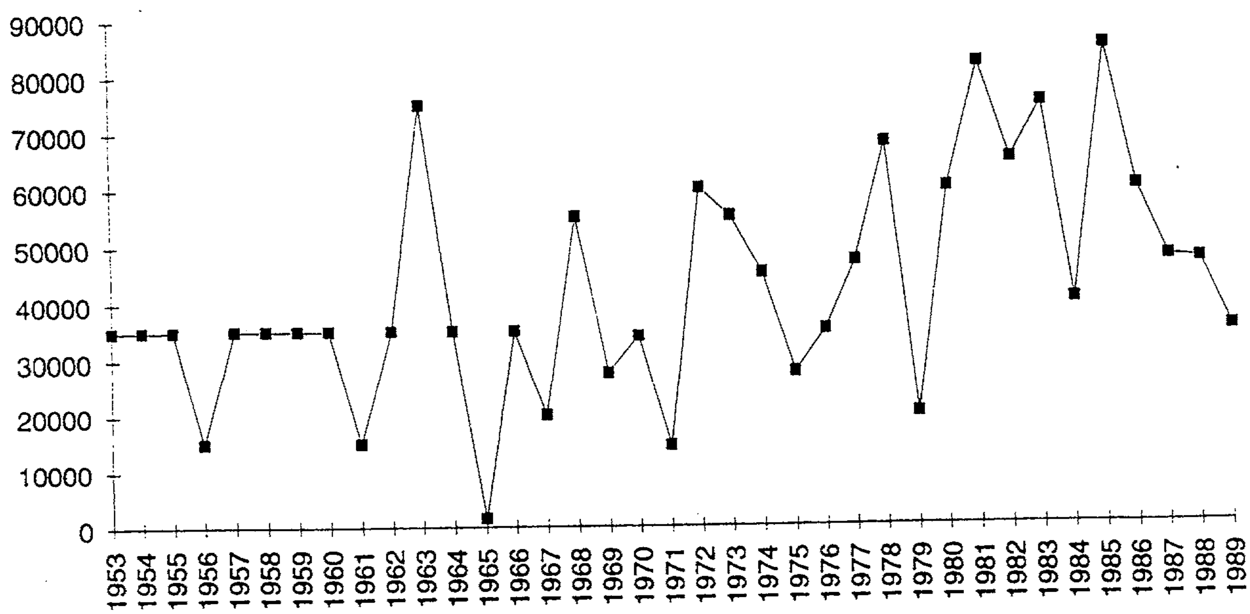

FIGURE 11. PUNTLEDGE RIVER COHO ESCAPEMENT

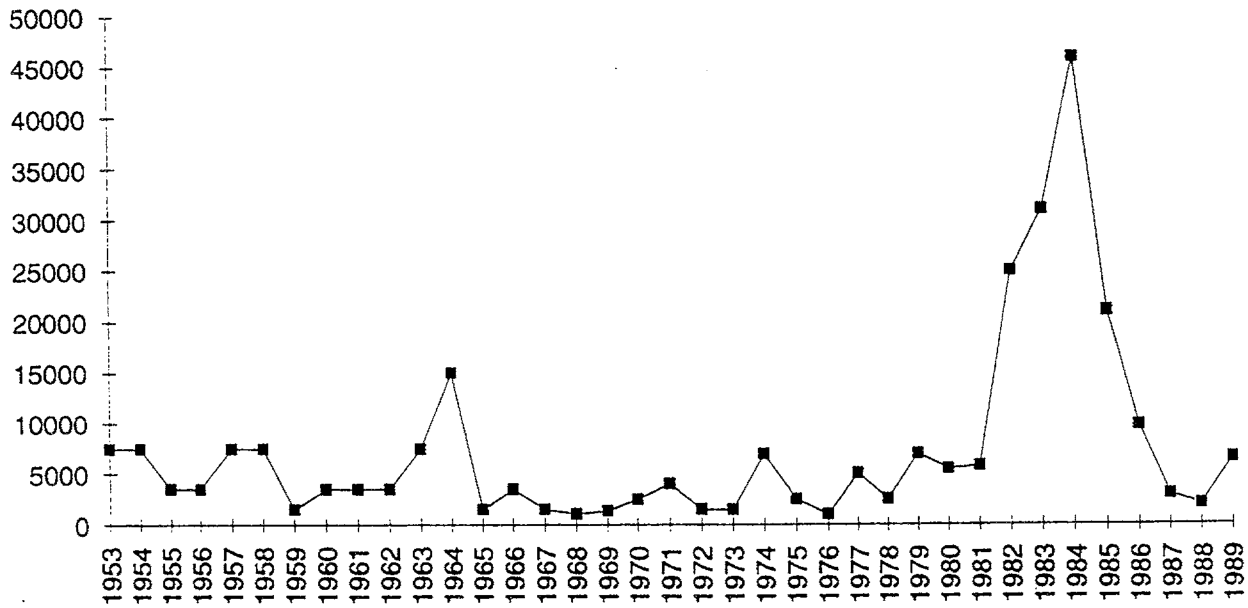

Table 1. Drainage area, elevation range and median elevation for the study watersheds.

	Drainage Area (km^2)	Elevation Range (m)	Median Elevation (m)
Pyrrhotite Creek near Branch 126	0.309	1230-1580	1300
Murex Creek above Duncan Bay Mainline	40.9	130-1580	670
Tsolum River above Murex Creek	36.9	130-1220	380
Tsolum River below Murex Creek	77.8	130-1580	520
Tsolum River near Courtenay	258	0-1580	230

Table 2a 08HBB09 Pyrrhotite Creek near Branch 126 D.A.= 0.309 km2

1986 Daily Discharge (m3/s)

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	DAY
1					0.014	0.105	0.007	0.001	0.000	0.000	0.008	0.006	1
2					0.014	0.090	0.005	0.001	0.000	0.000	0.005	0.004	2
3					0.013	0.089	0.007	0.000	0.000	0.000	0.004	0.002	3
4					0.014	0.060	0.009	0.000	0.000	0.000	0.004	0.003	4
5					0.014	0.052	0.005	0.000	0.000	0.000	0.003	0.003	5
6					0.014	0.052	0.003	0.000	0.000	0.000	0.003	0.003	6
7					0.013	0.041	0.003	0.000	0.000	0.000	0.002	0.003	7
8					0.020	0.049	0.003	0.000	0.002	0.000	0.001	0.003	8
9					0.022	0.045	0.003	0.000	0.000	0.000	0.001	0.002	9
10					0.020	0.046	0.004	0.000	0.000	0.000	0.000	0.002	10
11					0.013	0.043	0.003	0.000	0.000	0.000	0.001	0.002	11
12					0.014	0.043	0.002	0.000	0.000	0.000	0.003	0.002	12
13					0.019	0.048	0.002	0.000	0.000	0.000	0.004	0.002	13
14					0.014	0.044	0.006	0.000	0.000	0.000	0.003	0.002	14
15					0.011	0.072	0.006	0.000	0.000	0.000	0.002	0.002	15
16					0.011	0.060	0.004	0.000	0.000	0.000	0.001	0.002	16
17					0.032	0.064	0.010	0.000	0.001	0.000	0.001	0.002	17
18					0.077	0.068	0.007	0.000	0.000	0.000	0.001	0.002	18
19					0.083	0.031	0.004	0.000	0.000	0.000	0.002	0.002	19
20					0.063	0.026	0.003	0.000	0.000	0.000	0.019	0.002	20
21					0.038	0.021	0.003	0.000	0.000	0.000	0.009	0.003	21
22					0.024	0.023	0.002	0.000	0.000	0.000	0.005	0.122	22
23					0.020	0.020	0.002	0.000	0.039	0.000	0.077	0.030	23
24				0.011	0.111	0.016	0.001	0.000	0.000	0.000	0.019	0.014	24
25				0.011	0.278	0.013	0.001	0.000	0.000	0.006	0.015	0.010	25
26				0.012	0.234	0.009	0.001	0.000	0.000	0.028	0.011	0.007	26
27				0.012	0.093	0.009	0.001	0.000	0.000	0.016	0.008	0.006	27
28				0.013	0.093	0.008	0.001	0.000	0.000	0.009	0.006	0.044	28
29				0.014	0.104	0.006	0.001	0.000	0.000	0.009	0.005	0.026	29
30				0.014	0.119	0.004	0.001	0.000	0.000	0.123	0.006	0.012	30
31					0.133		0.001	0.000		0.017		0.009	31
MEAN					0.056	0.042	0.004	0.000	0.001	0.007	0.008	0.011	
MAX					0.278	0.105	0.010	0.001	0.039	0.123	0.077	0.122	
MIN					0.011	0.004	0.001	0.000	0.000	0.000	0.000	0.002	
dam3					150.5	108.6	9.5	0.3	3.8	18.0	20.4	29.2	
Year-	m3/s												
	dam3												

Estimated values shown in ***bold italics***

Table 2b 08HBB09 Pyrrhotite Creek near Branch 126 D.A.= 0.309 km2

1987 Daily Discharge (m3/s)

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	DAY
1	0.007	0.002	0.006	0.009	0.080	0.029	0.027	0.004	0.000	***0.000***	0.002	0.004	1
2	0.005	0.002	0.007	0.002	0.040	0.039	0.020	0.004	0.001	***0.000***	0.001	0.004	2
3	0.005	0.002	0.009	0.000	0.032	0.078	0.014	0.004	0.000	***0.000***	0.001	0.003	3
4	0.004	0.002	0.234	0.000	0.049	0.078	0.023	0.004	0.000	***0.000***	0.001	0.004	4
5	0.003	0.010	0.269	0.001	0.060	0.093	0.030	0.004	0.000	0.000	0.001	0.004	5
6	0.003	0.019	***0.100***	0.002	0.067	0.054	0.029	0.004	0.000	0.000	0.001	0.004	6
7	0.002	0.009	***0.050***	0.002	0.080	0.073	0.024	0.004	0.000	0.000	0.000	0.004	7
8	0.002	0.007	***0.020***	0.003	0.090	0.086	0.016	0.004	0.000	0.000	0.006	0.004	8
9	0.002	0.010	***0.030***	0.004	0.084	0.061	0.027	0.003	0.000	0.000	0.008	0.004	9
10	0.010	0.036	***0.030***	0.005	0.076	0.039	0.015	0.003	0.000	0.000	0.055	0.004	10
11	0.095	0.138	***0.010***	0.005	0.087	0.064	0.010	0.003	0.000	0.000	0.023	0.004	11
12	0.025	0.035	***0.050***	0.005	0.052	0.136	0.009	0.002	0.000	0.000	0.013	0.004	12
13	0.013	0.020	***0.010***	0.005	0.033	0.059	0.007	0.002	0.000	0.000	0.026	0.004	13
14	0.006	0.016	***0.009***	0.007	0.050	0.053	0.006	0.002	0.000	0.000	0.010	0.004	14
15	0.005	***0.012***	***0.008***	0.006	0.036	0.037	0.004	0.002	0.000	0.000	0.006	0.004	15
16	0.004	***0.020***	***0.008***	0.006	0.027	0.039	0.004	0.002	0.000	0.000	0.004	0.006	16
17	0.004	***0.015***	0.006	0.005	0.038	0.041	0.004	0.002	0.000	0.000	0.003	0.008	17
18	0.003	0.010	0.006	0.005	0.033	0.048	0.004	0.001	0.000	0.000	0.006	0.009	18
19	0.003	0.010	0.007	0.005	0.035	0.068	0.003	0.001	0.000	0.000	0.010	0.009	19
20	0.003	0.010	0.007	0.004	0.042	0.076	0.002	0.001	0.001	0.000	0.051	0.009	20
21	0.003	0.010	0.008	0.004	0.042	0.046	0.002	0.001	0.000	0.000	0.025	0.009	21
22	0.003	0.009	0.009	0.004	0.039	0.030	0.002	0.001	0.000	0.000	0.015	0.009	22
23	0.003	0.009	0.009	0.004	0.047	0.032	0.002	0.001	0.000	0.000	0.012	0.004	23
24	0.002	0.008	0.009	0.005	0.054	0.049	0.002	0.001	0.000	0.000	0.065	0.004	24
25	0.002	0.008	0.009	0.005	0.067	0.037	0.055	0.001	0.000	0.000	0.020	0.004	25
26	0.002	0.007	0.010	0.006	0.073	0.062	0.022	0.001	0.000	0.000	0.014	0.004	26
27	0.002	0.007	0.011	0.021	0.077	0.061	0.009	0.000	0.000	0.000	0.011	0.004	27
28	0.002	0.006	0.011	0.054	0.059	0.049	0.005	0.000	0.000	0.000	0.008	0.004	28
29	0.002		0.011	0.065	0.043	0.042	0.004	0.000	0.000	0.000	0.006	0.004	29
30	0.002		0.011	0.149	0.084	0.032	0.004	0.000	0.000	0.000	0.004	0.004	30
31	0.002		0.011		0.045		0.003	0.000		0.001		0.004	31
MEAN	0.007	0.016	0.032	0.013	0.056	0.056	0.013	0.002	0.000	0.000	0.014	0.005	
MAX	0.095	0.138	0.269	0.149	0.090	0.136	0.055	0.004	0.001	0.001	0.065	0.009	
MIN	0.002	0.002	0.006	0.000	0.027	0.029	0.002	0.000	0.000	0.000	0.000	0.003	
dam3	19.8	38.9	85.1	34.5	148.8	146.3	33.5	5.4	0.6	0.4	36.3	13.1	

Year= 0.018 m3/s

562 dam3

Estimated values shown in ***bold italics***

Table 2c 08HBB09 Pyrrhotite Creek near Branch 126 D.A.= 0.309 km2

1988 Daily Discharge (m3/s)

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	DAY
1	0.003	0.006	0.016	0.010	0.015	0.032	0.023	0.001	0.000	0.001	0.041		1
2	0.003	0.006	0.015	0.009	0.012	0.046	0.017	0.001	0.001	0.001	0.035		2
3	0.003	0.005	0.012	0.008	0.010	0.053	0.017	0.001	0.000	0.001	0.017		3
4	0.003	0.005	0.010	0.006	0.008	0.030	0.014	0.001	0.000	0.001	0.116		4
5	0.003	0.005	0.008	0.005	0.009	0.022	0.015	0.001	0.000	0.002	0.032		5
6	0.003	0.004	0.007	0.005	0.012	0.024	0.012	0.001	0.000	0.001	0.015		6
7	0.003	0.004	0.007	0.005	0.017	0.045	0.011	0.001	0.000	0.001			7
8	0.003	0.004	0.006	0.004	0.038	0.054	0.010	0.001	0.000	0.001			8
9	0.002	0.004	0.006	0.005	0.046	0.057	0.010	0.002	0.000	0.001			9
10	0.003	0.004	0.005	0.005	0.089	0.049	0.008	0.002	0.000	0.001			10
11	0.003	0.008	0.005	0.005	0.134	0.044	0.007	0.001	0.000	0.001			11
12	0.003	0.013	0.005	0.010	0.141	0.048	0.026	0.001	0.000	0.002			12
13	0.003	0.011	0.005	0.017	0.076	0.068	0.019	0.001	0.000	0.001			13
14	0.000	0.008	0.005	0.039	0.045	0.080	0.011	0.001	0.000	0.003			14
15	0.028	0.008	0.005	0.047	0.107	0.086	0.009	0.002	0.000	0.004			15
16	0.012	0.006	0.005	0.042	0.095	0.060	0.008	0.010	0.000	0.002			16
17	0.009	0.005	0.005	0.033	0.040	0.059	0.006	0.007	0.000	0.004			17
18	0.007	0.005	0.005	0.028	0.030	0.054	0.005	0.006	0.000	0.003			18
19	0.007	0.004	0.006	0.025	0.036	0.032	0.005	0.004	0.001	0.002			19
20	0.006	0.004	0.008	0.028	0.046	0.046	0.004	0.003	0.000	0.002			20
21	0.005	0.004	0.006	0.032	0.088	0.055	0.003	0.002	0.000	0.003			21
22	0.005	0.004	0.006	0.030	0.110	0.043	0.002	0.002	0.002	0.002			22
23	0.005	0.004	0.006	0.028	0.041	0.033	0.002	0.001	0.001	0.002			23
24	0.005	0.004	0.005	0.017	0.034	0.037	0.002	0.001	0.001	0.002			24
25	0.005	0.004	0.005	0.013	0.045	0.044	0.002	0.001	0.004	0.002			25
26	0.004	0.006	0.005	0.013	***0.064***	0.028	0.002	0.001	0.004	0.002			26
27	0.005	0.008	0.004	0.048	0.082	0.030	0.002	0.001	0.003	0.002			27
28	0.014	0.007	0.004	0.163	0.059	0.032	0.001	0.001	0.002	0.004			28
29	0.013	0.010	0.004	0.056	0.032	0.022	0.001	0.001	0.002	0.015			29
30	0.009		0.004	0.023	0.026	0.018	0.001	0.001	0.001	0.024			30
31	0.007		0.005		0.027		0.001	0.001		0.067			31
MEAN	0.006	0.006	0.006	0.025	0.052	0.044	0.008	0.002	0.001	0.005			
MAX	0.028	0.013	0.016	0.163	0.141	0.086	0.026	0.010	0.004	0.067			
MIN	0.000	0.004	0.004	0.004	0.008	0.018	0.001	0.001	0.000	0.001			
dam3	15.7	14.5	17.1	65.5	139.4	115.2	22.3	5.4	2.4	14.0			
Year-	m3/s												
	dam3												

Estimated values shown in ***bold italics***

Table 2d 08HBB09 Pyrrhotite Creek near Branch 126 D.A.= 0.309 km2

1989 Daily Discharge (m3/s)

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	DAY
1	0.005	0.013	0.001	0.000	0.059	0.137	0.036	0.011	0.002	0.003	0.005	0.006	1
2	0.005	0.006	***0.001***	0.000	0.061	0.106	0.039	0.007	0.002	0.006	0.005	0.578	2
3	0.010	***0.006***	0.001	***0.001***	0.062	0.086	0.039	0.006	0.002	0.009	0.026	0.620	3
4	0.007	***0.006***	0.001	0.001	0.074	0.075	0.018	0.005	0.001	0.020	0.017	0.048	4
5	0.006	***0.006***	0.001	0.001	0.126	0.079	0.011	0.004	0.001	0.029	0.009	0.015	5
6	0.005	***0.006***	0.001	0.006	0.089	0.055	0.008	0.004	0.001	0.022	0.006	0.010	6
7	0.004	0.007	0.001	0.013	0.088	0.053	0.012	0.004	0.001	0.016	0.004	0.009	7
8	0.004	0.005	0.001	0.006	0.086	0.039	0.020	0.004	0.001	0.011	0.023	0.012	8
9	0.004	0.003	0.002	0.005	***0.080***	0.037	0.012	0.004	0.001	0.007	0.069	0.007	9
10	0.004	0.003	0.002	0.005	0.051	0.034	0.007	0.004	0.001	0.005	0.020	0.006	10
11	0.004	0.003	0.002	0.007	0.027	0.034	0.006	0.006	0.001	0.002	0.010	0.005	11
12	0.004	0.006	0.001	0.010	0.021	0.027	0.005	0.004	0.001	0.001	0.005	0.005	12
13	0.003	0.003	0.001	0.016	0.025	0.030	0.005	0.004	***0.001***	0.001	0.004	0.005	13
14	0.003	0.002	0.001	0.031	0.042	0.023	0.004	0.005	***0.001***	0.000	0.004	0.005	14
15	0.003	0.008	0.001	0.033	0.057	0.017	0.004	0.006	***0.001***	0.000	0.004	0.005	15
16	0.004	0.002	0.001	0.019	0.059	0.015	0.010	0.004	***0.001***	0.000	0.004	0.005	16
17	0.003	0.002	0.001	0.016	0.040	0.017	0.010	0.002	***0.001***	0.001	0.005	0.005	17
18	0.003	0.002	0.001	0.021	0.024	0.010	0.008	***0.002***	***0.001***	0.006	0.008	0.003	18
19	0.003	0.002	0.001	0.057	0.017	0.009	***0.007***	0.001	***0.001***	0.003	0.015	0.003	19
20	0.003	0.002	0.001	0.173	0.014	***0.008***	0.006	0.003	***0.001***	0.031	0.024	0.003	20
21	0.003	0.002	0.001	0.052	0.016	0.007	0.006	0.004	***0.001***	0.021	0.009	0.003	21
22	0.002	0.002	0.001	0.023	0.022	0.008	0.006	0.004	***0.001***	0.020	0.005	0.003	22
23	0.002	0.002	0.001	0.016	0.021	0.007	0.005	0.005	***0.001***	0.221	0.004	0.003	23
24	0.002	0.001	0.001	0.016	***0.028***	0.006	0.005	0.003	***0.001***	0.030	0.004	0.004	24
25	0.002	0.001	0.001	0.021	0.035	0.006	0.004	0.003	***0.001***	0.022	0.004	0.004	25
26	0.002	0.001	0.001	0.026	0.036	0.004	0.004	0.002	***0.001***	0.031	0.004	0.007	26
27	0.003	0.001	0.001	0.029	0.032	0.007	0.004	0.002	***0.001***	0.014	0.004	0.008	27
28	0.003	0.001	0.001	0.034	0.054	0.029	0.004	0.002	0.000	0.008	0.003	0.007	28
29	0.044		0.001	0.051	0.074	0.020	0.003	0.002	0.001	0.006	0.003	0.005	29
30	0.044		0.001	0.061	0.084	0.034	0.003	***0.002***	0.002	0.006	0.003	0.006	30
31	0.018		0.001		0.136		0.004	0.002		0.006		0.006	31
MEAN	0.007	0.004	0.001	0.025	0.053	0.034	0.010	0.004	0.001	0.018	0.010	0.045	
MAX	0.044	0.013	0.002	0.173	0.136	0.137	0.039	0.011	0.002	0.221	0.069	0.620	
MIN	0.002	0.001	0.001	0.000	0.014	0.004	0.003	0.001	0.000	0.000	0.003	0.003	
dam3	18.7	9.1	3.1	64.8	141.9	87.8	27.1	10.4	3.0	48.3	27.9	121.7	

Year= 0.018 m3/s
563 dam3

Estimated values shown in ***bold italics***

Table 2e 08HBB09 Pyrrhotite Creek near Branch 126 D.A.= 0.309 km2

1990 Daily Discharge (m3/s)

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	DAY
1	0.005	0.005	0.002	0.027	0.044	0.013	0.006						1
2	0.004	0.006	0.002	0.021	0.052	0.070	0.021						2
3	0.004	0.005	0.001	0.014	0.044	0.070	0.008						3
4	0.005	0.005	0.002	0.012	0.046	0.018	0.004						4
5	0.018	0.006	0.001	0.011	0.054	0.012	0.008						5
6	0.014	0.005	0.001	0.013	0.020	0.036	0.015						6
7	0.010	0.005	0.002	0.016	0.010	0.015	0.008						7
8	0.009	0.005	0.002	0.018	0.014	0.018	0.005						8
9	0.008	0.004	0.002	0.011	0.020	0.023	0.004						9
10	0.007	0.004	0.001	0.010	0.025	0.068	0.003						10
11	0.007	0.004	0.001	0.025	0.025	0.022	0.003						11
12	0.008	0.003	0.001	0.021	0.026	0.013	0.002						12
13	0.021	0.004	0.001	0.017	0.031	0.010	0.001						13
14	0.018	0.003	0.001	0.023	0.031	0.006	0.001						14
15	0.010	0.003	0.001	0.037	0.025	0.004	0.001						15
16	0.009	0.003	0.001	0.061	0.056	0.003	0.001						16
17	0.008	0.003	0.015	0.088	0.035	0.003	0.001						17
18	0.008	0.003	0.015	0.035	0.032	0.002	0.001						18
19	0.008	0.003	0.008	0.048	0.026	0.002	0.001						19
20	0.008	0.002	0.006	0.035	0.049	0.002	0.001						20
21	0.008	0.002	0.005	0.027	0.040	0.002	0.001						21
22	0.008	0.002	0.005	0.021	0.092	0.001	0.001						22
23	0.006	0.003	0.004	0.035	0.022	0.001	0.001						23
24	0.006	0.007	0.003	0.027	0.026	0.001	0.001						24
25	0.008	0.007	0.003	0.016	0.026	0.001	0.001						25
26	0.007	0.004	0.003	0.012	0.032	0.001	0.001						26
27	0.007	0.003	0.003	0.009	0.107	0.001	0.001						27
28	0.007	0.002	0.003	0.008	0.038	0.003	0.001						28
29	0.006		0.004	0.009	0.022	0.004	0.001						29
30	0.006		0.006	0.013	0.023	0.004	0.001						30
31	0.006		0.013		0.015		0.001						31
MEAN	0.009	0.004	0.004	0.024	0.036	0.014	0.003						
MAX	0.021	0.007	0.015	0.088	0.107	0.070	0.021						
MIN	0.004	0.002	0.001	0.008	0.010	0.001	0.001						
dam3	22.8	9.4	10.2	62.2	95.8	37.0	9.0						
Year=	m3/s dam3												

Estimated values shown in ***bold italics***

Table 21 08HBB10 Murex Creek at Duncan Bay Mainline D.A.= 40.9 km2
1987 Daily Discharge (m3/s)

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	DAY
1							0.718	0.302	***0.035***	***0.031***	0.186	9.554	1
2							0.588	0.244	***0.035***	***0.031***	0.145	***7.771***	2
3							0.511	0.203	***0.035***	***0.029***	0.122	***6.340***	3
4							0.559	0.184	***0.034***	***0.029***	0.118	***5.317***	4
5							0.955	0.166	***0.033***	***0.028***	0.082	***4.295***	5
6							1.166	0.155	***0.033***	***0.027***	0.080	***5.317***	6
7							0.999	0.137	***0.033***	***0.026***	0.075	***4.704***	7
8							0.872	0.124	***0.033***	***0.025***	0.199	***4.090***	8
9							0.999	0.110	***0.033***	***0.023***	0.442	5.305	9
10							0.730	0.098	***0.034***	***0.022***	7.534	5.103	10
11							0.541	0.089	***0.034***	***0.020***	6.454	3.403	11
12							0.461	0.118	***0.037***	***0.018***	1.860	1.944	12
13							0.392	0.155	***0.041***	***0.017***	3.222	1.333	13
14							0.340	0.148	0.049	***0.016***	1.715	1.052	14
15							0.288	0.123	0.063	***0.013***	1.044	0.782	15
16							0.251	0.101	0.060	***0.012***	0.741	0.626	16
17							0.226	0.082	0.049	***0.010***	0.569	0.537	17
18							0.217	0.074	0.042	***0.008***	0.427	0.463	18
19							0.199	0.068	0.040	***0.006***	0.461	0.423	19
20							0.187	0.066	0.064	***0.004***	3.528	0.427	20
21							0.171	0.059	0.068	***0.002***	3.790	0.386	21
22							0.160	0.054	0.055	0.000	2.267	0.362	22
23							0.152	0.047	0.046	0.000	10.250	0.355	23
24							0.155	0.039	0.039	0.000	5.660	0.348	24
25							2.496	0.035	***0.039***	0.000	1.885	0.296	25
26							2.180	0.032	***0.037***	0.000	1.149	0.317	26
27							0.885	0.031	***0.036***	0.000	0.777	0.397	27
28							0.506	***0.034***	***0.035***	0.000	0.612	0.492	28
29							0.355	***0.035***	***0.034***	0.000	5.691	0.571	29
30							0.302	***0.036***	***0.033***	0.000	27.240	0.550	30
31							0.288	***0.035***		0.128		0.500	31
MEAN							0.608	0.103	0.041	0.017	2.944	2.366	
MAX							2.496	0.302	0.068	0.128	27.240	9.554	
MIN							0.152	0.031	0.033	0.000	0.075	0.296	
dam3							1,629	275	110	45	7,886	6,338	
Year=	m3/s												
	dam3												

Estimated values shown in ***bold italics***

Table 2g 08HBB10 Murex Creek at Duncan Bay Mainline D.A.= 40.9 km2

1988 Daily Discharge (m3/s)

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	DAY
1	***1.067***	2.010	2.510	1.485	1.931	1.627	0.698	0.111	0.064	0.108	5.950	3.492	1
2	***0.979***	1.604	2.575	2.795	2.010	2.709	0.751	0.103	0.061	0.096	4.017	2.646	2
3	***1.088***	1.267	2.641	3.242	1.905	4.935	0.692	0.097	0.043	0.098	2.369	3.738	3
4	***0.892***	1.101	2.037	2.023	1.719	3.087	0.616	0.095	0.018	0.112	5.867	3.833	4
5	***0.817***	1.013	2.191	2.064	2.205	2.415	0.611	0.091	0.012	0.101	5.416	7.954	5
6	***0.813***	0.930	2.278	2.220	2.191	1.931	0.590	0.094	0.012	0.092	3.644	5.244	6
7	0.266	0.881	1.854	1.804	2.369	2.293	0.575	0.091	0.012	0.094	6.301	***3.901***	7
8	0.279	0.840	1.892	1.464	2.993	2.709	0.556	0.090	0.012	0.082	6.452	***3.088***	8
9	0.390	0.902	1.604	1.343	3.202	2.338	0.606	0.090	0.013	0.075	6.605	***2.697***	9
10	0.590	***1.191***	1.267	1.495	3.788	2.120	0.566	0.087	0.013	***0.105***	4.309	***2.557***	10
11	0.537	***1.490***	1.052	1.957	4.381	1.957	0.547	0.084	0.013	***0.108***	4.238	***2.822***	11
12	0.692	2.866	0.930	2.323	3.971	1.767	0.923	0.081	0.013	***0.121***	2.789	4.273	12
13	2.338	2.384	0.867	3.144	3.570	1.854	1.324	0.078	0.014	***0.146***	2.095	2.576	13
14	6.212	2.726	0.840	4.160	2.608	2.148	0.888	0.077	0.014	***0.221***	2.192	2.001	14
15	5.132	1.970	0.833	4.160	3.678	2.308	0.704	0.083	0.014	***0.328***	1.983	1.616	15
16	3.465	1.413	0.820	3.811	4.282	1.892	0.648	0.152	0.014	***0.387***	1.947	1.456	16
17	2.415	***2.401***	0.827	3.423	2.778	1.650	0.492	0.176	0.015	***0.356***	1.694	1.428	17
18	1.719	***2.060***	0.874	3.144	2.264	1.549	0.427	0.172	0.103	***0.356***	2.839	1.211	18
19	1.464	***1.808***	1.392	2.938	2.478	1.231	0.408	0.146	0.108	***0.366***	2.839	1.142	19
20	3.068	***1.665***	3.087	3.183	2.220	1.117	0.365	0.122	0.075	0.133	5.821	1.200	20
21	2.249	***1.520***	2.234	3.222	2.830	1.258	0.323	0.109	0.052	0.147	5.548	***1.188***	21
22	2.092	***1.433***	2.278	2.813	3.485	1.204	0.268	0.099	0.166	0.185	***6.417***	1.188	22
23	1.841	0.833	2.760	2.462	2.559	1.151	0.238	0.091	0.166	0.204	***4.527***	1.003	23
24	1.485	0.745	2.134	1.816	1.743	0.997	0.217	0.084	0.158	0.210	***3.858***	0.862	24
25	1.213	0.709	1.841	1.495	1.957	1.052	0.210	0.083	0.198	0.193	***2.760***	0.853	25
26	1.109	1.177	1.593	1.638	2.191	1.028	0.200	0.081	0.200	0.178	2.399	0.819	26
27	1.013	1.866	1.305	3.506	2.447	0.938	0.165	0.081	0.200	0.165	1.965	0.810	27
28	4.407	1.879	1.117	6.799	2.559	1.213	0.159	0.080	0.158	0.168	1.601	1.087	28
29	4.991	1.983	1.092	3.833	2.050	0.982	0.152	0.076	0.132	0.769	***2.213***	1.498	29
30	3.068		1.068	2.591	1.527	0.733	0.139	0.074	0.117	1.517	1.947	1.374	30
31	2.278		1.117		1.792		0.124	0.067		5.276		1.300	31
MEAN	1.934	1.540	1.642	2.745	2.635	1.806	0.490	0.098	0.073	0.403	3.753	2.286	
MAX	6.212	2.866	3.087	6.799	4.381	4.935	1.324	0.176	0.200	5.276	6.605	7.954	
MIN	0.266	0.709	0.820	1.343	1.527	0.733	0.124	0.067	0.012	0.075	1.601	0.810	
dam3	5,181	4,125	4,399	7,353	7,057	4,838	1,312	263	195	1,080	10,053	6,122	
Year=	1.61 m3/s												
	50,850 dam3												

Estimated values shown in ***bold italics***

Table 2h 08HBB10 Murex Creek at Duncan Bay Mainline D.A.= 40.9 km2
1989 Daily Discharge (m3/s)

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP.	OCT	NOV	DEC	DAY
1	1.223	2.378	***1.589***	1.842	***1.542***	***0.965***	2.442	***0.900***	0.149	0.059	0.769	1.586	1
2	1.322	***3.106***	***1.372***	1.710	***1.473***	***0.926***	3.178	***0.800***	0.129	0.054	0.679	7.596	2
3	3.233	3.833	0.480	1.109	***1.313***	***0.856***	3.151	0.686	0.115	0.055	0.880	9.752	3
4	2.421	6.605	0.371	0.945	***1.352***	***0.726***	2.863	0.496	0.119	0.073	1.842	10.580	4
5	1.808	5.244	0.754	1.142	***1.561***	***0.659***	2.055	0.375	0.112	0.102	1.374	4.995	5
6	***1.783***	3.866	1.165	3.206	***1.550***	***0.598***	1.247	0.319	0.096	0.089	1.109	3.404	6
7	1.758	3.206	0.871	2.765	***1.405***	***0.517***	1.014	0.261	0.087	0.085	0.898	5.373	7
8	1.335	2.839	0.916	1.792	***1.297***	0.907	1.484	0.215	0.077	0.084	1.758	5.683	8
9	0.974	2.717	1.014	1.442	***1.152***	0.827	1.120	0.195	0.067	0.079	***1.700***	3.178	9
10	0.871	2.576	1.456	1.710	***1.023***	0.786	0.769	0.187	0.060	0.074	***1.300***	2.173	10
11	0.827	2.378	4.065	2.253	***0.997***	0.777	0.617	0.434	0.056	0.094	***1.000***	1.601	11
12	1.188	2.192	3.613	***2.359***	***0.858***	0.746	0.491	0.334	0.051	***0.110***	***0.900***	1.310	12
13	2.399	1.616	2.294	2.464	***0.792***	0.746	0.434	0.255	***0.049***	0.136	***1.000***	1.153	13
14	1.631	0.693	1.647	3.233	***0.738***	0.730	0.384	0.277	0.046	0.119	***0.920***	1.098	14
15	1.310	0.415	***1.500***	2.939	***0.783***	0.604	0.323	0.354	0.042	0.110	0.853	0.983	15
16	1.484	0.354	1.153	2.134	***0.817***	0.610	0.536	***0.294***	0.055	0.099	0.862	0.880	16
17	***1.254***	***0.682***	1.131	1.929	***0.826***	0.536	0.810	0.234	0.118	0.113	0.964	0.889	17
18	1.024	***0.680***	1.003	2.273	***0.877***	0.470	0.584	0.202	0.103	0.249	0.935	0.810	18
19	1.188	***0.728***	0.916	3.738	***0.728***	0.434	***0.530***	0.178	0.085	0.346	1.272	0.754	19
20	1.109	***0.984***	0.853	6.815	***0.663***	***0.411***	***0.480***	0.192	0.075	1.014	2.134	0.880	20
21	1.014	***1.752***	1.176	4.099	***0.645***	0.388	***0.440***	0.319	0.067	4.031	1.929	1.235	21
22	0.918	***2.761***	1.211	2.991	***0.641***	0.464	***0.440***	0.323	0.060	3.931	1.456	1.176	22
23	1.247	***5.191***	1.065	2.717	***0.624***	0.491	***0.400***	0.388	0.053	11.468	2.020	1.098	23
24	0.786	***4.621***	0.871	2.693	***0.630***	0.459	***0.370***	0.287	0.049	5.244	1.710	1.034	24
25	0.746	***3.178***	0.853	2.789	***0.645***	0.439	***0.340***	0.240	0.045	***4.500***	1.322	0.954	25
26	0.777	***2.380***	1.034	***1.655***	***0.726***	0.384	***0.320***	0.207	0.082	6.351	1.484	0.935	26
27	0.954	***2.012***	1.513	***1.541***	***0.961***	0.475	***0.300***	0.178	0.106	2.765	1.401	0.993	27
28	0.871	***1.805***	1.498	***1.449***	***0.864***	1.087	***0.280***	0.163	***0.090***	1.694	1.912	0.935	28
29	1.556		***1.500***	***1.566***	***0.826***	1.388	***0.260***	0.145	0.074	1.247	2.622	0.935	29
30	3.289		1.235	***1.586***	***0.838***	1.678	***0.270***	***0.142***	0.066	1.003	1.929	0.983	30
31	3.261		1.322		***0.853***		***1.000***	0.138		0.853		1.223	31
MEAN	1.470	2.528	1.337	2.363	0.968	0.703	0.933	0.314	0.079	1.491	1.364	2.457	
MAX	3.289	6.605	4.065	6.815	1.561	1.678	3.178	0.900	0.149	11.468	2.622	10.580	
MIN	0.746	0.354	0.371	0.945	0.624	0.384	0.260	0.138	0.042	0.054	0.679	0.754	
dam3	3,936	6,772	3,581	6,329	2,592	1,882	2,500	840	213	3,995	3,655	6,582	

Year= 1.33 m3/s
41,830 dam3

Estimated values shown in ***bold italics***

Table 2i 08HBB10 Murex Creek at Duncan Bay Mainline D.A.= 40.9 km2

1990 Daily Discharge (m3/s)

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	DAY
1	1.260	***1.497***	***1.227***	5.036	1.571	1.498							1
2	1.109	***2.703***	***1.180***	4.417	2.134	2.421							2
3	1.065	***6.128***	***1.177***	3.552	1.983	19.446							3
4	1.024	***4.041***	***1.483***	3.318	2.134	5.460							4
5	6.657	***3.991***	***1.706***	3.346	2.314	3.261							5
6	7.253	***3.738***	***1.664***	3.433	1.694	3.931							6
7	8.201	***2.645***	1.710	3.583	1.284	4.031							7
8	4.309	***2.025***	1.586	3.346	1.098	3.070							8
9	3.289	***1.851***	1.894	2.622	1.044	2.965							9
10	2.421	***1.796***	2.554	2.717	1.076	8.519							10
11	1.662	***1.878***	1.775	3.833	1.120	7.086							11
12	1.726	***1.892***	1.442	3.206	1.109	3.998							12
13	3.522	***1.755***	1.442	2.889	1.894	2.646							13
14	3.833	***1.526***	2.153	2.814	1.586	2.153							14
15	2.741	***1.407***	2.153	3.151	1.348	***1.281***							15
16	2.442	***1.291***	2.038	3.833	1.842	***1.074***							16
17	1.965	***1.219***	4.099	6.105	2.378	***0.945***							17
18	1.616	***1.184***	5.244	3.644	1.842	***0.832***							18
19	1.361	***1.138***	3.675	3.706	1.694	***0.752***							19
20	1.223	***1.104***	3.492	3.178	1.859	***0.663***							20
21	1.211	***1.088***	3.289	2.554	1.808	***0.592***							21
22	1.260	***1.076***	3.017	2.273	7.309	***0.526***							22
23	1.165	***1.062***	2.531	2.442	3.151	***0.482***							23
24	***1.570***	***1.099***	2.153	2.421	2.114	***0.451***							24
25	***2.318***	***1.219***	1.929	2.232	2.001	***0.420***							25
26	***2.154***	***1.345***	1.808	2.134	1.647	***0.400***							26
27	***1.878***	***1.314***	2.001	1.792	5.077	***0.379***							27
28	***2.281***	***1.297***	2.622	1.586	5.244	***0.374***							28
29	***2.103***		3.552	1.428	2.965	***0.615***							29
30	***1.892***		4.099	1.348	2.134	***0.732***							30
31	***1.727***		4.955		1.678								31
MEAN	2.524	1.940	2.440	3.065	2.198	2.700							
MAX	8.201	6.128	5.244	6.105	7.309	19.446							
MIN	1.024	1.062	1.177	1.348	1.044	0.374							
dam3	6,760	5,195	6,536	8,208	5,887	7,232							
Year=	m3/s												
	dam3												

Estimated values shown in ***bold italics***

Table 2j

Tsolum River below Murex Creek   D.A.= 77.8 km2

1987   Daily Discharge (m3/s)

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	DAY
1							1.001	0.426	0.061	0.061	0.281	22.542	1
2							0.827	0.351	0.060	0.062	0.239	16.872	2
3							0.718	0.290	0.061	0.062	0.199	14.849	3
4							0.772	0.262	0.059	0.058	0.187	10.893	4
5							1.299	0.241	0.057	0.056	0.138	8.503	5
6							1.611	0.219	0.057	0.055	0.137	12.073	6
7							1.392	0.192	0.056	0.055	0.130	9.197	7
8							1.245	0.176	0.056	0.054	0.282	11.159	8
9							1.388	0.164	0.055	0.051	0.603	13.507	9
10							1.048	0.143	0.056	0.052	10.182	12.412	10
11							0.773	0.127	0.056	0.050	10.023	7.646	11
12							0.657	0.161	0.059	0.049	2.930	4.517	12
13							0.555	0.211	0.064	0.048	4.713	3.125	13
14							0.481	0.205	0.074	0.045	2.722	3.070	14
15							0.413	0.171	0.094	0.042	1.684	2.181	15
16							0.349	0.142	0.089	0.041	1.198	1.649	16
17							0.310	0.118	0.075	0.035	0.931	1.350	17
18							0.300	0.107	0.068	0.034	0.717	1.144	18
19							0.277	0.100	0.065	0.033	0.738	1.053	19
20							0.261	0.098	0.094	0.031	4.613	1.167	20
21							0.242	0.086	0.100	0.029	5.558	1.193	21
22							0.224	0.080	0.083	0.025	3.654	1.006	22
23							0.209	0.071	0.071	0.027	13.219	0.895	23
24							0.213	0.063	0.063	0.026	12.342	0.833	24
25							3.224	0.056	0.063	0.023	4.745	0.736	25
26							3.184	0.054	0.062	0.023	2.728	0.744	26
27							1.386	0.055	0.063	0.022	1.821	0.833	27
28							0.799	0.060	0.065	0.021	1.370	1.006	28
29							0.541	0.061	0.066	0.023	7.483	1.180	29
30							0.446	0.061	0.064	0.024	35.015	1.206	30
31							0.419	0.060		0.192		1.109	31
MEAN							0.857	0.149	0.067	0.045	4.353	5.473	
MAX							3.224	0.426	0.100	0.192	35.015	22.542	
MIN							0.209	0.054	0.055	0.021	0.130	0.736	
dam3							2,295	398	180	122	11,658	14,658	
Year-	m3/s												
	dam3												

Preliminary data: all discharge values are estimated.

Table 2k

Tsolum River below Murex Creek

1988 Daily Discharge (m3/s)

D.A.= 77.8 km2

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	DAY
1	1.743	3.417	3.853	2.633	3.098	2.326	0.962	0.153	0.107	0.157	10.500	6.072	1
2	1.583	2.757	3.994	4.810	3.187	3.648	1.028	0.143	0.106	0.141	7.959	4.669	2
3	1.779	2.242	4.310	6.880	3.097	7.775	0.959	0.133	0.084	0.141	4.255	5.943	3
4	1.430	1.952	3.730	4.196	2.726	4.765	0.852	0.127	0.050	0.158	13.798	6.168	4
5	1.298	1.798	4.605	5.083	3.285	3.645	0.837	0.125	0.043	0.145	12.162	15.948	5
6	1.291	1.654	5.538	5.273	3.284	2.907	0.817	0.127	0.043	0.132	6.890	11.243	6
7	0.605	1.573	4.171	4.088	3.462	3.264	0.792	0.124	0.043	0.133	11.981	7.516	7
8	0.627	1.534	4.217	3.199	4.301	3.863	0.760	0.122	0.041	0.117	11.275	5.748	8
9	1.083	1.653	3.457	2.740	4.663	3.337	0.820	0.123	0.041	0.108	13.587	4.925	9
10	1.794	1.967	2.669	2.780	5.360	3.029	0.776	0.119	0.042	0.144	9.261	4.636	10
11	1.416	2.523	2.186	3.295	6.256	2.874	0.755	0.115	0.040	0.149	9.957	5.185	11
12	1.667	4.821	1.903	3.740	5.910	2.568	1.214	0.111	0.042	0.169	6.003	7.576	12
13	6.019	5.035	1.717	4.849	5.317	2.629	1.863	0.106	0.042	0.205	4.252	4.691	13
14	17.514	5.282	1.610	6.353	3.828	2.979	1.280	0.104	0.042	0.317	4.392	3.558	14
15	13.305	4.667	1.584	6.492	5.206	3.174	1.006	0.111	0.043	0.483	3.900	2.852	15
16	8.805	3.265	1.518	5.957	6.620	2.646	0.924	0.200	0.039	0.578	3.641	2.538	16
17	5.620	4.315	1.489	5.300	4.319	2.284	0.715	0.247	0.034	0.527	3.068	2.476	17
18	3.974	3.630	1.523	4.793	3.411	2.143	0.618	0.261	0.142	0.528	5.506	2.231	18
19	3.178	3.134	2.162	4.443	3.680	1.742	0.582	0.233	0.149	0.544	5.560	2.708	19
20	6.163	2.856	4.644	4.742	3.282	1.569	0.524	0.208	0.107	0.252	13.538	3.004	20
21	4.773	2.581	3.671	4.861	4.012	1.733	0.464	0.195	0.079	0.262	14.737	3.097	21
22	4.333	2.415	4.037	4.275	4.987	1.668	0.390	0.180	0.223	0.312	13.410	3.247	22
23	3.737	1.614	5.561	3.712	3.780	1.588	0.342	0.162	0.224	0.338	8.927	2.431	23
24	2.978	1.443	4.138	2.790	2.563	1.379	0.310	0.148	0.218	0.345	7.420	1.933	24
25	2.415	1.353	3.930	2.299	2.777	1.428	0.296	0.146	0.270	0.325	5.055	1.738	25
26	2.143	1.939	3.776	2.427	3.061	1.404	0.278	0.140	0.292	0.304	5.675	1.734	26
27	1.949	2.887	2.854	4.852	3.404	1.267	0.233	0.137	0.301	0.281	4.607	1.718	27
28	7.921	2.972	2.351	10.338	3.689	1.632	0.222	0.136	0.235	0.281	3.485	2.343	28
29	9.624	3.073	2.324	6.800	3.014	1.351	0.209	0.130	0.194	1.047	3.935	4.003	29
30	5.723		2.215	4.179	2.242	1.019	0.189	0.123	0.173	2.120	3.523	3.133	30
31	4.079		2.216		2.510		0.171	0.113		8.376		2.400	31
MEAN	4.212	2.771	3.160	4.606	3.882	2.588	0.683	0.148	0.116	0.617	7.742	4.434	
MAX	17.514	5.282	5.561	10.338	6.620	7.775	1.863	0.261	0.301	8.376	14.737	15.948	
MIN	0.605	1.353	1.489	2.299	2.242	1.019	0.171	0.104	0.034	0.108	3.068	1.718	
dam3	11,281	7,421	8,463	12,337	10,397	6,931	1,831	398	312	1,652	20,736	11,877	

Year= 2.90 m3/s
91,604 dam3

Preliminary data: all discharge values are estimated.

Table 2I Tsolum River below Murex Creek D.A.= 77.8 km2

1989 Daily Discharge (m3/s)

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	DAY
1	2.593	4.083	2.787	3.877	2.696	1.600	3.432	1.210	0.223	0.088	1.345	2.710	1
2	2.715	4.557	2.364	4.080	2.560	1.528	4.634	1.194	0.198	0.082	1.172	12.496	2
3	5.604	5.310	1.182	2.678	2.251	1.402	4.607	1.020	0.178	0.084	1.442	18.098	3
4	4.747	8.621	1.021	2.241	2.326	1.170	4.332	0.750	0.182	0.106	2.954	21.719	4
5	3.525	6.878	2.404	3.105	2.733	1.053	3.248	0.571	0.171	0.142	2.386	9.823	5
6	3.173	5.129	3.326	7.533	2.710	0.947	2.061	0.481	0.148	0.126	1.944	6.585	6
7	2.936	4.296	2.612	6.767	2.429	0.807	1.632	0.396	0.135	0.121	1.578	9.513	7
8	2.337	3.825	2.700	4.191	2.221	1.269	2.179	0.329	0.120	0.120	2.682	10.580	8
9	1.843	3.661	2.851	3.172	1.948	1.155	1.731	0.296	0.106	0.114	3.117	5.997	9
10	1.599	3.472	3.908	3.275	1.706	1.089	1.248	0.281	0.095	0.107	2.956	4.079	10
11	1.521	3.215	8.930	3.994	1.658	1.067	0.997	0.580	0.090	0.133	2.171	3.023	11
12	2.722	2.979	9.534	4.135	1.406	1.021	0.798	0.458	0.082	0.154	1.799	2.470	12
13	5.064	2.264	6.512	4.232	1.287	1.020	0.696	0.361	0.079	0.186	1.814	2.153	13
14	3.276	1.123	4.764	5.357	1.191	1.002	0.613	0.388	0.075	0.165	1.624	1.992	14
15	2.647	0.776	3.694	5.094	1.270	0.844	0.515	0.483	0.069	0.156	1.481	1.776	15
16	2.924	0.692	2.937	3.677	1.332	0.850	0.773	0.408	0.084	0.145	1.467	1.578	16
17	2.695	1.092	2.813	3.213	1.349	0.757	1.238	0.335	0.161	0.165	1.582	1.544	17
18	2.349	1.088	2.431	3.656	1.439	0.676	0.975	0.296	0.143	0.344	1.554	1.407	18
19	2.360	1.173	2.133	5.771	1.173	0.626	0.867	0.266	0.121	0.491	2.110	1.303	19
20	2.161	1.635	1.940	12.686	1.060	0.593	0.758	0.284	0.109	1.341	3.476	1.434	20
21	1.952	3.110	2.438	7.309	1.027	0.565	0.684	0.438	0.099	5.882	3.331	1.865	21
22	1.770	5.208	2.505	5.017	1.020	0.656	0.679	0.443	0.090	5.802	2.573	1.796	22
23	2.076	10.781	2.235	4.552	0.991	0.685	0.623	0.522	0.082	18.313	3.478	1.704	23
24	1.486	9.417	1.864	4.327	1.002	0.644	0.568	0.398	0.076	9.044	3.029	1.621	24
25	1.448	6.115	1.790	4.367	1.027	0.613	0.514	0.340	0.072	6.759	2.388	1.521	25
26	1.517	4.397	1.977	2.918	1.170	0.540	0.477	0.301	0.116	11.076	2.826	1.499	26
27	1.720	3.635	2.698	2.603	1.593	0.651	0.442	0.265	0.146	5.115	2.600	1.571	27
28	1.576	3.216	2.756	2.514	1.416	1.440	0.413	0.247	0.126	3.122	3.308	1.497	28
29	2.521		2.898	2.742	1.349	2.000	0.383	0.223	0.107	2.286	4.351	1.503	29
30	5.265		2.509	2.782	1.369	2.371	0.390	0.216	0.097	1.825	3.306	1.567	30
31	5.960		2.715		1.396		1.286	0.212		1.535		1.860	31
MEAN	2.777	3.991	3.136	4.399	1.616	1.021	1.413	0.451	0.119	2.424	2.395	4.461	
MAX	5.960	10.781	9.534	12.686	2.733	2.371	4.634	1.210	0.223	18.313	4.351	21.719	
MIN	1.448	0.692	1.021	2.241	0.991	0.540	0.383	0.212	0.069	0.082	1.172	1.303	
dam3	7,437	10,690	8,401	11,781	4,329	2,736	3,784	1,209	320	6,491	6,414	11,948	

Year= 2.34 m3/s
73,818 dam3

Preliminary data: all discharge values are estimated.

Table 2m

Tsolum River below Murex Creek

1990 Daily Discharge (m3/s)

D.A.= 77.8 km2

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	DAY
1	1.898	2.607	2.089	7.266	2.255	2.228							1
2	1.706	5.083	2.000	6.519	2.996	3.358							2
3	1.647	13.088	1.994	5.264	2.791	29.517							3
4	1.598	8.063	2.581	4.856	2.946	9.748							4
5	10.100	7.949	3.019	4.850	3.177	5.778							5
6	13.093	7.371	2.934	4.906	2.366	6.180							6
7	17.602	4.957	3.106	5.097	1.798	6.357							7
8	9.561	3.661	2.896	4.793	1.544	5.071							8
9	6.810	3.309	3.995	3.809	1.452	4.953							9
10	4.736	3.199	5.790	3.873	1.488	13.272							10
11	3.335	3.364	3.698	5.333	1.540	11.763							11
12	3.338	3.391	2.788	4.580	1.526	6.712							12
13	6.441	3.116	2.851	4.088	2.600	4.390							13
14	7.262	2.664	4.966	3.984	2.232	3.471							14
15	5.214	2.432	4.237	4.391	1.902	2.191							15
16	5.364	2.209	3.807	5.321	2.510	1.801							16
17	3.985	2.073	6.536	8.459	3.274	1.564							17
18	3.182	2.006	8.487	5.207	2.563	1.359							18
19	2.642	1.920	6.124	5.210	2.355	1.215							19
20	2.326	1.858	5.696	4.558	2.574	1.060							20
21	2.282	1.826	5.361	3.671	2.508	0.936							21
22	2.328	1.804	4.985	3.259	10.008	0.823							22
23	2.457	1.779	4.368	3.464	4.651	0.749							23
24	2.750	1.848	3.671	3.457	3.094	0.697							24
25	4.268	2.073	3.246	3.347	2.878	0.644							25
26	3.927	2.314	2.965	3.202	2.372	0.611							26
27	3.364	2.254	3.144	2.704	6.937	0.578							27
28	4.190	2.221	3.945	2.423	7.671	0.569							28
29	3.821		5.202	2.148	4.411	0.976							29
30	3.391		5.973	1.999	3.193	1.180							30
31	3.060		7.156		2.531								31
MEAN	4.76	3.59	4.18	4.40	3.10	4.33							
MAX	17.60	13.09	8.49	8.46	10.01	29.52							
MIN	1.60	1.78	1.99	2.00	1.45	0.57							
dam3	12,760	8,678	11,198	11,408	8,307	11,210							
Year=		m3/s											
		dam3											

Preliminary data: all discharge values are estimated.

Table 2n 08HB011 Tsolum River near Courtenay D.A.= 258 km2

1986 Daily Discharge (m3/s)

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	DAY
1	5.390	40.500	12.100	8.210	6.750	6.260	1.620	0.332	0.029	0.325	3.200	69.800	1
2	5.260	29.600	9.750	6.870	8.920	4.970	1.810	0.293	0.040	0.279	1.880	27.500	2
3	4.730	20.000	9.240	5.980	10.300	4.730	1.470	0.246	0.040	0.351	1.150	15.300	3
4	4.170	17.700	10.300	5.490	10.000	3.560	1.690	0.187	0.045	0.350	1.090	10.300	4
5	12.200	20.200	8.780	5.060	12.300	2.970	1.660	0.203	0.051	0.335	1.050	8.380	5
6	21.000	15.000	8.410	4.630	13.900	2.570	1.440	0.204	0.040	0.374	0.917	6.690	6
7	21.800	11.700	33.800	4.350	10.700	2.450	1.250	0.200	0.036	0.402	0.846	5.440	7
8	103.000	9.520	29.200	4.760	9.430	2.220	1.210	0.194	0.050	0.398	0.726	4.620	8
9	50.900	7.880	17.200	4.820	7.920	2.200	1.000	0.163	0.063	0.380	0.604	4.300	9
10	106.000	6.740	13.600	4.130	6.670	2.270	0.873	0.156	0.093	0.349	0.562	3.660	10
11	72.200	6.180	16.100	3.870	5.690	1.920	0.960	0.147	0.101	0.351	0.602	3.650	11
12	30.000	5.760	17.400	5.910	5.310	1.660	0.957	0.152	0.082	0.344	0.518	4.310	12
13	19.900	4.740	14.200	6.010	6.040	1.620	0.943	0.124	0.087	0.350	0.612	5.640	13
14	26.600	4.240	13.200	5.300	5.100	1.780	0.980	0.121	0.111	0.318	0.734	39.800	14
15	19.800	4.040	11.000	5.370	4.330	2.030	1.210	0.110	0.105	0.282	0.812	35.800	15
16	40.000	3.700	9.000	7.490	3.880	9.010	1.370	0.107	0.083	0.305	0.836	17.800	16
17	56.300	2.360	7.500	9.500	3.840	7.340	1.330	0.054	0.062	0.324	0.911	11.500	17
18	100.000	1.600	6.750	9.790	4.550	8.730	1.780	0.054	0.056	0.301	4.950	9.250	18
19	99.800	0.960	6.730	8.380	5.180	10.100	1.570	0.056	0.075	0.297	15.500	11.100	19
20	37.400	1.520	6.370	9.370	5.240	7.590	1.270	0.058	0.088	0.347	32.600	14.500	20
21	24.000	1.600	7.880	9.330	4.410	6.030	1.090	0.065	0.049	0.368	18.200	64.300	21
22	53.400	2.050	7.950	7.980	4.080	4.620	0.786	0.060	0.058	0.354	14.200	164.000	22
23	53.800	4.590	7.490	6.540	3.720	4.070	0.688	0.057	0.083	0.356	35.500	65.700	23
24	28.100	41.100	10.400	5.670	7.450	3.730	0.694	0.048	0.113	0.357	23.100	53.400	24
25	18.600	54.200	12.500	8.290	23.200	2.850	0.590	0.054	0.127	0.461	35.200	43.700	25
26	13.900	27.900	55.000	8.430	29.800	2.190	0.614	0.044	0.124	1.120	61.700	39.400	26
27	21.600	18.300	58.600	15.900	16.900	1.930	0.642	0.033	0.214	1.610	31.300	35.900	27
28	23.200	15.400	33.400	12.400	10.900	1.780	0.630	0.041	0.323	1.040	19.700	52.600	[illegible]
29	18.000		18.900	9.430	8.570	1.710	0.595	0.048	0.324	0.946	13.300	54.100	29
30	18.200		13.200	7.600	7.560	1.630	0.529	0.044	0.354	6.640	33.100	30.000	30
31	21.600		10.100		6.940		0.355	0.044		6.630		20.600	31
MEAN	36.479	13.539	16.002	7.229	8.696	3.884	1.084	0.119	0.104	0.859	11.847	30.098	
MAX	106.000	54.200	58.600	15.900	29.800	10.100	1.810	0.332	0.354	6.640	61.700	164.000	
MIN	4.170	0.960	6.370	3.870	3.720	1.620	0.355	0.033	0.029	0.279	0.518	3.650	
dam3	97705.4	36261.7	42858.7	19361.3	23291.7	10067.3	2903.6	319.6	277.3	2302.0	31730.1	80614.7	

Year= 10.86 m3/s
342,527 dam3

Table 2o 08HB011 Tsolum River near Courtenay D.A.= 258 km2
1987 Daily Discharge (m3/s)

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	DAY
1	36,30	30.60	3.91	3.19	12.70	4.77	1.13	0.53	0.17	0.22	0.50	101.00	1
2	29.20	20.00	5.25	4.48	12.70	3.43	0.99	0.49	0.16	0.23	0.57	68.50	2
3	87.10	16.30	16.00	5.82	12.10	2.87	0.86	0.39	0.17	0.24	0.47	66.00	3
4	53.00	57.40	86.50	5.77	14.70	3.18	0.80	0.35	0.16	0.21	0.40	40.80	4
5	34.50	64.70	136.00	5.07	11.20	3.60	1.20	0.35	0.16	0.21	0.34	30.20	5
6	21.70	52.30	59.30	4.85	9.51	3.04	1.70	0.27	0.15	0.21	0.37	51.80	6
7	15.10	27.40	29.70	6.55	8.72	2.25	1.56	0.23	0.15	0.22	0.35	32.00	7
8	11.40	18.60	18.90	8.97	8.66	2.42	1.64	0.22	0.15	0.22	0.36	57.30	8
9	9.40	15.70	15.00	7.55	8.05	2.56	1.53	0.27	0.14	0.21	0.57	65.30	9
10	14.20	22.00	30.30	12.20	6.39	2.44	1.43	0.22	0.14	0.23	8.84	57.40	10
11	60.30	59.90	40.00	9.30	5.87	1.96	1.02	0.16	0.13	0.24	19.70	32.40	11
12	41.50	50.20	42.60	7.08	5.40	4.09	0.85	0.16	0.13	0.24	6.06	19.90	12
13	25.40	56.60	43.20	6.77	3.97	6.21	0.70	0.20	0.13	0.26	7.12	13.90	13
14	16.10	42.60	28.90	12.00	4.03	3.68	0.60	0.21	0.14	0.24	5.78	16.60	14
15	11.70	23.70	20.30	10.00	3.52	2.69	0.55	0.19	0.16	0.24	3.77	11.40	15
16	9.61	18.30	18.20	9.78	2.79	2.04	0.39	0.17	0.15	0.24	2.70	8.22	16
17	8.26	15.00	25.60	7.60	2.59	1.81	0.32	0.16	0.15	0.21	2.18	6.45	17
18	7.37	12.10	19.10	6.13	2.35	1.68	0.32	0.15	0.15	0.22	1.80	5.38	18
19	6.31	9.59	13.60	5.19	2.05	1.65	0.31	0.15	0.15	0.24	1.61	4.98	19
20	5.60	8.43	10.60	4.65	1.97	1.85	0.29	0.15	0.15	0.24	2.69	6.00	20
21	5.08	7.91	9.24	4.24	2.05	2.00	0.30	0.13	0.15	0.25	8.51	6.71	21
22	4.75	6.97	7.33	3.87	2.18	1.51	0.26	0.13	0.15	0.23	8.17	5.25	22
23	6.99	5.91	6.07	3.56	2.07	1.14	0.22	0.13	0.14	0.25	6.12	4.29	23
24	21.70	5.10	5.64	3.40	2.07	1.10	0.22	0.14	0.14	0.24	50.40	3.79	24
25	21.00	4.49	5.06	3.19	2.12	1.17	1.54	0.12	0.14	0.21	22.70	3.48	25
26	17.50	4.09	4.88	3.07	2.52	1.36	4.78	0.14	0.16	0.21	12.30	3.32	26
27	24.10	3.89	4.20	3.40	2.53	1.52	2.80	0.16	0.18	0.20	8.10	3.23	27
28	70.30	3.62	3.65	5.63	2.54	1.45	1.66	0.17	0.21	0.20	5.78	3.75	28
29	68.90		3.38	5.99	2.16	1.31	0.98	0.17	0.23	0.21	4.74	4.48	29
30	82.00		3.30	8.91	9.49	1.27	0.71	0.16	0.23	0.22	15.20	4.96	30
31	44.10		3.14		8.03		0.61	0.16		0.33		4.63	31
MEAN	28.080	23.693	23.189	6.274	5.711	2.402	1.041	0.214	0.156	0.229	6.940	23.981	
MAX	87.100	64.700	136.000	12.200	14.700	6.210	4.780	0.525	0.229	0.325	50.400	101.000	
MIN	4.750	3.620	3.140	3.070	1.970	1.100	0.215	0.122	0.126	0.197	0.344	3.230	
dam3	75208.6	63458.9	62108.6	16803.4	15295.4	6225.1	2788.0	571.9	417.9	614.1	18588.2	64231.5	

Year= 10.12 m3/s
319,015 dam3

Table 2p 08HB011 Tsolum River near Courtenay D.A.= 258 km2

1988 Daily Discharge (m3/s)

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	DAY
1	4.050	8.890	7.240	7.580	6.820	3.100	1.000	0.162	0.269	0.230	29.900	16.700	1
2	3.580	7.370	7.810	12.900	6.750	3.060	1.000	0.151	0.293	0.217	28.300	13.300	2
3	4.160	6.420	10.000	27.100	7.110	16.100	1.030	0.135	0.294	0.188	12.600	12.700	3
4	3.140	5.620	11.500	16.000	5.770	9.150	0.906	0.104	0.268	0.189	61.600	13.700	4
5	2.770	5.190	17.900	23.800	5.430	6.390	0.823	0.117	0.264	0.200	51.500	57.800	5
6	2.750	4.790	25.600	23.800	5.590	5.040	0.872	0.112	0.266	0.177	22.600	44.900	6
7	2.600	4.600	17.700	17.500	5.210	4.230	0.812	0.115	0.263	0.169	39.700	25.500	7
8	2.660	4.700	17.700	13.100	5.900	5.060	0.728	0.107	0.243	0.159	31.400	18.300	8
9	5.650	5.110	13.900	10.200	6.880	4.390	0.729	0.112	0.234	0.156	51.200	15.100	9
10	9.980	4.730	10.400	8.830	6.690	4.020	0.775	0.117	0.240	0.150	37.100	14.000	10
11	7.060	6.500	8.360	8.360	8.260	4.440	0.789	0.118	0.225	0.157	44.400	16.100	11
12	7.630	12.200	7.110	8.320	9.730	3.750	0.770	0.110	0.240	0.185	24.100	21.800	12
13	29.400	19.700	6.100	9.280	8.780	3.330	2.240	0.096	0.232	0.241	15.700	14.300	13
14	92.300	18.100	5.410	11.700	5.890	3.230	1.790	0.094	0.238	0.432	15.900	10.300	14
15	65.400	21.000	5.240	13.000	6.510	3.220	1.340	0.090	0.243	0.758	13.700	8.120	15
16	42.500	14.300	4.780	12.000	12.800	3.050	1.210	0.126	0.197	0.960	11.700	7.030	16
17	24.800	12.800	4.430	10.300	8.530	2.450	1.040	0.295	0.145	0.851	9.250	6.760	17
18	17.400	10.300	4.210	8.760	5.940	2.280	0.884	0.470	0.148	0.852	18.900	6.960	18
19	12.900	8.560	4.250	7.850	5.990	2.180	0.767	0.504	0.152	0.887	19.400	12.200	19
20	22.400	7.610	8.020	7.840	5.240	1.860	0.713	0.550	0.140	0.825	59.700	14.300	20
21	18.800	6.690	8.700	8.500	5.060	1.780	0.637	0.571	0.140	0.762	74.000	15.300	21
22	16.500	6.150	11.600	7.720	6.670	1.800	0.569	0.542	0.180	0.789	51.700	16.700	22
23	13.800	5.520	20.300	6.470	6.010	1.650	0.467	0.464	0.189	0.823	31.500	11.200	23
24	10.800	4.940	14.200	5.260	3.980	1.460	0.409	0.422	0.230	0.815	25.100	8.170	24
25	8.660	4.510	15.600	4.350	3.530	1.290	0.354	0.411	0.263	0.823	15.600	6.460	25
26	7.310	4.630	17.000	3.910	3.510	1.340	0.313	0.380	0.440	0.801	25.500	6.810	26
27	6.600	5.590	11.700	5.170	3.780	1.100	0.292	0.356	0.527	0.736	20.500	6.760	27
28	23.500	6.240	9.150	18.700	5.160	1.360	0.249	0.358	0.393	0.694	14.200	9.420	28
29	32.700	5.990	9.180	19.600	4.670	1.370	0.205	0.342	0.299	0.969	11.400	20.200	29
30	18.300		8.450	9.350	3.450	1.130	0.172	0.307	0.274	2.440	10.600	13.500	30
31	12.000		7.890		2.930		0.175	0.295		17.800			31
MEAN	17.165	8.233	10.691	11.575	6.083	3.487	0.776	0.262	0.251	1.143	29.292	15.480	
MAX	92.300	21.000	25.600	27.100	12.800	16.100	2.240	0.571	0.527	17.800	74.000	57.800	
MIN	2.600	4.510	4.210	3.910	2.930	1.100	0.172	0.090	0.140	0.150	9.250	6.460	
dam3	45973.4	22050.6	28635.6	31002.5	16292.4	9038.3	2078.8	702.7	672.2	3061.6	78454.8	41460.7	

Year= 8.66 m3/s
273,111 dam3

Table 2q 08HB011 Tsolum River near Courtenay D.A.= 258 km2
1989 Daily Discharge (m3/s)

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	DAY
1	10.200	10.900	7.830	15.100	7.510	3.890	4.090	0.998	0.379	0.152	3.750	7.140	1
2	10.200	7.000	6.370	18.500	7.040	3.670	6.890	1.990	0.372	0.152	3.170	29.700	2
3	15.300	5.700	5.530	12.300	5.990	3.290	6.950	1.670	0.344	0.152	3.390	57.300	3
4	16.600	4.900	5.280	10.100	6.240	2.610	7.670	1.320	0.333	0.155	6.490	81.600	4
5	12.200	4.200	13.800	15.900	7.640	2.280	6.800	1.040	0.318	0.158	6.540	34.500	5
6	9.210	3.650	17.700	33.600	7.560	1.990	4.960	0.843	0.282	0.158	5.460	22.500	6
7	7.280	3.420	14.400	31.500	6.590	1.620	3.630	0.711	0.262	0.158	4.450	27.300	7
8	6.530	3.230	14.700	18.600	5.890	1.470	3.360	0.611	0.241	0.156	4.910	33.700	8
9	6.060	3.090	15.000	13.100	4.990	1.320	3.340	0.533	0.224	0.155	9.640	19.600	9
10	4.960	2.930	19.800	11.000	4.220	1.180	2.840	0.478	0.208	0.154	12.700	13.200	10
11	4.730	2.810	36.800	11.500	4.070	1.060	2.250	0.448	0.197	0.166	8.810	9.890	11
12	11.800	2.720	47.600	11.600	3.300	1.000	1.830	0.449	0.186	0.178	6.490	8.060	12
13	19.800	2.640	34.500	11.300	2.950	0.990	1.530	0.456	0.179	0.177	5.490	6.890	13
14	11.900	2.550	25.600	13.000	2.670	0.997	1.330	0.449	0.175	0.178	4.630	6.030	14
15	9.710	2.490	17.300	13.900	2.900	0.976	1.110	0.455	0.164	0.198	4.060	5.320	15
16	10.300	2.410	14.200	9.900	3.080	0.954	1.080	0.447	0.156	0.222	3.830	4.660	16
17	10.800	2.390	13.300	7.910	3.130	0.939	2.280	0.448	0.154	0.242	3.740	4.240	17
18	10.200	2.380	11.200	8.110	3.400	0.940	2.410	0.449	0.157	0.364	3.800	3.860	18
19	8.430	2.620	9.420	11.100	2.620	0.869	2.030	0.447	0.156	0.620	5.140	3.540	19
20	7.480	4.000	8.340	40.400	2.300	0.835	1.580	0.451	0.156	0.921	8.030	3.320	20
21	6.620	8.980	9.290	21.300	2.210	0.831	1.350	0.442	0.156	8.780	9.010	3.270	21
22	6.030	17.000	9.510	12.600	2.190	0.805	1.300	0.439	0.157	9.170	7.350	3.300	22
23	5.100	41.200	8.660	11.400	2.110	0.774	1.240	0.436	0.155	39.700	9.350	3.340	23
24	4.880	35.000	7.430	9.570	2.140	0.754	1.070	0.433	0.156	24.400	8.700	3.300	24
25	4.980	20.700	6.940	8.840	2.210	0.695	0.908	0.434	0.154	11.600	7.150	3.280	25
26	5.260	13.800	6.620	8.290	2.610	0.649	0.795	0.436	0.153	30.700	9.390	3.290	26
27	5.130	10.900	7.870	7.500	3.870	0.641	0.697	0.433	0.150	16.100	8.230	3.300	27
28	4.740	9.360	8.580	6.880	3.330	1.010	0.652	0.436	0.149	9.750	9.000	3.270	28
29	5.720		9.880	7.670	3.130	2.790	0.603	0.422	0.150	7.060	10.600	3.330	29
30	11.500		9.280	7.810	3.190	2.930	0.554	0.388	0.150	5.550	8.780	3.370	30
31	18.300		10.200		3.270		0.559	0.397		4.560		3.360	31
MEAN	9.095	8.320	13.965	14.009	4.011	1.492	2.506	0.625	0.206	5.554	6.736	13.508	
MAX	19.800	41.200	47.600	40.400	7.640	3.890	7.670	1.990	0.379	39.700	12.700	81.600	
MIN	4.730	2.380	5.280	6.880	2.110	0.641	0.554	0.388	0.149	0.152	3.170	3.270	
dam3	24360.5	22285.2	37405.2	37522.6	10743.8	3867.2	6712.2	1675.2	551.1	14876.9	18041.7	36180.9	
Year=	6.67 m3/s												
	210,256 dam3												

Table 2r 08HB011 Tsolum River near Courtenay D.A.= 258 km2

1990 Daily Discharge (m3/s)

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	DAY
1	3.30	7.20	5.45	10.20	3.07	3.65	2.15	0.14	0.09	0.25	11.20	8.30	1
2	3.24	16.50	5.16	10.30	3.55	3.65	2.06	0.15	0.12	0.25	8.43	6.20	2
3	3.18	52.00	5.14	8.49	3.36	53.00	2.85	0.13	0.18	0.30	10.50	74.20	3
4	3.20	29.00	7.11	7.36	3.09	28.50	2.25	0.11	0.24	0.39	11.10	74.00	4
5	18.10	28.50	8.65	6.98	3.17	16.60	1.87	0.10	0.22	0.51	9.01	37.00	5
6	39.20	26.00	8.35	6.51	2.70	12.70	2.23	0.10	0.20	0.47	7.53	10.00	6
7	70.40	16.00	9.42	6.58	2.09	13.20	2.64	0.09	0.14	0.43	10.80	6.60	7
8	39.90	11.00	8.88	6.45	1.85	12.20	2.45	0.09	0.45	0.44	10.60	12.50	8
9	25.90	9.70	15.60	5.55	1.60	12.30	2.11	0.09	0.11	0.50	24.00	10.30	9
10	16.50	9.30	24.80	5.07	1.58	26.40	1.64	0.09	0.10	0.47	41.70	6.00	10
11	12.10	9.90	14.20	5.92	1.56	28.70	1.29	0.09	0.10	0.59	71.00	4.80	11
12	11.40	10.00	9.52	6.07	1.56	16.90	1.15	0.07	0.05	0.92	73.10	5.20	12
13	19.80	9.00	10.10	5.11	2.60	10.70	0.95	0.08	0.08	0.73	54.10	5.40	13
14	23.90	7.40	21.70	4.99	2.69	7.76	0.82	0.08	0.08	0.78	27.20	7.50	14
15	17.30	6.60	14.90	4.94	2.33	5.79	0.72	0.09	0.11	0.81	19.30	12.40	15
16	22.10	5.85	12.20	5.81	2.35	4.52	0.63	0.09	0.13	0.65	22.20	8.00	16
17	14.70	5.40	14.10	9.11	3.36	3.78	0.51	0.10	0.09	0.74	19.60	6.00	17
18	11.20	5.18	19.20	6.91	2.85	3.16	0.46	0.09	0.09	1.33	14.40	5.30	18
19	9.08	4.90	15.10	6.23	2.60	2.74	0.39	0.09	0.10	1.53	12.10	4.85	19
20	7.71	4.70	13.20	6.18	2.75	2.30	0.38	0.09	0.13	1.52	10.30	4.60	20
21	7.43	4.60	12.40	5.05	2.72	1.96	0.31	0.08	0.15	4.89	9.07	4.25	21
22	7.31	4.53	12.00	4.41	9.79	1.66	0.27	0.07	0.17	4.75	9.61	3.92	22
23	9.60	4.45	11.80	4.39	7.36	1.47	0.24	0.07	0.20	3.28	100.00	3.70	23
24	7.70	4.67	9.62	4.57	4.69	1.34	0.24	0.07	0.21	10.50	94.30	3.45	24
25	13.30	5.40	8.22	5.70	3.96	1.21	0.22	0.06	0.22	41.70	20.00	3.20	25
26	12.00	6.20	6.98	5.47	3.30	1.13	0.22	0.06	0.22	20.10	10.00	3.00	26
27	9.90	6.00	6.44	4.74	6.66	1.05	0.20	0.06	0.23	22.30	5.00	2.80	27
28	13.00	5.89	6.82	4.47	11.60	1.03	0.15	0.06	0.24	32.90	10.00	2.60	28
29	11.60		7.91	3.71	7.24	2.07	0.15	0.06	0.24	30.00	51.00	2.44	29
30	10.00		8.85	3.23	5.39	2.64	0.16	0.08	0.24	35.90	16.00	2.30	30
31	8.80		10.10		4.42		0.14	0.11		17.50		2.20	31
MEAN	15.576	11.281	11.094	6.017	3.801	9.470	1.027	0.087	0.165	7.658	26.438	11.065	
MAX	70.400	52.000	24.800	10.300	11.600	53.000	2.850	0.151	0.446	41.700	100.000	74.200	
MIN	3.180	4.450	5.140	3.230	1.560	1.030	0.139	0.055	0.050	0.248	5.000	2.200	
dam3	41718.2	30215.2	29714.7	16115.0	10181.4	24547.1	2750.9	234.1	440.6	20512.1	70812.4	29636.1	

Year= 8.60 m3/s
271,135 dam3

Table 3. Mean Monthly Discharges (m^3/s) for Pyrrhotite Creek, Murex Creek and the Tsolum River

	Pyrrhotite Ck d/s mine (0125901)	Murex Ck u/s Tsolum (E206499)	Tsolum R d/s Murex (E207826)	Tsolum R u/s Puntledge (0127621)
January	0.009	1.975	3.918	21.28
Febraury	0.008	2.003	3.450	13.01
March	0.011	1.807	3.492	14.99
April	0.021	2.724	4.469	9.02
May	0.051	1.933	2.866	5.66
June	0.038	1.736	2.645	4.15
July	0.008	0.677	0.984	1.29
August	0.002	0.172	0.249	0.26
September	0.001	0.064	0.101	0.17
October	0.012	0.637	1.029	3.09
November	0.020	2.687	4.830	16.25
December	0.017	2.381	4.812	18.83
Average	0.016	1.560	2.737	8.99

Table4. Tsolum River near Courtenay, 08HB011, mean monthly discharge (m3/s)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1914						6.53	1.79	0.323	8.82		24.8	10.6	
1915	21.3	19.6	18.2	12.5	4.84	1.3	0.537	0.12	0.182	12.6	13.2	28	11.01
1916	1.49	6.21	23.6	21.1	19.5	13	8.21	1.16	0.094	1.58	8.25	9.44	9.47
1917	5.26	9.35	8.26										
1955			5.03	9.99			2.72	1.72	1.8	8.,62			
1956	28.1	6.03	14.5	16.1	14.2	19	2.44	0.23	0.744	8.68	9.7	21.3	11.13
1957	8.28	10.4	21	16.3	6.51								
1964				7.25	4.55	5.07	3.87	1.9	0.957	1.74	6.89	13.8	
1965	10.5	17.1	7.49	10.8	3.6	0.889	0.169	0.922	0.892	13.3	24.3	29.9	9.94
1966	33.6	17	21.6	8.72	4.79	3.07	1.4	0.741	1.55	3.38	24.5	51.4	14.34
1967	19.9	10.3	21.1	6.91	6.79	3.58	0.386	,21	0.687	15.3	8.53	17.3	9.29
1968	42.1	19.6	22.6	4.62	4.95	2.15	0.513	1.5	1.62	25.3	31	29	15.45
1969	5.94	22.6	19.5	30.6						5.45	22.8	29.3	
1970	10.2	10.8	9.16	6.21	3.36	1.86	0.709	0.406	0.245	8.47	10.9	26.5	7.4
1971	17.9	14.7	12.7	11.3	16.1	7.1	2.57	0.556	1.59	4.63	29	11.5	10.76
1972	5.35	17.4					1.88	0.496	2.27	1.55	15.2	23.3	
1973	34	7.76	14.7	5.94	8.57	3.9	1.74	0.498	1.11	6.24	16.8	42.2	12.06
1974	19.6	19.9	29.5	19.5	8.04	5.39	3.65	0.478	0.763	0.666			
1975	9.01	7.92	15.9	11.5	13.7	3.54	0.784	1.15	0.1	20.1	44.6	18.9	12.35
1976	15.8	10.2				4.16	2.5	0.654			5.02	10.1	
1977	5.66	19	17.1	8.28	5.34	4.65	0.719	0.203	2.34	13.2	25.3	18.6	9.96
1978	14	18.7	15	11.4	4.7	2.4	0.747	4.9	7.99	1.63	5.13	8.02	7.81
1979	4.03	24.7	14.5	11.2	7.35	1.42	1.61	0.423	6.09	12.8	7.82	28.9	9.99
1980	12.2	25.3	14.1	12.1	4.35	4.69	4.47	0.43	0.847	1.16	22.8	30.9	11.05
1981	20.4	17.5	5.47	7.42	6.72	3.49	1.8	1.09	3.77	14.4	29.9	23.6	11.25
1982	13.8	21.6	15.7	10.8	9.68	4.34	1	0.263	0.672	20.3	10.1	25.2	11.09
1983	30.7	43.2	26.7	8.02	5.13	2.81	2.56	0.682	1.5	3.63	44.9	6.81	14.49
1984	14.3	25.5	17.9	10.4	11.2	3.18	0.986	0.332	0.49	13.9	27.1	10.6	11.26
1985	3.46	6.76	8.3	11.5	6.5	1.76	0.135	0.039	0.871	6.52	4.17	8.26	4.84
1986	36.5	13.5	16	7.23	8.7	3.88	1.08	0.119	0.104	0.859	11.8	30.1	10.86
1987	28.1	23.7	23.2	6.27	5.71	2.4	1.04	0.214	0.156	0.229	6.94	24	10.12
1988	17.2	8.23	10.7	11.6	6.08	3.49	0.776	0.263	0.252	0.578	29.5	15.3	8.64
1989	9.1	8.32	14	14	4.01	1.49	2.51	0.625	0.206	5.55	6.77	13.5	6.67
1990	15.6	11.3	11.1	6.02	3.8	9.47	1.03	0.087	0.155	7.66	26.4	11.1	8.6
mean	16.6	15.9	15.8	11.2	7.49	4.17	1.82	0.73	1.66	8	18.5	20.9	10.2
max	42.1	43.2	29.5	30.6	19.5	13	8.21	4.9	8.82	25.3	44.9	61.4	15.5
min	1.49	6.03	5.03	4.62	3.36	0.889	0.135	0.039	0.094	0.229	4.17	6.81	4.84
std dev	10.82	8	6.16	5.39	4.13	2.79	1.62	0.91	2.21	6.76	11.46	10.68	2.39

Table 5. Estimated long-term discharge values for Pyrrhotite Creek, Murex Creek, the Tsolum River below Murex Creek, and the Tsolum River near Courtenay

1986-1990 mean
(prorated against Tsolum R. values for missing data)

	Pyrrhotite		Murex		Tsolum (upper)				Tsolum long term	ratio
	m3/s	mm	m3/s	mm	m3/s	mm	m3/s`	mm	m3/s	short:long
Jan	0.009	76	3.01	197	3.14	206	21.3	221	16.56	1.29
Feb	0.008	59	2.81	166	2.55	167	13	122	15.94	0.82
Mar	0.011	95	2.27	149	2.31	151	15	156	15.82	0.95
Apr	0.021	175	2.33	148	2.01	132	9.02	91	11.19	0.81
May	0.051	438	2.36	155	1.84	121	5.66	59	7.49	0.76
June	0.038	320	1.49	95	1.2	78	4.15	42	4.17	0.99
July	0.008	71	0.605	40	0.46	30	1.29	13	1.82	0.71
Aug	0.002	15	0.122	8	0.09	6	0.259	3	0.73	0.36
Sept	0.001	7	0.055	3	0.05	3	0.175	2	1.66	0.11
Oct	0.012	103	0.853	56	0.72	47	3.09	32	8	0.39
Nov	0.02	169	3.05	193	2.88	189	16.3	163	18.47	0.88
Dec	0.017	148	2.54	166	2.68	176	18.8	195	20.92	0.9
Annual	0.016	1,677	1.78	1,376	3.22	1,306	8.98	1,098	10.2	0.88

Estimated Long-Term Discharge
(adjusted for long-term values for Tsolum River)

	Pyrrhotite		Murex		Tsolum (upper)			
	m3/s	mm	m3/s	mm	m3/s	mm	m3/s`	mm
Jan	0.007	59	2.35	154	4.65	160	16.6	172
Feb	0.009	72	3.44	204	6.57	2.4	15.9	149
Mar	0.012	101	2.4	157	4.64	160	15.80	164
Apr	0.026	217	2.89	183	4.9	163	11.2	112
May	0.067	580	3.13	205	4.64	160	7.49	78
June	0.038	322	1.5	95	2.37	79	4.17	42
July	0.012	101	0.855	56	1.24	43	1.82	19
Aug	0.005	42	0.345	23	0.5	17	0.73	8
Sept	0.008	70	522	33	0.84	28	1.66	17
Oct	0.031	268	2.21	145	3.57	123	8	83
Nov	0.023	192	3.45	220	6.44	214	18.5	186
Dec	0.019	164	2.82	185	5.67	195	20.9	217
Annual	0.021	2,187	2.15	1,659	3.82	1,547	10.2	1,247

Table 6. Dilution Ratios for the Tsolum River Watershed.

	Murex/ Pyrrhotite	Tsolum/ Pyrrhotite	Tsolum/ Murex
January	218:1 or 0.5%	434:1 or 0.2%	1:1.0 or 50%
February	249:1 or 0.4%	430:1 or 0.2%	1:1.4 or 58%
March	163:1 or 0.6%	316:1 or 0.3%	1:1.1 or 52%
April	129:1 or 0.8%	211:1 or 0.5%	1:1.7 or 63%
May	37:1 or 2.7%	55:1 or 1.8%	1:2.0 or 67%
June	50:1 or 2.0%	68:1 or 1.4%	1:1.9 or 66%
July	84:1 or 1.2%	122:1 or 0.8%	1:2.2 or 69%
August	85:1 or 1.2%	123:1 or 0.8%	1:2.2 or 69%
September	63:1 or 1.6%	100:1 or 1.0%	1:1.7 or 63%
October	52:1 or 1.9%	84:1 or 1.2%	1:1.6 or 62%
November	133:1 or 0.8%	240:1 or 0.4%	1:1.3 or 57%
December	139:1 or 0.7%	282:1 or 0.4%	1:1.0 or 50%

Murex = Murex upstream of Tsolum (E206499)

Tsolum = Tsolum 500 meters downstream of Murex (E207826)

Pyrrhotite = Pyrrhotite Creek below mine (0125901)

Table 7 a). Summary of Fisheries Enhancement Work on the Tsolum Watershed

Adult Pink Salmon Releases to the Tsolum Watershed

	LOCATION	FEMALES	MALES	TOTAL
1987	Tsolum R.	1738	1019	2757
1987	Headquarters Creek	3288	3719	7007
1988	Headquarters Creek	1282	1459	2741
1989	upstream Headquarters	197	312	509
1990	Headquarters Creek	1098	2607	3705

Juvenile Pink Salmon Releases to the Tsolum Watershed

	Stock	Location	Total
1980	Tsolum	Tsolum	51,547
1981	Tsolum	Puntledge	125,822
1981	Tsolum	Tsolum	665,175
1982	Tsolum	Tsolum	598,890
1982	Tsolum	Seapen Bay and Comox Bay	142,454
1984	Tsolum	Headquarters Creek	41,156

Juvenile Coho Releases to the Tsolum Watershed

Release Year	Stock	Total
1984	Puntledge River	345,019
1985	Puntledge River	296,774
1986	Tsolum River	53,542
1986	Puntledge River	246,025
1987	Tsolum River	12,611
1987	Puntledge River	185,893
1988	Tsolum River	19,322
1988	Puntledge River	150,777

Table 7 b) Tsolum River Salmonid Escapement Data

Year	Coho Salmon	Pink Salmon	Chum Salmon
1980	1,800	5,000	7,000
1981	1,000	5,095	11,000
1982	2,000	200	300
1983	1,000	1,200	11,000
1984	500	10	75
1985	800	1,000	200
1986	200*		400*
1987	14	9,007(9,760)**	100
1988	50	2,000(2,741)	
1989	100	5,000	
1990	100	5,5150(3705)**	

*Questionable data

**Figures in brackets represent adult fish released into the Tsolum River watershed

Note that escapement figures include released fish

Table 8. Economic Value of Tsolum Fisheries (from Robertson and Malick, 1987)

Estimated 50 Year Values in 1987$ - Tsolum River

	1987 CHV($)	1987 NCHV($)	1987 NCEHV ($)
Steelhead	56,593	693,322	1,044,483
Cutthroat	28,297	348,161	522,242
Salmon	1,542,005	8,440,694	10,550,870
TOTAL	1,627,895	9,485,177	12,117,595

CHV: current harvest values

NCHV: natural capability harvest values

NCEHV: natural capability and enhancement values

Estimated Angler Days - Tsolum River

	A.D./year	P.U.A.D./year	P.E.A.D./year
Steelhead	124	2,000	4,000
Cutthroat	64	1,000	2,000

A.D.: Angler Days

P.U.A.D.: Potential unenhanced angler days

P.E.A.D.: Potential enhanced angler days

Table 9. Water Chemistry Summary for the Tsolum River Upstream of Murex Creek (E206513) - 1985 to 1991

	Maximum	Minimum	Average	Std.Dev.	N
pH	7.5	6.4	6.9*	0.2	44
Spec.Cond.(uS/cm)	64	21	41	13	36
Acidity:8.3(mg/L)	9.9	4.0	7.0	4.2	2
Alkalinity:4.5(mg/L)	19.0	13.0	16.0	2.9	3
Residue,NFilt.(mg/L)	80	<1	3.82	13.6	34
Calcium,Diss.(mg/L)	7.52	1.69	4.23	1.44	76
Magnesium,Diss.(mg/L)	2.21	0.62	1.27	0.4	76
Sulphate,Diss.(mg/L)	2.2	1.0	1.32	0.39	37
Aluminum,Diss.(mg/L)	0.14	0.02	0.057	0.037	39
Cadmium,Diss.(mg/L)	<0.010	<0.010	<0.010	0.000	76
Cadmium,Total(mg/L)	<0.010	<0.010	<0.010	0.000	99
Copper,Diss.(mg/L)	0.010	<0.001	0.002	0.001	74
Copper,Total(mg/L)	0.030	0.001	0.004	0.005	97
Iron,Diss.(mg/L)	0.69	0.04	0.23	0.14	76
Iron,Total(mg/L)	2.52	0.05	0.42	0.33	99
Lead,Diss.(mg/L)	0.001	<0.001	0.001	0.000	9
Lead,Total(mg/L)	0.007	<0.001	0.002	0.002	10
Manganese,Diss.(mg/L)	0.100	<0.010	0.030	0.020	76
Manganese,Total(mg/L)	0.110	<0.010	0.030	0.030	99
Molybdenum,Diss.(mg/L)	0.060	<0.010	0.010	0.010	76
Molybdenum,Total(mg/L)	0.020	<0.010	0.010	0.010	99
Zinc,Diss.(mg/L)	0.010	<0.010	0.010	0.000	76
Zinc,Total(mg/L)	0.020	<0.010	0.010	0.005	99

*geometric mean

Table 10. Water Chemistry Summary for Mckay Creek (E206685) - (1986-1990)

	Maximum	Minimum	Average	Std.Dev.	N
pH	7.3	6.3	6.8*	0.2	26
Spec.Cond.(uS/cm)	37	15	25	7.3	17
Acidity:8.3(mg/L)	7.5	1.0	3.2	1.8	12
Alkalinity:4.5(mg/L)	9.2	4.3	6.1	1.7	12
Residue,Filt.(mg/L)	40	40	40		1
Residue,NFilt.(mg/L)	188	<1	14	48	15
Calcium,Diss.(mg/L)	5.2	1.6	3.0	0.9	31
Magnesium,Diss.(mg/L)	1.0	0.4	0.6	0.2	31
Sulphate,Diss.(mg/L)	14	1.6	5.8	2.5	26
Aluminum,Diss.(mg/L)	0.14	0.02	0.08	0.03	18
Cadmium,Diss.(mg/L)	<0.01	<0.01	<0.01	0.00	31
Cadmium,Total(mg/L)	0.01	<0.01	<0.01	0.00	38
Copper,Diss.(mg/L)	0.020	0.001	0.006	0.004	31
Copper,Total(mg/L)	0.120	0.001	0.010	0.019	37
Iron,Diss(mg/L)	0.24	<0.01	0.03	0.04	31
Iron,Total(mg/L)	5.55	<0.01	0.21	0.89	38
Lead,Diss.(mg/L)	<0.10	<0.10	<0.10	0.00	31
Lead,Total(mg/L)	<0.10	<0.10	<0.10	0.00	38
Manganese,Diss.(mg/L)	0.02	<0.01	0.01	0.00	31
Manganese,Total(mg/L)	0.16	<0.10	0.01	0.02	38
Molybdenum,Diss.(mg/L)	<0.01	<0.01	<0.01	0.00	31
Molybdenum,Total(mg/L)	0.01	<0.01	<0.01	0.00	38
Zinc,Diss.(mg/L)	<0.005	<0.005	<0.005	0.000	15
Zinc,Total(mg/L)	0.020	<0.005	0.009	0.006	16

*geometric mean

Table 11. Water Chemistry Summary for Murex Creek Upstream of Pyrrhotite Creek (E206686) - (1986-1991)

	Maximum	Minimum	Average	Std. Dev	N
pH	7.6	6.2	6.9*	0.7	51
Spec.Cond.(uS/cm)	38	14	21	7.1	37
Acidity:8.3(mg/L)	9.2	1.1	3.4	2.1	13
Alkalinity:4.5(mg/L)	11.3	4.5	7.4	2.6	13
Residue,Filt(mg/L)	48	16	32	22.6	2
Residue,NFilt(mg/L)	340	<1	11.9	57.4	35
Calcium,Diss(mg/L)	4.4	1.5	2.5	0.8	52
Magnesium,Diss.(mg/L)	0.6	0.2	0.4	0.1	52
Sulphate,Diss.(mg/L)	6.7	2.0	3.5	1.3	47
Aluminum,Diss.(mg/L)	0.16	<0.02	0.07	0.04	20
Cadmium,Diss(mg/L)	<0.010	<0.010	<0.010	0.000	52
Cadmium,Total(mg/L)	0.010	<0.010	0.010	0.000	58
Copper,Diss.(mg/L)	0.020	<0.001	0.006	0.003	52
Copper,Total(mg/L)	0.180	0.002	0.010	0.023	58
Iron,Diss.(mg/L)	0.41	<0.01	0.06	0.08	52
Iron,Total(mg/L)	16.2	<0.01	0.44	2.13	58
Lead,Diss.(mg/L)	<0.001	<0.001	<0.001	0.000	10
Lead,Total(mg/L)	0.003	<0.001	0.002	0.001	10
Manganese,Diss.(mg/L)	0.020	<0.010	0.010	0.000	52
Manganese,Total(mg/L)	0.380	<0.010	0.020	0.050	58
Molybdenum,Diss.(mg/L)	0.010	<0.010	0.010	0.000	52
Molybdenum,Total(mg/L)	0.010	<0.010	0.010	0.000	52
Zinc,Diss.(mg/L)	0.020	<0.005	0.006	0.004	18
Zinc,Total(mg/L)	0.040	0.005	0.008	0.007	25

*geometric mean

Table 12. Water Chemistry Summary for Pyrrhotite Creek at Branch 126 (0125901) - (1985-1991)

	Maximum	Minimum	Average	Std.Dev.	N
pH	4.7	3.6	4.1*	0.2	124
Spec.Cond.(uS/cm)	646	53	313	121	89
Alkalinity:4.5(mg/L)	45.2	1	9.9	7.8	75
Acidity:8.3(mg/L)	94	12.5	54.7	21.7	86
Residue,Filt.(mg/L)	410	272	337	69	3
Residue,NFilt.(mg/L)	40	<1	2.4	6.2	39
Calcium,Diss.(mg/L)	81.6	5.0	28.0	17.3	96
Magnesium,Diss.(mg/L)	10.2	0.23	3.87	2.05	96
Sulphate,Diss.(mg/L)	356	15.6	134	66	123
Aluminum,Diss.(mg/L)	16.9	0.49	6.8	3.6	64
Arsenic,Diss.(mg/L)	0.007	<0.001	0.002	0.002	13
Arsenic,Total(mg/L)	0.007	<0.001	0.002	0.002	21
Boron,Diss.(mg/L)	0.020	<0.010	0.010	0.001	94
Barium,Diss.(mg/L)	0.030	<0.010	0.011	0.003	95
Barium,Total(mg/L)	0.040	<0.010	0.020	0.010	28
Cadmium,Diss.(mg/L)	0.010	0.002	0.004	0.005	3
Cadmium,Total(mg/L)	0.010	0.0013	0.003	0.003	15
Cobalt,Diss.(mg/L)	0.200	<0.100	0.110	0.030	95
Cobalt,Total(mg/L)	0.200	<0.100	0.110	0.040	127
Chromium,Diss.(mg/L)	0.010	<0.010	0.010	0.0	95
Chromium,Total(mg/L)	0.030	<0.010	0.010	0.010	131
Copper,Diss.(mg/L)	16.9	0.4	6.58	2.63	100
Copper,Total(mg/L)	17.4	0.013	6.17	2.20	255
Iron,Diss.(mg/L)	4.01	0.15	0.73	0.61	94
Iron,Total(mg/L)	16.9	0.16	1.09	2.2	135
Lead,Diss.(mg/L)	0.001	<0.001	0.001	0.00	12
Lead,Total(mg/L)	0.005	<0.001	0.002	0.001	28
Manganese,Diss.(mg/L)	3.4	0.04	1.11	0.76	94
Manganese,Total(mg/L)	4.1	0.01	1.17	0.82	127
Molybdenum,Diss.(mg/L)	0.030	<0.010	0.010	0.00	95
Molybdenum,Total(mg/L)	0.040	<0.010	0.010	0.010	127
Nickel,Diss.(mg/L)	0.110	<0.010	0.060	0.014	96
Nickel,Total(mg/L)	0.120	<0.010	0.064	0.021	128
Zinc,Diss.(mg/L)	0.430	0.010	0.215	0.093	95
Zinc,Total(mg/L)	1.50	0.020	0.230	0.102	135

*geometric mean

Table 13. Water Chemistry Summary for Pyrrhotite Creek Upstream of Murex Creek (E206501) - (1985-1991)

	Maximum	Minimum	Average	Std.Dev	N
pH	7.8	5.5	6.7*	0.5	79
Spec.Cond.(uS/cm)	57	14	30.8	13.8	46
Alkalinity:4.5(mg/L)	19.9	1.8	7.44	5.2	36
Residue,Filt.(mg/L)	42	18	26.8	8.1	15
Residue,NFilt.(mg/L)	40	<1	2.76	6.81	33
Calcium,Diss.(mg/L)	8.8	1.3	3.7	1.7	77
Magnesium,Diss.(mg/L)	1.53	0.34	0.73	0.28	77
Sulphate,Diss.(mg/L)	27.9	1.8	7.0	5.3	79
Aluminum,Diss.(mg/L)	0.210	<0.020	0.100	0.05	62
Arsenic,Diss.(mg/L)	<0.250	<0.250	<0.250	0.000	20
Arsenic,Total(mg/L)	<0.250	<0.250	<0.250	0.000	20
Boron,Diss.(mg/L)	<0.010	<0.010	<0.010	0.000	77
Barium,Diss.(mg/L)	<0.010	<0.010	<0.010	0.000	77
Barium,Total(mg/L)	<0.010	<0.010	<0.010	0.000	27
Cadmium,Diss.(mg/L)	<0.010	<0.010	<0.010	0.000	77
Cadmium,Total(mg/L)	0.010	<0.010	<0.010	0.000	89
Cobalt,Diss.(mg/L)	<0.100	<0.100	<0.100	0.000	77
Cobalt,Total(mg/L)	<0.100	<0.100	<0.100	0.000	89
Chromium,Diss.(mg/L)	<0.010	<0.010	<0.010	0.000	77
Chromium,Total(mg/L)	0.090	<0.010	<0.011	0.008	89
Copper,Diss.(mg/L)	0.90	0.02	0.29	0.22	81
Copper,Total(mg/L)	0.99	0.02	0.20	0.21	115
Iron,Diss.(mg/L)	0.38	<0.01	0.051	0.052	77
Iron,Total(mg/L)	1.4	<0.01	0.11	0.17	89
Lead,Diss.(mg/L)	<0.100	<0.100	<0.100	0.000	77
Lead,Total(mg/L)	<0.100	<0.100	<0.100	0.000	89
Manganese,Diss.(mg/L)	0.24	<0.01	0.036	0.037	77
Manganese,Total(mg/L)	0.26	<0.01	0.036	0.038	89
Molybdenum,Diss.(mg/L)	0.02	<0.010	0.010	0.001	77
Molybdenum,Total(mg/L)	0.02	<0.010	0.010	0.002	89
Nickel,Diss.(mg/L)	0.080	<0.050	0.050	0.003	77
Nickel,Total(mg/L)	0.09	<0.050	0.050	0.004	89
Zinc,Diss.(mg/L)	0.05	<0.005	0.017	0.011	36
Zinc,Total(mg/L)	0.05	<0.005	0.018	0.011	49

*geometric mean

Table 14. Water Chemistry Summary for Murex Creek at Duncan Main (E206499) - (1985-1991)

	Maximum	Minimum	Average	Std.Dev	N
pH	7.7	6.2	6.9*	0.3	99
Spec.Cond.(uS/cm)	50	15	24.2	9.1	69
Acidity:8.3(mg/L)	16.1	1.6	6.6	6.5	4
Alkalinity:4.5(mg/L)	8.5	4.8	6.7	1.5	4
Residue,Filt.(mg/L)	40	16	24.5	8.1	17
Residue,NFilt.(mg/L)	33	<1	2.7	5.2	54
Calcium,Diss.(mg/L)	5.1	1.5	2.9	0.8	101
Chloride,Diss.(mg/L)	0.6	0.6	0.6		1
Magnesium,Diss.(mg/L)	1.1	0.3	0.6	0.2	101
Sulphate,Diss.(mg/L)	8.9	1.7	4.6	1.8	103
Aluminum,Diss.(mg/L)	0.320	0.020	0.100	0.050	62
Cadmium,Diss.(mg/L)	<0.010	<0.010	<0.010	0.000	101
Cadmium,Total(mg/L)	<0.010	<0.010	<0.010	0.000	101
Copper,Diss.(mg/L)	0.110	0.001	0.036	0.025	106
Copper,Total(mg/L)	0.130	0.003	0.041	0.027	139
Iron,Diss.(mg/L)	0.940	<0.010	0.057	0.098	101
Iron,Total(mg/L)	4.6	<0.010	0.220	0.580	113
Lead,Diss.(mg/L)	<0.100	<0.100	<0.100	0.000	101
Lead,Total(mg/L)	<0.100	<0.100	<0.100	0.000	113
Manganese,Diss.(mg/L)	0.030	<0.010	0.010	0.002	101
Manganese,Total(mg/L)	0.050	<0.010	0.010	0.010	113
Molybdenum,Diss.(mg/L)	0.010	<0.010	<0.010	0.000	101
Molybdenum,Total(mg/L)	0.010	<0.010	<0.010	0.000	113
Zinc,Diss.(mg/L)	0.010	<0.010	0.009	0.002	101
Zinc,Total(mg/L)	0.020	<0.010	0.010	0.004	113

*geometric mean

Table 15. Water Chemistry for Tsolum River 500 Meters Downstream of Murex Creek (E207826) - (1989-1991)

	Maximum	Minimum	Average	Std.Dev.	N
pH	6.7	6.7	6.7*		1
Calcium,Diss.(mg/L)	2.84	2.46	2.65		2
Magnesium,Diss.(mg/L)	0.58	0.5	0.54		2
Boron,Diss.(mg/L)	<0.01	<0.01	<0.01		2
Barium,Diss.(mg/L)	<0.01	<0.01	<0.01		2
Barium,Total(mg/L)	0.02	<0.01	0.0111	0.0033	9
Cadmium,Diss.(mg/L)	<0.01	<0.01	<0.01		2
Cadmium,Total(mg/L)	<0.01	<0.01	<0.01		15
Cobalt,Diss.(mg/L)	<0.1	<0.1	<0.1		2
Cobalt,Total(mg/L)	<0.1	<0.1	<0.1		15
Chromium,Diss.(mg/L)	<0.01	<0.01	<0.01		2
Chromium,Total(mg/L)	<0.1	<0.010	0.016	0.0232	15
Copper,Diss.(mg/L)	0.06	0.040	0.05		2
Copper,Total(mg/L)	0.11	0.019	0.0451	0.0224	15
Iron,Diss.(mg/L)	0.09	0.07	0.08		2
Iron,Total(mg/L)	0.21	0.08	0.122	0.0359	15
Lead,Diss.(mg/L)	<0.1	<0.10	<0.10		2
Lead,Total(mg/L)	<0.1	<0.10	<0.10		15
Manganese,Diss.(mg/L)	0.01	<0.010	<0.010		2
Manganese,Total(mg/L)	0.01	<0.010	0.010		15
Molybdenum,Diss.(mg/L)	<0.01	<0.010	<0.01		2
Molybdenum,Total(mg/L)	<0.01	<0.010	<0.010		15
Nickel,Diss.(mg/L)	<0.05	<0.050	<0.05		2
Nickel,Total(mg/L)	<0.05	<0.050	<0.050		15
Zinc,Diss.(mg/L)	<0.01	<0.010	<0.01		2
Zinc,Total(mg/L)	0.02	<0.010	0.0107	0.0026	15

*geometric mean

Table 16. Comparison of Average Concentration and Provincial Water Quality Criterion for the Protection of Aquatic Life for Dissolved Metals at Pyrrhotite Creek below the Mine Site (0125901)

METAL	Average Concentration (mg/L)	Water Quality Criterion (mg/L)	Ratio
Copper	6.58	0.002	3300:1
Cadmium	0.004	0.00001	400:1
Aluminum	6.8	0.05	136:1
Manganese	1.11	0.05	22:1
Zinc	0.215	0.014	15:1
Chromium	0.01	0.002	5:1
Iron	1.09	0.3	4:1
Nickel	0.06	0.025	2:1
Cobalt	0.11	0.05	2:1

Table 17 a). Copper Loading Estimates (kg/month) for Pyrrhotite Creek, Murex Creek

	Pyrrhotite Creek below mine	Murex Creek upstream Tsolum
May 1986	1076	no data
June 1986	503	no data
July 1986	80	no data
August 1986	2.1	no data
September 1986	26	no data
October 1986	188	no data
November 1986	190	no data
December 1986	250	no data
January 1987	173	no data
February 1987	300	no data
March 1987	594	no data
April 1987	212	no data
May 1987	789	no data
June 1987	511	no data
July 1987	185	34
August 1987	40	3.3
September 1987	4.6	1.0
October 1987	3.1	0.5
November 1987	452	114
December 1987	132	66
January 1988	91	77
February 1988	79	56
March 1988	90	54
April 1988	393	113
May 1988	885	314
June 1988	513	288
July 1988	114	67
August 1988	42	3
September 1988	14.5	3

Table 17 a) (continued)

	Pyrrhotite Creek below mine	Murex Creek upstream Tsolum
October 1988	79	32
November 1988	no data	208
December 1988	no data	174
January 1989	105	64
February 1989	46	71
March 1989	13	41
April 1989	347	129
May 1989	835	171
June 1989	355	90
July 1989	129	51
August 1989	56	22
September 1989	14.7	3.2
October 1989	366	134
November 1989	199	120
December 1989	738	146
January 1990	91	102
February 1990	38	70
March 1990	34	115
April 1990	295	340
May 1990	434	263
June 1990	161	156
July 1990	57	no data

Table 17 b) Prediction of Copper Concentrations (mg/L) Using the Copper Loading Model

	Pyrrhotite Creek (Cu)	Murex: Pyrrhotite Ratio	Percent Copper Retention	Murex Creek (Cu)	Predicted Murex (Cu)	Error	Predicted* Tsolum ** (Cu)
Jul 1987	5.8	47:1	82%	0.021	0.022	+5%	0.015
Aug 1987	7.7	52:1	92%	0.013	0.012	-8%	0.010
Sep 1987	7.8	205:1	78%	0.010	0.008	-20%	0.007
Oct 1987	8.6	130:1	84%	0.011	0.011	0%	0.005
Nov 1987	12.3	210:1	75%	0.017	0.015	-12%	0.012
Dec 1987	10.3	473:1	50%	0.011	0.011	0%	0.006
Jan 1988	6.1	322:1	15%	0.015	0.016	+7%	0.008
Feb 1988	5.3	257:1	29%	0.014	0.015	+8%	0.009
Mar 1988	5.3	274:1	40%	0.012	0.012	0%	0.007
Apr 1988	5.7	110:1	71%	0.015	0.015	0%	0.010
May 1988	6.3	51:1	65%	0.045	0.043	-4%	0.032
Jun 1988	4.5	41:1	44%	0.063	0.061	-3%	0.045
Jul 1988	6.0	61:1	41%	0.042	0.058	+38%	0.031
Aug 1988	7.9	49:1	93%	0.011	0.011	0%	0.008
Sep 1988	6.5	73:1	79%	0.015	0.019	+27%	0.010
Oct 1988	6.3	81:1	60%	0.021	0.031	+49%	0.014
Nov 1988	no data						
Dec 1988	no data						

	Pyrrhotite Creek (Cu)	Murex: Pyrrhotite Ratio	Percent Copper Retention	Murex Creek (Cu)	Predicted Murex (Cu)	Error	Predicted* Tsolum ** (Cu)
Jan 1989	5.8	210:1	39%	0.017	0.017	0%	0.010
Feb 1989	5.0	632:1	-54%	0.012	0.011	-12%	0.008
Mar 1989	4.1	1337:1	-215%	0.012	0.010	-17%	0.006
Apr 1989	.8	95:1	63%	0.021	0.019	-10%	0.012
May 1989	5.9	18:1	80%	0.067	0.064	-3%	0.041
Jun 1989	4.1	21:1	75%	0.048	0.050	+4%	0.034
Jul 1989	5.6	93:1	60%	0.021	0.024	+14%	0.015
Aug 1989	5.3	79:1	60%	0.026	0.027	+4%	0.019
Sep 1989	5.1	79:1	78%	0.016	0.018	+13%	0.011
Oct 1989	6.5	83:1	63%	0.022	0.029	+32%	0.014
Nov 1989	7.3	136:1	40%	0.034	0.032	-6%	0.022
Dec 1989	5.1	55:1	80%	0.019	0.018	-5%	0.011
Jan 1990	4.0	280:1	-12%	0.016	0.016	0%	0.009
Feb 1990	4.0	485:1	-84%	0.015	0.015	0%	0.009
Mar 1990	3.2	610:1	-238%	0.017	0.018	+6%	0.011
Apr 1990	4.8	128:1	-15%	0.044	0.043	-3%	0.031
May 1990	4.5	61:1	39%	0.045	0.045	0%	0.032
Jun 1990	5.6	192:1	-3%	0.027	0.030	+11%	0.018

* prediction based on flows in Table 2 and a mean copper concentration of 0.002 mg/L in the Tsolum above Murex

** Tsolum River 500 d/s Murex

Table 18 a) ORGANIC COMPLEXING CAPACITY (mg/L)

SITE	91/04/30	91/08/21	91/11/05	91/12/11
TSOLUM UPSTREAM MUREX (E206513)	0.100	0.254	0.116	0.049
MUREX UPSTREAM PYRRHOTITE (E206686)	-	0.081		0.038

Table 18 b) Humic Acid Concentrations (mg/L)

	May 12, 1992	Aug. 19,1992	Oct. 22, 1992
Tsolum River 500 meters d\s Murex	1.8	1.1	3.4

Table 19. Rainbow Trout 96-h LC50 Bioassay Results (mg copper/L) Using Three Different Sources of Dilution Water

DILUTION WATER USED IN BIOASSAY	APRIL 30, 1991	AUGUST 21, 1991	NOV. 5, 1991	DEC. 11 1991
TSOLUM UPSTREAM MUREX (E206513)	0.296	0.329	>0.53	0.348
MUREX UPSTREAM PYRRHOTITE (E206686)	-	0.121	0.149	0.124
AQUATIC TOXICITY LAB WATER	0.076	-	0.100	0.101

Table 20. COPPER CONCENTRATIONS AND COHO SALMON MORTALITY FOR 1989 IN SITU BIOASSAY

SITE	MEAN COPPER (mg/L)	MAX COPPER (mg/L)	MIN COPPER (mg/L)	% MORTALITY in 21 DAYS
TSOLUM UPSTREAM MUREX (E206513)	<0.001	0.001	<0.001	0%
TSOLUM 500 METERS D/S MUREX (E207826)	0.061	0.110	0.04	100%
TSOLUM U/S HEADQUARTERS CREEK	0.038	0.05	0.03	80%
TSOLUM AT FARNHAM (0127620)	0.029	0.04	0.017	20%
MCKAY U/S PYRRHOTITE (E206685)	0.006	0.010	0.003	0%
MUREX U/S PYRRHOTITE (E206686)	0.006	0.007	0.004	0%

Table 21. Hepatic Biochemical Analyses of Steelhead Trout Livers and Exposure Conditions in 1990 In-Situ Bioassay (28 days)

SITE	MEAN COPPER (mg/L)	MAX. COPPER (mg/L)	MIN. COPPER (mg/L)	METALLO-THIONEIN COPPER	CYTOSOL COPPER/ TOTAL COPPER	% MORT-ALITY
TSOLUM AT FARNHAM (0127620)	0.022	0.050	0.007	43 ±17.2 nmol/g	0.82	50%
TSOLUM U/S PUNTLEDGE (0127621)	0.015	0.050	0.004	33.2 ±7.4 nmol/g	0.75	40%
TSOLUM UPSTREAM MUREX (E206513)	0.002	0.003	0.001	20 ±4 nmol/g	0.73	0%

Table 22. Hepatic Biochemical Analyses of Rainbow Trout Livers and Exposure Conditions in 1991 Laboratory Study

PERCENT OF 96-h LC50	MEAN TOTAL COPPER (mg/L)	METALLOTHIONEIN COPPER	CYTOSOL COPPER/ TOTAL COPPER	% MORTALITY(21 days)
0%	0.025	125.6 nmol/g	0.71	0%
15%	0.085	152.3 nmol/g	0.79	0%
30%	0.125	140.4 nmol/g	0.80	20%
45%	0.130	134.3 nmol/g	0.79	0%
60%	0.160	132.83 nmol/g	0.76	10%

Table 23. Tsolum River 500 meters downstream Murex Creek - Predicted organic binding of dissolved copper using the MINE1.2 model and a humic acid content of 1.8 mg/L

dissolved copper (mg/L)	percent bound organically	"free" copper (mg/L)
0.002	79.5	0.0004
0.004	76.7	0.0009
0.006	73.4	0.0016
0.007	71.6	0.0020
0.008	69.7	0.0024
0.010	65.7	0.0034
0.011	63.6	0.0040
0.015	55.3	0.0067
0.020	46.2	0.0108
0.025	39.2	0.0152