Report No. 033001/3

003166

ANVIL RANGE MINING COMPLEX -

INTEGRATED COMPREHENSIVE ABANDONMENT PLAN

Volume 1 of 3

Background

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Preface

This document contains an Integrated Comprehensive Abandonment Plan (ICAP) for the Anvil Range Mining Complex near Faro, Yukon Territory. This ICAP is a requirement by the water licences IN #89-001, Part D Section 8(a) (Faro minesite) and IN #89-002, Part G Section 4 (Vangorda Plateau minesite) issued by the Yukon Territory Water Board to Anvil Range Mining Corporation.

The Integrated Comprehensive Abandonment Plan presented in this document consists of three Volumes:

- Volume 1: Background
- Volume 2: Site Characterization
- Volume 3: Closure

Volume 1 provides background information relevant to the closure plan including:

Chapter 1. Anvil Range Mining Complex

Chapter 2. Closure Plan Philosophy

Chapter 3. Regional Setting

Volume 2 describes the physical and geochemical aspects of the two minesites including:

Chapter 4. Faro Mine - Site Characterization

Chapter 5. Vangorda Plateau Mine - Site Characterization

Chapter 6. Minesite Water Chemistry

Volume 3 discusses all issues related to minesite closure including:

Chapter 7. Faro Closure Plan

Chapter 8. Vangorda Plateau Closure Plan

Chapter 9. Post-Closure Water Management and Treatment

Chapter 10. Post-closure monitoring and Maintenance

Chapter 11. Schedule and Costing

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10. Post-closure Monitoring and Maintenance
11. Schedule and Costing

1. The Anvil Range Mining Complex

1.1 Location and Description

The Anvil Range Mining Complex, currently owned and operated by Anvil Range Mining Corporation, is located near the town of Faro, approximately 200 km NNE of Whitehorse, the capital of Yukon Territory. Figure 1-1 shows the general location of this mining operation, while Figure 1-2 and 1-3 show the location of mines, mill and tailings facilities. The operations are located in the vicinity of the headwaters of Rose Creek, a tributary of Anvil Creek, and in the mid reach of Vangorda Creek. Both Anvil Creek and Vangorda Creek are tributaries of the Pelly River.

The Anvil Range Mining Complex consists of the Faro mine site located approximately 15 km north of the Faro town site, and the Vangorda Plateau mine site located approximately 9 km northeast of the Faro town site (Fig. 1-3). The Faro mine site includes the Faro Pit and Dumps, mill facilities as well as a series of tailings impoundments (Fig. 4-1). The Faro Pit was mined out in August, 1992. An underground operation mined from a portal in the lower East Pit wall, was closed down at approximately the same time. The Vangorda Plateau mine site includes the Vangorda Pit Dumps and stockpiles, the Grum Pit Dumps and stockpiles as well as the mine office, dry shops, fuel lube facilities and water treatment facilities (Fig 5-1). Currently Grum Pit, and from time to time the Vangorda Pit, are being excavated and ore is being hauled on a haul road from the Vangorda Plateau to the Faro mine site for milling. Tailings are currently deposited in the mined out Faro Pit. The concentrate is then trucked to Skagway, Alaska, for shipment to overseas markets.

1.2 History of Development and Ownership

The Vangorda deposit, the initial mineral discovery in the Anvil Range, was first drilled by Prospector Airways, a predecessor of Kerr Addison Mines, between 1953 and 1955. However, the area was too remote and the deposit was considered to small to warrant production at that time. The Faro lead-zinc deposit, discovered in 1964, was first developed and brought into production by Anvil Mining Corporation in 1969, initially producing 5,000 tonnes of ore per day. The Anvil operation was amongst the major world producers of lead and zinc concentrates. In 1975 Anvil Mining Corporation was reorganised to form Cyprus Anvil Mining Corporation (CAMC). In 1979 CAMC purchased the Kerr Addison mineral deposits and claims including Grum, Vangorda and Swim. Cyprus Anvil discovered the Dy (now called "Grizzly") deposit in 1976. Until June of 1982 when CAMC terminated its mining and milling operations, all mining was confined to Zones 1 and 2 of the Faro open pit.

During the 18 years of mining CAMC and its predecessor mined approximately 35 million tonnes of ore, generated 10 million m^3 of tailings, and stripped 62 million m^3 of waste rock which was stored in the Faro waste dumps. Further waste stripping operations at the Faro Pit were carried out between June 1983 and October 1984, with about 7.4 million cubic metres of waste being removed.

Curragh Resources restarted the Faro mining and milling operation in June, 1986 focusing primarily on Zone 3 of the Faro open pit (with small amounts of mining of remnants of in Zone 1 at a rate of

approximately 13,500 tonnes of ore per day. Open pit mining was augmented by underground mining under the east wall of the Zone 1 and 3 pit, starting in 1989. From 1986 through 1992, Curragh mined an estimated 23.4 million tonnes of ore, generated 6 million m^3 of tailings, and stripped 30 million m^3 of waste rock in the Faro open pit which was stored in the waste dumps and the Vangorda haul road. Curragh also mined 1.8 million tonnes from an underground mine accessed through the Faro Pit. Curragh iniated development of the Grum and Vangorda ore deposits. By 1992, when Curragh Resources. went into receivership, the Vangorda open pit was nearly fully developed, and 5.7 million tonnes of ore had been mined and approximately 22 million tonnes of overburden rock had been stripped at the Grum location.

In November 1994 the property was bought by the current owner, Anvil Range Mining Corporation, and waste rock stripping in the Grum pit commenced in that month. Full processing of ore from Grum began in August 1995. Anvil has mined approximately 6 million tonnes of ore to date.

1.3 Background to the Closure Plan

An Integrated Comprehensive Abandonment Plan (ICAP) for the Faro site has been required by the Yukon Water Board as a condition of licence IN89-001 to ensure that all elements of the mining and milling complex are considered, and provided for, in a comprehensive closure plan, and to closure standards which they consider appropriate for 1996. The following design standards and/or environmental requirements for the Faro site stipulated in Amendment #3 of licence IN89-001, substantially change the viability of previous closure plans:

- the maximum credible earthquake (MCE) for tailings area structures;
- the probable maximum flood (PMF)for tailings area structures; and,
- CCREM water quality standards at some point in Rose Creek.

Similarly the Vangorda-Grum mine sites' water licence requires submission of a detailed abandonment plan. The above noted criteria have not been incorporated into the requirements for the Vangorda-Grum plan. The required dates of submission of these two plans were December 31, 1994, and July 15, 1994, respectively. Due to the shut-down of the Faro mine and mill complex from April 1993 - November 1994, it was not possible to submit these plans. Anvil Range Mining Corporation took over the Faro complex in November 1994 and after review of the situation proposed to prepare one comprehensive closure plan incorporating both the Faro and Vangorda-Grum sites. It proposed to submit this plan in November 1996. Anvil made application to the Yukon Territory Water Board in June 1995 to modify both its water licences to incorporate that deadline. A public hearing to discuss that application was held by YTWB on November 20, 1996.

1.4 Key Closure and Environmental Reports

A considerable amount of information related to the Anvil Range Mining Complex has been generated as a result of studies and reports completed from 1973 onwards. Over twenty related reports have been reviewed during the preparation of this Final Closure Plan (see reference section). Many of the ideas and data discussed in this Conceptual Closure Plan were originally presented in one of the following ten reports:

Faro Mine Tailings Abandonment Plan, by Klohn Leonoff Ltd., September, 1981.

Faro Mine Abandonment Plan, Curragh Resources Inc., April, 1988.

Other Facilities Abandonment Plan, Curragh Resources Inc., June, 1989.

Vangorda Plateau Development - Water License Application, by Curragh Resources Inc., December, 1989 (SRK No. 60609).

Down Valley Tailings Impoundment Decommissioning Plan, by Steffen, Robertson and Kirsten, April, 1991 (SRK No. 60635).

Water Recycle and Tailings Deposition Plan, Kilborn Inc., June, 1991.

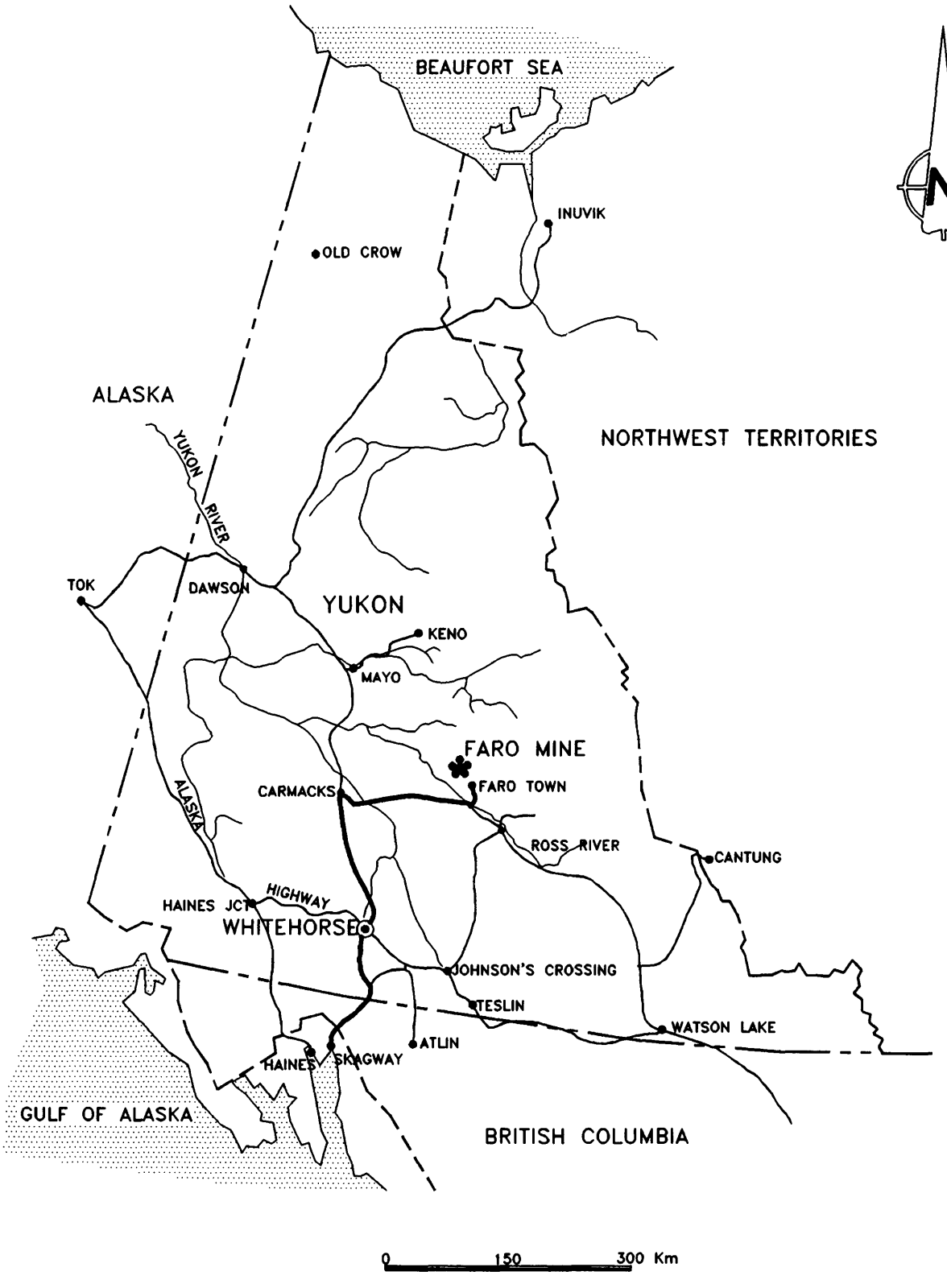
Faro Decommissioning Overview of the Environmental Plans, Curragh Resources Inc., Dec. 1991

Summary Report on Schedule D to Water License #IN89-001, Faro Mine, Yukon, by Steffen, Robertson and Kirsten, August, 1992 (SRK No. 60648).

Construction Report Vangorda Rehabilitation PWGSC Project 760831, Vangorda Plateau, *Faro Mine, Yukon Territory*, Steffen, Robertson and Kirsten, Nov., 1994.

Proposed Modifications to the Grum Waste Rock Dump, Anvil Range Mining Corporation, Feb., 1996.

FIGURES



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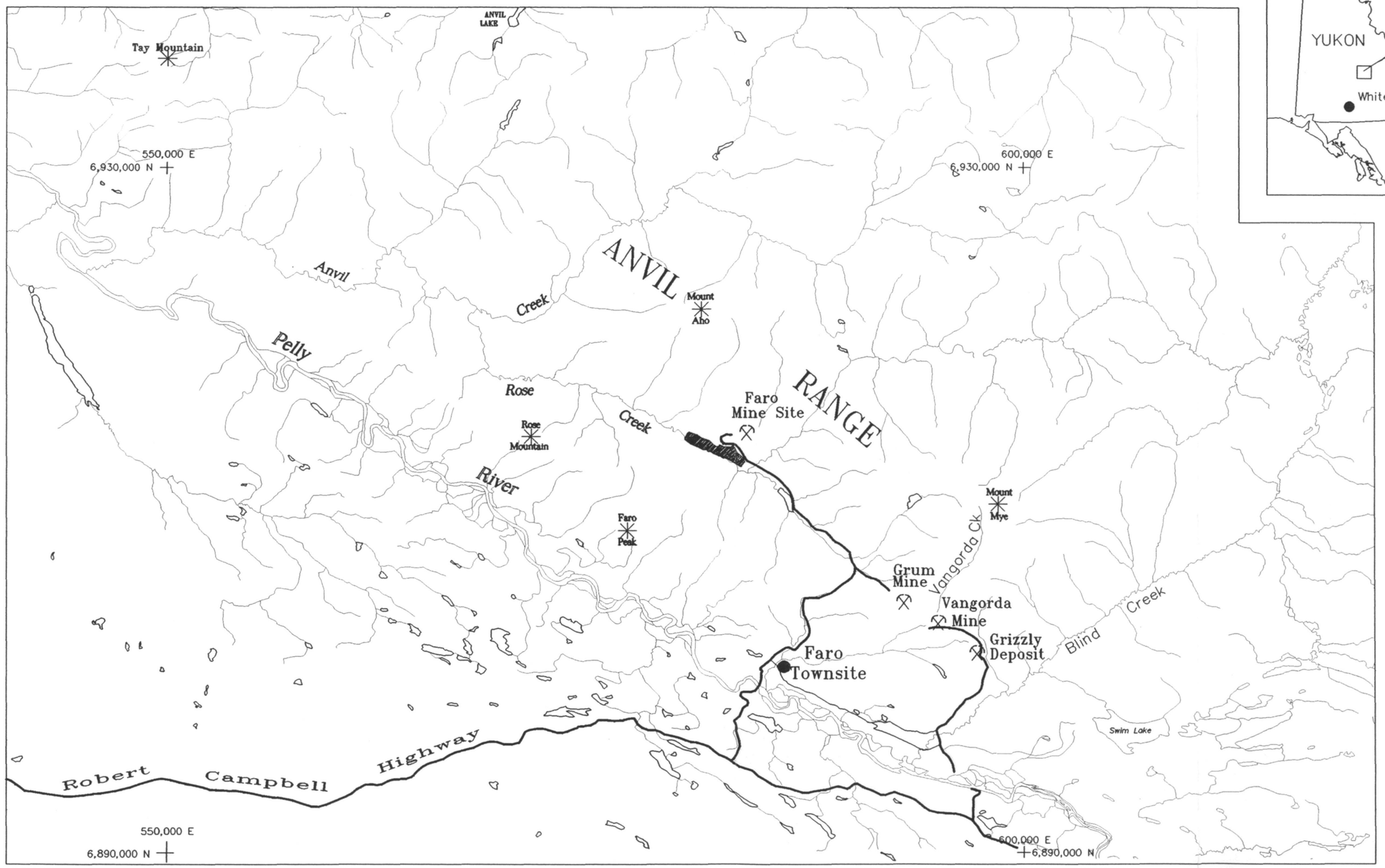
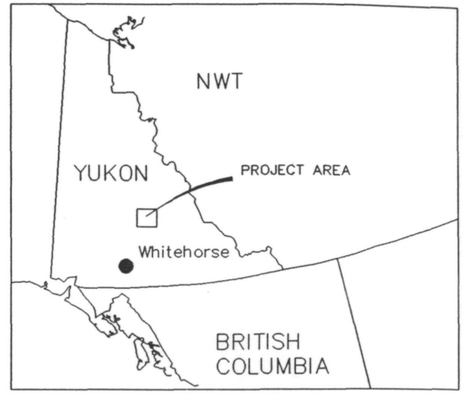
Anvil Complex Closure Plan

Yukon Territory

PROJECT NO.	DATE	APPROVED	FIGURE
033001	Sept. 1996		1-1

FARO\completed\1-1 Yukon-Plot Wed Sep 18 10:51:53 1996





Legend

- Streams
- Roads
- Tailings
- Mountain Peaks
- Minesite
- Lakes

Note: True North 1° 33' W of Grid North
Magnetic North 30' East
Magnetic Declination decreasing annually 4.1'

Notes: Map derived from 1:250,000 scale
NTS Mapsheet 105 K
North American Datum 1927
Transverse Mercator Projection

0 2500 5000 7500 10,000 12,500 METRES
SCALE: 1: 250 000

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Anvil Complex Closure Plan

REGIONAL OVERVIEW

PROJECT NO.	DATE	APPROVED	FIGURE
033001	Nov. 1996		1-2

Faro Mine

HAUL ROAD

Rose Creek

FRESH WATER RESERVOIR

Faro Tailings

Grum Mine

Grum Dump

GRUM CREEK

Vangorda Creek

Vangorda Mine

Vangorda Dump

Grizzly Deposit

Blind Creek

Faro Peak

TINTINA TRENCH

PELLY R

Faro Town

Airfield

PELLY RIVER

Buttle Creek

0 1000 2000 3000 4000 5000 6000 meters

Scale 1:75 000

Contour Interval 500 metres

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Anvil Complex Closure Plan

Mine Vicinity Map

PROJECT NO.	DATE	APPROVED	FIGURE
033001	Sept. 1996		1-3

2. Closure Plan Philosophy

2.1 Philosophy and Approach

In the mid to late 1960's, when the Faro lead-zinc deposit was first identified, the general public had little involvement with, or appreciation of, the mining industry. The technological advances of the time focused on improving production, reducing costs, and improving worker safety. Recognition of the potential environmental impact of mining operations was only beginning to develop.

Since the early 1970's, the first years of mining at Faro, there have been significant advances made by the industry in the integration of environmental management practices into mining operations. In terms of environmental impact, the major area of concern is the oxidation and leaching of metals releasing contaminants into receiving waters. In the past decade, there have been remarkable advances in the technology both to predict and control these reactions, and the resultant potential adverse impacts on water quality. The Faro mine, under the operation of Curragh Resources, participated in some of the early research on acid mine drainage prediction and control for both waste rock and tailings.

For the mining industry, much of the applied technology has only been available in the past 15 years or less - mines in production before this time were not generally designed or operated with this awareness of environmental management. The Anvil Range complex is one such site, where mining began in the late 1960's and has continued, with two periods of temporary cessation, to this day. Thus, approaching closure, these sites must assess the environmental impact and develop plans for closure that address not only current, but past, operational practices. Clearly the funds available for closure are not unlimited; the assessment of environmental impact and closure requirements must look at the components of the site and the site as a whole (an "integrated" or comprehensive plan) and must select measures and allocate resources to address the major issues of environmental impact.

All countries are increasing their environmental protection requirements and adopting more stringent standards. Globally, there is a trend towards "Designing for Closure" with environmental protection and closure measures being designed into existing mine operations, and being mandatory for opening new mines. Closure plans have been developed for various aspects of the Anvil Range Mining Complex under different operators. This plan represents the first, comprehensive closure plan for the Faro, Vangorda and Grum mines. Under Anvil Range, progressive reclamation is part of the Vangorda Plateau mine operations and will increasingly be so, once this comprehensive closure plan is accepted for the three mining areas of the complex.

The Ontario Ministry of Northern Development and Mines has produced a guideline for the "Rehabilitation of Mines - Guidelines for Proponents" (October 1994) which discusses some of the philosophy and technology for closure planning. The general principles of closure planning which are used throughout the international mining industry are summarized below, and are also discussed in the above reference.

As a mining company or regulatory authority considers the "acceptable" closure of a mine, there are some hard facts that must be faced; there are some mines from which we can never "walk away" - to achieve an acceptable environmental impact from the closed out mine, there may be a requirement for long term care or maintenance. Clearly this is the least desirable state of closure, and one which would only be faced at an older operation which was not designed for closure and is facing problems such as acid mine drainage or unstable major structures requiring continued maintenance. The Anvil Range Mining Complex, with the longer term potential for oxidation and acid rock drainage is a site that will require long term care - either active care in terms of treatment or passive care in which at least periodic treatment, monitoring and maintenance is required. These terms are described more fully in the Ontario Guidelines.

In planning for closure, there are three key aspects that must be considered in determining if the site requires active care, passive care or is potentially a "walk-away" solution:

- protection of public health and safety;
- alleviate or eliminate environmental damage; and,
- allow a productive use of the land in its original condition or an acceptable alternative.

These are often broadly discussed as the "impact" or environmental impact of a site or a closure plan. For each of the considerations of impact there are three technical aspects that must be considered:

Physical Stability: buildings, structures, workings must be stable and "must not move". In the Ontario Guidelines the description is provided, "Physical structures such as crown pillars, pit slopes, underground openings, tailings dams and spillways must be stable to eliminate any hazard to public health and safety... " to which could be added ...or the terrestrial or aquatic receiving environment.

(Geo)chemical Stability: metals and "other" contaminants must be stable, that is, must not leach and/or migrate into the receiving environment, or, as described in the Ontario Guidelines for Closure, "Surface waters and groundwater must be protected against adverse environmental impacts resulting from mining and processing activities."

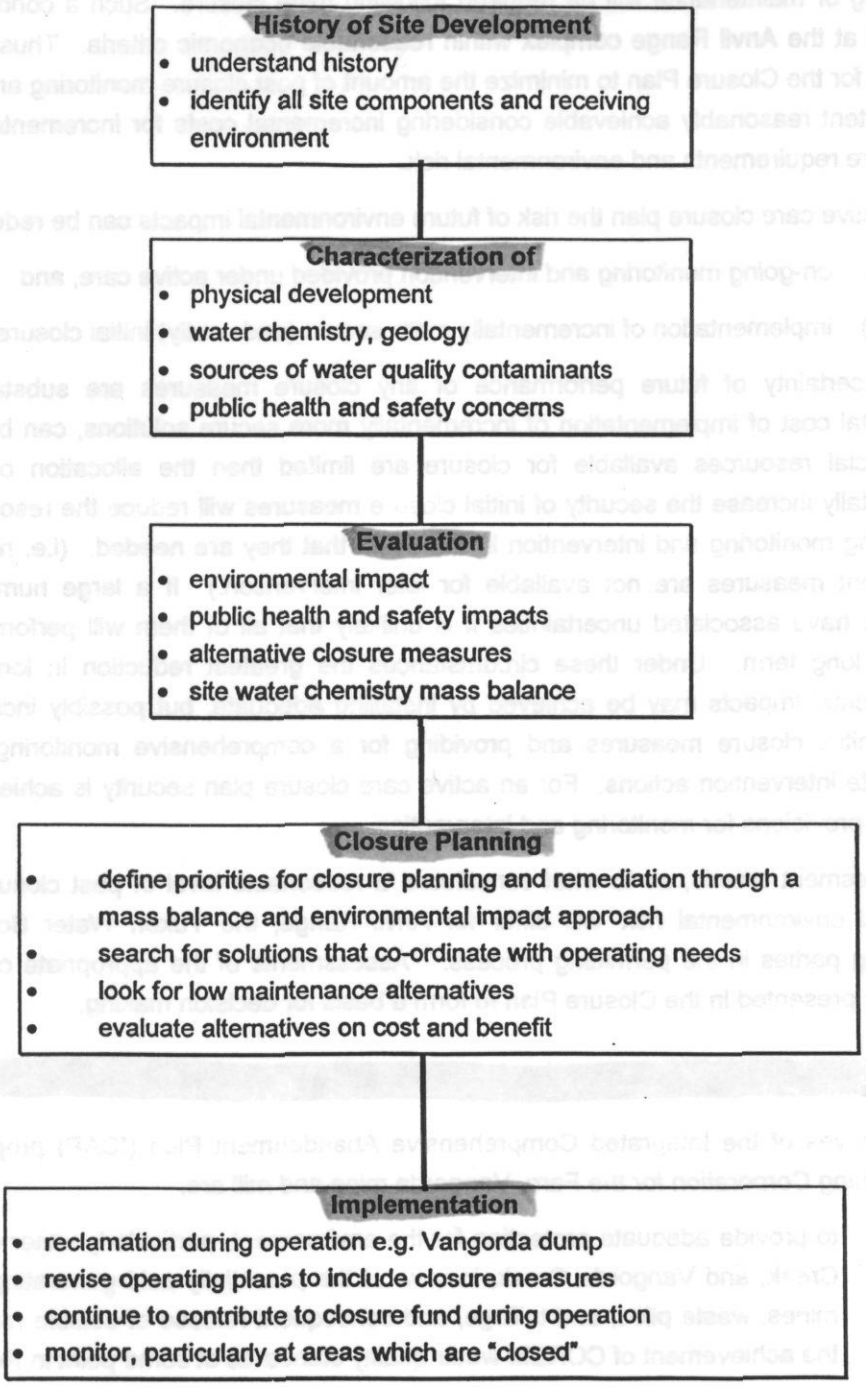
Land-use "In a closed out condition the rehabilitated site should be compatible with the surrounding lands." (Ont. Guidelines).

Thus the major topics that would be addressed in any closure plan would include:

- naturally occurring physical hazards;
- level of environmental impact or benefit and the associated costs;
- expected post-operational use of the mine site and the compatibility with the land surrounding the site;

- traditional and current use of the land;
- conditions prior to mining.

To address these topics and technical areas in a logical manner for each site component, the following flowsheet was developed for the preparation of this Closure Plan:Closure Plan:



2.2 Plan

2.2.1 Considerations in Objectives Selection

It is an objective of all closure plans to achieve 'walk away' conditions such that no long term monitoring or maintenance will be required following mine closure. Such a condition cannot be achieved at the Anvil Range complex within reasonable economic criteria. Thus it becomes an objective for the Closure Plan to minimize the amount of post closure monitoring and maintenance to the extent reasonably achievable considering incremental costs for incremental reductions in active care requirements and environmental risk.

For an active care closure plan the risk of future environmental impacts can be reduced by:

i) on-going monitoring and intervention provided under active care, and

ii) implementation of incrementally more secure (and costly) initial closure measures.

If the uncertainty of future performance of any closure measures are substantial then the incremental cost of implementation of incrementally more secure solutions, can be very high. If the financial resources available for closure are limited then the allocation of resources to incrementally increase the security of initial closure measures will reduce the resources available for ongoing monitoring and intervention in the event that they are needed. (i.e. resources spent on up front measures are not available for later intervention.) If a large number of closure measures have associated uncertainties it is unlikely that all of them will perform inadequately over the long term. Under these circumstances the greatest reduction in long term risk of environmental impacts may be achieved by installing adequate, but possibly incrementally less secure, initial closure measures and providing for a comprehensive monitoring program and appropriate intervention actions. For an active care closure plan security is achieved by making adequate provisions for monitoring and intervention.

The assessment criteria, as to what constitutes 'a reasonable level of post closure active care, costs and environmental risk' will differ for Anvil Range, the Yukon Water Board and other intervening parties in the permitting process. Assessments of the appropriate criteria must be made and presented in the Closure Plan to form a basis for decision making.

2.2.2 General Objectives of the Integrated Comprehensive Abandonment Plan

The objectives of the Integrated Comprehensive Abandonment Plan (ICAP) proposed by Anvil Range Mining Corporation for the Faro, Vangorda mine and mill are;

- to provide adequate protection for the environment, particularly water quality in Rose Creek, and Vangorda Creek, in view of the potentially acid generating nature of the mines, waste piles, and tailings, and consequent release of soluble metals; including the achievement of CCREM water quality standards at some point in Rose Creek;
- to ensure the satisfactory design and long-term stability of structures to minimize the potential for failures, and provide for the long-term maintenance of these structures

with designs to provide for the maximum credible earthquake (MCE) and probable maximum flood (PMF) where appropriate ;

- to implement a plan that remains within the financial resources available to Anvil Range Mining Corporation, both during on-going mining operations, and after cessation of mining;
- to propose a plan which is consistent with the objectives of Yukon Waters Act, namely to ensure the use of water in a way which provides the optimum benefit to Canadians, and Yukon residents in particular;
- to provide for exploitation of the natural resource to its fullest and preserve infrastructure while exploration for additional resources is incomplete;
- to implement a plan that is internally consistent and employs resources in complimentary fashion, for example, one treatment is selected at one place consider the limitations on other feasible option selections elsewhere.
- to implement a plan which employs the most current technology, and site specific information, while continuing to participate in investigation and research, and to include the application of the most efficient and cost effective technology of closure, in future re-evaluations and designs to address remaining areas of uncertainty or risk.
- to propose a plan in which uncertainties of initial closure measure performance are provided for with adequate monitoring and maintenance measures to achieve these objectives over the long term.

2.2.3 Some Specific Objectives of the ICAP

A number of specific long term closure issues are of particular concern for the ICAP and have substantially influenced the alternatives option selection in the development of the proposed closure measures. These are:

1. The location of the tailings placed in Rose Creek valley in the Down Valley tailings scheme. These tailings have a high acid generating potential and are vulnerable to the erosive forces of Rose Creek. Specific objectives for the physical and chemical stabilization of these tailings are:
   i) To the maximum extent achievable, remove the tailings from the active erosion environment of Rose Creek valley to minimize the potential for erosion over the long term.
   ii) Tailings remaining in the valley should be securely protected from erosion. This requires the secure stabilization of Rose Creek across or adjacent to the tailings. For long term stabilization of Rose Creek it is desirable that the flow channel be non-erosive or installed in bedrock.
   iii) Any dams remaining in Rose Creek valley should be constructed with minimum heights and downstream slopes that will achieve long term stability.

iv) The potential for acid generation of any tailings remaining in Rose Creek valley should be eliminated by achieving a secure stable long term water cover to prevent any significant rates of oxidation. With such acid generating source control the need for contaminant migration control or collection and treatment is eliminated.

1. The size and location of the Faro mine rock piles are such that they can not be placed back in the open pit which is partly occupied by the tailings. Much of the mine rock is acid generating and there is no known technology by which to economically achieve acid generation source control for such large rock piles in-situ. The area is poor in low permeability cover materials and the installation of impermeable covers which would be sufficient, of themselves, to control contaminant migration is not economically achievable The control of contaminant migration from the rock piles is therefore dependent on the implementation of collection and treatment systems. Long term environmental protection requires active care. Specific objectives relating to the ICAP in this respect are:

   ii) To the extent economically justifiable, to minimize the ongoing cost of active care.

   iii) To the extent economically justifiable to minimize the risk of contaminant releases during active care.

   iv) To implement a monitoring, collection and treatment system that is flexible and which provides for response to monitoring observations which indicate that additional or alternative collection measures are required.

   v) To provide secure facilities for contaminated water storage with adequate capacity for extreme events and operating uncertainties, with minimal potential for seepage releases.

   vi) To provide secure long term storage for treatment sludges.

1. Since active care is a requirement for the ICAP, optimization of the closure plan should take advantage of the ongoing resources and flexibility for the long term protection of the environment.
2. The closure requirements of the Vangorda Plateau mines and rock piles has only marginal influence on the considerations for the closure issues and impacts of the Faro mine complex. Thus there is little change in the considerations applicable to the Vangorda Plateau complex from those applicable when the closure measures for this complex was permitted by the Yukon Water Board in 1989/90 together with the subsequent modifications. The closure measures for the Vangorda Complex should therefore rely substantially on previously proposed closure measures and evaluations with account being taken of changes and the long term presence of active care required by the ICAP.

2.2.4 Global Objective of ICAP

The ICAP represents the first integrated closure plan for the Anvil Range mining complex. A number of radically different options have been considered and evaluated during the selection process for the proposed closure plan. All options and approaches have associated benefits and

disadvantages. Indeed, there is no 'ideal closure plan' but alternative sets of compromises, though all may ultimately be protective of the environment. It is a global objective of this ICAP to present the issues, options, and an evaluation of the effectiveness, risks and costs associated with each option and a preferred overall plan, which may form the basis for a 'Current Closure Plan and Financial Assurance'. Since many of the options have, or will be, rejected in the evaluation and selection process for the preferred option, it is not economically justifiable to complete investigations, designs and evaluations for all possibilities to high levels of certainty Additional investigation and evaluation work will be required to finalize some of the final closure plan details and to increase the confidence levels of some of the evaluations. It is an objective of this ICAP to define the additional investigations, designs and assessments required to complete the final closure plane for the various options selected.

3. Regional Setting

It is important that any closure measures be consistent with the region and its land uses. This chapter gives an overview of the physical, geochemical and biological characteristivs of tthe study region. An evaluation of the natural resiources of the study region are important in order to select the important issues for closure and to help with the selection of appropriate standards that should be aimed for at closure.

3.1 Location and General Property Description

The physiography of the region is dominated by the northwest trending Tintina Valley (Figure 3-1), a structural valley (trench) occupied, at the latitude of the Anvil Range, by the northwest flowing Pelly River. Rose Mountain (el. 1985 m a.s.l.) is the highest point of the Rose Mountains, a ridge of resistant basalt, parallel to and immediately northeast of the Tintina Valley. The Anvil Range is a northwest elongate, alpine mountain complex northeast of the Tintina Valley. Mt. Mye (el. 2061 m a.s.l.) is the local summit of the Anvil Range in the area of the ore deposits. The ore deposits occur in recessive strata between the southwest flank of the granitic highlands of Mt Mye and the Rose Mountains.

The area immediately southwest of the summit of Mt. Mye is a shelf or tableland at an intermediate elevation between the granitic highlands and the Tintina Valley. This area is locally referred to as the Vangorda Plateau. The Grum, Vangorda and Grizzly deposits occur on the Vangorda Plateau; intensive surface mining development is currently limited to the northwest part of the plateau at Grum and Vangorda; elsewhere exploration activities have been carried out but have not progressed beyond locally intensive drilling and road building. The topography of the Vangorda Plateau is gently rolling and moderately incised by several southwest flowing streams of which Vangorda Creek is the most significant. Bedrock outcrop is poor on the Vangorda Plateau but much of the plateau is underlain by shallow bedrock covered by a thin veneer of colluvium and soil. Forest cover is nearly complete on the plateau. Portions of the plateau are underlain by glacial till and glacio-fluvial deposits, which in the vicinity of the Grum and Vangorda pits are many tens of meters thick.

To the northwest of the Vangorda Plateau is a narrow valley occupied by northwest flowing Rose Creek. The Faro mine, mill, tailings pond and water supply reservoir are all in this valley, two major access roads connect the Faro and Vangorda plateau areas and run down the axis of the valley. Development to the northwest of the Faro complex is minimal. Outcrop on the ridges on either side of this valley is good but the flanks of the valley show only sporadic outcrop and an extensive mantle of colluvium and soil with local patches of thin glacial till. The valley bottom is underlain by thicker deposits of glacial till and glacio-fluvial deposits. These deposits are significant as a local groundwater flow path and are discussed in more detail in section 4.3.5. Much of this valley is forested but adjacent the ridges above 4000 ft are alpine tundra.

To the southeast of the Vangorda Plateau is a broad lowland occupied by several lakes, the largest of which is Swim Lake. This area is referred to locally as the Swim Basin, a structural

basin though not a proper topographic basin. Several mineral deposits occur in the Swim Basin, but only the Swim deposit is lead-zinc-silver bearing; there is no significant mining development in the basin. The Swim Basin is heavily blanketed by thick glacial till and gravel deposits; outcrop is very limited in this area and occurs mainly on the ridge southwest of the Swim deposit and on the hill in the center of the basin. Blind Creek forms the boundary between the Vangorda Plateau and the Swim Basin.

3.2 Geology

The geology of the Anvil Range and it's ore deposits has been described at length in several previous reports both with a geological and with an environmental focus. These include Tempelman-Kluit (1972), Gordey (1983), Gordey and Irwin (1987) and Jennings and Jilson (1986) all of which describe the district as a whole from a regional geologic and ore deposit geology perspective. Discussion of specific areas from an environmental perspective is included in: Curragh Resources (1987) and Steffan Robertson and Kirsten (1990) both for the Faro site and Curragh Resources Inc. (1989) for the Vangorda Plateau site.

The following sections review the geology of the area, its ore deposits and attempts to tie the geology of the several areas together into a integrated whole appropriate for this plan. This section provides the basis for the rock sampling program and for the interpretation of rock characterization test work results presented in chapter 4. The discussion of the structural setting is also of significance in understanding the hydrogeological setting discussed in section 3.8.

3.2.1 Regional Geology

The Anvil District is underlain by Paleozoic meta-sedimentary and lesser meta-volcanic strata. A major northwest trending Cretaceous granitic body, the Anvil Batholith, is the central feature of the district and forms the core of the Anvil Arch (Figure 3-2). The metamorphic rocks dip northeast and southwest away from the Batholith. On the south flank of Anvil Arch five stratiform Pb-Zn-Ag bearing massive sulphide ore bodies occur in Cambrian phyllites or schists of the metamorphic sequence.

STRATIGRAPHY

The stratigraphic sequence of Anvil District ranges in age from latest Precambrian to Permian. The lower part of the sequence (Silurian and/or earlier) is most important with respect to the ore. The lower part of the stratigraphy is divisible into three major mappable units (Figure 3-3). From the base these are non-calcareous meta-pelite of the Mt. Mye formation, calcareous meta-pelite of the Vangorda formation, and meta-basalt of the Menzie Creek formation (Jennings and Jilson, 1986). All formational names in this sequence are informal. The aggregate thickness for this pre-Silurian sequence is approximately 5,000 m.

The Paleozoic strata that overlie the above sequence are characterized by shale, chert, coarse clastics rich in chert fragments, minor limestone, and an uppermost basalt unit. Strata of the

Devonian-Mississippian Earn Group (Gordey, et al., 1982) and Pennsylvanian-Permian Anvil Range Group (Tempelman-Kluit, 1972) are present. All or part of this upper sequence may be allochthonous with respect to the underlying units. The boundary between allochthonous and parautochthonous strata is inferred to be at the base of the Anvil Range group where red cherts first become prominent in the section although a discreet fault has not been identified there. The Earn Group locally contains stratiform barite deposits.

The Menzie Creek and younger rocks are not related to the ore deposits in the district and consequently are not discussed further (details can be found in Tempelman-Kluit, 1972 and Jennings and Jilson, 1986). The oldest two units are considered in more detail below as only these formations are significant near the ore deposits and on the mine sites.

Mt. Mye formation consists dominantly of non-calcareous, biotite-muscovite +/- andalusite +/- staurolite +/-garnet schist in areas of amphibolite facies metamorphism (units 1C, 1D, 1CD). The dominant rock type is non-calcareous, weakly carbonaceous, light to medium grey muscovite-chlorite phyllite in areas of greeenschist facies metamorphism (unit 3G). It contains lesser, interlayered black carbonaceous phyllite or schist (unit 3E), calcite marble (unit 3F), calc-silicate phyllite or schist (unit 3D), greenstone or amphibolite (unit 3C), and psammitic schist (included in unit 1C). The formation has a structural thickness of at least 2,000 m.; the base is not exposed. The reddish brown weathering colour of the schists and phyllites of the formation is characteristic and helps distinguish it from non-calcareous portions of the overlying Vangorda formation.

Dark grey to black carbonaceous phyllite or schist members comprise about 10 percent of the formation. They are more abundant in the upper 400m of the formation. A distinctive assemblage of carbonaceous siliceous phyllite and black carbonaceous limestone appears to underlie, or be laterally equivalent to the lowest sulphide horizons.

Coarse-grained, white, calcite marble and calc-silicate also constitute about 10 percent of the Mt. Mye formation. The marble is light grey, medium crystalline, calcite marble with boudins of pelite, amphibolite and calc-silicate. Marble bodies may be up to 75m thick, but are generally only a few tens of meters thick. They can be traced laterally for several kilometers. The calc-silicate lithology is a thinly interbanded sequence of purplish brown biotite pelite and pale green actinoite - epidote calc-silicates. Typically, the calc-silicates are spatially associated with the marbles. The calc-silicates are identical to Vangorda formation calc-silicates, but a protolith for the associated clean marbles is not common in the Vangorda formation. The most persistent horizon of lenticular marble and calc-silicate bodies occurs about 500 to 700m below the top of the Mt. Mye formation. The marble plus calc-silicate assemblage appears to underlie the carbonaceous phyllite plus black limestone assemblage noted above.

Mafic meta-igneous bodies in the Mt. Mye formation are generally only a few meters thick and have lateral extents of well under 1 km.. Volumetrically they constitute less than one percent of the Mt. Mye formation. They are generally strongly foliated, dark green amphibolites lacking relict igneous texture. Compositions are similar to basalts of the Menzie Creek formation (Jennings and Jilson, 1986). They are interpreted as subvolcanic feeder dykes and sills of the Menzie Creek basalts.

The upper portion of the Mt. Mye formation is very similar to the Gull Lake formation, described by Gordey (1983), to the east near Howard's Pass, and unit 8A of Blusson (1966). Correlation with these units would imply the top of the formation is lower Cambrian, or possibly middle Cambrian. Jennings and Jilson (1986) suggested that the persistent marble and calc-silicate package in the Mt. Mye formation may correlate with the widespread early Cambrian limestone conglomerate of Selwyn Basin. Parts of the Mt. Mye formation also resemble rocks underlying those presumed correlative units, implying that Mt. Mye may include rocks as old as Hadrynian.

The phyllites and schists comprising the bulk of the Mt. Mye formation have the composition of an average shale (Jennings and Jilson, 1986). Sulphide minerals, typically pyrite and lesser pyrrhotite, occur in the rocks as coarse, isolated, equant blebs, consisting of one or a few crystals. The blebs lie along the foliation. Typically the unit contains only 1 to a few percent iron sulphide (total sulphur in 163 typical samples averages 0.25 % and ranges from 0% to 4.8 %). There are few carbonate minerals in these rocks. Based on regional surface geological mapping, exposures are slightly rusty brown coloured but not gossanous. These features suggest that the Mt. Mye formation schists and phyllites may be weakly acid generating but rapid and intense acid generation will not be significant on weathering.

The **Vangorda formation** is characterized by light to medium grey to greenish grey, calcareous, phyllitic rocks made up of very thin (0.1-2cm) interlayers of medium grey, non-calcareous, weakly carbonaceous, muscovite-chlorite pelite and light grey, generally calcareous quartz-calcite +/- dolomite siltstone (unit 5B). At the higher metamorphic grade of amphibolite facies, the Vangorda formation calcareous phyllites are transformed to a thinly banded, pervasively foliated, green, cream, and purplish brown, calc-silicate (unit 3D). Major interbanded units include mafic meta-igneous rocks, e.g. greenstone, (unit 5C) and carbonaceous pelite (unit 5A). Minor phyllitic limestone (unit 5G) occurs locally. The Vangorda formation varies between 0.5 and 2 km. in apparent thickness. The formation becomes more calcareous up section. The light grey to tan coloured, drusy weathering of the formation is characteristic both within the district and elsewhere.

The greenstone bodies range from 1m to 100m in thickness and are up to several kilometres in length. They comprise approximately 15 percent of the Vangorda formation and are more prevalent near the top of the formation. Whole rock analyses show that the greenstones are compositionally similar to the overlying Menzie Creek basalts (Jennings and Jilson, 1986). Locally, the greenstones contain coarsely crystalline serpentinized pyroxenite subunits, which may be pyroxene cumulates. Most greenstone bodies have medium-grained, equigranular centers with strongly foliated margins. Although marginal contacts of the bodies are superficially conformable, detailed inspection indicates the units are locally slightly crosscutting. The greenstones are thus interpreted as subvolcanic dykes and sills feeders to the Menzie Creek formation. Where the mafic units are thin, the entire body may be a foliated chloritic phyllite (unit 5D), commonly calcareous, with thin white bands of quartz and calcite. Some of these chloritic phyllites contain relict pyroxenes or feldspars, and develop a fine augen texture, while others have flat, ovoid, dark chloritic spots on the foliation after vesicles or pyroxenes. In places, particularly near the ore deposits, the phyllitic mafic rocks have been metasomatised to a tan weathering, white, quartz - muscovite - ferroan ankerite rock (unit 5D4*) containing minor amounts of a bright green mineral thought to be a nickel rich clay or serpentine mineral but resembling mariposite.

Typically, the Vangorda formation adjacent to the greenstones is a thinly banded, hard, pale green, calcareous, chloritic phyllite (unit 5F). This lithology had been interpreted as a marginal tuff adjacent to basaltic flows (as noted in Jennings and Jilson, 1986). More extensive drill core inspection and additional outcrop exposure examination indicate that, rather than a tuff, this rock type represents a slight contact metamorphic aureole caused by intrusion of the greenstone bodies; further evidence that the greenstones are intrusive. Where the mafic bodies are thin, these altered phyllites can be difficult to distinguish from the sill, and if the alteration is intense, the contact with the mafic rock may not be noticeable at all, even in drill core.

The greenstones are resistant and dominate outcrop in the district. Since the greenish chlorite altered phyllites are always near the greenstones, outcrop examination gives a misleading impression of the chlorite content of Vangorda formation phyllites, compared to drill core examination. The overwhelming bulk of the formation is grey to greenish-grey, but that lithology does not crop out well. This green coloration has led previous workers to suggest that the Vangorda formation is tuffaceous (Tempelman-Kluit, 1972), but there is little evidence of this.

Black, slightly calcareous to dolomitic, carbonaceous pelite members occur throughout the Vangorda formation. Dimensions and lateral continuity of these members are poorly known. The thickest and most extensive of these occurs at the base of the formation (unit 5A); it ranges from only a few tens of meters to 100m in thickness. This basal member becomes thicker in the immediate vicinity of the ore deposits, siliceous and contains minor pyrite where it appears to be laterally equivalent to black, sulphide-bearing, ribbon-banded, carbonaceous, quartzite ores within some of the mineral deposits. Southwest of the Grum and Vangorda deposits the basal member is very siliceous and slightly pyritic, enhancing the impression of equivalence to the carbonaceous quartzite ores.

The Vangorda formation is lithologically very similar to, though more argillaceous than, the Rabbitkettle Formation seen to the east (Gordey, 1978; Gabrielse et al., 1973). Based on this correlation, the Vangorda formation may range in age from middle or late Cambrian through early Ordovician.

The phyllites that comprise the bulk of the Vangorda formation are almost always calcite bearing, commonly containing 10% to 30% calcite. Sulphide minerals occurring in the phyllites are minor (1 to 2 %) and consist of pyrite with lesser pyrrhotite (no total sulphur data available, but probably a similar range and average as the Mt. Mye shales). The sulphides typically occur as relatively coarse porphyroblasts showing the typical cubic form of pyrite and in the range of 0.5 cm on an edge. These porphyroblasts consist of a few distinct grains of crystalline pyrite. With greater depth in the stratigraphic/structural sequence the pyrite is gradually replaced by pyrrhotite, initially as rims, and the cubic form of the porphyroblast becomes less distinct. Surface geological mapping shows that outcrops are nearly always covered by drusy secondary carbonate minerals and there is no evidence of acid generation upon weathering, indeed, geologic evidence alone suggests that the bulk of the meta-sedimentary rocks of the Vangorda formation will be acid consuming. The only rock of the formation that appears to represent an acid generation concern is the carbonaceous phyllite which has a few percent pyrite and does not always have minerals which would provide neutralization potential. Mafic rocks of the formation contain very minor to negligible

pyrite and commonly contain calcite thus will not likely pose an acid generation concern based on geologic observation alone. Section 4.1.2 discusses these matters in more detail and provides specific test results for the major rock types

FOLD DEFORMATION

The structural and metamorphic history of the Anvil District is complex and of considerable significance to present form and nature of the ore deposits since all of the deposits have experienced the full deformation history. Five phases of fold deformation have been recognized in the district. The first two are periods of intense fold deformation and concurrent metamorphism which determined the gross structure of the mineral deposits. The remaining deformations are only locally developed, but can be important on a mining scale.

The first deformation (D_1) produced a regional metamorphic foliation (S_1) axial planar to tight to isoclinal mesoscopic folds (F_1) in bedding (S_0). Mesoscopic D_1 early folds are rarely preserved in the district. D_1 folds that have been observed are northeasterly inclined to upright, northeasterly verging (shaped like a "Z" in cross-section looking northwest) structures with shallow northwesterly or southeasterly plunging axes.

During the second deformation event (D_2), S_1 was strongly crenulated and ubiquitous close to tight mesoscopic folds (F_2) in S_1 were produced. Primary bedding (S_0) and S_1 had been transposed into near parallelism with the S_2 foliation. Parallel to the axial planes of the D_2 folds is a crenulation cleavage (S_2), which imparts a well developed lithon structure to most rocks of the district, especially the strongly banded phyllites of the Vangorda formation. F_2 axial planes and S_2 axial plane foliations dip shallowly to the southwest or northeast, with fold axes subparallel to F_1 fold axes. The largest megascopic folds known to have been formed during D_2 are those at the Grum Deposit (Figure 3-4) and comparable folds in the Swim Deposit.

Southwest of the Anvil Batholith the S_2 surfaces dip dominantly southwest, and F_2 minor folds have southwest vergence (shaped like a "S" in cross-section looking northwest). Northeast of the batholith S_2 surfaces dip dominantly northeast and F_2 minor folds appear, on the basis of limited evidence, to have northeast vergence. The shallow dip of F_2 axial planes, the isoclinal nature of F_2 folds, and the transposition of bedding into foliation means rock units are flat lying or shallowly dipping on the average, although there are local exceptions (eg. Grum).

Three later, less intense periods of folding and associated faulting followed D_2. The later events (D_3 through D_5) generally produced open folds and weak crenulations in S_2 related to broad, regional structures. An important exception to this general rule is found in the vicinity of the Faro deposit, where the fourth event (D_4) is intense with tight mesoscopic folds developed in nearly pervasive S_2. D_4 minor folds have appreciable mica growth along S_4 axial plane crenulation cleavages.

METAMORPHISM

With the exception of Cretaceous igneous intrusives, all rocks of the district are metamorphosed and have physical characteristics typical for schists or phyllites. Metamorphism was polyphase and concurrent with deformation; it was most intense during the major D_1 and D_2 folding deformations. D_1 metamorphism has been largely overprinted by the later D_2 metamorphism. Metamorphic grades during these two events appear to be comparable since mica mineral assemblages between microlithons (i.e. S_1 foliations) are similar to those defining the S_2 foliation surfaces. The rest of the discussion will focus on the D_2 metamorphism.

Metamorphic grade ranges from upper amphibolite facies (sillimanite-muscovite zone) to lower greenschist facies (muscovite-chlorite zone) in a low pressure Buchan type facies series. In pelites adjacent to the intrusions, the typical assemblage is andalusite - staurolite - garnet - biotite - muscovite - quartz - plagioclase with local fibrolite. Lower greenschist facies pelites contain the assemblage muscovite - chlorite - quartz - plagioclase.

Metamorphic isograds are roughly concentric about the Anvil Batholith. Locally isograds are truncated and juxtaposed by extensional faults. The Faro deposit (closer to the Batholith) is metamorphosed to amphibolite facies. All other deposits are metamorphosed to lower greenschist facies. This difference in intensity of metamorphism is reflected in decreased grain size and increased degree of mineral intergrowth in the less metamorphosed deposits (Tempelman-Kluit, 1970). This has a significant impact on metallurgical response of Anvil District ores. The degree of metamorphism also affects acid generation characteristics as only meta-sediments contain significant sulphide (the ores are meta-sediments, see below). Due to metamorphism, sulphide minerals tend to form larger coarser crystal aggregates, they are generally are not readily available on joint surfaces and very fine highly reactive pyrite (for example frambiodal pyrite), if ever present, has been re-crystallized and is no longer found.

IGNEOUS INTRUSIVES

During the later stages of the deformation history a large granitic body (Anvil Batholith) was intruded into the metamorphic sequence. Anvil Batholith ranges in composition from a biotite-muscovite peraluminous granite to a metaluminous to peraluminous hornblende-biotite granodiorite (Pigage and Anderson, 1985). Textures include equigranular massive, megacrystic massive, and various strongly to weakly foliated variants. Foliation within the intrusive rocks is concordant with S_2 surfaces in the surrounding metasediments. Several K-Ar ages on the granitic rocks yielded ages of 85-100 Ma (Tempelman-Kluit, 1972). Rb-Sr isochron ages of 99-100 Ma (Pigage and Anderson, 1985) and unpublished zircon model ages (Mortenson, pers. comm.) are concordant with the K-Ar ages and indicate rapid cooling after high-level emplacement.

Anvil Batholith and surrounding meta-sedimentary rocks are crosscut by two families of post-tectonic dykes. The majority of the dykes are northeast-trending, medium to dark green, porphyritic, unfoliated, hornblende-biotite quartz diorite. These quartz diorite dykes appear to be associated with late extensional faults. Unfoliated, pale tan, smoky quartz-feldspar porphyry also occurs as late crosscutting dykes. The dyke suites have not been extensively isotopically dated;

their absolute ages are thus uncertain. One important date has been obtained on an unsheared quartz-feldspar porphyry intruding the Tie fault zone (see below). This zircon age indicates that the dyke cooled at 100ma (Mortenson, pers. comm., 1991), essentially the same age as the Batholith. This leaves little doubt that the Tie Fault is coeval with late stage, high level emplacement and rapid cooling of the Batholith.

FAULTING

During the first and second phases of deformation, low angle faulting appears to have occurred, but the details are, as yet, poorly understood. Thrust faulting during the first phase of folding is likely and several candidates have been found. The most obvious of these are along the north flank of the district (Gordey, 1983; Jennings and Jilson, 1986), but additional, smaller thrusts may occur in the vicinity of the ore deposits. Gordey and Irwin (1987) have indicated a major thrust northwest of the Faro mine (the Faro Thrust). It is not likely that such a structure crops out in that area, but a similar thrust fault could exist if it is below the level of exposure in the core of the district. Brown and McClay (1992 and in preparation) have hypothesized the existence of such a thrust which would reach the surface along the north flank of the district and presumably would correspond to the Two Pete Thrust recognized there by Gordey and Irwin (op.cit.).

During the second phase of deformation, S_2 parallel displacement occurred along attenuated second phase fold limbs. These S_2 parallel faults (tectonic slides) have been recognized in the Grum deposit and are thought to exist at Vangorda. The role of these S_2 parallel structures is not well understood, but they are thought to have displacements of no more than a few 100s of metres. In general these early, low angle, compressional faults, if present, will be of immense exploration importance but of relatively little significance from a groundwater migration perspective since the faults would be well healed, this is clearly true for the relatively few identified D_2 tectonic slides.

Post folding and post metamorphism faulting is widespread in the district. Intrusion of the Anvil Batholith further deformed the metamorphic sequence so that the overall structure of the district is an elongate dome cored by the Batholith. In the later stages of emplacement, large extensional fault displacement occurred along the margins of the Batholith (Pigage and Jilson, 1985).

S-C mylontic banding within these fault zones, and in the granitic footwall of some, is consistent with development of the faults during late D_2 deformation. These faults determine the present day limits of several of the deposits. The faults with known offset appear to result from extension along the trend of the District and the Tintina Fault. The Tie Fault is one of the best examples of such a structure. As noted above, its age is well constrained at 100 ma. and it is coeval with the final stage of emplacement of the Batholith. These relationships suggest that the Anvil Batholith may have been intruded during the strike slip regime of the Tintina Fault. Figure 3-5 is a longitudinal section through Grum and the Tie Fault. The slip line of the fault is in the plane of the section. The section shows the relationship of Firth to Grum and the relatively large displacements of this family of faults. Other similar structures occur at the southeast end of Grum, between Dy and Vangorda, and below Swim. These structures typically juxtapose a less intensely metamorphosed hanging wall against a more metamorphosed footwall. The identification of these structures is

significant for exploration as they have the potential to open up large gaps in the stratigraphy because of their extensional nature and large displacement. Some of these structures are marked by tight, well healed, fault planes however most are marked by gouge and adjacent highly fractured rock and must be considered as possible groundwater flow paths.

The youngest faults of the district are steeply dipping and diversely oriented. One of the most prominent sets strikes northeast. A second important set strikes approximately north-south. The northeast striking set is sub-vertical and commonly shows left lateral strike slip offset. This set may represent second order structures to the Tintina Fault. The best example of such a fault is the Blind Creek Fault which offsets the favourable trend of deposits by 1.3 km. Many late faults show sub-horizontal slickenslides, suggesting the last displacements were strike slip. This is true even of structures in the Faro Pit which are well constrained to have small horizontal displacement compared to the vertical component of movement.

Jennings (personal comment, 1972) and Brown and McClay (1992, in preparation) have noted late stage, northeast directed, small displacement, post metamorphic thrust faults in the Faro and Vangorda pits respectively. These structures are not regionally significant, but can be important on a mining scale.

The youngest faults are of the greatest importance from a groundwater migration perspective as they are invariably marked by highly fractured rock and gouge and represent the only zones f high permeability in the rock mass. Figure 3-4, a cross section through the Grum deposit, illustrates several of the above types of faults.

3.2.2 Seismic

The maximum credible earthquake (MCE) has been re-evaluated on the basis of a new analysis of regional fault patterns by Dr. Scott Dunbar (see Appendix A). The substance of his findings follow.

3.2.2.1 Criteria for Ground Motion Estimation

The Canadian Dam Safety Association Dam Safety Guidelines (CDSA, 1995, Section 5.0) specify the following criterion for estimation of the ground motions:

- Dams shall be designed and evaluated to withstand ground motions associated with a Maximum Design Earthquake (MDE), without release of the reservoir.
- Selection of the MDE for a dam shall be based on the consequences of dam failure.

The above criterion was developed for application to water storage dams. However, Section 11.0 of the Guidelines specify that tailings dams shall meet the same requirements. The last sentence above implies that the MDE ground motions should increase with increasing severity of the consequences (or risks) associated with failure of dams or embankments. Table 5-1 of the Guidelines provides specific criteria for derivation of MDE ground motions. A copy of this table is given below.

Usual Minimum Criteria for Design Earthquakes
(from Table 5-1 of CDSA, 1995)

Consequence Category	MAXIMUM DESIGN EARTHQUAKE (MDE)	
	Deterministically Derived	Probabilistically Derived Average Return Period (years)
Very High	MCE[1]	10,000
High	50% to 100% MCE	1,000 to 10,000
Low	-	100 to 1,000

[1] Maximum Credible Earthquake

The description of consequence categories is given in Section 1.4 of the Guidelines. In the case of the Anvil Range Mining Complex, failure of the dams or embankments could result in release of acid water and tailings and considerable damage to the river environment and fisheries. Such consequences are considered "Very High" and therefore the average return period of ground motions derived by a probabilistic method should be 10,000 years.

Although probabilistic estimates of ground motion are made herein, a comment concerning the term "Maximum Credible Earthquake" and deterministic estimates is in order. The MCE is basically an earthquake magnitude. In the Guidelines, the MCE is defined as the largest reasonably conceivable earthquake that could occur under the presently known or interpreted tectonic framework. Once the magnitude of the MCE is determined, ground motion attenuation relationships or previously recorded strong motion accelerograms due to earthquakes having magnitudes similar to the MCE may be used to estimate MCE ground motions. However, the estimation of MCE magnitude requires a high degree of physical and seismological understanding of the tectonic framework and the identification of specific earthquake sources (faults). Such an understanding is not available in most parts of Canada and the identification of sources is usually not possible. Thus, in the above table, the apparent relationship between MCE ground motions and ground motions corresponding to a 10,000 year return period is vague. Much of the vagueness results from attempting to define the word "credible". Experience in the United States shows that the definition can depend heavily on different seismological interpretations and even involve societal issues. For this reason the term "maximum magnitude" is preferable, i.e., the issue of credibility is avoided. In Canada, the maximum magnitude is typically based on a combination of historical seismicity and what is known of the tectonic framework. In most areas, including the Yukon, the maximum magnitude cannot be associated with any particular source.

3.2.2.2 Ground Motion Estimation Methodology

A probabilistic method was used in which the annual rates of exceeding particular values of ground motion are estimated. A brief description of the methodology is given in the following paragraphs. The method used is similar to that used by the Geological Survey of Canada (GSC) to compute values of seismic ground motion for the National Building Code of Canada.

A basic component of a quantitative seismic hazard analysis is a model of ground motion attenuation. Ground motion attenuation equations describe the amplitude of ground motion as a function of earthquake magnitude, M, and distance, R. Such equations show that to obtain a ground motion value, y, at a site, an earthquake of magnitude m at a distance r has to occur. The ground motion y would be exceeded if the magnitude exceeds m (M>m) or the distance is less than r (R<r) and would not be exceeded if the magnitude is too small (M<m) or the earthquake is too far away (R>r). The task of probabilistic seismic hazard analysis is to determine the annual rate at which exceedances of the ground motion y occur (i.e., the annual rate of scenarios M>m and R<r). For example, in most regions of Canada where seismic activity is low, the annual rate of exceeding ground motion amplitudes of engineering interest (peak ground accelerations of 0.05g or greater) may be 0.002/year. The average return period of ground motion exceeding 0.05g is approximately the reciprocal of the exceedance rate, i.e., 500 years.

Probabilistic seismic hazard analysis also requires a seismic zonation which defines areas or zones having uniform tectonics and/or seismological characteristics in which earthquakes are assumed to occur at a uniform rate. The rate at which a particular magnitude is exceeded is given by a magnitude recurrence relationship for the zone. Such relationships are derived from historical observations of earthquakes in the zone. The magnitudes of the earthquakes are limited to values below a maximum magnitude estimated by an assessment of the historical seismicity and tectonic framework of the zone. The geometry of a zone may range from an individual fault to a polygonal area. Since seismic activity in most parts of Canada is diffuse and not related to particular faults, seismic zonations in Canada are typically polygonal in nature. Thus, a seismic zonation allows the rates of earthquake occurrences to be estimated and allows definition of the location of earthquakes with respect to the site in question.

To compute the rates of exceeding a particular value of ground motion, the analysis considers possible combinations of magnitude and distance which lead to exceedance of that value. This can be done by random sampling of the magnitude recurrence relationship in each zone and by random location of earthquakes within the zones. (This random sampling is referred to as Monte Carlo analysis.) The attenuation relationship is then used to compute the ground motion corresponding to each magnitude-distance combination. The rates of exceedance of particular ground motion values are computed by simple counting. A computer program, called *McHazard*, was written to perform these calculations.

3.2.2.3 Ground Motion Estimates at Faro

A recent GSC Open File report describes the development of new seismic hazard maps of Canada (Adams et al, 1996). Two seismic zonations are proposed for Canada: the H (for Historical) and the R (for Regional). Each of these zones is assumed to be an equally valid interpretation of the seismological observations and data. The H and R zonations for western Canada as well as the location of Faro are shown on Figures 1 and 2, respectively.

The following zones were used to estimate ground motion at Faro:

H Zonation	R Zonation
MCK - Mackenzie Mountains	MMB - Mackenzie Mountains
SYT - Southern Yukon	SOY - Southern Yukon

Other zones are considered to be too distant to have much effect on the ground motion at Faro. Zone geometries, parameters of the magnitude recurrence equation, and maximum magnitudes for each zone were obtained from the Open File report. Probabilistic estimates of peak ground acceleration were then made for each zonation.

The attenuation relationship used by GSC for western Canada is that derived by Boore et al (1993). This relationship computes peak ground acceleration on a rock site given earthquake magnitude and distance from the site. The relationship was derived using strong motion data recorded in California and it is assumed that the relationship describes ground motion attenuation in western Canada (where no data are available). From the point of view of seismic wave propagation, the structure of the two regions is similar, (i.e., mountainous terrane composed of geologically young rocks) and it is reasonable to assume that ground motion attenuation is similar in both regions.

The resulting seismic hazard curves, which relate values of peak ground acceleration to exceedance probability or return period, are shown in Figure 3. The approach recommended by GSC is to adopt the larger estimate. Thus, if the selected return period is 10,000 years, the curve for the R zonation should be used. From this curve the peak ground acceleration corresponding to a 475 year return period is approximately 0.05g and that corresponding to a 10,000 year return period is approximately 0.13g. Note that these values apply to rock sites.

3.2.2.4 The Tintina Fault

Figure 4 shows the locations of earthquake epicenters recorded in southwestern Yukon during 1980-1991. This figure is taken from a paper by Lowe et al (1994) who discuss geological and geophysical data used to interpret the tectonics and geology of the region. Seismic activity in the region is concentrated in southwestern Yukon and there is a general decrease in activity to the northeast. Of particular interest is seismic activity along the Tintina fault which is close to Faro. Numerous small (M<4) events occur west of the fault, while immediately east of the fault there is little seismic activity. There is little seismic activity along the trace of the fault. This is consistent with the geophysical data presented by Lowe et al (1994) which show that the fault separates two regions with distinct physical properties: a relatively homogeneous region to the northeast and a more heterogeneous region to the southwest in which considerable strain is built up and sometimes released as earthquakes.

The offsets of major geological features along the fault indicate that about 450 km of displacement has occurred on the fault since Late Cretaceous time (70 million years ago). However, there is no

evidence of more recent displacement along the Tintina fault and the fault is not included as an earthquake source zone in either the H or R zonations given in the GSC report, i.e., the fault is not considered active and no maximum magnitude has been defined for the fault. Thus, it is unrealistic to consider a deterministic estimate of seismic ground motion at Faro in which an earthquake is assumed to occur on the Tintina

3.3 LANDFORMS AND SOILS

The physiography of the area has been described in section 3.1. All but the highest peaks in the area were ice covered in the last glaciation. Ice flow and transport direction was from southeast to northwest or east to west, as evidenced by glacial striae and elongate land forms, as well as transport of distinctive rock types such as the serpentinized pyroxenites in the upper Dixon Creek area and the spread of geochemically anomalous soils away from the subcrop of the ore deposits.

Discontinuous deposits of glacial till and glacio-fluvial deposits are common in the area, however, with local exceptions, the deposits are not thick. Important exceptions are a buried valley filled with up to 70m of overburden over the subcrop of the Grum deposit and a ridge of highly compacted till up to 40m thick overlying the Vangorda deposit. Thick till and fluvial deposits also occur in the Rose Creek, the west fork of Vangorda Creek, and in the Blind Creek valleys. In Swim Basin there is a widespread, thick blanket of glacial deposits.

The following sections describe surficial materials and soils in more detail.

3.3.1 General

The Anvil Range Mining Complex is within the central Yukon section of the Boreal Forest Region (Rowe, 1972). Five major types of surficial deposits have been identified within the Anvil Range complex area and are based on investigations undertaken by Montreal Engineering Company, 1975. These include morainal, colluvial, glaciofluvial, alluvial, and organic. The major surficial deposit types have been further subdivided into landforms according to the modes of deposition and the resultant surface relief patterns (Figure 3-6). The area studied by Montreal lies between the summit of Mount Mye and the Pelly River, and extends from Blind Creek to the Faro Mine.

The studies conducted included aerial photographic interpretation to prepare a 1:50,000 base map showing the five major groups of surficial deposits within which specific landforms were delineated (Figure 3-6). Field investigations were also conducted during the summer of 1975 for vegetation, soils, surficial geology and wildlife usage in the area. A preliminary classification of the sampled soils is presented in Appendix A of a report entitled "1975 Biophysical and Socio-economic Program", Montreal Engineering Co, 1975. All sites referred to in the following sections are shown in Figure 3-6 and described in detail in the above mentioned report Appendix.

The following sections describe each of the landform units, the surficial material that characterize them, and the soils developed. A brief description of the forest community that typifies the landform unit is also provided. Section 3.4 discusses vegetation in greater detail. This

information was extracted and modified from the Montreal Engineering report and provides a good basis for understanding the terrestrial ecosystem in the area of the Anvil Range Mining complex.

3.3.2 Morainal Landforms

The majority of the mine workings on the Vangorda Plateau are located in areas underlain by morainal materials, which range in depth from 0-10 m. (Figure 3-6) and in which bedrock control is usually evident. The predominant textures are loam and sandy loam with isolated granitic boulders, but in several locations the till is capped by a layer of sandy outwash and volcanic ash. The till is typically quite dense and compacted. In places these inclusions are sufficiently extensive to be marked by the presence of lodgepole pine denoting improved drainage conditions.

Parts of the surface are marked by deep grooves, indicating high pressure glaciation which suggests that much of the morainal material is likely to be quite compact.

The dominant soils near the Vangorda Plateau mine workings is a Gleyed Brunisolic Gray Luvisol (Figure 3-6, Sites 1 and 2) which merges in better drained locations to a Brunisolic Gray Luvisol (Figure 3-6, Sites 6 and 9). The dominant surface texture in both these soils is sandy loam, while slightly heavier textures (loam - silt loam) predominate in the subsurface. Other soils occupying smaller areas reflect local differences of soil parent material, slope, physiographic position, vegetation and drainage (Figure 3-6, Sites 4, 7 and 13).

The white spruce tends to predominate at the lower elevations, but is replaced by alpine fir at higher altitudes. In some better drained sandy sites or where the till material is overlain by a mantle of sandy volcanic ash, lodgepole pine replaces the other conifers (Figure 3-6,Site 4).

A large part of the area studied was burned in 1969. This burn covered much of the terrain between the Anvil Range Complex and the Pelly River, but did not reach as far as the complex itself. During the course of this investigation, other earlier fires were discovered. An extensive fire burned in the vicinity of Vangorda Creek just east of the mine site about 60 years ago (Figure 3-6, Sites 4, 5 and 16). Another fire occurred in this region about 95 years ago (Figure 3-6, Site 6).

Although fires appear to be common and extensive within the Upland Forest Zone, there are localized sites which appear to have escaped the effects of fire for considerable periods (Figure 3-6, Sites 2, 7 and 9).

3.3.3 Colluvial Landforms

The colluvial deposits are divided into Steepland Colluvial and Alpine Colluvial landforms. This is done in order to emphasize the influence of the harsh climatic regime and the periglacial processes that take place in the Alpine zone, which make this environment especially sensitive to disturbance. The Faro mine site including pits, dumps and concentrator occur within the Steepland Colluvial landform type.

3.3.3.1 Steepland Colluvial Landforms

The Steepland Colluvial landform occurs on mountain slopes below the treeline where the gradients are between 20 and 60%. The soils are relatively shallow and bedrock outcrops are common, especially at the higher elevations. The parent material is a till-colluvium mixture. The

soils that have developed on the upper slopes are generally well drained (Figure 3-6, Site 14), while those on the lower slopes tend to be deeper and generally poorly drained (Figure 3-6, Sites 5 and 11). In some cases these poor drainage conditions lead to the build-up of organic layers and the development of permafrost conditions (Figure 3-6, Site 11).

The Steepland Colluvium is generally associated with the Subalpine Transition vegetative zone which occurs on the steep upper mountain slopes between the Upland Forest and the Alpine Tundra, and also at lower elevations, where there are steep slopes and shallow soils. The shallowness of the soils in this zone generally limits tree growth, and in the most adverse locations, at higher elevations, shrubs tend to predominate (Figure 3-6, Site 5 and 14). Only in relatively stable locations, at the base of some slopes, is deeper soil encountered, and consequently it is in these locations that better tree growth is encountered (Figure 3-6, Site 11).

Grassy meadows (Figure 3-7) are encountered on a few steep, south facing slopes at elevations of 2500 to 3500 ft, and are usually associated with rocky outcrops in which draughty conditions predominate. Such areas were observed on the mountain just north of the Blind Creek bridge and on the left hand side of the road about one mile north of Faro.

3.3.3.2 Alpine Colluvial Landforms

This landform occurs above the treeline where the soils are formed on shallow colluvium and minor till deposits derived from the local bedrock (Figure 3-6, Sites 15 and 17). They are generally well drained with slopes of up to 40% and numerous rock outcrops. Periglacial features such as solifluction slopes, snow avalanches and minor cirques are evident, particularly on steep exposed sites.

Much of this landform, with its associated Alpine Tundra vegetation, is located at higher elevations above the treeline which lies between 4500 and 5000 ft. The exact elevation depends on the interaction of factors such as fire history, slope, aspect and soil conditions. Other than a few exploration roads, there has been little disturbance within this landform due to mining.

3.3.4 Glaciofluvial Landforms

Extensive areas of various forms of Glaciofluvial deposits occur along Vangorda, Rose and Blind Creeks and their tributaries. The Rose Creek Tailings Facility is located with in this surficial deposit type. The materials are generally coarse, consisting of well sorted, well rounded sands and gravels (Figure 3-6, Site 16). The soils of these landforms are generally excessively drained. The dominant soil types are Brunisols and Podzols. The vegetation is generally similar to the drier phases of the Upland Forests described in Section 3.4.

3.3.5 Alluvial Landforms

Alluvial deposits occur in the valleys of Vangorda and Rose Creeks and their tributaries, as well as along the Pelly River. The slopes of this landform are gentle and generally less than 5°. The soils in the basins of Rose and Vangorda Creeks consist of Gleysols in the poorly drained locations (Figure 3-6, Sites 10, 18 and 19), or Brunisols and Podzols in locations having slightly better drainage (Figure 3-6, Sites 8 and 12). The Gleysolic soils are generally very wet and

massive. The Alluvial Plain shrub vegetation occurs at high elevations in the valleys of Vangorda and Rose Creeks and their tributaries.

The flood plains along the Pelly River and the lower reaches of Blind Creek are flat, undulating and up to two miles wide in some places. They are composed of gravel, sand and silts which are generally better drained than the previously mentioned materials. Included in this landform type are oxbow lakes, alluvial fans, slumped banks and organic backswamps. Only one stand (Figure 3-6, Site 3) was sampled in this landform type due to limited mine development here.

Three major forest communities encountered on the flood plains are the white spruce-feathermoss community, the balsam fir-shrub community and the depressional backswamps. These species may be used as indicators of drainage and soil conditions. The white spruce-feathermoss forests are located in those sections where flooding is infrequent. The balsam fir-shrub forests occur in locations subject to more frequent flooding, where active deposition is still occurring. Stands of black spruce have developed in the depressional backswamps where organic soils predominate; pine, aspen, birch and spruce have infiltrated the areas above the flood level.

3.3.6 Organic Landforms

Organic deposits occur as inclusions within other landforms. They are a result of poor drainage and the presence of a water table at or near the surface. These poor drainage conditions lead to the growth of mosses, which in time promote the accumulation of peat and eventually the development of permafrost.

This landform occurs rather extensively in the lowlands adjacent to the Pelly River and in flat depressional areas adjacent to stream beds and lacustrine depressions. Doal Lake, now dewatered due to excavation of the Grum pit, was typical of this landform type. Material excavated from Doal Lake has been stock piled in the "wet" dump at Grum for reclamation purposes. Apart from the organic terrain mapped, numerous other areas too small to map also occur.

3.4 Vegetation

The Anvil Range Mining Complex is located within the Pelly River Ecoregion (Oswald and Senyk, 1977). A more recent classification by the Yukon Ecoregions Working Group includes this area in the Yukon Plateau (North) Ecoregion (Yukon Conservation Society, 1995). The region lies within the zone of discontinuous, widespread permafrost. Depressional areas consist of peat bogs, fens and locally palsas. Lowlands frequently contain hummocks and sedge tussocks. Upland areas commonly include scree slopes and steep south facing slopes with grassland vegetation. Treeline occurs at 1350-1500 m a.s.l..

Six vegetation zones were mapped within the study area and are based upon the field studies and mapping undertaken by Montreal Engineering,, 1975. Figure 3-4 presents a regional vegetation map for the vicinity of the Anvil Range Mining Complex. The vegetation zones include flood plain

forest, upland forest, bog forest, alpine tundra, subalpine transition and alluvial plain shrub. The structure and species composition of these vegetation zones is outlined as follows:

3.4.1 Flood Plain Forest

The flood plain forest zone in the Anvil Range study area is restricted to the alluvial landforms along the Pelly River and the lower reaches of Blind Creek.

Flood plain vegetation communities represent the most developed forest stands in the study area. White spruce (*Picea glauca*) forests occur where flooding is less common and alpine fir (*Abies lasiocarpa*) stands occur in frequently flooded areas. Lodgepole pine (*Pinus contorta*), balsam poplar (*Populus balsamifera*), trembling aspen (*Populus tremloides*) and paper birch (*Betula papyrifera*) also occur in the flood plain forest zone.

Dense shrub stands, consisting primarily of willow (*Salix* spp.) and balsam poplar, are common in riparian zones where active deposition is occurring.

Feathermoss layers are extensive within the older stands of white spruce

3.4.2 Upland Forest

Upland forests are found on the morainal landforms above the Pelly River and the upper Vangorda Creek area. Much of this upland forest area was burned in the 1969 fire.

Upland forest is also found on the glaciofluvial landforms along Rose Creek.

The upland forest zone is dominated by stands of either white spruce, lodgepole pine, or alpine fir. A well developed layer of tall and medium shrubs includes trembling aspen, shrub birch (*Betula glandulosa*), Scouler's willow (*Salix scouleriana*), and other willow species.

The dwarf shrub strata of the upland forest consists of dwarf dogwood (*Cornus canadensis*), crowberry (*Empetrum nigrum*), Labrador tea (*Ledum groenlandicum*), blueberry (*Vaccinium uliginosum*), low-bush cranberry (*Vaccinium vitis-idaea*), prickly rose (*Rosa acicularis*), arctic willow (*Salix arctica*) and net-veined willow (*Salix reticulata*).

Herb development is not extensive in the upland forest zone. Herb species in this zone include fireweed (*Epilobium angustifolium*), arctic lupine (*Lupinus arcticus*), arrow-leaved coltsfoot (*Petasites sagittatus*), and sedges (*Carex* spp.).

The moss layer, particularly feathermoss, is extensive in the closed-canopy portions of the upland forest. Lichens include spotted dog lichen (*Peltigera aphthosa*), coral lichen (*Stereocaulon paschale*) and *Cladonia* spp.

3.4.3 Bog Forest

The bog forest is limited to the organic landforms adjacent to the Pelly River. It is characterized by peat accumulation and stunted black spruce (*Picea mariana*). Permafrost commonly occurs in these areas.

Black spruce is commonly the only tree species found in the bog forest. Shrub species include shrub birch, northern Labrador tea (*Ledum decumbens*) and cloudberry (*Rubus chamaemorous*).

The herb layer is poorly developed in the bog forest zone. It consists mainly of sedges.

A characteristic feature of the bog forest is the extensive layers of moss, usually *Sphagnum* spp. It is these moss layers that accumulate into peat.

3.4.4 Alpine Tundra

The alpine tundra vegetation zone occurs above 1350-1500 m a.s.l.. In the Anvil Range study area, alpine tundra is found primarily on the upper slopes of Mount Mye and Rose Mountain. Smaller communities of alpine tundra vegetation are found in areas such as Sheep Mountain (the mountain just north of the Blind Creek bridge).

Alpine tundra consists of vegetation communities dominated by dwarf shrubs and lichens. Shrubs include dwarf birch (*Betula pumila*), mountain avens (*Dryas octopetala* and *Dryas integrifolia*), crowberry, low-bush cranberry, blueberry, arctic willow, snow-bed willow (*Salix polaris*) and other willow species. Lichens, predominately *Cetraria* spp., are prevalent in well-drained rocky sites.

A variety of herb species occur in the alpine tundra zone, including arctic lupine, Langsdorf's lousewort (*Pedicularis langsdorffii*), alpine harebell (*Campanula lasiocarpa*), black-tipped groundsel (*Senecio lugens*), wormwood (*Artemesia arctica*), grass (*Arctogrostis latifolia*) and sedges.

3.4.5 Subalpine Transition

The subalpine transition zone is associated with colluvial landforms. It occurs on the steep upper mountain slopes between the upland forest and the alpine tundra. It is also found at lower elevations where there are steep slopes and shallow soil. The mid-slopes of Mount Mye and Rose Mountain (below 1350-1500 m a.s.l.), as well as the uplands adjacent to the Rose Creek alluvial plain, are included in this zone.

Well developed forests of white spruce and feathermoss occur at lower elevations in the subalpine transition zone. Tall and medium shrubs in these lower elevation forests include shrub birch and Scouler's willow, and the dwarf shrub layer consists of arctic willow, crowberry, Labrador tea and blueberry.

The herb layer, not well developed at lower elevations, is limited to sedges and shade-tolerant species such as arctic lupine and bluebell (*Mertensia paniculata*).

At higher elevations in the subalpine transition zone, vegetation is dominated by tall and medium shrubs such as trembling aspen, shrub birch, Scouler's willow other willow species. Alpine fir, lodgepole pine, white spruce and black spruce are also found in the upper subalpine transition zone. Dwarf shrubs include crowberry, Labrador tea, blueberry, net-veined willow and kinnikinick (*Arctostaphylos uva-ursi*).

The herb layer at higher elevations in the subalpine transition zone is much more developed. It includes fireweed, arrow-leaved coltsfoot, Labrador lousewort (*Pedicularis labradorica*), dwarf

dogwood, one-sided wintergreen (*Pyrola secunda*), rayless alpine butterweed (*Senecio pauciflorus*), aster (*Aster* sp.), running clubmoss (*Lycopodium clavatum*), grass (*Arctagrostis latifolia*), and sedges.

Lichens in the subalpine transition zone include spotted dog lichen and *Cladonia* spp.

3.4.6 Alluvial Plain Shrub

The upper reaches of the Vangorda Creek valley and the south fork of Rose Creek and its tributaries are included in the alluvial plain shrub vegetation zone.

Shrub birch, shrubby cinquefoil (*Potentilla fruiticosa*), Scouler's willow and other willow species dominate the vegetation communities in the alluvial plain shrub zone. Scattered stands of white spruce and alpine fir also occur. Dwarf shrubs consist of crowberry, Labrador tea, low-bush cranberry, dwarf dogwood, dwarf blueberry (*vaccinium caespitosum*) and arctic willow.

The herb strata may be well developed in this zone. Herbs species include arrow-leaved senecio (*Senecio triangularis*), tall Jacob's ladder (*Polemonium acutiflorum*), sweet coltsfoot (*Petasites hyperboreus*), alpine harebell, wormwood, arctic lupine, club moss, common horsetail (*Equisetum arvense*), grass (*Arctagrostis* sp.) and sedges.

Feathermoss may form extensive mats in the alluvial plain shrub zone. Lichens, not well represented in this zone, include *Cladonia alpina* and other *Cladonia* species.

3.5 Wildlife

3.5.1 Background and History of Wildlife Information Base

The entire area encompassing the Faro Townsite, the Faro open pit mine and concentrator complex, the Down Valley tailings project in the Upper Rose Creek Valley, eastward onto the Vangorda Plateau and the lower Blind Creek drainage, supports a variety of wildlife including ungulates, large carnivores, furbearers, small mammals and upland game birds. The discussion presented here focuses on the Vangorda Plateau.

A pre-development assessment of the abundance and seasonal distribution of wildlife on the area is largely anecdotal and intimately tied to the historical land use patterns of the Ross River Native People (Weinstein, 1992). Prior to the completion of the Campbell Highway in the mid to late 1960's, and the development of the Faro Townsite and associated industrial activities in 1969 - 1970, the Government of Yukon and the proponent had neither the necessity, initiative, nor the infrastructure to conduct science-based wildlife studies (Weinstein, 1992, p. 40).

Post-development wildlife assessments, particularly for the Vangorda Plateau and the extraction of the Vangorda and Grum deposits, focused on the most notable feature of the areas wildlife resource - the Mt. Mye sheep population. Figure 3-8 outlines seasonal migration routes for the Mt. Mye sheep and moose ranges.

Commencing in 1975, several cooperative and comprehensive studies by previous mine operators and Yukon Territorial Government ("YTG") have been conducted. Among the most important are:

- Preliminary engineering and environmental investigation of the proposed Kerr-Aex Grum Joint Venture (Montreal Engineering Company Ltd. 1971). This publication clearly anticipated direct and indirect effects of Grum-Vangorda development.
    i. direct effects on the terrestrial environment and wildlife;
    ii. indirect effects of recreational use of the area, including hunting, with a recommendation for a 'No Hunting' control zone.
- Co-operative investigation of migration patterns of the Mt. Mye sheep population (McCleod, H., Sept. 1981).
- Stone Sheep and the Grum-Vangorda Open Pit Mine near Faro, Yukon: Impact Assessment & Mitigation Recommendations (Brian Horesji, Feb. 1988).

From these investigations and their recommendations for mitigation, two important documents were produced:

1. *Proposal to Implement Mitigative Measures to Reduce the Impact of Mining Activity on the Resident Fannin Sheep Population* (Curragh Resources Inc., June 1987).

   This document provides a truncated but interesting history of exploration and background of sheep studies up to the time of publication. Several of the mitigation options for the movement of sheep between winter and summer ranges have been unsuccessful. Bulldozer trails and hand-cleared trees on or near known but infrequently used sheep trails (Figure 3-8, Route F), and the attempt to encourage sheep to use these 'enhanced' alternative migration routes has not been successful to date (Hoefs, personal communication).

2. Proposal - *Management Plan - For Sheep Mountain near Faro and its Fannin Sheep Population* (Manfred Hoefs, Fish & Wildlife Branch, 1988).

   This document is much more comprehensive in scope and detail. Production of the management plan required the co-operation of the former mine operator, Curragh Resources Inc., the Town of Faro, the Ross River First Nation, and YTG. Further, it thoroughly addresses a wider range of issues regarding the welfare of the Mt. Mye sheep population. It includes both a well-researched recent development history of the Vangorda Plateau and available research findings on the resident sheep.

   In view of the mitigation proposals for sheep movement between winter and summer ranges, this proposal prioritises the 'enhanced' route 'F' alternative which is not a demonstrated success. This theme will be explored further in a later section, given the advanced state of development on the Vangorda and Grum deposits and the surmised behaviour of these sheep in the face of these developments.

   As a result of the co-operative initiatives that went into this sheep management proposal, a hunting closure was put into effect (1989) on a newly designated game management subzone

(4-51), which includes Sheep Mountain, the Fingers, the Faro Townsite, and the proximal portions of several known sheep migration routes below the haul road and east of the west fork of Rose Creek to the old Aex road down Blind Creek.

Further exploration of the non-consumptive uses of this sheep population in this management plan provides for the designation of the Sheep Mountain winter range, associated mineral lick and lambing area.

As a 'special wildlife management area', priorities are to improve sheep habitat through prescribed management and enhance the wildlife viewing potential by constructing viewing sites, non-intrusive trail development and interpretative signs.

To this end, Government of Yukon, Renewable Resources, contracted a study to evaluate this potential entitled: *Wildlife Viewing and Nature Appreciation in the Vicinity of the Town of Faro*, Jan. 1991. (Laurie A. Henderson, Tuak Environmental Services).

These information resources and the recommendations obtaining therefrom are what is readily known about the Mt. Mye sheep population. Indeed, the wildlife information base pertaining to development of the Vangorda Plateau, is completely dominated by the early recognition and commitment by successive operators of the mine, YTG, and the general public to addressing the long-term survival of this sheep population.

3.5.2 Current Status of Ungulate Species

3.5.2.1 Caribou

The development area lies marginally within the known range of the Tay woodland caribou population. These caribou are known to range in summer in the alpine and sub-alpine zones of the Anvil Range, including Mt. Mye and adjacent plateau's and ridges. No development-related investigations of these caribou have been conducted, except for incidental observations by government personnel while conducting sheep surveys on Mt. Mye. A radio-collaring and monitoring study was undertaken in the late 1980's by YTG, Dept. of Renewable Resources. The data, as yet unpublished, is on file (Larsen, D., personal communication).

The Tay Herd, numbering about 4,000 animals, is a naturally regulated herd with limited access and is subject to a recreational harvest by resident and non-resident hunting and a subsistence harvest by local First Nation's people.

When last surveyed in March 1991, herd status was stable.

3.5.2.2 Moose

In general terms, given that the development area is semi-urban and industrialized, moose occur in the area at low density. Relatively undisturbed pockets of habitat in the Shrimp Creek drainage, lower Blind Creek drainage, and the shrub regeneration after the 1969 forest fire, contribute to the welfare of moose locally.

Development related moose surveys and government sponsored moose inventory work have not been undertaken on the area.

Local opinion suggests that moose numbers have increased in recent years in the Ross River and Faro areas. But a formal statement on the status of the moose population is not possible (Ward, R., personal communication).

Historically, the riparian habitats of the Pelly River flood plain likely supported and, particularly in deep snow winters, continues to support over-wintering moose.

3.5.2.3 Sheep

Apparent in the previous section is the considerable body of detailed information on the Mt. Mye sheep population. In addition to these major contributions to the understanding of the population ecology and demographics of these sheep, several summer aerial surveys and ground based winter surveys have been conducted between 1980 and the present by YTG, Dept. of Renewable Resources, and contract personnel (data on file, Hoefs, M., personal communication).

The most recent of the winter surveys was conducted between November 1995 and late March 1996 on a bi-weekly basis by members of the Faro Fish & Game Association (YTG service contract).

An aerial survey of Mt. Mye was flown on July 11, 1996, by YTG, Dept. of Renewable Resources, with a Faro Fish & Game Association observer.

Results of these two recent surveys conclude that the Mt. Mye sheep population status remains stable.

3.5.2.4 Status of Grizzly & Black Bear

Both species of bears have been very much in evidence at the Faro community dump since the town was established. A major attraction and food source, this dump had as many as 25 bears in attendance. During peak periods of summer use, this situation has been a wildlife management problem for 25 years. Recent improvements to the facility, with improved household waste management practices by the Town of Faro, have dramatically reduced the towns' summer bear population (Frankish, K., personal communication).

Chinook Salmon runs in Tay River, and especially Blind Creek, are important seasonal local food sources for bears of both species.

In late July 1996, a grizzly bear sow with two cubs of undetermined age, were observed in a small patch of remaining trees adjacent to the Grum till dump (Denholm, E., personal communication).

Black bear are known to be abundant in the development area with grizzly bear numbers increasing slowly after years of suspected illegal hunting (Smith, B., personal communication).

3.5.2.5 Status of Fur Bearers, Small Mammals and Upland Game Birds

The Vangorda Development lies wholly within the Ross River group trapping area. Fur harvest records are not currently available, and on group areas, can only be ascertained with a considerable degree of difficulty (Slama, H., personal communication).

While no annotated list of species from these faunal groups has been compared, generally speaking the area is rich and diverse. So far as is practically known, development of the Vangorda Plateau has had no significant regional influence on the abundance and distribution of species from these groups - locally perhaps. Weinstein (1992) comments: "It is rare when there have been sufficient observations to have an understanding of such things as natural variability and historical change of animal range and populations. Nonetheless, northern science speaks with considerable authority."

3.5.2.6 Overview of Mt. Mye Sheep Migration Routes

The available literature, Montreal Engineering (1976), McCleod (1981), and Horesji (1987), provide confirmed and unconfirmed migration routes and timing of migration of the Mt. Mye sheep population. Route identification will conform to that established by McCleod (1981). See Figure 3-8 which outlines the various identified sheep migration routes.

Route 'A', between Sheep Mountain and the Fingers near the CN Tower above the Faro Townsite, is a virtual certainty. The body of local direct observation evidenced by local residents and other observers over a long period of time supports this position. Route 'A' is used primarily by rams in their seasonal movements between Rose Mountain and Sheep Mountain, and their known winter range above the Faro Townsite.

Routes 'B' and 'C' crossing the haul road west of the Grum Pit remain unconfirmed. Route 'F' is an infrequently used alternate route commencing at the confluence of Shrimp and Vangorda Creeks following an old cat road and crossing the old airstrip to the east of the present Vangorda pit and dump. Historical anecdotal information suggests that route 'F' was used during fall migration by nursery bands returning to their Sheep Mountain winter range (McCleod, 1981).

More recent work by Schweinsburg (199__, unpublished field reports, Y.T.G., Dept. of Renewable Resources) confirm routes 'D' and 'E' as those preferentially used by nursery sheep during, and in spite of, advanced mining activities in the immediate Grum-Vangorda vicinity.

Routes 'D' and 'E', commencing at the Shrimp-Vangorda Creek confluence, proceed up Vangorda Creek to a point near the confluence of Grum Creek, where route 'D', now overlain by the present and expanding Grum main dump, proceeds across the haul road to the present Grum Pit. Route 'E' continues up Vangorda Creek, following the approximate present location of a recently constructed access road below Grum main dump, crossing the haul road just west of Vangorda Creek culvert, and continues north where it is completely overlain by the Grum overburden dump and onto the present water treatment plant location.

Routes 'D', 'E' and 'F' all join near the Shrimp Creek - Vangorda Creek confluence, where a common, and much used, trail ascends Sheep Mountain to the southwest.

During a recent site tour by Eric Denholm (Anvil Range Mining Corporation) and Grant Lortie on August 12, 1996, a fresh set of sheep tracks (ewe and lamb) were noted on top of the Grum overburden dump (Route 'E'). Sporadic older tracks were also encountered. Earlier that summer and in previous years, sheep were observed on the overburden dump by the local workforce, and several excellent photos were taken of a nursery band at the water treatment plant site (Denholm, E., personal communication).

3.6 Climate

The records from a total of seven climate stations and one snow course were utilized in this study to characterize the mine site climate. The most important station, known as Anvil, is located at the mine site itself and has operated since 1967. This station has an elevation of 1158 m and records daily temperature, rainfall and snowfall. The snow course, operated by Indian and Northern Affairs (IANA), is also located at the mine site and has a record that spans the period 1975 to 1985. Details of all the selected stations are provided in Table 3.1.

3.6.1 Temperature

The 1951-80 temperature normals for the Anvil station, as published by the Atmospheric Environment Service (Environment Canada, 1982), are presented in Table 3.2. These data show a mean annual temperature of -3.4 °C. July is the warmest month, with a mean daily temperature of 11.5 °C, and January is the coldest month, with a mean daily temperature of -19.8 °C. Over the period of record, temperature extremes of 29.4 and -46.1 °C have been measured.

3.6.2 Precipitation

The mean annual precipitation (MAP) at the Anvil station is 368 mm, according to the 1951-80 climate normals (Environment Canada, 1982). This total comprises roughly equal proportions of rainfall and snowfall as water equivalent. The mean monthly distribution of precipitation is plotted in Figure 3-9a and is listed in Table 3.2. This information reveals that precipitation is common throughout the year with the driest month typically being April, and the wettest being July. The greatest 24-hour rainfall measured at the Anvil station was 36.8 mm while the greatest 24-hour snowfall was 21.3 cm. The average number of days with measurable precipitation at the mine site was 120.

Table 3.1

Details of regional climate stations

STATION NAME	LATITUDE		LONGITUDE		ELEVATION	MEAN ANNUAL PRECIP.	AUTHORITY[1]	INFORMATION APPLICABLE
	Deg	Min	Deg	Min	(m)	(mm)		TO STUDY
Anvil	62	22	133	23	1158	368	AES	Precipitation/Temperature
Faro	62	14	133	21	694	288	AES	Precipitation
Grum	62	18	133	16	1150	460[2]	AES	Precipitation
Mayo A	63	37	135	52	504	306	AES	Humidity/Sunshine/Temperature
Rose Creek	62	20	133	23	1080	-	DIAND	Snowpack
Ross River	61	59	132	27	698	264	AES	Precipitation
Snag A	62	22	140	24	587	339	AES	Humidity/Sunshine/Temperature
Whitehorse A	60	43	135	4	703	261	AES	Humidity/Sunshine/Temperature

NOTE: [1] AES: Environment Canada. Atmospheric Environment Service.
DIAND: Department of Indian Affairs and Northern Development.
[2] Estimated equivalent 1951-80 normal, derived by correlating short record at Grum station with long records at Faro and Ross River.

Table 3.2

Mean monthly climatic parameters for Anvil climate station

CLIMATE PARAMETER	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Rainfall (mm)	0	0	0	1	11	35	46	42	30	3	0	1	167
Snowfall (cm)	28	17	18	11	13	0	0	1	4	30	31	28	179
Total Precipitation (mm) [1]	26	22	30	16	16	42	50	42	33	37	30	25	368
Lake Evaporation (mm) [2]	0	0	8	53	90	112	108	81	31	10	0	0	493
Actual Evapotranspiration (mm) 2	0	0	8	20	30	43	40	23	14	8	0	0	186
Daily Maximum Temperature (deg C)	-15.1	-8.3	-5.3	2.2	9.3	16.0	17.5	15.2	9.6	1.6	-7.0	-12.6	1.9
Daily Minimum Temperature (deg C)	-24.9	-18.8	-17.3	-8.7	-1.8	3.0	5.0	3.3	-0.9	-8.1	-16.7	-22.4	-9.0
Daily Temperature (deg C)	-19.8	-13.9	-11.2	-3.2	4.0	9.9	11.5	9.5	4.6	-3.1	-11.6	0	-3.4

NOTE: [1] Snowfall for Anvil station is converted to a water equivalent by assuming a snow density of 0.1.

[2] Calculated using program WREVAP (National Hydrology Research Institute)

In order to estimate the MAP for mine elements located both above and below the Anvil climate station, an approximate precipitation-elevation relationship was required for the area. Development of this relationship was based on precipitation records at a second mine site station and at two stations on the valley floor of Pelly River. (The second mine site station, known as Grum, was installed in 1983 near the Vangorda Plateau Development. This station has an equivalent 1951-80 MAP normal of about 460 mm, as estimated by statistical methods.) The regional relationship between MAP and elevation is illustrated in Figure 3-9b. A linear regression fitted to the data of the climate stations indicates a precipitation gradient of about 30 mm per 100 m of ascent.

Extremes in annual precipitation were estimated by assuming that the Anvil data roughly conforms to a normal distribution. Inspection of regional climate stations with longer and more complete precipitation records than Anvil confirmed the validity of this assumption. The standard deviation for annual precipitation totals at the Anvil station is 78 mm, one of the highest values for stations within the Yukon. Table 3.3 shows the estimated 25-year and 100-year annual precipitation extremes for wet and dry conditions.

Table 3.3

Estimated Extremes in Annual Precipitation for Anvil Climate Station

RETURN PERIOD	ANNUAL PRECIPITATION (mm)
100-year high	550
25-year high	500
mean annual	368
25-year low	230
100-year low	190

3.6.3 Snowpack

The Rose Creek snow course was located near and at a similar elevation (1080 m) as the tailings impoundment area. The mean monthly snow depths and water equivalents for this snow course are presented in Figure 3-10. The accumulation of snow at the tailings impoundment typically begins in October, and the snow has generally melted by the end of April, although in 1985 it persisted into May. At maximum snowpack in March or April, the density of the snowpack is about 200 kg/m^3.

3.6.4 Evaporation

Two rates of evaporation are of interest, namely lake evaporation and actual evapotranspiration. The former refers to evaporation from a free-water surface while the latter refers to evaporation from a land surface including transpiration from plants. Both rates were estimated from meteorological data using a computer program known as WREVAP which was developed by the National Hydrology Research Institute (Morton, 1985).

The meteorological inputs to the WREVAP model comprise humidity, temperature and sunshine duration. Of these three factors, only temperature is measured at the mine site. Sunshine duration can readily be estimated from records of neighbouring climate stations but the third factor, humidity, is difficult to assess with certainty. The WREVAP model requires accurate humidity data which, therefore, precluded using the model to obtain a direct estimate of evaporation at the mine site. Instead, the model was used to estimate lake evaporation and actual evapotranspiration at regional climate stations that measure humidity and that also experience reasonably similar meteorological conditions as the mine site. Observed trends in the estimated evaporation rates at the regional stations were then extrapolated to the mine site.

Three climate stations, located at the airports of Mayo, Snag and Whitehorse, were identified as candidates for performing the analysis outlined above. Of the stations in the region that measure humidity, these three have meteorological conditions that most closely resemble those expected at the mine site. The major similarity between the three stations and the mine site is remoteness from a large body of water. The major detraction is that the three climate stations are located at elevations of 400 to 600 m below that of the mine site and accordingly, experience warmer air temperatures.

Figure 3-11 displays the results of applying the WREVAP model to the meteorological conditions at each of the three regional climate stations. The top graph shows estimates of mean monthly lake evaporation while the bottom graph shows the monthly distribution of actual evapotranspiration.

The three airport stations experience remarkably similar rates of lake evaporation despite the fact that the stations are located at different elevations. Since no trend with elevation was evident, the calculated lake evaporation at the Whitehorse Airport was arbitrarily selected to represent conditions at the mine site. The average annual lake evaporation works out to about 490 mm.

In contrast to lake evaporation, actual evapotranspiration appears to decrease with increasing elevation. Insufficient information is available, however, to extrapolate this trend to the mine site with any degree of certainty. As a best estimate, the calculated evapotranspiration values at the highest elevation station, Whitehorse Airport, were adopted for the mine site. The calculated actual evapotranspiration for this station is about 190 mm per annum, or 38% of lake evaporation. Table 3.2 presents the estimates of average monthly lake evaporation and actual evapotranspiration for the mine site.

3.7 Hydrology

3.7.1 General

Throughout the years since the late 1960's, a large number of investigations have been undertaken to characterize the hydrology of the Faro and Vangorda Plateau minesites and their immediate receiving environments. Most of these studies were prepared on an ad hoc basis, providing such information as the design flood for a proposed diversion channel, or the minimum size of reservoir required to provide a reliable water supply to the mill. A few studies were also undertaken to assess the minesite hydrology on a broader basis, both in terms of the number of locations examined and the number of hydrological variables studied (such as low flows and flood flows). These more comprehensive studies were completed during the preparation of earlier closure plans for the Faro site and during preparation of the Initial Environmental Evaluation for the Vangorda Plateau development. All of these ad hoc and comprehensive studies had to deal with one common problem: a sparse database of site-specific flow measurements, particularly for smaller drainage basins.

Some site-specific data were available for two of the larger streams in the immediate vicinity of the mine, but these were generally judged to be insufficient for the purposes of the various hydrological studies, largely because they were collected for a short period or were monitored only during the open water season. To compensate for this deficiency in the local data, the investigators of these hydrological studies invariably had to rely on regional data collected by government agencies at their networks of streamflow gauging stations. Various techniques were used to transfer these regional data to ungauged points on the minesite streams. These transferred data likely provided the best estimates of minesite streamflow that could be made at the time. However, two potential weaknesses existed in the database used to conduct these hydrological studies. Firstly, most of the government stations were sited on large rivers, with catchments one to three orders of magnitude larger than those commanded by the minesite streams. Secondly, stations some distance from the minesite (i.e., over 200 km away) had to be utilized in order to provide sufficient data to perform the hydrological assessment.

Most of these earlier hydrological investigations were conducted prior to about 1990. In the intervening period since that time, the streamflow monitoring network in the vicinity of the Anvil Range Mining Complex (ARMC) has been significantly enhanced. These enhancements have been realized by both the mine and the government. In the case of the mine, the flow monitoring program was improved by installing automatic water level recorders and by expanding the number of sites at which spot flow measurements were regularly taken. The government, on the other hand, stepped up their monitoring network with the addition of several new stations in reasonably close proximity to the mine complex.

Because of the improvements noted above, the decision was made to use the data collected since 1990 to update the general understanding of the minesite hydrology, as had been built up

over the years by the previous hydrological studies. Given that many of the improvements in data collection had occurred at the minesite itself, the further decision was made to rely on the site-specific data as much as possible and to place somewhat less emphasis on the data collected at the regional streamflow monitoring network. This latter decision posed some problems because much of the data collected at the minesite were regulated or, in other words, influenced by the operation of the mine in one fashion or the other. These influences were caused by such activities as the construction of diversion ditches, the operation of reservoirs and tailings impoundments, the abstraction of water for mill supply, and the discharge of tailings slurry and mine water. In examining ways of interpreting the available site-specific data, it was recognized that conventional hydrological techniques were inappropriate for dealing with regulated data. Accordingly, a method was sought which could accommodate regulated data and, at the same time, further the understanding of the minesite hydrology.

The adopted approach involved reconstructing the historical water balance for the Faro and Vangorda Plateau minesites for the period 1990 to 1995. To perform this task in an efficient manner, the water balance calculations were performed on a spreadsheet. The site-specific data served either of two purposes in developing the water balance, namely: as a direct input to the spreadsheet or as verification of the output generated by the spreadsheet. Full details on the development of the historical water balance are presented in Section 6.0. The remainder of this section is devoted to describing the hydrological analysis that had to be performed before the spreadsheet could be assembled. As it turned out, this preliminary work involved a considerable amount of data processing and interpretation. Much of the detail of this work has been reserved for the technical appendices (see Appendix B). A general description of the hydrological analysis and its main conclusions are presented below. Section 3.7.2 lists the data available at the minesite proper and also in the general region. Sections 3.7.3 and 3.7.4 describe how the data collected by the government and the mine, respectively, were processed into a form suitable for the hydrological analysis and the water balance assessment. Section 3.7.5 presents the adopted method for estimating the average annual runoff at ungauged points around the minesite. Finally, section 3.7.6 examines how the flows in the minesite streams are distributed on a seasonal basis.

3.7.2 Available Data

A variety of sources of information were used to supply data for the hydrological analysis, namely:

- the series of Annual Reports prepared for Water Licence IN89-001 (which present and evaluate water quality and quantity data collected at the Faro Mine and its immediate receiving environment);
- the series of Annual Reports prepared for Water Licence IN89-002 (which serve a similar function as above but for the Vangorda Plateau development);
- the streamflow records collected by the Water Survey of Canada (WSC) at their regional network of streamflow gauging stations;

- the streamflow records collected at the hydrometric monitoring network operated by the Water Resources Division of the Department of Indian Affairs and Northern Development (DIAND);
- the records of spot flow measurements made by DIAND personnel at many of the water quality monitoring sites throughout both the Faro and Vangorda Plateau developments;
- environmental reports prepared by various consultants (Steffen, Robertson and Kirsten Inc. and Laberge Environmental Services); and,
- unpublished data gathered by mine personnel, such as the raw data extracted from the mine's automatic water level recorders.

After reviewing the data available from the government monitoring networks, the records from a total of 19 streamflow gauging stations were selected for use in the hydrological assessment (16 of which were operated by the WSC and 3 by DIAND). Table 3.4 provides details of these stations, including their period of record and catchment area. Other information provided in this table will be discussed below in Section 3.7.5. The locations of these stations, together with the outlines of their catchment boundaries, are shown on a figure contained in Appendix B.

Two of the government stations listed in Table 3.4 were operated on minesite streams. The WSC operated a station on Rose Creek below Faro Creek (Station No. 09BC003) for the period August 1966 to December 1969. This record contained some data gaps. The flows measured at this station were natural up to September 1968 and afterwards were affected by operation of the mine's water supply dam on the South Fork of Rose Creek. DIAND presently operate a hydrometric station on Vangorda Creek upstream of the Faro Townsite road crossing (Station No. 29BC003). Initially, this station was operated in 1975 and 1976 by a consultant as part of a baseline study for the Vangorda Plateau development. DIAND then assumed responsibility for this station and operated it from 1977 to present with a three year break from 1986 to 1988. The Vangorda Creek station has only been operated during ice-free periods.

As indicated above in Section 3.7.1, the government streamflow monitoring network in the vicinity of the ARMC has recently been expanded. Recent additions to the network are Stations 09AH005 (Drury Creek), 09BC005 (Tay River), and 29BC004 (Blind Creek). The first two stations belong to the WSC monitoring network while the latter station is part of the DIAND network. Drury Creek is located some 50 km to the west of the ARMC. Tay River shares its catchment divide with both Anvil Creek and Vangorda Creek. The catchment of Blind Creek adjoins that of Vangorda Creek.

As also indicated above in Section 3.7.1, the mine itself operates a fairly extensive flow monitoring network which covers both the Faro and Vangorda Plateau developments. This observation is in stark contrast to the one that would have been made as little as six years ago when only a few locations were monitored for flow. The mine now measures the flow at over 25 locations. Table 3.5 provides details of the primary locations monitored within the Anvil Creek watershed while Table 3.6 presents the same information for the Vangorda Creek watershed. As noted in these

tables, the flows were measured using a wide range of techniques (viz., weir, bucket and stopwatch, current meter, staff gauge, and pressure transducer).

Table 3.4
Details of Regional Streamflow Gauging Stations

Streamflow Gauging Station		Period of Record	Catchment Area	Catchment Median Elevation	Mean Annual Runoff For Period 1990 - 1995		Mean Annual Runoff For Period 1966 - 1995	
ID No.	Name		(km^2)	(m)	(m^3/s)	(mm)	(m^3/s)	(mm)
WATER SURVEY OF CANADA								
09AH003	Big Creek near the mouth	1974 - 1994	1750	1070	9.3	168	8.3	150
09AG001	Big Salmon River near Carmacks	1953 - 1995	6760	1300	72.3	338	67.7	316
09AH005	Drury Creek at km 469 Robert Campbell Highway	1994 - 1995	559 [1]	1250	5.73	323	5.37	303
09BB002	MacMillan River near the mouth	1984 - 1995	13800	1130	147	336	135	309
09AD001	Nisutlin River above Wolf River	1979 - 1995	8030	1260	96.4	379	88.5	348
09AH004	Nordenskiold River below Rowlinson Creek	1982 - 1995	6370	1090	16.7	83	14.9	74
09BA002	Pelly River below Fortin Creek	1986 - 1994	5020	1290	77.1	485	70.8	445
09BC002	Pelly River at Ross River	1954 - 1974	18400	1160	197	338	177	304
09BC004	Pelly River below Vangorda Creek	1972 - 1995	22100	1210	223	318	201	287
09BC001	Pelly River at Pelly Crossing	1952 - 1995	49000	1110	435	280	390	251
09BC003	Rose Creek below Faro Creek	1966 - 1969	208	1430	2.27	344	2.08	316
09BA001	Ross River at Ross River	1960 - 1995	7250	1130	73.2	319	67.2	293
09AD002	Sidney Creek at km 46 South Canol Road	1982 - 1994	372	1250	4.50	382	4.13	350
09AG003	South Big Salmon River below Livingstone Creek	1982 - 1995	515	1340	4.38	268	4.02	246
09BB001	South MacMillan River at km 407 Canol Road	1974 - 1995	997	1440	21.5	681	19.7	624
09BC005	Tay River near the mouth	1990 - 1995	3810 [1]	1160	27.5	228	24.7	205
DEPARTMENT OF INDIAN AFFAIRS AND NORTHERN DEVELOPMENT								
29BC004	Blind Creek near Faro	1992 - 1995	618	1180	4.52	231	4.15	212
29BA002	180 Mile Creek at km 295.8 North Canol Highway	1975 - 1993	97.9	1310	0.90	290	0.83	268
29BC003	Vangorda Creek at Faro Townsite Road	1977 -1985, 1989 - 1995	91.2	1210	0.74	256	0.68	235

Notes: 1. The Water Survey of Canada has not yet published official values for the catchment areas of these two new stations. The values presented in this table were measured from 1:250,000 scale topographic maps.

Table 3.5
Flow Monitoring Network for Faro Development

Station ID No.	Description of Flow Stream	Period of Record Used in Study	Control	Typical Gauge Type	Typical Monitoring Frequency	Comment
FC	Faro Creek above diversion channel	1987 - 1991	Channel	Current meter	Monthly during open water	This gauging location is upstream of the inflows from the Faro Valley Interceptor Ditch.
R4	Rose Creek above Anvil Creek	1990 - 1994	Channel	Current meter	Quarterly	
R5	Anvil Creek below Rose Creek	1990 - 1994	Channel	Current meter	Quarterly	
R6	Anvil Creek above Rose Creek	1990 - 1994	Channel	Current meter	Quarterly	
R7	North Fork of Rose Creek above outlet of Faro Creek Diversion Channel	1990 - 1995	Channel	Current meter	Monthly	An automatic water level recorder was installed at R7 in 1990 but the pressure transducer malfunctioned. ARMC installed a new recorder at this location in 1996.
W1	Discharge from low-level outlet of the Fresh Water Reservoir	1986 - 1990	Weir	Staff gauge	Weekly	Flows were measured in discharge channel below low-level outlet.
X2	North Fork of Rose Creek at mine access road	1991 - 1994	Channel & culvert (at high flows)	Current meter and staff gauge	Varied	This site was equipped with a staff gauge. Readings of the gauge were periodically made during 1991 and 1992.
X5	Surface releases from the Cross Valley Dam to Rose Creek	1990 - 1995	Various	Pump and siphon	Weekly	Releases were accomplished in three ways, namely: spill over the embankment spillway, siphoning, and pumping.
X10	Rose Creek Diversion Channel near the outlet	1990 - 1995	Constructed channel	Current meter	Monthly	Flows were monitored year-round.
X13	Seepage at toe of Cross Valley Dam	1986 - 1995	Weir	Staff gauge	Weekly	This station is located approximately 100 m below the toe of the dam.
X14	Rose Creek below diversion and Down Valley Tailings Impoundment	1990 -1995	Channel	Pressure transducer	15 or 30 minutes	Water levels at X14 are monitored by a pressure transducer and data logger. Frequent spot flow measurements have been made with a current meter.
X22	Dewatering of Main Pit (water accumulating in bottom of pit)	1987 - 1992	Pump	Bucket and stopwatch	Monthly	Dewatering program ceased in July 1992 when pit became repository for tailings.
X22A	Dewatering of Main Pit (water accumulating in sump located below Faro Valley Waste Dump)	1987 - 1992	Pump	Bucket and stopwatch	Monthly	Dewatering program ceased in summer of 1992 when the Main Pit became the repository for tailings.
X23	Old Faro Creek channel at toe of waste dumps	1986 -1995	Rectangular weir	Measurement at brink of weir with ruler	Monthly	Prior to 1993, some portion of the Main Pit dewatering flows may have contributed to the flows gauged at this station.
X26	Dewatering of Zone II Pit	1991 - 1995	Pump	Record of pumping hours	Varied	An approximate flow record was reconstructed based on pumping hours. In 1995, mine personnel began monitoring pump operation with automatic recorder.

Table 3.6
Flow Monitoring Network for Vangorda Plateau Development

Station ID No.	Description of Flow Stream	Period of Record Used in Study	Control	Typical Gauge Type	Typical Monitoring Frequency	Comment
V1	Vangorda Creek above Blind Creek Road	1991 - 1995	Channel	Current meter	Quarterly	The V1 flows exclude the drainage conveyed by the ditches located on the north side of the Blind Ck Road.
V2	Grum Creek near the mouth	1992 and 1995	Channel	Various	Monthly	For the period up to spring 1995, the discharge from the Grum Northeast Interceptor Ditch was a component of the flow measured at V2. This ditch was subsequently rerouted to the plunge pool at the outlet of the Vangorda Creek Diversion flume.
V4	Shrimp Creek near the mouth	1991 - 1992	Channel	Current meter	Quarterly	The Vangorda Northeast Interceptor Ditch diverts flow to the catchment of Shrimp Creek.
V5	West Fork of Vangorda Creek above the mine access road	1991 - 1995	Channel	Current meter	Quarterly	
V6A	AEX Creek near the mouth	1991 - 1995	Channel	Various	Monthly	This station provided flow data for a small catchment (4.4 km^2) in the vicinity of the mine. Some flow measurements were made in the winter months.
V7	Overflow from Grum Portal	1991 - 1992	Unknown	Unknown	Monthly	The discharge from the portal ceased in Sep. 1992.
V8	Vangorda Creek near the mouth	1991 - 1995	Channel	Current meter	Quarterly	This station is located some 2.5 km downstream of a streamflow gauging station (29BC003) operated by DIAND. Minimal inflows occur in the reach of Vangorda Creek between Stations 29BC003 and V8.
V18	Grum Northeast Interceptor Ditch below discharges from the Grum interceptor wells	1991 - 1995	Channel	Various	Monthly	This station monitored most of the flows pumped from the local aquifer in the Grum Pit area, together with the runoff generated by the catchment of the ditch.
V19	Vangorda Northwest Interceptor Ditch	1995	Channel	Various	Monthly (open water)	Ditch freezes in winter.
V20	Vangorda Northeast Interceptor Ditch	1991 -1992 and 1995	Channel	Various	Monthly (open water)	Flow is intermittent.
V21	Discharge from Vangorda Waste Dump Collection Ditch	1992	Channel	Unknown	Infrequent	Only one flow measurement was located for this station.
V24	Influent to Water Treatment Plant (WTP)	1991 - 1995	Pump	Meter or record of pumping hours	Varied	During the period 1991 to 1995, most of the feed for the WTP originated from dewatering of the Vangorda Pit and drainage from the Vangorda Waste Dump. Accordingly, this record provided a measure of the combined contribution from these two sources.
V27	Vangorda Creek above Shrimp Creek	1991 - 1995	Channel	Current meter	Quarterly	

3.7.3 Processing of Government Data

Most of the government stations listed in Table 3.4 were operated on a year-round basis and possessed long periods of record. Processing of the data for these particular stations was a straightforward task, involving nothing more than importing the monthly flow record of each station into a spreadsheet and then computing averages.

Some stations, however, were operated for only a short period or had records which contained gaps of missing data. The value of these stations to the current hydrology study was significantly improved by "patching" their streamflow records (i.e., infilling the gaps or extending the length of record with estimated flows). This section describes the analysis that was undertaken to patch the incomplete and/or short streamflow records.

The method adopted to patch the records involved correlation with a nearby streamflow station. The implementation of the method was broken down into four broad steps. Firstly, a preliminary selection process was undertaken. For each station to be patched, i.e. each "target" station, a search was made of all possible candidate stations that could be used as a "control" (i.e., a station which provided the required independent data for the correlation). Candidates were selected on the basis of two criteria, namely: their period of record must overlap that of the target station; and, their flows must be monitored all year-round.

The second step in the process involved screening the candidates to identify the most suitable control station. To accomplish this, the daily streamflow records of the target station and all the candidate stations were imported into a spreadsheet program (EXCEL 5.0). For each candidate station, the statistical module of the spreadsheet was used to fit a regression curve between the overlapping sets of data from the target station record (dependent variable) and from the candidate station record (independent variable). The candidate station yielding the highest correlation coefficient was then adopted as the control.

The third step entailed using the control station's streamflow record and its associated regression curve to make estimates for the missing pieces of data in the target streamflow record. These estimates were then inserted into the appropriate position within the daily record of the target station. The estimates were flagged with a plus sign (+) so that patched flows could be distinguished from the actual observed flows.

The final step was to convert the patched daily record into a monthly record. Plus signs were retained for the monthly records to identify those computed monthly flows that were based on one or more patched daily values.

The process described above was applied to the following government streamflow stations:

- Drury Creek at km 469 Robert Campbell Highway;
- Rose Creek below Faro Creek;
- Tay River near the mouth;
- Blind Creek near Faro;

- Mile Creek at km 295.8 North Canol Highway; and,
- Vangorda Creek at Faro Townsite Road.

Appendix B fully documents the patching process for all six streamflow stations. The results for one of the stations, Blind Creek near Faro, are presented below to illustrate the patching process. This station was operated only during the period of open water and, accordingly, its winter flows were missing. The daily flows measured at this station were correlated with the flow records of several nearby gauging stations. Of all the correlations examined, the one between the flows of Blind Creek and Tay River turned out to have the highest correlation coefficient (r^2=0.90). Figure 3.12 shows a scatter plot of the coincidental data measured at these two stations. Also shown on this figure is the regression curve fitted to these data. This curve is a power function and not a straight line (i.e., the least-squares regression was performed on log-transformed data rather than on the raw data). A power function was selected over a straight line for two reasons. Firstly, this recognized that small streams exhibit greater variability in their flows than do large streams (i.e., the ratio between the annual maximum and annual minimum flows is greater for a small stream than for a large stream). As a consequence of this trend of increasing streamflow variability with decreasing stream size (or catchment size), one would expect scatter plots for differently-sized streams to have a curved appearance. In particular, if the vertical axis is used to represent the flows generated by a small catchment and the horizontal axis is used for the flows from a large catchment, then the resulting relationship should exhibit a concave-upwards form. A power function can better fit this form than can a straight line.

The second reason for adopting a power function was to force the correlation through the origin. This avoided the generation of negative flow estimates during the low-flow months which could occur with the use of a straight line (i.e., a linear regression fitted to data with a concave-upward shape would normally have a negative value for its intercept constant).

Figure 3.13 presents the observed daily streamflow record for Blind Creek at Station 29BC004. Superimposed on this figure is the "transposed" flow record obtained by correlation between the Blind Creek and Tay River flows. As can be seen, the observed and transposed flows match remarkably well.

3.7.4 Processing of Mine Data

The processing of mine data comprised any combination of the following three tasks:

- data acquisition;
- conversion of water level data to corresponding flow rates; and,
- data patching.

To accomplish the first task, an effort was made to assemble all reports and databases which likely contained flow measurements collected at the mine over the past decade. The single most important source of information was the Annual Reports prepared by mine personnel, but valuable information was also provided by various consultant reports and from a database maintained by DIAND. All of the assembled reports and databases were scoured to extract any data pertaining

to flow measurement at the mine. The extracted data were then checked for accuracy (where possible), converted to consistent units, and entered into spreadsheets. Flow records were created for all of the monitoring stations listed in Tables 3.5 and 3.6.

The second "data processing" task only had to be undertaken for one flow monitoring station, namely Station X14 (Rose Creek below the Down Valley Tailings Impoundment). A pressure transducer and datalogger were installed at this location in September 1990. This equipment has remained functional ever since. Accordingly, the potential existed for this equipment to monitor an uninterrupted record of water level from September 1990 to present. However, for various reasons discussed below, it was not possible to assemble the complete water level record for this station. The first gap in the record spanned the period May 1992 to March 1993. The water level record for this period had undoubtedly been measured by the X14 gauging station and subsequently downloaded from the datalogger. However, an exhaustive search of the mine's environmental records failed to locate these data. Two other shorter gaps occurred in the record, covering periods of from two to three months during the winters of 1994 and 1995. These gaps were caused when the memory of the datalogger filled between maintenance visits to the X14 gauging station.

A total of 53 current meterings have been conducted at X14 since the installation of the datalogger (see Appendix B for a listing of these measurements). Figure 3.14 shows a stage-discharge relationship for X14 based on the measured discharges and the coincident water levels recorded by the pressure transducer. A power regression was fitted to these data to enable extension of the rating curve to higher flows. This rating curve was used to convert the water level measurements at X14 to corresponding flow rates on a daily basis. Figure 3.15 shows the computed daily flows at X14 for the period September to December 1990. The remainder of the X14 discharge record is presented in Appendix B.

The third task in processing of the mine data involved patching flow records. As discussed above in Section 3.7.3, the term "patching" refers to the infilling of gaps in the flow records using estimated values. Although all of the flow records listed in Tables 3.5 and 3.6 contain gaps of missing data, it was neither practical nor necessary to infill each and every one of these flow records. The following two "categories" of flow records were identified as suitable candidates for patching:

- records slated for use as input to the historical water balance spreadsheet (as discussed above in Section 3.7.1); and,
- records which were reasonably complete and also designated for the purpose of verifying the output from the water balance spreadsheet.

Most of the flow records in the first category were patched by linear interpolation or by infilling with average flows. Other techniques were also utilized. Owing to the large number of records involved, the patching techniques for the "first category" records are not reviewed further here. Instead, details of the patching process may be obtained by referring to the spreadsheet used to reconstruct the site historical water balance. As described later in Section 6.0, much of the detail involved in developing the water balance spreadsheet was documented in the spreadsheet itself.

Only one monitoring site, namely Station X14, met the criteria set out for the second category of mine flow records. The flow record for this station was patched in much the same manner as described in Section 3.7.3 for the government flow records. Correlations were performed between the daily flows of Station X14 and those of several neighbouring WSC gauging stations. Based on the resulting correlation coefficients, the best correlation was identified to be the one with the flows of Tay River. The data used for the correlations were limited to the period subsequent to August 1992. For the period prior to this, the winter flows at Station X14 were significantly influenced by the discharge of tailings into the Down Valley Tailings Impoundment (i.e., the discharge from the tailings impoundment was the dominant component of flow at X14 during the winter months). Figure 3.15 shows the patchings which were derived by the correlation to infill missing data within the 1990 daily record for Station X14. Full details of the patching process for Station X14 are contained in Appendix B. Table 3.7 shows the patched monthly flow record for this station for the period 1990 to 1995, as derived from the patched daily record. Plus signs denote those months in which one or more of the daily values within the month had to be patched.

Table 3.7
Patched Monthly Discharge Record for Station X14 for Period 1990 to 1995
(Rose Creek below tailings impoundment and diversion channel)

Year	Monthly and Annual Average Discharges (m^3/s)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1990	0.78 +	0.61 +	0.57 +	0.72 +	5.56 +	4.52 +	2.83 +	2.32 +	5.30 +	2.34	0.83	0.50	2.25
1991	0.54	0.58	0.56	0.93	5.38	4.91	5.16	3.67	4.24	2.23	1.13	0.67	2.51
1992	0.55	0.61	0.53	0.80	4.36 +	10.5 +	5.03 +	2.62 +	2.44 +	0.78 +	0.39 +	0.20 +	2.40
1993	0.14 +	0.11 +	0.14 +	0.64	7.71	6.01	3.58	2.39	2.77	2.22	1.10 +	0.93 +	2.33
1994	0.41 +	0.20 +	0.13 +	0.78 +	4.22	5.31	2.92	1.80	1.81	2.12	1.41 +	0.60 +	1.82
1995	0.36 +	0.35 +	0.49 +	0.75 +	2.92	2.71	2.92	2.38	4.19	2.19	1.03 +	0.32 +	1.72
Mean	**0.46**	**0.41**	**0.40**	**0.77**	**5.02**	**5.67**	**3.74**	**2.53**	**3.46**	**1.98**	**0.98**	**0.54**	**2.17**

Note: Patched monthly values are flagged with a plus sign (+).

3.7.5 Mean Annual Runoff

As discussed above, great strides have been made in the collection of site-specific flow data at the Faro and Vangorda Plateau Developments. These site-specific data proved to be a great aid in characterizing the minesite hydrology, particularly in deciphering the various influences the mine operation has had on the local hydrology. Despite the improvements in the mine's monitoring network, considerable reliance still had to be placed on the regional WSC and DIAND data to derive a more complete picture of the minesite hydrology. This and the following subsection describe how these regional data were incorporated into the current hydrological assessment.

In general, the data collected by the WSC and DIAND were used to characterize the minesite hydrology by employing a technique known as regional analysis. Essentially, this involved deriving empirical relationships between the measured streamflow of the regional stations and the physical characteristics of the catchments which generated the streamflow. These empirical relationships then formed the basis for estimating flows at ungauged points around the Faro and Vangorda Plateau minesites.

To derive a specific relationship for estimating mean annual runoff (MAR), a well-known observation about precipitation variability was exploited. As noted in Section 3.6, elevation generally accounts for a large proportion of the variation in mean annual precipitation within a mountainous region. It follows, therefore, that MAR must also be a function of elevation. Figure 3.16 shows how this observation was used to estimate the average flows of the minesite streams. The vertical axis of this figure displays values of MAR expressed as equivalent depths of water. The horizontal axis, on the other hand, shows values of median elevation, which is the variable adopted to characterize the elevation properties of the regional and minesite catchments. Median elevation is defined as the contour which divides a catchment exactly into halves. The following sources of data were assembled to derive a relationship between the two variables on this figure:

- nineteen pairs of MAR and median elevation data provided by the WSC and DIAND stations listed in Table 3.4; and,
- four pairs of MAR and median elevation values provided by four incremental catchments monitored by the WSC (as explained below).

Four tasks were undertaken to assemble the first source of data. Firstly, the government streamflow records with missing data were patched (as already described above in Section 3.7.3). Secondly, the series of annual average discharges for each station were averaged to arrive at a preliminary estimate of MAR. Thirdly, using various techniques, the preliminary MAR estimates were adjusted so they were all representative of a common 30-year period from 1966 to 1995 (much like what is typically done for climatic normals). Finally, the median elevations for all the stations were measured from topographic maps using a planimeter.

The second source of data is essentially a subset of the first. Where more than one streamflow gauge was located on a river, it was possible to provide a set of MAR and median elevation

values for the intervening catchment area between the gauges. For example, the runoff generated by the lower Pelly River catchment was quantified by subtracting the flows measured at Stations 09BB002 and 09BC004 from those at Station 09BC001. The median elevation of this incremental catchment was measured by examining only the area which lies between these three gauging stations.

Once all the data were assembled and processed, a curve was fitted to the data to develop a relationship which was believed to represent the conditions at the minesite. Fitting of this curve turned out to be a straightforward task because the stations in closest proximity to the mine all fell within a narrow band on Figure 3.16. (To aid the reader's evaluation of the fitted curve on Figure 3.16, the data labels for these closest stations were printed in bold type.)

The relationship on Figure 3.16 was used to estimate the average flows on the minesite streams using the following four-step algorithm:

- a point of interest was defined and its catchment boundary outlined on a topographic map;
- using a planimeter, both the catchment area and catchment median elevation were measured;
- the curve on Figure 3.16 was entered at the appropriate value of median elevation and the corresponding unit MAR value was read from the graph's vertical axis; and,
- the product of unit MAR and measured catchment area was calculated to estimate the long-term average annual runoff volume for the point of interest.

3.7.6 Seasonal Runoff Distribution

Two different approaches were used to derive a typical monthly runoff distribution for the minesite streams. One involved examining how the distributions for the regional stations correlate with catchment characteristics. The other entailed making comparisons between the regional and minesite data.

Figure 3.17 graphically presents the analysis undertaken for the first approach. This figure shows the monthly distributions, expressed as percentages of MAR, of six regional stations. These stations were selected to illustrate the distributions from catchments with a broad range of physical characteristics. All distributions are characterized by high spring flows during snowmelt and low winter flows during prolonged freezing conditions. Examination of the distributions indicates median elevation is a reasonably good predictor of the shape of a stream's average monthly hydrograph. As expected, low elevation catchments generally experience earlier peaks than high elevation catchments.

Figure 3.18 illustrates part of the analysis employed in the second approach. Essentially, the monthly flow records of the regional streamflow stations were plotted on graphs for the period 1990 to 1995. The observed (not patched) data for Rose Creek at Station X14 and Vangorda Creek at Station 29BC003 were then superimposed on these graphs. To facilitate comparison between the regional data and the minesite data, all monthly flows were standardized. Two

different methods were used to standardize the data, namely division by catchment area (to get units of L/s/km2), and division by the long-term average flow (to get values which are a proportion of the MAR).

Based on the first approach, one might select the runoff distribution for South Big Salmon River as being the most representative of the minesite streams, strictly on the basis of a similarity in catchment median elevation. In contrast, the second approach indicated that the seasonal distribution of the Tay River was clearly the most representative of all the stations examined. Since the second approach was undoubtedly the most reliable, the distribution for the Tay River was adopted to represent the monthly streamflow distribution of the minesite streams.

3.8 Hydrogeology

3.8.1 Regional Hydrogeology

The study area is underlain almost exclusively by bedrock consisting of schist and phyllite of Proterozoic and Paleozoic age, which have been intruded in Mesozoic time by the granodiorites and quartz monzonites of the Anvil Batholith. This bedrock does not support deep, contiguous aquifers of any significant size. Groundwater flow in bedrock is structurally controlled, i.e. occurs predominantly along structural features such as fault zones and individual fractures provided the bedrock is competent and supports open fractures. The anisotropy of groundwater flow is further enhanced by the schistosity of the bedrock in the study region.

At present, little is known regarding the direction of regional groundwater flow at depth. Sub-vertical faults have been mapped between Rose Creek and the Pelly River which probably inhibit groundwater flows at depth between those two watersheds.

Most groundwater flow in the study region is confined to local, shallow aquifers in surficial deposits of glacial till and/or alluvial sediments. These surficial deposits are distributed irregularly within the region typically comprising thin deposits in the upland areas and thicker deposits in the valleys. The direction of shallow groundwater flow is largely controlled by surface and/or bedrock topography. In many uphill areas surficial sediments comprise only a thin veneer of glacial till over bedrock, and shallow groundwater flow occurs at the bedrock/overburden interface, often within a narrow zone of intensely weathered bedrock and overlying permeable sediments. In those upland areas with deeper surficial deposits, groundwater is often confined to narrow zones of sand and gravel which represent high-permeability conduits that deliver shallow groundwater from the sidehills to the valley bottom.

Shallow groundwater from the sidehills either discharges to a near-by creek or discharges into a valley aquifer located further downstream. Deep groundwater may also recharge these valley aquifers at depth, albeit at a much smaller rate than shallow groundwater. The valley aquifers are typically unconfined with the water table at or very close to the elevation of the stream bed. Once the groundwater has reached the valley aquifer it moves gradually within the thick, permeable deposits of glacio-fluvial sediments downstream, discharging into the stream and its flood plain

during periods of high flow. During periods of low flow these aquifers are being recharged by the stream.

The larger glaciated valleys in the study area such as Pelly River flood plain, Rose Creek Valley (North Fork and South Fork) and Blind Creek Valley (Figure 1-2) represent primary locations for valley aquifers of significant size. These glaciated valleys typically comprise thick deposits of glacio-fluvial sediments which can support significant flows of groundwater. This consideration spurred a hydrogeological investigation conducted by International Water Supply in 1967 to determine the feasibility of using the aquifer in Rose Creek Valley as seasonal water supply for the milling operation at the planned Faro mill site (see below).

Several boreholes were drilled in Rose Creek Valley near the confluence of Faro Creek and Rose Creek. The drilling program indicated that the valley contained up to 70 feet of permeable sands and gravel in the centre of Rose Creek valley. Pump tests suggested that significant groundwater flows (~4600m^3/day) occur in the overburden material of Rose Creek Valley. Based on water level readings it was estimated that 2/3 of this groundwater flow originated from further upstream in Rose Creek valley whereas 1/3 comprised groundwater inflows from Faro Creek valley to the north of Rose Creek valley (IWS, 1967).

The 1967 groundwater investigation is the only source of pre-mining ("baseline") data on hydrogeology at the Faro mine site. All subsequent hydrogeological studies were motivated by issues of water management, including groundwater seepage into open pits and associated slope stability problems and monitoring of groundwater quality. Table 3.8 lists all groundwater investigations which have been reviewed as part of this study. All pertinent groundwater data presented in these reports, including borehole information and piezometer installation details are compiled in Appendix C for ease of reference.

Table 3.8

List of Hydrogeological Studies at Anvil Range Mining Complex

DATE	AUTHOR	TITLE
Dec., 1967	International Water Supply	Anvil Mine Yukon Territories - Groundwater Investigation
Feb., 1976	Piteau Gadsby MacLeod Limited	Results of Test Holes Drilled for Stratigraphy and Groundwater Observations
Jan., 1978	Piteau and Associates	Drainhole Installation and Related Monitoring for Groundwater Drainage of Faro Valley
Sept., 1981	Klohn Leonoff	Faro Mine Tailings Abandonment Plan
Oct., 1986	Piteau and Associates	Assessment of Groundwater Conditions in Faro Pit, East Wall
July, 1986	International Water Supply	An Outline of the 1986 Groundwater Investigation and Water Supply Development
July,1989	Hydrogeological Consultants Ltd.	Grum Pit - 1988 Dewatering Assessment
July,1989	EBA Engineering Consultants Ltd.	Piezometer and Dewatering Well Installation Report - Grum, Vangorda and Faro Mine Sites, Faro, Yukon
Dec., 1990	Piteau Associates	Hydrogeological Assessment and Development of Groundwater Control Strategy
Jan., 1991	Piteau Associates	Grum Pit Review and Analysis of Hydrogeological Data and Design of Phase I Dewatering System
April, 1991	Piteau Associates	Grum Pit Dewatering Well GDW 91-2 - Pump Test Analysis and Pump Selection
Nov., 1994	SRK - Robinson Inc.	Construction Report Vangorda Rehabilitation PWGSC Project 760831, Vangorda Plateau, Faro Mine Yukon Territory
Dec., 1994	Steffen, Robertson and Kirsten	Groundwater Investigation North Fork of Rose Creek, Faro Mine, Yukon Territory
June, 1995	Piteau Associates	Current Groundwater Conditions in the Southeast Walls of the Grum Pit
Dec., 1996	Robertson GeoConsultants Inc.	Anvil Range Mining Complex - 1996 Piezometer Installation Program

3.8.2 Groundwater Chemistry

As a result of short flow paths shallow groundwater generally has a low solids content and its water chemistry is similar to that of surface water in the area. In contrast, deep groundwater within the bedrock typically has a higher solids content due to much longer residence times. In general, the chemical composition of deep groundwater is controlled by the solubility of primary and secondary minerals present in the bedrock and fracture zones.

Data on pre-mine groundwater quality in the Rose Creek Valley aquifer is limited to the groundwater investigation undertaken by International Water Supply in 1967. Table 3.9 shows pre-mining water quality in several boreholes drilled into the valley aquifer (field analyses done by IWS). Only a few selected parameters were analysed in this first groundwater investigation. Field pH ranged from 6.5 to 7.5 and hardness from 85 mg/L to 187 mg/L. Iron was less than 0.5 mg/L in all boreholes. The data suggest that shallow groundwater (at least in the upper unconfined layers) was similar in composition to that of Rose Creek prior to mine development. Unfortunately, no samples of deep groundwater in bedrock were taken prior to start-up of the mine.

Table 3.9

Pre-mining Groundwater Quality in Rose Creek Valley Aquifer (from IWS, 1967).

TEST WELL	SCREENED INTERVAL (FEET B.G.S.)	HARDNESS[2] PPM	FE[2] PPM	CHLORIDE[2] PPM	pH[2]
1/67	31 - 50	136	0.0	<50	7.0
2/67	93 - 115	85 (1375)	0.5 (0.5)	<25 (<25)	6.5 (7.8)
3/67	37 - 59	187	0.1	<25	6.5
6/67	37 - 57	153	0.2	<25	7.1
8/67	57 - 77	102	0.2	<25	7.0
Anvil Camp Well	62 - 72	85	0.2	<25	7.6
Rose Creek	n.a.	102	0.0	<50	7.5

[2] all values shown are results of field analyses; only values in brackets are lab analyses

3.8.3 Impact of Mine Development

The development of the Faro mine site and subsequently the Grum/Vangorda mine site has had a substantial impact on the local hydrogeology, i.e. groundwater flows and groundwater quality in the immediate vicinity of each site. Table 3.10 lists the various components of each mine site, their impact on the local hydrogeology, and references to field studies on the hydrogeology of the respective mine components. Foremost has been the development of three open pits (Faro, Grum and Vangorda open pits) which were excavated into the overburden soils and underlying bedrock. These pits represent local sinks in particular for shallow groundwater which is flowing into the pits from upstream along the overburden/bedrock interface. Inflows of deep groundwater from the surrounding bedrock appears to be very limited and is restricted to those areas where fault zones and/or contact zones resulted in some secondary permeability. In general, the pit walls do not appear to be free-draining and a large-scale lowering of the water table has not been observed.

The Rose Creek Tailings Facility has had a significant impact on the hydrogeology and hydrogeochemistry of the Rose Creek valley aquifer. Tailings pore water has infiltrated into the underlying aquifer for some 25 years now resulting in elevated concentrations of oxidation products such as iron, zinc and sulphate immediately beneath the impoundment. Thus far, no significant increase has been observed in the concentration of these contaminants in monitoring wells some 100 meters downstream of the tailings facility suggesting that contaminant transport in this alluvial aquifer is relatively slow.

For a more detailed discussion of the impact of the various mine components on the local hydrogeology and hydrogeochemistry, the reader is referred to the respective sections indicated in Table 3.10.

Table 3.10a

Influence of Various Mine Developments on Local Hydrogeology at Faro Mine Site.

MINE COMPONENT	INFLUENCE ON LOCAL HYDROGEOLOGY	REFERENCE SECTION IN TEXT	HYDROGEOLOGICAL INVESTIGATIONS
Faro main pit (Zone 1 and 2 I)	interception of shallow groundwater from upslope (esp. from Faro Creek valley); some inflow of deep groundwater at exposed fault zones ("depressurization")	see sections 4.1.3.3 and 4.1.3.4	Piteau, Gadsby, Macleod Ltd., 1976 Piteau & Associates, 1978 Piteau & Associates, 1986
Zone 2 pit	interception of shallow groundwater from surrounding sub-watershed; pumping required to maintain water level in backfilled pit below rock sill elevation to avoid seepage of contaminated groundwater towards North Fork of Rose Creek	see section 4.1.4.3	Steffen, Robertson & Kirsten, 1994
Faro Rock Dumps	possible attenuation of local runoff: increased solids content in shallow groundwater	see section 4.2.13	EBA Engineering Consultants, 1989 Steffen, Robertson & Kirsten, 1992 Steffen, Robertson & Kirsten, 1994 Robertson GeoConsultants, 1996
Rose Creek Tailings Facility	increased recharge to valley aquifer in ponded areas and reduced recharge in beach areas; seepage of contaminated tailings pore water into underlying valley aquifer	see section 4.3.5 and 4.3.6	International Water Supply Ltd., 1967 Klohn Leonoff, 1981 International Water Supply Ltd., 1987 Steffen, Robertson & Kirsten, 1991 Robertson GeoConsultants, 1996
Freshwater Reservoir	increased recharge to aquifer in South Fork Rose Creek valley		Klohn Leonoff, 1981 International Water Supply Ltd., 1987

Table 3.10b

Influence of Various mine Developments on Local Hydrogeology at Grum/Vangorda Mine Site.

MINE COMPONENT	INFLUENCE ON LOCAL HYDROGEOLOGY	REFERENCE SECTION IN TEXT	HYDROGEOLOGICAL INVESTIGATIONS
Vangorda pit	interception of shallow groundwater from upslope (esp. from Vangorda Creek channel); little inflow of deep groundwater at exposed fault zones ("depressurization")	see section 5.3.1	EBA Engineering Consultants, 1989
Vangorda Rock Dump	possible attenuation of local runoff;	see section 5.3.1	Steffen, Robertson & Kirsten, 1995
Grum pit	interception of shallow groundwater from upslope; significant dewatering of a confined sand & gravel aquifer	see section 5.3.2	Piteau & Associates, 1987 EBA Engineering Consultants, 1989 Hydrogeological Consultants Ltd., 1989 Piteau & Associates, 1991 Piteau & Associates, 1995
Grum Main Dump	possible attenuation of local runoff	see section 5.3.2	Piteau & Associates, 1995 Robertson GeoConsultants, 1996

3.9 Surface Water Chemistry

3.9.1 Database Contents and Organization

Water quality sampling and analysis has been carried out by both the mine and by various regulatory authorities over the years of operation. The data have been compiled using the EQWin Water Quality Database Program and used for the calculations of loadings and trend analysis.

The database comprises the following sources of data:

- monthly water quality sampling by the various mine operators with analysis at an external laboratory, including the water license stations and additional stations sampled by the mine;
- water quality sampling and analysis by Environment Canada, Environmental Protection Service;
- seep survey sampling and analysis carried out by the mine as per the water license.

The data for the compilation of this database were collected from several sources:

- database from Environment Canada which was modified to include detection limits, and samples at the "less than detection" values, and to standardize the units for flow;
- database from DIAND which was modified to include detection limits, and samples at the "less than detection" values, and to standardize the units for flow;
- mine data;
- data compiled for the Down Valley Tailings Impoundment Decommissioning Plan, SRK Report 60635, April 1991.

Data has been collected by a variety of laboratories and in a variety of databases. The original source of each data set was used for this compilation wherever possible. Attempts were made to evaluate apparently anomalous data by comparison with original data sheets or data sources.

3.9.2 Sampling Stations

The surface water sampling stations for the Faro site are shown on Figure 3-19 and are listed in Tables 3.11 and 3.12. Details of the stations are provided in Appendix D.

The groundwater monitoring stations for the Faro Site are listed in Tables 3.13 and 3.14. Details of the monitoring stations and observed groundwater quality in the Faro Pit and Dump area and Rose Creek Valley are discussed in sections 4.2.13 and 4.3.6, respectively.

Table 3.11

Licence Specified Surface Water Sampling Sites at Faro Mine Site

STATION	DESCRIPTION
X1	Old Tailings Pond decant
X2	North Fork of Rose Creek u/s of mine access road
X3	South Fork Rose Creek at the pumphouse reservoir
X4	Intermediate Dam decant
X5	Cross Valley Dam decant
X7	Old Faro Creek Channel at mine access road
X9	Tailings Line Discharge
X10	Rose Creek Diversion Channel below weirs
X11	Seepage from north toe of Cross Valley Dam
X12	Seepage from south toe of Cross Valley Dam
X13	Combined seepage from Cross Valley Dam
X14	Rose Creek downstream of the diversion channel
X22	Faro Pit dewatering (from bottom of pit)
X22A	Faro Pit dewatering (from Sump A30)
X22B	Faro Pit Water while Filling with Tailings
X23	Old Faro Creek channel at toe of waste dumps
R4	Rose Creek upstream of Anvil Creek
R5	Anvil Creek downstream of Rose Creek
R6	Anvil Creek upstream of Rose Creek
R7	North Fork of Rose Creek above Faro Ck Diversion
R8	North Fork of Rose Creek 900 m below Faro Ck Div.
R9	North Fork of Rose Creek adjacent BH1 and BH2
R10	North Fork of Rose Creek downstream of BH1 and BH2

Table 3.12

Additional Surface Water Sampling Sites at Faro Mine Site

STATION	DESCRIPTION
FC	Faro Creek above diversion channel
FCD	Faro Creek Diversion adjacent NE Waste Dumps
FCO	Old Faro Creek Site 29/30
FDU	Faro Creek Diversion Upstream
A30	Upper Pit Wall Zone MPA6 Sump
FVW	Faro Valley Intercept
GHSCR1	Guardhouse Creek below Waste Dump
GHSCR2	Guardhouse Creek u/s of Intermediate Dam Imp.
NF1	North Fork Rose Creek Site 1 u/s of Haul Road
NF2	North Fork Rose Creek Site 2 d/s of Haul Road
NWI	North Wall Interceptor
SP5-6	Zone 2 Area Seep Survey Interceptor Ditch
W10	North West Waste Dump Toe - W10
W8	Upper Guardhouse Creek d/s of NW Dump

Table 3.13

Licence Specified Groundwater Monitoring Sites at Faro Mine Site

STATION	DESCRIPTION	COMMENTS
X16A	Monitoring Well 81-K1 shallow piezometer at depth of 5 m	
X16B	Monitoring Well 81-K1 deep piezometer at depth of 30 m	
X17A	Monitoring Well 81-K2 shallow piezometer at depth of 5 m	
X17B	Monitoring Well 81-K2 deep piezometer at depth of 20 m	
X18A	Monitoring Well 81-K3 shallow piezometer at depth of 10 m	
X18B	Monitoring Well 81-K3 deep piezometer at depth of 20 m	
X19A	Monitoring Well 81-K4 shallow piezometer at depth of 12 m	destroyed; not sampled any longer
X19B	Monitoring Well 81-K4 deep piezometer at depth of 27 m	destroyed; not sampled any longer
X20	Monitoring Well 81-K5 piezometer at depth of 20 m	frozen; not sampled any longer
X21A	Monitoring Well 81-K6 shallow piezometer at depth of 12 m	destroyed in 1989; replaced in fall of 1996 by new monitoring well (96-5)
X21B	Monitoring Well 81-K6 medium piezometer at depth of 28 m	as above
X21C	Monitoring Well 81-K6 deep piezometer at depth of 40 m	as above
X24A	Monitoring Well - North Abutment of Intermediate Dam - shallow piezometer	destroyed in 1990; replaced in fall of 1996 by new monitoring well (96-4)
X24B	Monitoring Well - North Abutment of Intermediate Dam - deep piezometer	as above
X25A	Monitoring Well - South Abutment of Intermediate Dam - shallow piezometer	destroyed in 1989; replaced in fall of 1996 by new monitoring well (96-3)
X25B	Monitoring Well - South Abutment of Intermediate Dam - deep piezometer	as above
PW 4	Groundwater Well - water supply prior to discharge into pumphouse pond	pumping well not used since 1989; not sampled any longer
PW 5	Groundwater Well - water supply prior to discharge into pumphouse pond	pumping well not used since 1989; not sampled any longer
BH 1	Monitoring well southeast of Zone 2 pit, west of North Fork Rose Creek	
BH 2	Monitoring well southeast of Zone 2 pit, west of North Fork Rose Creek	
BH 3	Monitoring well southeast of Zone 2 pit, west of North Fork Rose Creek	destroyed in 1990; not sampled any longer
BH 4	Monitoring well southeast of Zone 2 pit, west of North Fork Rose Creek	
X26	Zone 2 pumping well	

Table 3.14

Additional Groundwater Monitoring Sites at Faro Mine Site

STATION	DESCRIPTION
BH 94-5	Monitoring well southeast of Zone 2 pit, west of North Fork Rose Creek shallow piezometer in alluvial sediments
BH 94-6	Monitoring well southeast of Zone 2 pit, west of North Fork Rose Creek shallow piezometer in alluvial sediments
BH 94-7A/B	Monitoring well southeast of Zone 2 pit, west of North Fork Rose Creek nested piezometers in alluvial sediments
BH 94-8	Monitoring well near Zone 2 pit, west of North Fork Rose Creek deep piezometer in bedrock
BH 94-9	Monitoring well near Zone 2 pit, west of North Fork Rose Creek deep piezometer in bedrock
BH 94-10A/B	Monitoring well southeast of Zone 2 pit, west of North Fork Rose Creek nested piezometers in alluvial sediments
BH 94-11	Monitoring well near Zone 2 pit, west of North Fork Rose Creek deep piezometer in bedrock
BH 94-12A/B	Monitoring well at toe of Northwest Dump, west of North Fork Rose Creek nested piezometers in (weathered) bedrock
BH 94-13A/B	Monitoring well at toe of Northwest Dump, west of North Fork Rose Creek nested piezometers in overburden soil and bedrock
BH 94-14A/B	Monitoring well at toe of Northwest Dump, west of North Fork Rose Creek nested piezometers in (weathered) bedrock
BH 94-15A/B/C	Monitoring well between Main pit and Zone 2 pit nested piezometers in bedrock
BH 94-16A/B/C	Monitoring well between Main pit and Zone 2 pit nested piezometers in bedrock
1A/B	Monitoring well southeast of Intermediate Dump and Sulphide Dumps nested piezometers in overburden soil and weathered bedrock
2A/B	Monitoring well southeast of Intermediate Dump and Sulphide Dumps nested piezometers in overburden soil and weathered bedrock
3	Monitoring well southeast of Intermediate Dump and Sulphide Dumps shallow piezometer in overburden soil
BH 96-3A/B	Monitoring Well - South Abutment of Intermediate Dam nested piezometers in alluvial sediments
BH 96-4A/B/C/D	Monitoring Well - North Abutment of Intermediate Dam nested piezometers in alluvial sediments
BH 96-5A/B/C	Monitoring Well - below North Abutment of Second Embankment nested piezometers in alluvial sediments
BH 96-6	Monitoring well at eastern toe of Intermediate Dump, west of North Fork deep piezometer in confined gravel
BH 96-7	Monitoring well at southern toe of Intermediate Dump, north of Rose Creek valley; shallow piezometer in overburden soil
BH 96-8A/B	Monitoring Well - lower Faro Creek Valley near X23 nested piezometers in alluvial sediments

The surface water sampling stations for the Vangorda Plateau are shown on Figure 3-20 and are listed in Tables 3.15 and 3.16. Details of the stations are provided in Appendix E. At present, there are no licence specified groundwater monitoring stations at the Vangorda Plateau site. However, ARMC is monitoring several groundwater piezometers as part of their on-going monitoring work. These additional sites are listed in Table 3.17. Details of the monitoring stations and observed groundwater quality at the Vangorda Plateau mine site are discussed in section 5.4.

Table 3.15

Licence Specified Surface Water Sampling Stations at Vangorda Plateau

STATION	DESCRIPTION
V1	Vangorda Cr., upstream from mine & Blind Cr. Rd
V2	Grum Creek, upstream of Vangorda Ck
V4	Shrimp Creek, upstream of Vangorda Creek
V5	Vangorda Creek, west fork, upstream of road
V6A	AEX Creek
V7	Grum exploration portal decant
V8	Vangorda Creek, near Faro town bridge
V14	Southwest Sump Grum Dump
V15	Grum Dump, sulphide cell sump
V16	Grum Dump, southeast sump
V17	Grum Dump, NW interceptor ditch
V18	Grum Dump, SE interceptor ditch
V19	Vangorda pit, NW interceptor ditch
V20	Vangorda pit, NE interceptor ditch
V21	Vangorda dump, collector sump
V22	Vangorda pit water
V23	Grum pit water
V24	Influent to water treatment plant
V25	Effluent from treatment plant
V27	Vangorda Creek, just upstream of Shrimp Creek

Table 3.16
Additional Surface Water Sampling Stations at Vangorda Plateau

STATION	DESCRIPTION
DRAIN1 (V28)	Vangorda Dump Drain 1
DRAIN2 (V29)	Vangorda Dump Drain 2
DRAIN3 (V30)	Vangorda Dump Drain 3
DRAIN4 (V31)	Vangorda Dump Drain 4
DRAIN5 (V32)	Vangorda Dump Drain 5
DRAIN6 (V33)	Vangorda Dump Drain 6
V3	Pre-mining
V10	Pre-mining
V11	Pre-mining
V25AF	Effluent from treatment plant, after flume
V25BF	Effluent from treatment, before flume
V26	Little Creek, between pit and dumps

Table 3.17
Additional Groundwater Monitoring Stations at Vangorda Plateau

STATION	DESCRIPTION	COMMENTS
94GW-01 (V34)	groundwater well GW-94-01 in deeper till downstream of Vangorda Rock Dump	
94GW-02 (V35)	groundwater well GW-94-02 in deeper till downstream of Vangorda Rock Dump	
94GW-03 (V36)	groundwater well GW-94-03 in deeper till downstream of Vangorda Rock Dump	
94GW-04 (V37)	groundwater well GW-94-04 in deeper till downstream of Vangorda Rock Dump	
94GW-05 (V38)	groundwater well GW-94-05 in deeper till downstream of Vangorda Rock Dump	piezometer damaged; not sampled any longer
P-9401 A/B (V39 & V40)	shallow standpipe piezometer in till at Vangorda dump berm	
P-9402 A/B/C (V41,V42 & V43)	shallow standpipe piezometer in till at Vangorda dump berm	
P-9403 A/B (V44 & V45)	shallow standpipe piezometer in till at Vangorda dump berm	dry piezometers, not sampled to date
P-9404 A/B (V46 & V47)	shallow standpipe piezometer in till at Vangorda dump berm	dry piezometers, not sampled to date
BH-96-9 A/B	Monitoring Well in small valley d/s of Grum Rock Dump; nested piezometers in alluvial sediments	

3.9.3 Surface Water Chemistry Assessment

The objectives in the assessment of water quality are to identify sources, quantify the current release and transport of contaminants, and evaluate the impact on the receiving environment.

The monitoring network is designed to sample:

- the receiving environment both upstream and downstream of the site;
- the existing or potential pathways for contaminant migration; and,
- the existing and potential sources of contaminants.

The water chemistry database is discussed in two sections; regional or "baseline" water chemistry unaffected by mining and then the areas afffected by mine including receiving water chemistry. The following section discusses the water chemistry of the baseline or upstream stations for both the Faro and the Vangorda Plateau developments. In Chapter 4, the water chemistry of the

different components and the associated receiving waters is discussed for the Faro mine. Similar discussions are provided in Chapter 5 for the Vangorda Plateau mine site.

The overall objectives in this assessment of the database are to evaluate the trends and mechanisms in contaminant release, compare the relative contributions to the total loading for the site, and from this identify priorities for closure and remediation. Baseline water chemistry data are used to compare loadings from the mine site to the receiving environment and to establish objectives for water chemistry in the receiving environment after closure. Trends are evaluated graphically in the following discussion. Although the entire database is evaluated in the appendices, the summary tables generally look at two time periods for which detailed and comparable data are available; the period at which the last detailed evaluation of water chemistry was done (1988 to 1991) for the tailings facility closure plan, and the most recent data set (1995 and 1996). This is also done as the data are somewhat limited for the period of 1993 and 1994, particularly during the shutdown.

3.9.4 Baseline Water Chemistry - Faro

In the development of a closure plan for the mine, one of the considerations in terms of water quality is the "natural" or "background" condition; that is, the chemistry of the water prior to mine development. Often this quality of water provides a basis for determining the quality of water that is the goal for after closure of the mine. It must, however, be recognized that a mine is built in an area of mineralization, and one of the exploration tools is often stream water chemistry - the enriched mineralization causing naturally "elevated" metal concentrations. Thus an "elevated" concentration of a metal is a relative term.

Water chemistry data have been collected for the Faro mine since the start of mine development. However, there are no data for the pre-existing conditions. Thus there are no background data for comparison with either current or predicted post-closure water quality for the mine area. Some indication the water quality in areas not affected by mining can be developed from sampling of tributaries to the mine area, upstream of the mine. Such comparisons have to be used carefully however, as the mine was developed in an area of mineralization - mineralization which could certainly affect the water chemistry.

There are six surface water quality monitoring stations that could be considered to represent "natural" or upstream conditions for the Faro site:

- SRC South Fork of Rose Creek, upstream of the Fresh Water Reservoir;
- SMC Small Creek, upstream of the Fresh Water Reservoir;
- R6 Anvil Creek immediately upstream of Rose Creek;
- R7 North Fork of Rose Creek, upstream of the confluence with the Faro Creek Diversion;
- FC Faro Creek upstream of the Diversion, also called FC5 or FC Site 25; and,
- W10 Upper Guardhouse Creek, upstream of the waste dumps.

3.9.4.1 Faro Creek (FC or FC #25)

The upstream or background water quality in Faro Creek is represented by Station FC, located on Faro Creek upstream of the Faro Creek Diversion. This station is also referred to in the database as station FC5, or FC Site 25.

This station in not a licence station and is generally monitored as part of special sampling programs, such as seep surveys, rather than routine permit monitoring. Data for this station is available for 1988 through 1991. There was no sample collection carried out at FC by the receiver. Seep surveys in 1995 and 1996, however, have included this station.

The data are summarized in Table 3.18, and shown graphically in Figures 3-21 and 3-22. A statistical summary of the data by year and/or season is provided in Appendix D. No seasonal trends could be delineated due to the limited number of samples.

TABLE 3.18

Data Summary for Station FC: Faro Creek above diversion channel.

	LAB pH	TOTAL ALKALINITY	TOTAL SULPHATE	TOTAL ARSENIC	TOTAL COPPER	TOTAL IRON	TOTAL ZINC
Date	pH unit	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
JAN 1988 - OCT 1996							
Mean	7.57	13.0	1.87	0.2	0.003	0.06	0.009
Minimum Value	6.38	1.0	0.90	0.2	0.001	0.02	0.002
Maximum Value	9.75	20.0	4.00	0.2	0.010	0.10	0.023
Median	7.54	13.5	1.89	0.2	0.002	0.08	0.007
Num. Values	16.00	16.0	14.00	2.0	14.000	9.00	16.000
JAN 1988 - DEC 1991							
Mean	7.66	13.3	1.89		0.002	0.06	0.010
Minimum Value	6.38	1.0	0.90		0.001	0.02	0.002
Maximum Value	9.75	20.0	4.00		0.003	0.10	0.023
Median	7.59	13.5	1.89		0.002	0.08	0.007
Num. Values	14.00	14.0	12.00		12.000	7.00	14.00
JAN 1995 - OCT 1996							
Mean	6.88	10.8	1.80	0.2	0.010	0.07	0.005
Minimum Value	6.72	7.2	1.50	0.2	0.010	0.03	0.005
Maximum Value	7.05	14.4	2.00	0.2	0.010	0.10	0.005
Median	6.88	10.8	1.80	0.2	0.010	0.07	0.005
Num. Values	2.00	2.0	2.00	2.0	2.000	2.00	2.000

The station was moved downstream in 1990, to a point just upstream of the confluence with the Faro Valley Interceptor drain, and the start of the constructed Faro Creek Diversion Channel. While it has been suggested that this station may be influenced by the Faro Creek Diversion dike, the water chemistry is consistently good with little variability in terms of chemistry and seasonal changes in terms of flow.

It is important to note however that this upstream station probably does not represent the chemistry of the Faro Creek water that entered Rose Creek prior to the mine operation. As has been discussed in other reports (SRK, 1991 report 60635), "..the water quality measured at Station FC probably underestimates the concentrations of lead, zinc and sulphate (among other parameters) in Faro Creek as it entered Rose Creek prior to mine development. As Faro Creek formerly passed over the centre of the orebody, it is probable that is would have picked up some loadings of these constituents downstream of Station FC, prior to entering Rose Creek."

Faro Creek is consistently neutral to alkaline with pH values averaging 7.6 over the period of record, and a peak measurements 9.8 in 1989. The stream is moderately alkaline, with an average value of 13 mg/L, and a peak value of 20 mg/L in 1989. There is essentially no sulphate in the waters, with a maximum value of 4 mg/L.

As shown in Figure 3-21, zinc concentrations are somewhat variable, although very low, particularly in recent years. In both the 1995 and 1996 surveys, total zinc concentrations were less than 0.005 mg/L.

Zinc concentrations increased slightly in late 1989 and remain relatively level at approximately 0.02 mg/L. Iron concentrations also increased in 1989/90 to 0.075 mg/L, however are low in 1995 and 1996 (<0.03 and 0.10 mg/L respectively). These increases may have been due to the relocation of the station in 1990, however the effect appears to have been temporary.

Calcium and magnesium concentrations are relatively low averaging 3.1 and 0.6 mg/L respectively over the period of record. All other metals are at or near detection levels.

3.9.4.2 North Fork of Rose Creek (R7, NFRC)

The background water quality in North Fork Rose Creek is measured at R7 which is located upstream of the confluence with the Faro Creek Diversion. This station is also referred to as "The background water quality in North Fork Rose Creek is measured at R7 which is located NFRC".

This station has been monitored by the mine operators since 1986 for both flow and chemistry, however there are no flow data available for 1993. This station was not sampled during the shutdown between the Curragh and Anvil Range operations.

The flow and water chemistry data are summarized in Table 3.19, and shown graphically in Figures 3-23 through 3-27. A statistical summary of the water chemistry data by year and/or season are provided in Appendix D.

TABLE 3.19

Data Summary for Station R7: North Fork of Rose Creek above Faro Creek Diversion

	LAB pH	TOTAL ALKALINITY	TOTAL SULPHATE	TOTAL ARSENIC	TOTAL COPPER	TOTAL IRON	TOTAL ZINC
Date	**pH unit**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**
JAN 1988 - OCT 1996							
Mean	7.86	92.6	10.2	0.02	0.003	0.33	0.016
Minimum Value	7.20	45.0	2.0	0.02	0.001	0.05	0.001
Maximum Value	8.47	166.0	52.0	0.04	0.012	2.12	0.140
Median	7.76	87.0	8.0	0.02	0.002	0.14	0.010
Num. Values	26.00	19.0	24.0	7.00	28.000	20.00	27.000
JAN 1988 - DEC 1991							
Mean	7.78	86.5	6.1		0.002	0.15	0.012
Minimum Value	7.20	45.0	2.0		0.001	0.05	0.001
Maximum Value	8.47	130.0	10.0		0.007	0.45	0.051
Median	7.70	82.0	6.0		0.002	0.12	0.005
Num. Values	15.00	15.0	17.0		17.000	13.00	17.000
JAN 1995 - OCT 1996							
Mean	7.90	116.0	20	0.02	0.006	0.65	0.029
Minimum Value	7.40	89.0	9	0.02	0.002	0.13	0.01
Maximum Value	8.40	166.0	52	0.04	0.012	2.12	0.14
Median	7.80	104.0	13	0.02	0.004	0.4	0.01
Num. Values	7.00	4.0	7.0	7.0	7.0	7.0	7.0

The water quality in the North Fork of Rose Creek has been reasonably consistent over the period of record, as shown in Figures 3-23 through 3-26 for pH, alkalinity, lead and zinc. Since most of the metals are at relatively low concentrations, the apparent variability is due more to changes in laboratory detection limits, than to any geochemical changes over time.

The pH is alkaline with an average value of 7.9 over the period of record (Figure 3-23). The alkalinity values are higher than seen in Faro Creek, ranging from 45 to 166 mg/L $CaCO_3$ eq. since 1986 (Figure 3-24) and Table 3.19. This is a reflection of geology in the drainage basin as upper Faro Creek drains only granitic rocks of the Anvil Batholith whereas the upper North Fork of Rose Creek drainage includes Vangorada formation calcarious rocks.

As shown in Figure 3-25, there appears to have been a slight increase in sulphate concentrations from 5 mg/L in 1989 to 20 mg/L in 1995, however at such low concentrations this may, to some degree, be a function of changing laboratories. Copper has also been increasing from detection levels since 1991 with concentrations peaks of 0.012 mg/L in 1995.

There has been little change in the water chemistry over time for most parameters (Figures 3-26 and 3-27) other than an apparent peak in 1995 in copper, iron, zinc, sulphate and alkalinity. The reason for this is not obvious as there is no mining activity in this area by Anvil Range. Unfortunately there are no flow data from 1993 to 1996, as well as no samples taken during 1993/94, to provide a basis for comparison. There was no peak associated with the TSS at this time. It has been suggested that perhaps there was some confusion with these samples or, alternatively, that there was a natural disturbance within the watershed upstream of the mine which affected the water quality at R7, such as a small land slide. There are several known mineralized areas upstream from this site.

3.9.4.3 South Rose Creek Upstream of Fresh Water Reservoir (SRC, SMC)

The South Fork of Rose Creek was monitored at two stations, Station SRC and Station SMC. Until 1990, this station was located just upstream of the Fresh Water Reservoir, on the downstream side of the Vangorda Haul Road, as shown in Figure 3-19. In 1990, this station was moved to the upstream side of the haul road. The second station, SMC, is located on Small Creek which is a tributary of the South Fork of Rose Creek. It is also sampled upstream of the Fresh Water Reservoir.

Both of these stations were sampled by the mine operators as part of the comprehensive site monitoring program, and are not licence stations. Data are available from the early 1970's and again in 1989 and 1990. These data are not analyzed in detail as there are some problems with the data set; notably, the values for the dissolved metal concentrations exceed the values for the total metal concentrations, indicating problems with sampling and/or analysis.

The flow and water chemistry data are summarized in Tables 3.20 and 3.21. A statistical review for the 1970's and 1989/90 data is provided in Appendix D.

TABLE 3.20

Data Summary for Station SRC: South Fork Rose Creek u/s of Water Reservoir

	LAB pH	TOTAL ALKALINITY	TOTAL SULPHATE	TOTAL ARSENIC	TOTAL COPPER	TOTAL IRON	TOTAL ZINC
Date	pH unit	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
JAN 1988 - OCT 1996							
Mean	7.68	33.3	8.0				0.014
Minimum Value	7.07	1.4	2.0				0.002
Maximum Value	8.52	55.0	21.0				0.100
Median	7.70	28.0	5.0				0.006
Num. Values	11.00	11.0	8.0				11.000
JAN 1988 - DEC 1991							
Mean	7.68	33.9	8.0				0.015
Minimum Value	7.07	1.4	2.0				0.002
Maximum Value	8.52	55.0	21.0				0.100
Median	7.69	34.5	5.0				0.007
Num. Values	10.00	10.0	8.0				10.00
JAN 1995 - OCT 1996							
Mean	7.70	26.8					0.002
Minimum Value	7.70	26.8					0.002
Maximum Value	7.70	26.8					0.002
Median	7.70	26.8					0.002
Num. Values	1.00	1.0					1.000

TABLE 3.21
Data Summary for Station SMC: Small Creek Tributary to Fresh Water Reservoir

	LAB pH	TOTAL ALKALINITY	TOTAL SULPHATE	TOTAL ARSENIC	TOTAL COPPER	TOTAL IRON	TOTAL ZINC
Date	pH unit	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
JAN 1988 - OCT 1996							
Mean	8.30	215.0	35.0				0.012
Minimum Value	8.17	212.0	27.0				0.002
Maximum Value	8.44	218.0	47.0				0.029
Median	8.30	215.0	31.0				0.004
Num. Values	2.00	2.0	3.0				3.000
JAN 1988 - DEC 1991							
Mean	8.30	215.0	35.0				0.012
Minimum Value	8.17	212.0	27.0				0.002
Maximum Value	8.44	218.0	47.0				0.029
Median	8.30	215.0	31.0				0.004
Num. Values	2.00	2.0	3.0				3.000
JAN 1995 - OCT 1996							
Mean							
Minimum Value							
Maximum Value							
Median							
Num. Values							

Generally, the water chemistry in the South Fork of Rose Creek and the Small Creek tributary is alkaline with pH values about pH 8. The average alkalinity in the 1989/1991 period was 33.9 mg/L for Rose Creek (which drains granitic rocks and Mt. Mye formation) and 215 mg/L in Small Creek (which drains large areas of Vangorda formation calcarious phyllites). Metal concentrations are low in the South Fork of Rose Creek at 0.015 mg/L total Zn. In Small Creek, an average concentration of 0.012 mg/L total zinc is seen in the 1989/91 data set.

3.9.4.4 Anvil Creek (R6)

Station R6 is a site licence monitoring station located on Anvil Creek, just upstream of Rose Creek (see inset in Figure 3-19). This creek is also monitored at Station R5, just downstream of the confluence with Rose Creek.

Station R6 was monitored regularly until the shutdown, and is included in the Anvil Range water sampling program. There are no data available for 1993/1994.

Sample pH values are consistently alkaline, ranging around pH 8. Alkalinity values range between about 100 and 150 mg/L, with an average value of 121 mg/L $CaCO_3$ eq. and a similar value for the median (122.6 mg/L). Sulphate concentrations are low but variable, ranging from 13 to 91 mg/L over the period of record.

Although total and dissolved metal concentrations are generally low, approaching detection limits, there are occasional peaks in metals (see Table 3.22). As shown in Figure 3-28, zinc has shown the greatest variability although average and median total zinc concentrations are still low at 0.025 and 0.008 mg/L respectively.

TABLE 3.22

Data Summary for Station R6: Anvil Creek upstream of Rose Creek

	LAB pH	TOTAL ALKALINITY	TOTAL SULPHATE	TOTAL ARSENIC	TOTAL COPPER	TOTAL IRON	TOTAL ZINC
Date	pH unit	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
JAN 1988 - OCT 1996							
Mean	7.95	122.6	25.0	0.05	0.006	0.19	0.025
Minimum Value	7.59	89.0	1.0	0.02	0.001	0.13	0.001
Maximum Value	8.20	144.0	91.0	0.06	0.027	0.32	0.118
Median	8.00	121.0	17.0	0.06	0.002	0.14	0.008
Num. Values	10.00	8.0	90.0	3.00	11.000	5.00	11.000
JAN 1988 - DEC 1991							
Mean	7.93	124.6	27.0	0.06	0.006	0.20	0.034
Minimum Value	7.59	89.0	13.0	0.06	0.001	0.13	0.001
Maximum Value	8.20	144.0	91.0	0.06	0.027	0.32	0.118
Median	8.00	124.0	17.0	0.06	0.002	0.14	0.008
Num. Values	7.00	7.0	7.0	1.00	7.000	3.00	7.000
JAN 1995 - OCT 1996							
Mean			24.0	0.02	0.002	0.13	0.010
Minimum Value			24.0	0.02	0.002	0.13	0.010
Maximum Value			24.0	0.02	0.002	0.13	0.010
Median			24.0	0.02	0.002	0.13	0.010
Num. Values			1.0	1.00	1.000	1.00	1.000

3.9.4.5 Upper Guardhouse Creek (W10)

There has been some confusion in the description of this station, and this water course throughout the history of the Faro site. This water course, which has been referred to in many reports as Next Creek, is in fact the upper portion of Guardhouse Creek. The actual Next Creek is in fact in a different drainage to the west of the site, and to the west of Guardhouse Creek. Stations W10 and W8 are therefore located on Upper Guardhouse Creek and will be referred to as such hereafter.

Upper Guardhouse Creek flows under a portion of the Northwest Dumps, and is sampled during seep surveys at two points; W10 which is upstream of the dumps and W8 which is downstream of the dumps. Neither station is a licence station. W10 would be considered a background station for Guardhouse Creek.

Sampling results from the seep surveys in 1995 and 1996 show that Upper Guardhouse Creek is alkaline with pH values between 7.3 and 8, alkalinity up to 44 mg/L $CaCO_3$ eq., and very low sulphate concentrations at <5 mg/L. Total and dissolved metal concentrations are also low, at detection limits for most elements (see Table 3.23). Zinc concentrations are <0.005 mg/L. Other metals of interest are at less than detection, with the exception of Ca (15.6 and 9.2 mg/L in 1995 and 1996 respectively) and magnesium (2 and 1.2 mg/L in 1995 and 1996 respectively).

These values are consistent with previous sampling data for this station, reported in SRK, 1992 (report 60648).

Table 3.23

Data Summary for Station W10: North West Waste Dump Toe - W10

	LAB pH	TOTAL ALKALINITY	TOTAL SULPHATE	TOTAL ARSENIC	TOTAL COPPER	TOTAL IRON	TOTAL ZINC
Date	pH unit	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
JAN 1988 - OCT 1996							
Mean	7.40	48.5	2.6	0.2	0.007	0.04	0.009
Minimum Value	6.50	27.0	0.9	0.2	0.001	0.01	0.002
Maximum Value	8.29	68.0	4.0	0.2	0.010	0.06	0.032
Median	7.54	52.2	3.0	0.2	0.010	0.03	0.005
Num. Values	9.00	8.0	9.0	2.0	3.000	3.00	9.000
JAN 1988 - DEC 1991							
Mean	7.36	52.9	2.3		0.001	0.014	0.010
Minimum Value	6.50	36.8	0.9		0.001	0.014	0.002
Maximum Value	8.29	68.0	4.0		0.001	0.014	0.032
Median	7.54	53.0	2.0		0.001	0.014	0.005
Num. Values	7.00	6.0	7.0		1.000	1.000	7.000
JAN 1995 - OCT 1996							
Mean	7.53	35.3	3.8	0.2	0.010	0.05	0.005
Minimum Value	7.35	27.0	3.7	0.2	0.010	0.03	0.005
Maximum Value	7.71	43.6	3.9	0.2	0.010	0.06	0.005
Median	7.53	35.3	3.8	0.2	0.010	0.05	0.005
Num. Values	2.00	2.0	2.0	2.0	2.00	2.00	2.000

3.9.5 Baseline Water Chemistry - Vangorda Plateau

Pre-mining water chemistry data are available for the Vangorda Plateau and have been included in the EQWin water chemistry database discussed herein. The pre-mining data were presented and discussed in some detail in the Vangorda Plateau Development Initial Environmental Evaluation, Volume II. However, it must be recongized that some of the sampling stations from the pre-mining sampling programs are no longer "background" due to the development of the mine workings, e.g. V10 and V11.

The following summarizes the water chemistry for the stations that are still relatively unaffected by the mining operations; Station V1 on Vangorda Creek upstream of the mine, Station V18 in the Northeast Interceptor Ditch for Grum, and Station V20 in the Vangorda Pit Northeast Interceptor Ditch. The latter two stations are in constructed ditches and collect runoff from some stripped areas of the mine, thus potentially contain higher suspended solids loads than "natural" streams during times of construction. In addition, the Grum Northeast Interceptor Ditch receives groundwater from the groundwater pumping for pit dewatering.

A fourth station, Shrimp Creek upstream of the confluence with Vangorda Creek, could also be considered a background station at least during the early years of mining. This station is located downstream of the Vangorda waste dump and there is a potential that drainage from the waste dump would report to Shrimp Creek via groundwater flow. However, since groundwater monitoring wells at the perimeter of the waste dump have not detected contaminated drainage from the waste dumps, it is possible that Shrimp Creek remains unaffected by mining.

The water quality data for the three stations are summarized graphically in Figures 3-29 through 3-38 for selected parameters. Statistical summaries of the key parameters are provided in Appendix E.

3.9.5.1 Vangorda Creek

Vangorda Creek has been monitored upstream of the mine at a point just upstraem of the Blind Creek Road, as shown on Figure 3-20, since 1988.

The water chemistry data are reasonably consistent over the life of the mine, although seasonal variations are evident where there are several samples are collected within the year. Sample pH values are slightly alkaline, averaging 7.5 and ranging from 6.7 to 8.2 over the period of record as shown in Figure 3-29. Alkalinity values are slightly more variable, ranging up to about 100 mg/L. Figure 3-30 would suggest that the highest values are seen during the late winter or early spring periods although the seasonal data are limited during the 1993 - 1994 period. Low values of alkalinity in any given year are generally seen in late summer.

Sulphate concentrations in Vangorda Creek are low at generally less than 20 mg/L (Figure 3-31). Similarly, suspended solids loads are low with slight peaks seen in early spring (Figure 3-32). The variability in suspended solids corresponds to slight peaks in total metal concentrations as shown, for example, in Figures 3-33 and 3-34 for iron and zinc respectively. Most other metals are very low - at detection limits as sumamrized in the statistical tables appended.

3.9.5.2 Vangorda NE Interceptor

The Vangorda NE Interceptor Ditch collects water from upstream of the pit and diverts this water into the Vangorda Diversion Channel. Water samples are collected at Station V20. The station has been sampled since construction of the ditch in 1991, although data are limited during the shutdown.

Generally, the data show that the natural surface waters upstream of the pit are similar to Vangorda Creek, as would be expected. The water is slightly more alkaline with pH values averaging 7.7 over the period of record and slightly higher alkalinity values, as shown in Figures 3-29 and 3-30.

Although the data are limited, suspended solids measurements show peak values initially and during higher flow period, Figure 3-32. There may be corresponding increases in concentrations of some metals during these periods, however concentrations of metals are low and data are limited.

3.9.5.3 Grum SE Interceptor

Water samples collected from the Grum SE Interceptor could also be considered representative of "natural" waters comprising surface runoff and groundwater pumped from groundwater wells as part of pit watering (but not including water pumped from the pit itself). The water chemistry in this ditch is consistent with other baseline samples, being slightly alkaline in pH. Solution alkalinity is higher than the previous two stations, averaging 112 mg/L $CaCO_3$ equivalent since 1991. Solution pH values and alkalinity also appear to have been increasing since construction in 1991 - probably influenced by mine operations including groundwater pumping.

Figure 3-31 shows a similar trend to increasing sulphate concentrations in 1994 and 1995 although data are sparse in 1993 and 1994. Metal concentrations are generally low and show no trends, expect a positive correlation between peaks in suspended solids and in iron and, to a lesser degree, zinc concentrations.

3.9.5.4 Shrimp Creek

The monitoring station on Shrimp Creek is located upstream of the confluence with Vangorda Creek, as Station V4.

Figures 3-35 and 3-36 compare the pH and alkalinity values measured in Vangorda Creek and Shrimp Creek. Shrimp Creek is considerably more alkaline than is Vangorda Creek with pH values in Shrimp Creek averaging pH 8 and alkalinity 284 mg/L $CaCO_3$ equivalent since 1988. Suspended solids concentrations are also low at <5 mg/L, although peak values are occasionally measured in late winter or early spring. There is an apparent increasing trend in alkalinity in 1995, although only represented by three samples.

Sulphate concentrations are somewhat variable but generally below 100 mg/L. The data in Figure 3-37 suggest that there may be an increasing trend to sulphate concentrations in 1995, but again the data set is only three points. A similar peak was seen in December of 1990, suggesting that

natural variability affects Shrimp Creek concentrations as the Vangorda waste dump was under construction at the time.

Metal concentrations in Shrimp Creek are consistently low, and similar to Vangorda Creek.

The observation of increasing concentrations in 1995, with a peak in 1990 or 1991, is also seen in ammonia concentrations, as shown in Figure 3-38.

3.10 Aquatic Resources

3.10.1 General

The following sections provide a summary of the aquatic resources present in Rose Creek/ Anvil Creek and Vangorda Creek drainages. Aquatic resources discussed include benthic invertebrates, fisheries, and stream sediments. A number of specific aquatic studies or surveys have been conducted over the course of development at the Anvil Range mining complex. The approach taken with each of these sections has been as follows

- provide a summary of the historical information and studies undertaken within each drainages;
- summarize all relevant data
- discuss pertinent results with emphasis on interesting observations or trends.

The intent has not been to provide detailed results from each individual study or survey. The reader is referred to individual reports for further discussions. A general description for each of the drainage is provided.

3.10.1.1 Drainage Description

An overview of the local drainages within Anvil Range's Faro and Vangorda operations is presented in Figure 1-2. The drainages discussed here are the Rose Creek/ Anvil Creek drainage and the Vangorda Creek drainage.

Anvil Creek/Rose Creek

The Anvil Creek drainage encompasses an area of approximately 1,100 km^2. Rose Creek, one of the largest tributaries to Anvil Creek has a drainage area of approximately 400 km^2. Rose Creek flows in a southerly direction near it's headwaters and then westerly where it enters Anvil Creek some 29 km upstream of the Pelly River Anvil Creek confluence. Anvil Creek enters the Pelly River 63 km downstream of Faro.

The Anvil/Rose Creek system drains the south east slopes of the Anvil Range Mountains from an elevation of 2100 m to 600 m at the Pelly River. The terrain is mountainous and characterized with relatively narrow valleys. Headwater lakes and ponds occur within Anvil Creek tributaries and in the Rose Creek drainage. The Rose Creek drainage divides into the North and South Forks upstream of the Down Valley Tailings at the pumphouse pond. A man made reservoir

supplying freshwater to the concentrator exists within the lower reaches of the South Fork of Rose Creek upstream of the tailings facility.

Vangorda Creek

Vangorda Creek drains an area of approximately 93 km^2. The creek divides into the West Fork and East Fork (main channel) 3 km upstream of the Pelly River confluence and located just north of the town of Faro. The main channel drains the southern slope of Mount Mye near elevation 1675 m and flows southwest and empties into the Pelly River near Faro (600 m). Shrimp Creek drains Shrimp Lake and flows into the main creek channel. Doal Lake, now dewatered, previously drained into the main channel. The West Fork originates near the headwaters of the South Fork of Rose Creek at elevation 1370 m and flows southwest into the main creek channel. Stream gradients are relatively steep within the majority of the Vangorda Creek drainage.

3.10.2 Fisheries

3.10.2.1 General

A summary of the fisheries investigations conducted in the Anvil/Rose Creek and Vangorda Creek drainages is discussed in this section. Table 3.24 summarizes the fish studies undertaken within the various drainages since 1972. This table outlines the method of capture, survey objective, fish species caught including total numbers, and individual study reference for each survey.

Table 3.24
List of fisheries studies undertaken on Rose/Anvil and Vangorda Creek Drainages

YEAR	DRAINAGE	METHOD OF CAPTURE[a]	SURVEY OBJECTIVE	FISH[b]	CATCH[c]	REFERENCE
1974	Rose/Anvil	Electro-shock	Fish Survey/Tissue Analysis	ag, ss,	54	S.A. Baker, 1979
1975	Rose/Anvil	Electro-shock	Fish Survey/Tissue Analysis	ag, rw, hw, ls, ss, ch, b	50	S.A. Baker, 1979
"	Rose/ Anvil, Vangorda	Electro-shock	Fish Survey/Tissue Analysis	ag, rw, ss, ls, b, ch	101	Mtl. Engineering Co., 1976
1976	Rose/Anvil	Electro-shock	Fish Survey/Tissue Analysis	ag, rw, ls, ss, b, ch	52	S.A. Baker, 1979
1976	Vangorda	Electro-shock	Fish Survey/Tissue Analysis	ag, ss	45	Mtl. Engineering Co., 1977
1977	Vangorda	Electro-shock	Fish Survey/Tissue Analysis	ag, ss	28	Mtl. Engineering Co., 1978
1981	Rose/ Anvil	Electro-shock, GN, Ang, FN	Impact of Rose Cr diversion	ag	35	K. Weagle, 1981a
1981	Rose/ Anvil	Electro-shock, GN, Ang.	Arctic Grayling Survey	ag	405	K. Weagle, 1981b
1986	Rose		Preliminary investigation			Leverton & Associates, 1986
1987	Vangorda	Electro-shock	Baseline/ Habitat Assessment	ch, ag	148	P.A. Harder & Assoc., 1987
1988	Rose	Electro-shock, GN	Causeway/ Spawning Survey	ag, b, ss, rw	40	P.A. Harder & Assoc., 1988
1989	Vangorda	Electro-shock, MT	Production / Overwintering	ch, ag	5565	P.A. Harder & Assoc., 1989
1989/90	Rose/ Anvil	Electro-shock, GN, BS	Habitat/ Production/ Feeding	ch, ag, ss, rw, b	581	P.A. Harder & Assoc., 1991
1990	Vangorda	Electro-shock, MT	Feeding/ Growth/ Population	ch, ag, ss, rw, ls, b	2263	P.A. Harder & Assoc., 1992
1992	Rose/Anvil	Electro-shock, GN	Habitat Assessment/Tissue	ch, ag, ss, rw, b	77	P.A. Harder & Assoc., 1993
1996	Vangorda	MT	Habitat Use/Assessment	ch, ag, ss, rw, ls, np	528	P.A. Harder & Assoc., 1996

[a]Capture Method: GN = gillnet; Ang = Angling; FN = Fyke net; MT = minnow trap;

BS = Beach Sien

[b]Fish Species: ch = chinook salmon; ag = arctic grayling; rw = round whitefish; ss = slimy sculpin; ls = longnose; hw = humpback whitefish sucker; np = northern pike; b = burbot;

cNote 1. Catch refers to total species captured during the survey, in all drainages

Fish species sampled in Anvil/Rose Creek and Vangorda Creek during the fisheries studies include chinook salmon, arctic grayling, round whitefish, humpback whitefish, burbot, slimy sculpin and longnose sucker. Table 3.25 describes other species that have been reported in the upper Pelly River drainage and may also be present in the Anvil and Vangorda drainages.

Table 3.25

List of fish species found in the upper Pelly River drainage and summary of general life history requirements (after Montreal Engineering Co. Ltd. 1976).

FAMILY	SPECIES	COMMON NAME	LIFE HISTORY/REQUIREMENTS
Salmonidae	Onchorhynchus tschawytscha *	Chinook salmon	Anadromous; 1 year fresh water residence as juvenile; occasionally 2; mainstem and tributary spawners - August
	Onchorhynchus keta	Chum salmon	Anadromous; juvenile fish migrate seaward as fry; mainstem spawners - August
	Salvelinus namaycush	Lake trout	Non-anadromous; rear in lakes and large rivers; Fall spawners
	Coregonus clupeaformis	Lake whitefish	Generally lake dwelling; Fall spawning along shallow lake shores
	Coregonus nasus	Broad whitefish	Generally lake dwelling; Summer to Fall spawner; downriver
	Coregonus sardinella	Least cisco	Migrating and non-migrating populations; Fall spawners - lake shore or river margins
	Prosopium cylindraceum *	Round whitefish	Northern populations are found in rivers as well as lakes; Fall spawning - lake shores and river mouths
	Stenodus leucichthys	Inconnu	Anadromous and non-anadromous forms; juveniles rear in rivers up to 2 years, spawn in Summer to Fall
	Thymallus arcticus *	Arctic grayling	Inhabit clear cold water - rivers, streams, lakes, and ponds; Spring spawning, complex seasonal migrations are common
Esocidae	Esox lucius	Northern pike	Spring spawner - in shallow vegetated areas of rivers and lakes; generally sedentary, predacious
Gadidae	Lota lota *	Burbot	Spawns during mid-winter in rivers, streams, and lakes; migrates into rivers after spawning
Catostomidae	Catostomus catostomus *	Longnose sucker	Spawns during Spring in streams and along lake shores
Cottidae	Cottus cognatus *	Slimy sculpin	Occupy a wide range of lake, stream, and river habitats; Spring spawning, nest builders, usually feed on aquatic invertebrates, other fish are also taken

* - indicates species has been recorded in Anvil Creek and Vangorda Creek drainages

Habitat descriptions of the drainages are provided along with a data summary of the studies by drainage. Pertinent findings or conclusions from the various studies are discussed in the following sections.

3.10.2.2 Habitat Descriptions - Anvil and Rose Creeks

Habitat types for Anvil and Rose Creeks have been documented during previous fish studies. The habitat descriptions described here are based on classifications presented by P.A. Harder and Associates, 1991. Anvil Creek was divided into five stream reaches from the Pelly River confluence upstream to the headwaters. Rose Creek was divided into three stream reaches up to the confluence with the North and South Forks of Rose Creek, while the North and South Forks were further divided into four and five stream reaches, respectively. These habitat classifications were established on the basis of similar bio-physical characteristics within a particular reach.

Figure 3-39 outlines the reach boundaries and provides a summary of the bio-physical characteristics by reach. For a complete description of fish habitat types see P.A. Harder and Associates, 1991.

3.10.2.3 Review of Fish Studies - Anvil and Rose Creeks

A summary of the results of fish studies undertaken in Anvil and Rose Creeks is provided in Figure 3-40 and Figure 3-41 Figure 3-40 summarizes fisheries data for the Anvil and Rose drainage, while Figure 3-41 shows data collected around the immediate Faro mine site.

Both of these figures provide details of fish species caught during various fish surveys. A summary of the relevant findings from these fish investigations within these drainages follows:

- the drainage is typically utilized by chinook salmon, arctic grayling, round whitefish, burbot, slimy sculpin and suckers, although other species may be present in Anvil Creek (Table 3.25). Within the Rose Creek drainage, arctic grayling are by far the most abundant and widespread. Juvenile or adult chinook salmon have not been reported or documented in the Rose Creek drainage;
- chinook salmon spawner surveys conducted in Anvil Creek in 1989 and 1990 indicate low numbers of adult spawners in lower Anvil Creek, however adult chinook were not observed during the 1992 spawning survey;
- juvenile chinook salmon utilize the lower 23 km of Anvil Creek. Abundance of juvenile salmon was considered moderate when compared with other drainages in the region during the 1989 and 1990 surveys, but abundance was lower during the 1992 survey. Juvenile chinook abundance and distribution in Anvil Creek is influenced by annual spawning distribution and fry immigration from the Pelly River;
- fish production in upper Anvil Creek above Rose Creek is considered extremely low;
- historically fish (arctic grayling, sculpin) have been reported in lower Rose Creek, however during more recent surveys there has been a virtual absence of fish reported.

It is likely that fish productivity within this section of the creek has been historically effected by previous tailings spills and effluent discharging from the mine workings;

- initial fisheries habitat compensation options were investigated in Rose Creek following the completion of the North Fork of Rose Creek haul road causeway. This causeway forms a barrier to upstream fish movement;
- sections of the Rose Creek diversion provide moderate rearing habitat for juvenile and adult arctic grayling, and;
- the South Fork of Rose Creek including the freshwater reservoir and the headwaters is one of the more productive areas in the Rose and Anvil Creek drainage.

3.10.2.4 Habitat Descriptions - Vangorda Creek

The habitat descriptions described here are based on classifications presented by P.A. Harder and Associates, 1987 during their baseline survey of the drainage. Vangorda Creek, main channel, was divided into eight stream reaches from the Pelly River confluence upstream to the headwaters. The West Fork of Vangorda Creek was treated as one stream reach. These habitat classifications were established on the basis of similar bio-physical characteristics within a particular reach.

Figure 3-42 outlines the reach boundaries and provides a summary of the bio-physical characteristics by reach. For a complete description of fish habitat types see P.A. Harder and Associates, 1987.

3.10.2.5 Review of Fish Studies - Vangorda Creek

A summary of the fish studies undertaken in Vangorda Creek is provided in Figure 3-43. This figure provides details of fish species caught during various fish surveys. The following provides a summary of the pertinent finding from these fisheries studies:

- the drainage is utilized by chinook salmon, arctic grayling, round whitefish, burbot, slimy sculpin and suckers;
- the lower reaches of Vangorda Creek (Figure 3-42, Reach 1, 2, and 3) provide important rearing habitat for the above noted species and in particular juvenile chinook salmon which are the dominant fish species present;
- all studies undertaken in this drainage indicate the absence of fish species in Vangorda Creek above the Faro Road culvert. The physical characteristics of this culvert represents a total barrier to the upstream movement of both adult and juvenile fish;
- minnow trapping data from previous studies indicates that juvenile chinook salmon migrate into the lower stream reaches during spring and summer with an outward migration in the fall prior to freeze up. It is expected that the lower reaches provide overwintering habitat for resident arctic grayling and possibly juvenile chinook salmon, and;

- recent fisheries investigations conducted in lower Vangorda Creek (P.A. Harder & Associates, August 1996) indicate that high numbers of juvenile chinook salmon are still utilizing the creek. Habitat characteristics were still comparable with pre-development habitat assessment surveys, although a relatively high level of fines (20%) were noted in the gravels deposited adjacent to the main channel. A large unstable beaver dam now exists in Reach 2 upstream of the foot bridge and adjacent to "Lions Park". This dam has restricted some channel usage and may disturb downstream habitat should the dam fail and release large volumes of water and silts now accumulated behind the dam.

3.10.2.6 Fish Tissue Analysis

This section summarizes fish tissue metal analysis results from fish samples collected in the Rose/Anvil and Vangorda Creek drainages from 1975 to 1992. The data contained within this section was obtained from reports published by Montreal Engineering Company Limited (1976-79), Environment Canada, (1979) and P.A. Harder (1993).

The results of the tissue analysis for mercury, copper, lead, zinc, nickel, manganese and iron are shown in Tables 3.26a and 3.26b for the Rose/Anvil and Vangorda Creek drainages, respectively. The tables provide data on the year, location, species caught, tissue sampled and metal concentration from each study performed. Not all metals were analyzed during the various study years. The fish species examined in the watersheds include; arctic grayling, burbot, chinook salmon, sculpin, sucker, and whitefish.

Table 3.26a

Summary of metals in fish tissue from the Rose/Anvil Creek drainage

YEAR	DRAINAGE	SPECIES	TISSUE	NUM. IN SAMP. /AVG MASS (g)	METALS ppm (wet weights)							REFERENCE
					Hg	Cu	Zn	Pb	Ni	Mn	Fe	
1975	Rose	Sculpin	muscle	4 / 6.3	0.08	0.35	29.0	1.90	1.80	3.07	21.9	Montreal Engineering Company Limited, 1976
1975	L. Anvil (EP8)	Grayling	muscle	1		0.40	04.0	0.20				S. Baker, Environment Canada, 1979
			liver	1		1.80	20.0	0.20				
1976	Rose (EP1)	Grayling	muscle	2	0.07							S. Baker, Environment Canada, 1979
			liver	2	0.20							
1976	Anvil (EP7)	Sucker	muscle	2	0.07							S. Baker, Environment Canada, 1979
			liver	2	0.42							
1976	Anvil (EP7)	Whitefish	muscle	2	0.31							S. Baker, Environment Canada, 1979
			liver	2	0.18							
			eggs	1	0.05							
1976	Anvil (EP7)	Grayling	muscle	2	0.11							S. Baker, Environment Canada, 1979
			liver	1	0.26							
1976	L.Anvil (EP8)	Grayling	muscle	N/A	0.10							S. Baker, Environment Canada, 1979
			liver	N/A	0.11							

Table 3.26a cont'd

Summary of metals in fish tissue from the Rose/Anvil Creek drainage

YEAR	DRAINAGE	SPECIES	TISSUE	NUM. IN SAMP. /AVG MASS (g)	METALS ppm (wet weights)							REFERENCE
					Hg	Cu	Zn	Pb	Ni	Mn	Fe	
1992	Rose Diversion	Burbot	whole tissue	1		5.2	155	5				P.A. Harder, 1993
		Grayling	whole tissue	4		3.9	110	-				
1992	Rose Reservoir	Grayling	muscle	10	0.8	2.6	21.7	-				P.A. Harder, 1993
			liver	10		7.4	83.3	-				
1992	Rose/Pump house Pond	Grayling	muscle	10		2.3	25.7	-				P.A. Harder, 1993
			liver	10		9.2	96.2	-				
1992	L.Anvil (EP8)	Chinook	whole tissue	compo-site		8	108	<2				P.A. Harder, 1993
	L.Anvil	Grayling	whole tissue	compo-site		6.9	113	<2				
	L.Anvil	Sculpin	whole tissue	compo-site		3.7	138	<2				
1992	Anvil (EP7)	Sculpin	whole tissue	compo-site		3.8	127	2				P.A. Harder, 1993

Table 3.26b

Summary of metals in fish tissue from the Vangorda drainage

YEAR	DRAINAGE	SPECIES	TISSUE	NUM. IN SAMP. /Avg. Mass (g)	METALS ppm (wet weights)							REFERENCE
					Hg	Cu	Zn	Pb	Ni	Mn	Fe	
1975	L. Vangorda	Burbot	muscle	N/A	0.14	0.33	6.4	0.52	5.6	0.65	11.6	Montreal Engineering Company Limited, 1977
		Grayling	muscle	N/A	0.08	0.75	11.8	1.1	3.5	1.5	26.5	
		Sculpin	muscle	N/A	0.19	0.73	26.8	1.9	3.6	5.1	30.9	
		Whitefish	muscle	N/A	0.12	0.72	14.1	0.38	0.52	0.78	14.2	
1976	L. Vangorda	Chinook	muscle	14 / 2.3	0.008	1.3	27.3	0.59	0.72	3.2	39.7	Montreal Engineering Company Limited, 1977
		Grayling	muscle	12/ 22.4	0.01	0.96	14.6	0.86	0.69	2.90	28.3	
		Sculpin	muscle	15 / 2.7	0.02	1.90	39.3	2.80	1.30	7.00	57.8	
1977	L.Vangora	Grayling	muscle	N/A	<0.06	1.39	16.8	<1.0	<1.0	<1.3	18.5	Montreal Engineering Company Limited, 1978
		Sculpin	muscle	N/A	<0.05	2.93	29.3	<1.0	<1.0	5.50	23.0	
1992	L. Vangorda	Chinook	whole tissue	1		6.70	131	5.0				P.A. Harder, 1993
		Grayling	whole tissue	8		4.3	142	6.0				
		Sculpin	whole tissue	1		4.9	184	23				
		Whitefish	whole tissue	3		3.8	90.3	12.7				

Rose/Anvil Creek Results

- Metal concentrations were generally higher in the liver than in the muscle tissue. The liver tends to accumulate heavy metals in higher concentrations than muscle tissue.
- The highest concentration of mercury occurred from a graying muscle sample in 1992 at the Rose Creek Reservoir. The 0.8 ppm wet weight concentration was the only sample above 0.5 ppm, the maximum acceptable concentration set by the EPA (USEPA, 1974). A high mercury level from fish in the reservoir is not surprising since the creation of the reservoir resulted in the flooding of a vegetated area. The permanent water cover results in the natural release of mercury from the vegetation.
- The highest level of copper was found in a grayling muscle collected from the pumphouse pond. Copper is an non-essential element to fish and can be concentrated up to 1000 times in tissue (Env. Canada, 1979).
- A burbot whole tissue sample from the Rose Creek Diversion caught in 1992 had the highest zinc level. All whole tissue and liver samples collected in 1992 reported relatively high zinc levels.
- The lead concentrations were fairly low with the highest value appearing in a burbot whole tissue sample in 1992 at the Rose Creek Diversion.
- The only nickel, manganese and iron data was collected from a sculpin in 1975. However, the concentration of these elements is relatively low.

Vangorda Creek Results

- A comparison between the metal concentrations in the liver and muscle tissue cannot be performed because separate liver data is not available.
- The mercury concentrations were well below the 0.5 ppm guideline set by the EPA.
- The highest levels of copper, zinc and lead occurred in 1992 along lower Vangorda Creek. Although the copper levels were relatively low, the zinc and lead concentrations were elevated and appear higher than results reported in 1975, 1976 and 1977. However, a direct comparison of the results is not possible due to the types of tissues sampled. The highest zinc and lead concentrations were from the sculpin sample.
- The levels of nickel, manganese and iron were relatively low from 1975 to 1977, however these metals were not analyzed during the 1992 survey.

Although complete data between survey years and on tissue types is unavailable, it appears that most of the samples collected in 1992 have higher metal concentrations than in previous years.

3.10.3 Benthic Invertebrates

This section summarizes the benthic invertebrates investigations conducted in the Anvil/Rose Creek and Vangorda Creek drainages. Table 3.27 summarizes the benthic invertebrate surveys undertaken within the various drainages since 1973. Sampling methodology and references for

individual studies are provided in this table. Data from all surveys are summarized and a discussions of the findings presented.

Table 3.27

Benthic invertebrate surveys undertaken within the various drainages since 1973

YEAR	METHOD	DRAINAGE	REFERENCE
1973	Circular Sampler	Rose, Anvil	Hoos & Holman, 1973
1974	Artificial Substrate Sampler	Rose, Anvil	S.A. Baker, 1979
1975	Artificial Substrate Sampler	Rose, Anvil	S.A. Baker, 1979
"	Surber Sampler /Plankton Net	Rose, Anvil, Blind, Vangorda	Mtl. Engineering Co., 1976
1976	Artificial Substrate Sampler	Rose, Anvil	S.A. Baker, 1979
"	Artificial Substrate Sampler	Rose, Vangorda, Blind	Mtl. Engineering Co., 1977
1977	Artificial Substrate Sampler	Rose, Anvil	K. Weagle, 1981(EPS)
"	Artificial Substrate Sampler	Rose, Vangorda, Shrimp	Mtl. Engineering Co., 1978
1978	Surber Sampler	Rose, Anvil	K. Weagle, 1980
1980	Artificial Substrate Sampler	Rose, Anvil, Vangorda, Blind	K. Weagle, 1980
1981	Artificial Substrate Sampler	Rose, Anvil	K. Weagle, 1981
1982	Artificial Substrate Sampler	Rose, Anvil	K. Weagle, 1982
1983	Artificial Substrate Sampler	Rose, Anvil	B. Godin & T. Osler, 1985
"	Artificial Substrate Sampler	Rose, Anvil	K. Weagle, 1983
1984	Artificial Substrate Sampler	Rose, Anvil	K. Weagle, 1984
1986	Artificial Substrate Sampler	Rose, Anvil	Leverton & Assoc., 1987
1987	Artificial Substrate Sampler	Rose, Anvil	EPS, unpublished
1988	Artificial Substrate Sampler	Rose, Anvil	B. Burns, 1989
1990	Artificial Substrate Sampler	Rose, Anvil, Vangorda	P.A. Harder & Assoc., 1992
1991	Artificial Substrate Sampler	Vangorda	B.Burns, 1991
1992	Artificial Substrate Sampler	Rose, Anvil, Blind	P. A. Harder & Assoc., 1993
1993	Artificial Substrate Sampler	Vangorda	B. Burns, 1993
1994	Artificial Substrate Sampler	Rose, Anvil	B. Burns, 1994
1995	Artificial Substrate Sampler	Vangorda	B.Burns, 1995

EPS = Environmental Protection Services

3.10.3.1 Review of Benthic Community Monitoring - Anvil and Rose Creeks

Since 1973, a total of twenty-two annual benthic surveys were conducted in the Anvil/Rose Creek drainage (Table 3.27). During the 1970's, the Environmental Protection Service (EPS) conducted benthic surveys in the Anvil and Rose Creek drainage. Starting in the 1980's, Cyprus Anvil Mining Corporation (CAMC) and Curragh Resources Inc. (CRI), company's operating the Faro mine complex, were responsible for conducting benthic monitoring as part of their water use licences. Anvil Range's present water use licence (IN89-001, Part C, Section 3) requires that benthic surveys be undertaken every two years.

Benthos monitoring has been undertaken at a number of locations within the Anvil and Rose Creek drainages over the years however, the following sampling stations have been monitored on a fairly consistent basis and are now part of the company's water licence biological monitoring program. Figure 3-44 illustrates the locations of these benthos monitoring stations.

- R1 - Rose Creek above the confluence of the South and North Forks of Rose and downstream of the freshwater pumphouse
- R2 - Rose Creek in the mixing zone downstream of the intersection of the Rose Creek diversion channel and the outlet of the tailings pond
- R3 - Rose Creek approximately 5km upstream of the confluence with Anvil or midway between the tailings pond and Anvil Creek
- R4 - Rose Creek upstream of the confluence with Anvil Creek
- R5 - Anvil Creek downstream of the confluence with Rose Creek
- R6 - Anvil Creek upstream of the confluence with Rose Creek
- R7 - North Fork of Rose Creek upstream of the Faro Creek diversion

Anvil Range's present water use licence requires that benthos monitoring be undertaken every second year at the seven stations listed above. Sample station R7 was added to the monitoring network for the 1988 benthos survey.

All of the relevant benthic data from surveys conducted in the Anvil and Rose Creek drainage have been summarized and are presented in Table 3.28. The sampling method used during the majority of benthos surveys was artificial substrate samplers however, surber samplers and circular samplers were also used during earlier studies. For the assessment of benthic community health and diversity, abundance (total population) and taxonomic richness (total number of taxonomic groups found) were examined at each site. A healthy community in clean waters would be characterized by an abundance of individual benthos organisms, many different types of organisms, and pollution sensitive species would be present. The data summarized in Table 3.28 presents benthic invertebrate abundance and taxonomic richness at each station where the information exists. After reviewing the raw data, some information could not be summarized due to the identification methods that were used. The reader is referred to the individual study reference for complete details on study methodologies and results.

Table 3.28

Benthic invertebrate abundance and taxonomic richness at Anvil/Rose Creek sites

YEAR	SITE														REFERENCE
	R1		R2		R3		R4		R5		R6		R7		
	Abundance	Richness	Abundance	Richness	Abundance	Richness	Abundance	Richness	Abundance	Richness	Abundance	Richness	Abundance	Richness	
1973	1193	22	4	2	60	10	nes		434	23					Hoos & Holman, 1973
1974	25	7	33	7	3	4	nes		24	7	247	9			S.A. Baker, 1979
1975	182	9	213	6	65	7	nes		466	10	547	15			S.A. Baker, 1979
*					111	12	194	12							Mtl. Engineering Co., 1976
1976	137	16	32	6	45	11			190	17	328	23			S.A. Baker, 1979
*	215	30													Mtl. Engineering Co., 1977
1977	398	23	99	10	47	13			226	17					K. Weagle, 1981(EPS)
*	72	22													Mtl. Engineering Co., 1978
1978	74	10	5	3	8	4			375	17					K. Weagle, 1981
1980	333	34	191	13	6	3	37	10	434	24					K. Weagle, 1980
1981	2457	35	634	21	166	19	274	20	4126	33					K. Weagle, 1981
1982	784	40	2193	30			1856	28	777	26					K. Weagle, 1982
1983	2906	56	5187	41	5436	47	2336	38							B. Godin & T. Osler, 1985
*	1226	40	1709	29	517	28	907	31	2401	39					K. Weagle, 1983
1984	1736		320		101		4780		161						K. Weagle, 1984
1986	469		2736		3250		5903		4702						EPS printout
*	156	29	911	58	1083	48	1973	50	1605	51					Leverton & Assoc., 1987
1987	374		93		1619		1106		2226						EPS, unpublished
1988	128	24	115	24	32	8	116	15	452	22			218	19	B. Burns, 1989
1990	1373	21	4564	20	2455	20	2175	20	3470	25	3477	25	2467	26	P.A. Harder & Assoc., 1992
1992	1141	27	400	14	321	12	312	14	1263	25	3911	31	1053	22	P.A. Harder & Assoc., 1993
1994	5489	60	920	47	54875	49	2366	53	4115	55	15431	46	14756	44	B. Burns, 1994

EPS = Environmental Protection Services

A summary of the benthic community abundance and diversity is graphically presented in Figures 3-45 and 3-46, respectively. As can be seem from the benthos invertebrate data presented, abundance and diversity at each individual site has fluctuated between the years surveyed. This variance can be attributed to many natural factors such as climate, stream flow, life cycles of various organisms, timing of sampling, sampling methodology, as well as the chemistry of the water. In the background control station, R1, there has been a trend towards increased community abundance.

Benthos monitoring stations downstream of the tailings pond decant (R2, R3, & R4) have historically shown low community abundance and diversity when compared with background monitoring stations. This reduced benthos productivity and lack of benthic invertebrate taxa that are sensitive to metal contamination in lower Rose Creek as compared with the control sites indicates a negative response to mine effluent discharge.

This trend has changed in recent years (1990 and 1994 surveys) where the downstream Rose Creek stations have reported improved benthos abundance and diversity. The latest surveys do suggest a recovery in the benthic community from impacts associated with tailings discharge. A number of factors are attributed to this change including temporary cessation of milling operations and discharge of tailings solids into the Faro pit.

3.10.3.2 Review of Benthic Community Monitoring - Vangorda Creek

Benthic surveys were initiated in the Vangorda Creek drainage in 1975 and since that time, seven surveys have been conducted (Table 3.27). The company's present water use licence (IN89-002, Part D, Section 2) requires that benthic invertebrate surveys be undertaken every two years. The first licensed survey was undertaken in 1991. Benthos surveys conducted prior to 1991 provide background data prior to mine development at the Vangorda Plateau.

Figure 3-47 illustrates the location of the water licence benthos monitoring stations. Other stations were monitored on Vangorda, however this data is infrequent. A description of these monitoring stations follows:

- V1 - Vangorda Creek upstream from the Vangorda pit and the Blind Creek road at the headwaters of the creek diversion
- V5 - West Fork of Vangorda Creek upstream of the Anvil Range Complex access road
- V8 - Vangorda Creek near the bridge to the Faro town water supply
- V27 - Main stem of Vangorda Creek just upstream of the confluence with Shrimp Creek

Relevant benthic data from surveys conducted in the Vangorda Creek drainage is summarized and are presented in Table 3.29. The sampling method used during the majority of benthos surveys was artificial substrate samplers although a surber sampler was used during the 1975 study. The data summarized in Table 3.29 presents benthic invertebrate abundance and taxonomic richness at each station where the information exists. For the assessment of benthic community health and diversity, abundance (total population) and taxonomic richness (total

number of taxonomic groups found) were examined at each site. Periphyton samples were also collected during the 1990 study (P.A. Harder & Associates, 1992) however the results are not summarized here. The reader is referred to the individual study references for complete details on study methodologies and results.

Table 3.29

Benthic invertebrate abundance and taxonomic richness at Vangorda Creek sites

YEAR	SITE								REFERENCE
	V1		V27		V5		V8		
	Abundance	Richness	Abundance	Richness	Abundance	Richness	Abundance	Richness	
1975			307	15			36	10	Mtl. Engineering Co., 1976
1976	136	15							Mtl. Engineering Co., 1977
1980	350	24	216	21			133	26	K. Weagle, 1980
1990	300	7	1299	7	2985	15	3162	16	P.A. Harder & Assoc., 1992
1991	736	17	953	17	1298	28	594	21	B. Burns, 1991
1993	3090	19	5953	19	2193	21	3042	19	B. Burns, 1993
1995	1758	34	4929	34	1550	42	8340	48	B. Burns, 1995

A summary of the benthic community abundance and diversity is graphically presented in Figures 3-48 and 3-49, respectively. Variations in abundance and diversity at each individual site has fluctuated between the years surveyed and this variance was discussed previously. Natural fluctuations in benthic communities can poses difficulties in data interpretation, especially with a long term monitoring program. It is also apparent that station V1 (upstream control station) has consistently reported marked differences in productivity and community structure between sites V27 and V8, with the downstream stations reporting better productivity and diversity. This may be attributable to the nature of the stream reach in the control location.

A slight reduction in community abundance and diversity was noted during the 1991 survey at the downstream monitoring stations and this may reflect some impact associated with silt loadings to the creek during initial mine construction. However, based on recent surveys, the benthic community continues to be productive and diverse in the lower reaches of Vangorda Creek.

3.10.4 Stream Sediments

3.10.4.1 Introduction

The following section provides a summary of the stream sediment investigations and metal concentrations in sediments along the Rose/Anvil Creek and Vangorda Creek drainages. Table 3.30 summarizes the sediment surveys undertaken within the drainages since 1973. This table provides the year of the study, method of sample collection and source for the data. Results from the surveys are summarized and a discussion of the findings are presented.

Table 3.30

List of sediment studies on Rose/Anvil and Vangorda Creeks

DRAINAGE	DESCRIPTION	COLLECTION METHOD	REFERENCE
Rose, Anvil	Stream Sediments	Shovel / 1 Sample	R.Hoos & W. Holman, Environment Canada, 1973
Rose,Anvil	Stream Sediments / Particle Size	Aluminum Shovel / 3 Replicates	B.Godin & T. Osler, Environment Canada, 1985
Vangorda	Stream and Suspended Sediments	Teflon Scoop and Centrifuge /3 Replicates	D.Davidge, Environment Canada, 1996.
Vangorda	Stream Sediments	Stainless Steel Trowel / 3 Replicates	B. Burns, Laberge Environmental Services, 1993
Vangorda	Stream Sediments	Teflon Trowel / 3 Replicates	B. Burns, Laberge Environmental Services, 1996

3.10.4.2 Methodology

The sediment studies along Rose and Anvil Creek were conducted by Environment Canada in 1973 and twice in 1983. Vangorda Creek sites were sampled by Environment Canada in 1991

and 1993 and by Laberge Environmental Services (LES) for KPMG and Anvil Range in 1993 and 1996. Although the sampling was performed by different organizations the collection and analysis procedures are similar.

Sediment samples were collected from an exposed area of the stream bank, generally characterized by the finest grain size evident at the site. All samples were of recently transported stream bed load. Samples were collected using either a trowel or shovel, placed in sealed bags and packed with ice for transport to the laboratory performing the analysis. Triplicate samples were collected at each site to ensure that an average metal concentration in the sediments for that area could be obtained. The exception was the 1973 sediment survey, where only one sample from each site was collected.

The Environment Canada samples were sent to their laboratory in Vancouver and analyzed for up to eighteen metals using ICP analysis of the dried and sieved samples. In addition, in 1991 and 1993 some metals including copper (Cu), iron (Fe), lead (Pb), and zinc (Zn) were analyzed using a sequential extraction procedure. The extraction was performed on the dried section of the sample passing through a 63 μm sieve. The Environment Canada data provides total metal levels in the sediments.

The samples collected by LES were shipped to Quanta Trace Laboratories in B.C. where they were dried, passed through a 100 mesh (0.15 mm) stainless steel sieve, and then run through an ICP analysis to determine total metals levels of Cu, Fe, Pb and Zinc using methods found in *Standard Methods for the Examination of Water and Wastewater 17th Edition* (Clesceri et. al., 1989) and U.S. EPA protocols found in *Test Methods for Evaluating Solid Waste, Physical Chemical Method, SW846.*

Stream sediment levels of copper, iron, lead and zinc are summarized for each drainage. The level of these metals in the sediments are of particular importance as the Anvil Range complex is a base metal mine and these compounds can be toxic to aquatic organisms.

3.10.4.3 Rose/Anvil Creek Results

The average concentrations of copper, iron, lead and zinc in sediments along Rose/Anvil Creek for 1973, July (83) and September (83) is summarized in Table 3.31.

TABLE 3.31

Metal Concentrations in Sream Sediments at Rose/Anvil Creek Sites

STATION NUMBER	DESCRIPTION		COPPER (Cu) (ug/g)			IRON (Fe) (ug/g)			LEAD (Pb) (ug/g)			ZINC (Zn) (ug/g)		
			1973	July '83	Sept. '83	1973	July '83	Sept. '83	1973	July '83	Sept. '83	1973	July '83	Sept. '83
EP1 (R1)	Rose above confluence of South and North Forks	Mean	64	26.1	25.0	34000	25633	25450	280	124	198	270	215	304
		S.D.		1	4.0		3927	919		22.1	36		49.3	46
EP2	Diversion Channel near new tailings pond	Mean	68	54.2	45.4	71000	25367	26600	830	368	338	2000	300	298
		S.D.		3.2	1.0		4840	283		37	24.7		29	3.5
EP3	Combined seepage flows u/s of decant confluence	Mean	48	43.3	45.5	28000	35167	29300	274	93.3	87.5	290	282	327
		S.D.		4.6	0.4		3262	848		34.5	2.1		73.3	11.3
EP4 (R2)	Rose in mixing zone d/s of intersection of diversion and tailings outlet	Mean	24	130	102	29000	66400	53050	83	775	554	180	967	868
		S.D.		13.5	0.7		6657	8697		50.2	97.6		92.3	19.8
EP5 (R3)	Rose 5 km u/s of confluence with Anvil	Mean	44	119	114	34000	68067	66050	280	681	682	440	1000	992
		S.D.		4	2		6179	212		53.3	31.8		78.2	82.7
EP6a (R4)	Rose u/s of confluence with Anvil	Mean		224	120		39500	35400		585	899		1020	750
		S.D.		98.8	3.5		30200	424		107	157		20.8	144.2
EP7a (R6)	Anvil u/s of confluence with Rose	Mean		119	116		50100	54700		510	504		977	778
		S.D.		2.6	12		7700	6080		75.8	41		75.1	38.2
EP6	Anvil above confluence with North Fork		93			45000			650			1100		
EP7	Anvil North Fork u/s of confluence with Anvil		40			27000			<45			130		
EP8	Anvil u/s of confluence with Pelly River	Mean		28.8	30.7		23000	27800		46	54		133	156
		S.D.		2.2	1.1		1740	707		3.6	5.7		12.9	3.5

Data obtained from Environmental Protection, Environment Canada, 1973 and 1985

The locations of the sample sites are shown on Figure 3-44 and descriptions of each site summarized below.

- EP1 (R1) Rose Creek near confluence of South and North Forks
- EP2 Diversion Channel near new tailings pond
- EP3 Combined seepage flows upstream of decant confluence
- EP4 (R2) Rose Creek in mixing zone downstream of intersection of diversion and tailings outlet
- EP5 (R3) Rose Creek 5 km upstream of confluence with Anvil Creek
- EP6a (R4) Rose Creek upstream of confluence with Anvil Creek
- EP7a (R6 Anvil Creek upstream of confluence with Rose Creek
- EP6 Anvil Creek upstream of confluence with the North Fork of Anvil Creek
- EP7 North Fork of Anvil upstream of confluence with Anvil Creek
- EP8 Anvil Creek upstream of confluence with Pelly River

Sample site R1 is upstream of EP1 but the data from both have been compared due to there relative proximity.

By contrasting the 1973 and 1983 data a comparison can be made before and after significant develop occurred. Aside from the major development changes during this time some notable spills including the release of $2.45*10^5$ m^3 of tailings slurry (Environment Canada, 1985) and $CuSO_4$ spill into Rose Creek (Environment Canada, 1979) have occurred. These spills would have had a direct impact on the level of metals in the sediments. The two studies from 1983 allow seasonal variations to be studied.

The levels of copper, iron, lead and zinc at the various stations and years has been graphed to make trends and anomalies evident. Figures 3-50, 3-51, 3-52 and 3-53 show the concentrations of copper, iron, lead and zinc along Rose and Anvil Creeks, respectively.

The trends and variations are summarized below:

General Trends

- Stations R2, R3 and R4, along Rose Creek downstream of the tailings outlet and diversion, had among the highest metal concentrations particularly when compared to stations upstream of the tailings outlet or near the confluence with the Pelly River.
- Station R6 on Anvil Creek upstream of the confluence with Rose Creek had concentrations comparable to stations R2, R3 and R4 in 1983. This indicates that background stream sediments at Anvil Creek are comparable to lower Rose Creek.

- Sites R2 and R3 displayed two to three fold increases in metal concentrations in the 1983 sampling as compared to the 1973 data. The higher levels may have resulted from the tailings spill.
- The 1983 levels at EP8, Anvil Creek near the confluence with the Pelly River, were comparable to the those reported in Rose Creek upstream of the tailings outlet indicting attenuation of metals in the sediments in lower Anvil Creek.
- With the exception of copper levels, the 1973 data from EP2 indicted a metal concentration more than twice as high as values from stations upstream of the tailings outlet and slightly higher than most of the levels at R2 and R3 on Rose Creek. However, the data is based on one sample and may not be representative of the area in 1973. The sample may reflect initial mine development at this location.
- Only iron levels showed a significant decline at R4 from R2 and R3.

Notable Trends

- Copper concentrations from the two periods in 1983 were similar for all sample sites. The exception was R4, immediately upstream of the confluence with Anvil Creek, which reported a July concentration almost twice as high as September and more than twice that of the other 1983 values at sites further upstream along Rose Creek. The concentration at R4 was an average of three triplicate samples with a standard deviation near 100 so it might not be representative of the general area.
- The lead concentrations from the 1983 samplings were similar except for R4 in September, which was almost twice as in the July sampling. The high lead concentrations are probably the result of naturally high lead levels in the sediment since none of the other metals showed this trend.

3.10.4.4 Vangorda Creek Results

The levels of copper, iron, lead and zinc at various stations for the years of 1991, 1992 and 1995 are shown on Table 3.32

TABLE 3.32

Metal Concentrations in stream sediments at Vangorda Creek sites

	SITE	DESCRIPTION		COPPER (Cu), (ug/g)			IRON (Fe), (ug/g)			LEAD (Pb) (ug/g)			ZINC (Zn), (ug/g		
				1991	1993	1995	1991	1993	1995	1991	1993	1995	1991	1993	1995
	V1[a]	U/s of Vangorda pit and Blind Creek Road at headwaters of creek diversion	Mean		24	33		37000	30767		30	43		120	177
			S.D.		3.6	2		4636	2566		7.9	14		13	40
	EP6[b]	D/s side of haul road adjacent to Vangorda Creek	Mean		137			62025			1136			1512	
			S.D.		62			7681			566			645	
	V27[a]	Main stem of creek just u/s of conf. With Shrimp Creek	Mean		52.3	59		31667	24667		587	1305		436	519
			S.D.		4.2	11		1504	3968		518	1215		126	43
	V5[a]	West Fork u/s of Anvil Range access road	Mean		28	36		22433	18233		23	52		98	129
			S.D.		1	2		611	289		1	2		4.5	4
	V8[a]	Vangorda Creek near bridge to town water supply	Mean		37	48		27767	21733		214	218		251	391
			S.D.		0	4		322	1026		11.1	70		12.5	111
	V8[b]	Vangorda Creek near bridge to town water supply	Mean	57	50		29500	36300		1801	161		321	441	
			S.D.	5	2		1726	1409		618	8		19	11	

Data obtained from [a] L.E.S., 1993 and 1996, and [b] Env. Canada, 1995

The location of each sample site is shown on Figure 3-47 and described below.

- V1 Vangorda Creek upstream of Vangorda pit and Blind Creek road at the headwaters of creek diversion
- V27 Main stem of creek just upstream of the confluence with Shrimp Creek
- V5 West Fork of creek upstream of Anvil Range access road
- V8 Vangorda Creek near bridge to the Faro town water supply
- EP6 Vangorda Creek downstream side of haul road adjacent to creek

Unfortunately data from the Vangorda drainage prior to development is not available so long term changes in sediment metal levels cannot be evaluated. However the 1991,1993 and 1995 data was analyzed to compare fluctuations over time. Unfortunately only station V8 was sampled in 1991 so a detailed comparison between 1991 and the other years cannot be completed. The 1993 data for station V8 shown in the figures is the average from two studies, the individual values are shown on Table 3.32.

The concentrations of copper, iron, lead and zinc at the various stations and years appears in figures 3-54, 3-55, 3-56 and 3-57.

Evident trends are summarized below:

General Trends

- Since station EP6, immediately downstream of the haul road on Vangorda Creek, was only examined in 1993 it is not shown on the figures. However, the levels of all four metals are the highest at this particular site indicating the possible deposition of sediments into the creek from road maintenance or the road fill material.
- With the exception of the iron results, stations V1 and V5 reported similar metal levels which were significantly below the concentrations at V8 and V27. This was expected since both stations are not directly effected by the mine development in the area.
- As expected, station V8 generally reported lower levels than V27, the upstream station directly effected by the development.
- The metal levels determined in 1995 were higher than in 1993 for all of the stations. The only exception to the trend was the iron data in which the 1993 concentrations were higher.
- With the exception of the iron analysis, the 1991 data for station V8 showed comparable levels to samples collected in the other years.

Notable Trends

- Iron levels at station V1 were among the highest of all sites, unlike the trend shown by the other metals.

- Lead concentrations were higher in 1995 than 1993 at all sites, however station V27 showed a two fold increase unlike the other sites.
- The highest lead concentration of all stations occurred at V8 in 1991, however the standard deviation was high.

3.11 Land Use

3.11.1 Kaska Use of the Land (Just Like People Get Lost)

The report "Just Like People Get Lost (JLPGL) (Weinstein, 1992) provides a retrospective assessment of the traditional use of the land by the Ross River Kaska Dena and the changes the use of the land which are attributable, in part, to the development of the Faro mine complex. The report is a good reference regarding First Nations land use in the areas affected by mine development.

The JLPGL report is based on land use maps constructed by the people of the Rose Rive Kaska. The land use maps cover a large period of time and were used to perform a comparison of the utilization of traditional areas before, during and after development of the Faro mine complex (Faro and Vangorda Plateau).

The author (Martin Weinstein) states that the comparisons are not detailed since a complete record of information was not available. In addition, the author states that it is very difficult to separate social and economic changes which resulted directly from the mine development form those which resulted from other non-related events. In general terms, however, there is good information presented which is relevant to planning land reclamation for the mine affected lands.

There are tow core areas which have been traditionally utilized for trapping, hunting, fishing and gathering by the Ross River Kaska. The areas are informally under the stewardship of different family groups with each family group using Ross River as a central meeting place. Ross River serves as a loose dividing point between the eastern and western areas. The family groups share land s across the eastern/western divide and the boundaries described are used in a general rather than a definitive way.

The western core area is centered around Mt. Mye with intensive use of Swim Lakes, Blind Creek and Anvil Creek. Mt. Mye and the surrounding area are important to traditional Kaska land use lifestyle because the area provides in one location all the seasonally utilized resources. This includes big game, small mammals, fresh water fish, salmon and berries.

The JLPGL report shows that both the frequency and intensity of utilization of the are has changed dramatically since the time prior to development of the Faro mine complex.

The mouths of Blind and Vangorda Creeks and Fish Hook (near the mouth of Anvil Creek) were traditionally utilized as fishing camps and base cabin sites from which inland hunting and trapping excursions were based. These locations along the Pelly River provided salmon during the spawning run, freshwater fish and berry gathering areas.

Primary travel routes inland from these base cabin sites were identified which accessed the uplands areas on and around Mt. Mye. The upland areas provided opportunity to hunt and trap small game and to hunt big game. One of the primary travel routes proceeded up the West Fork of Vangorda Creek valley to Rose Creek where direction could be taken either up the Rose Creek Valley to the western slopes of Mt. Mye or down the Rose Creek Valley towards the current Faro mine site. Another way of access to the Mt. Mye area was up the Blind Creek valley and overland to the Vangorda Plateau and the southern slopes of Mt. Mye.

The Rose Creek Valley was also utilized as a primary travel route either connecting the Fish Hook camp areas with the Vangorda Creek area or accessing the upland areas above the current Faro mine site via a route near the current tailings/mine site.

The JLPGL report provides a progressive recounting of the relationship between mine related activities and changes in the social and economic status of the Ross River Kaska people.

The period of prospecting and mineral exploration activities of the 1950's and 1960's which also affected the traditional use of the land. These included construction of the Robert Campbell highway and relocation of the town of Ross River. A general depression related to a crash in the fur market also played a role in altering the economic and social status of the Kaska People. One of the effects of these events was to promote village residency year round using increased vehicular access to the closer, easily accessed bush areas. Children began to attend school in the village which restricted family movements.

The impact on Kaska traditional land use during the mine development and operations period were continuance and intensification of those impacts previously started. Further restrictions on access due to safety reasons, increase traffic, non-native resident population , the Pelly River bridge, and perceived impacts on water quality, fish and meat all combined to create an atmosphere unappealing, in some accounts, hostile to continued use to the area for traditional purposes by the Kaska people.

Overlain on the exploration and mine activities were important regional and federal events which played a great role in altering the traditional Kaska land use. As stated by the author of JLPGL report, it is nearly impossible to differentiate between the impacts associated with the local mine related events and the impacts resulting from the over riding larger scale social and economic events.

One of the important impacts on land use resulting from the presence of a local non-native resident population was simply competition and more intensive harvesting of wildlife resources. The traditional Kaska way of managing wildlife through assessment and flexibility in hunting and trapping areas would include leaving areas fallow for several years if necessary. The imposition of trapline registrations and the intensive annual use by non-native hunters was far removed from the traditional management style.

More recently, during the 1980's and 1990's (to 1992 when the report was compiled), the land is used for limited hunting and fishing but not nearly at the intensive levels associated with the pre-mine development period. The continued use of the land has as much to do with cultural attachment and environmental assessments as with harvesting . In a general sense, the family

groups who traditionally used the Mt. Mye areas as their primary harvesting area have shifted their activities to the east in response to both the actual and perceived barriers to continuance of utilization of the traditional area..

3.11.2 Current

The fact that the Ross River Dena are not currently utilizing the Mt. Mye and Anvil Creek areas as intensely as in previous years does not mean that these areas are not currently important for cultural and economic reasons. Furthermore, the use of the land for traditional purposes may recover to pre-mine development levels following successful implementation of the proposed land reclamation measures.

The proposed closure measures will increase the opportunities for use of the land by wildlife and by the Kaska people. The closure plan proposed for the Vangorda and Faro sites is an "active" closure in that operation of water treatment facilities is required for the indeterminate future. However, the scale of the required activities is not in the same order as that required during mine operations and the on-going activities themselves are not expected to have a negative impact on land use other than some potential for local area animal avoidance behaviour.

The most obvious and immediate result of mine closure will be the reduction of the non-native resident population which will mitigate that issues of resource competition, over the harvesting and the presence of "strangers" in the bush.

The proposed measures for collection and treatment of contaminated water will mitigate the issues of water quality impacts. In fact, the plan for reprocessing of the tailings from the Down Valley will result in the movement of a large portion of the tailings to the more secure and manageable Faro Open Pit. Measures such as this reduce the possibility of negative impacts on water quality and, thereby, on the quality of fish and game.

The alterations to the landscape on the Vangorda Plateau and Faro sites resulting from the open pits and rock dumps are generally permanent but they are not, in themselves, without potential benefit. The land reclamation measures proposed for the Vangorda Plateau site may enhance the opportunities for Sheep utilization through recontouring, revegetation and specific remedial efforts to encourage their use of the rock and overburden dumps. A further example of the potential for beneficial use of the pits and dumps is the use of the Faro and Vangorda Pits as contaminated water storage ponds. This eliminates the need to construct large new ponds and dams to contain contaminated water requiring treatment prior to release into the environment.

The success of the proposed closure measures on reducing the perceptions of impacts on water quality, fish and meat will depend upon the sharing of up to date information regarding the environmental status of the mine affected areas. The terms of the existing cooperation agreement between Anvil Range Mining Corporation and the Rose River Dena Council ensure that the sharing of information between parties will take place.

3.12 References

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Larsen, D. , Wildlife Management Section, Dept. of Renewable Resources, Government of Yukon

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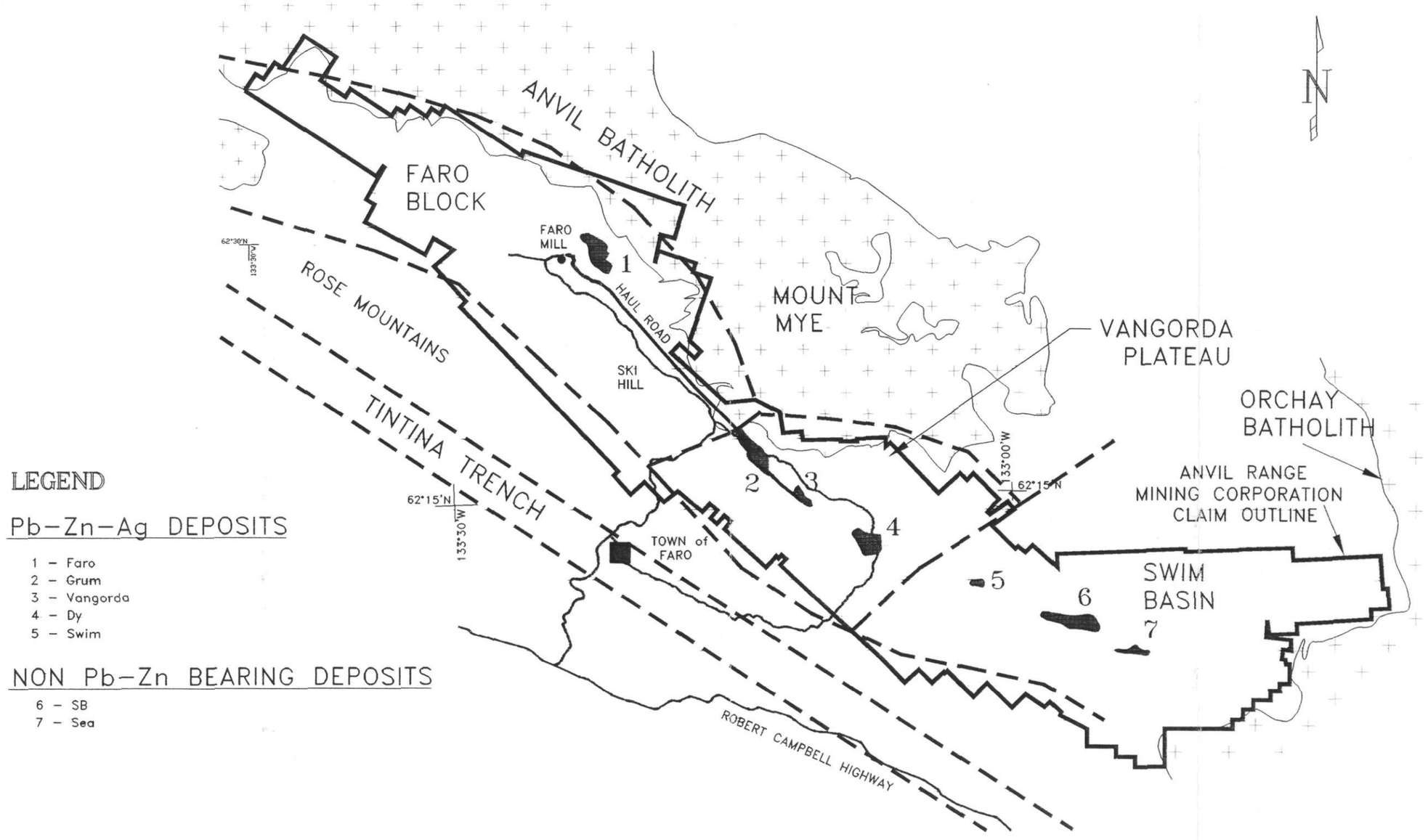
FIGURES



LEGEND

Pb–Zn–Ag DEPOSITS

1 – Faro
2 – Grum
3 – Vangorda
4 – Dy
5 – Swim

NON Pb–Zn BEARING DEPOSITS

6 – SB
7 – Sea

0 5 10 20

kilometres

Scale 1:200 000

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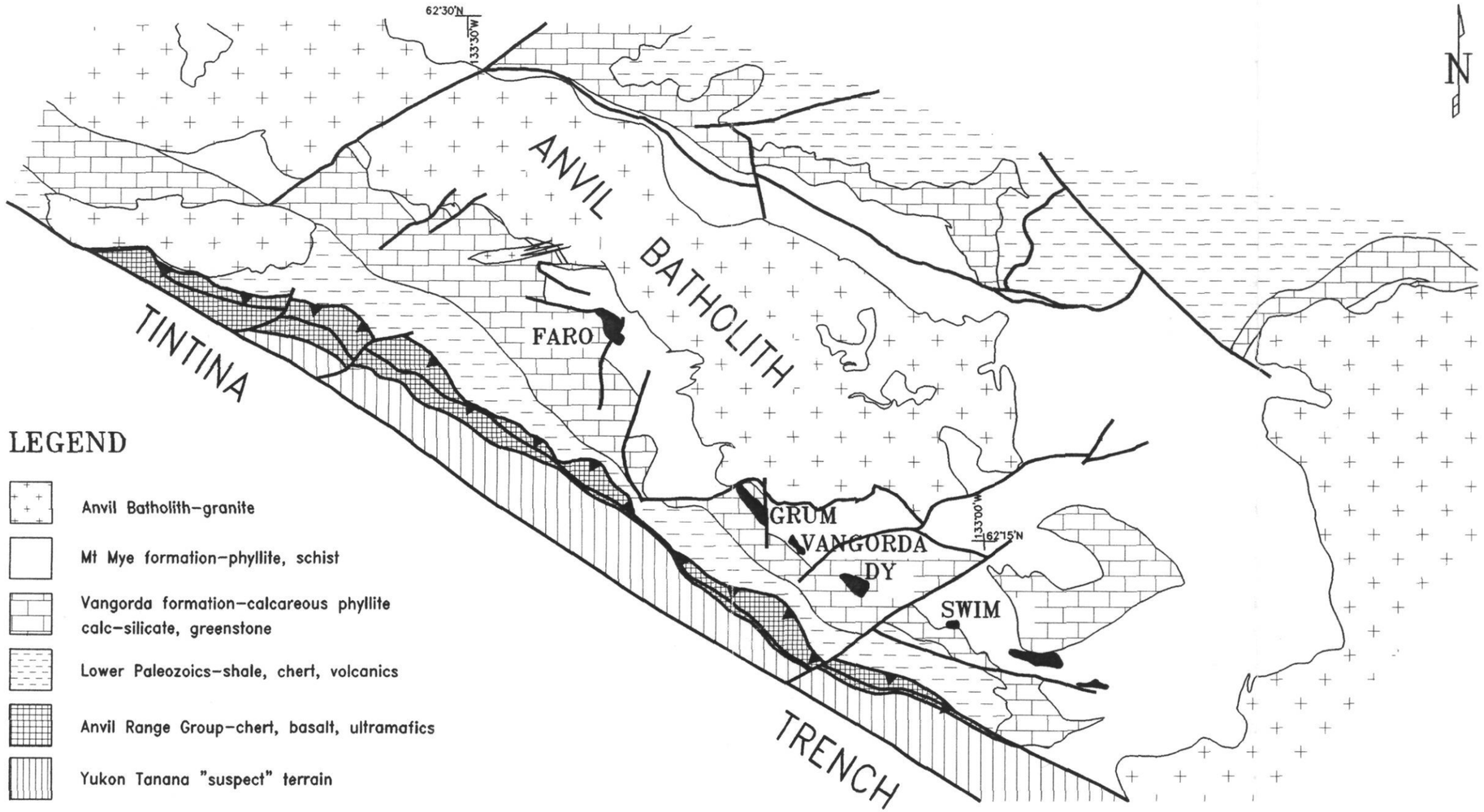
Consulting Geotechnical and Environmental Engineers

Anvil Range Mining Corporation

Anvil Complex Closure Plan

Geographic Regions of the Anvil Range

PROJECT NO.	DATE	APPROVED	FIGURE
033001	Nov. 1996		3-1



LEGEND

- Anvil Batholith–granite
- Mt Mye formation–phyllite, schist
- Vangorda formation–calcareous phyllite calc–silicate, greenstone
- Lower Paleozoics–shale, chert, volcanics
- Anvil Range Group–chert, basalt, ultramafics
- Yukon Tanana "suspect" terrain
- Sulphide deposit
- Fault
- Thrust fault

0 5 10 20

kilometres

Scale 1:250 000

Drawing taken from Access Mining, 1996.

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Anvil Complex Closure Plan

Geological Map of the Anvil Range

PROJECT NO.	DATE	APPROVED	FIGURE
033001	Nov. 1996		3–2

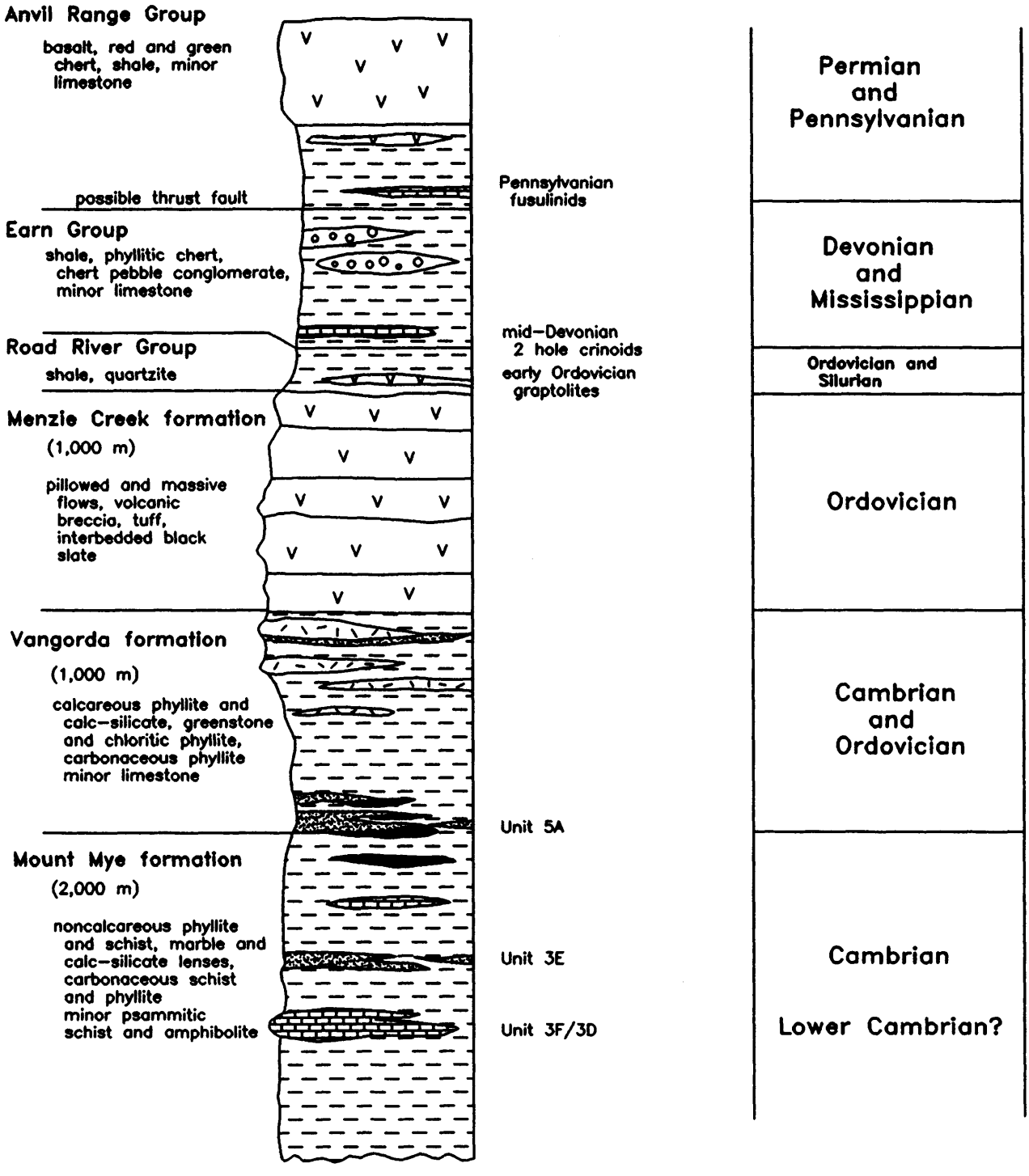

Figure 2. Schematic stratigraphic section for Anvil District. Vangorda and Mt. Mye formations contain carbonaceous phyllite (dark stipple-units 5A, 3E) interbanded with sulphide horizons (black). Sulphides form massive and disseminated beds through a 200 metre stratigraphic interval straddling the Mt. Mye-Vangorda contact. Upper Vangorda formation is characterized by abundant dark green greenstone lenses (hatchure pattern).

Drawing taken from Access Mining, 1996.

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Anvil Complex Closure Plan

Stratigraphic Column of the Anvil Range

PROJECT NO.	DATE	APPROVED	FIGURE
033001	Nov.1996		3-3

SW

LONG SECTION 04N

NE

+1300.00

+1200.00

+1100.00

+1000.00

FINAL PIT

Phase II Fold

Phase II Fold

Phase I Fold

metres

0 20 40 60 100

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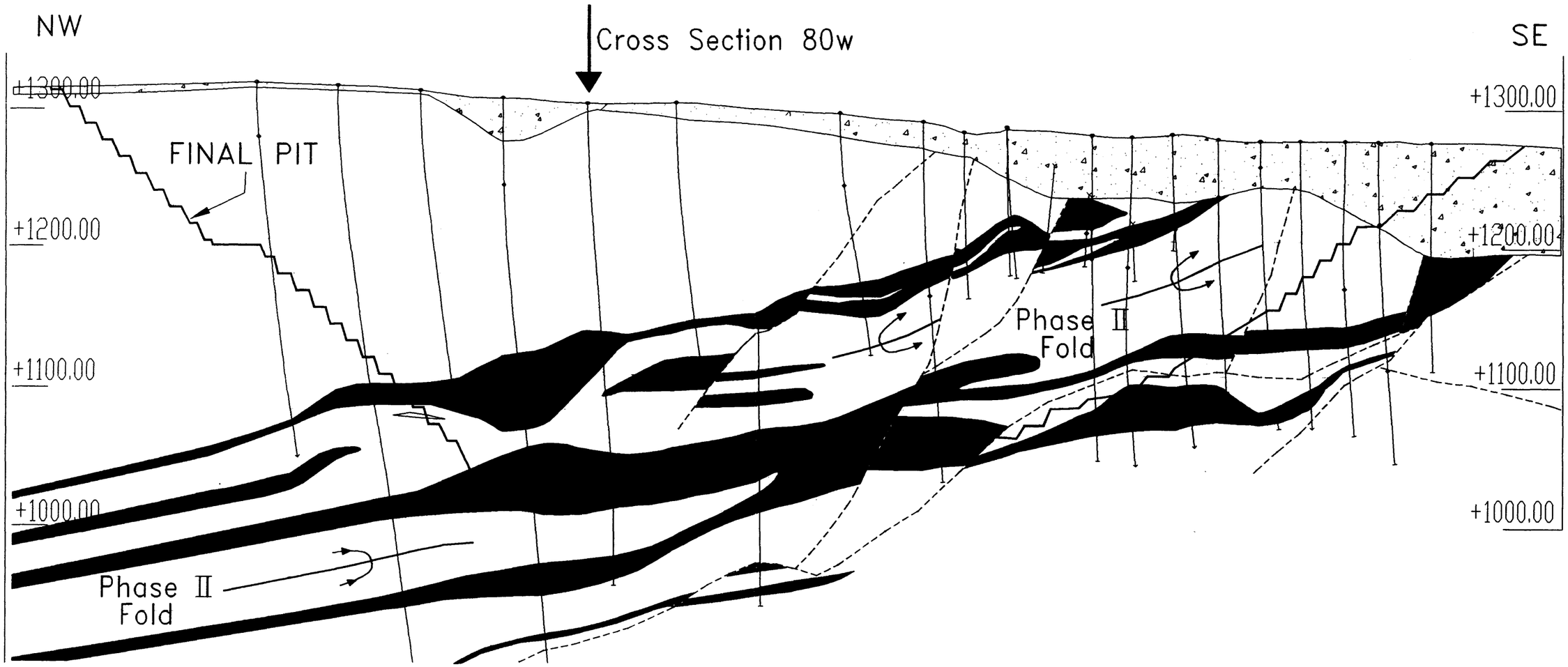
Anvil Complex Closure Plan

GRUM DEPOSIT VERTICAL CROSS SECTION 80W

PROJECT NO.	DATE	APPROVED	FIGURE
033001	Nov. 1996		3-4



metres

0 40 80 120 200

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GRUM DEPOSIT VERTICAL LONG SECTION 4N

PROJECT NO.	DATE	APPROVED	FIGURE
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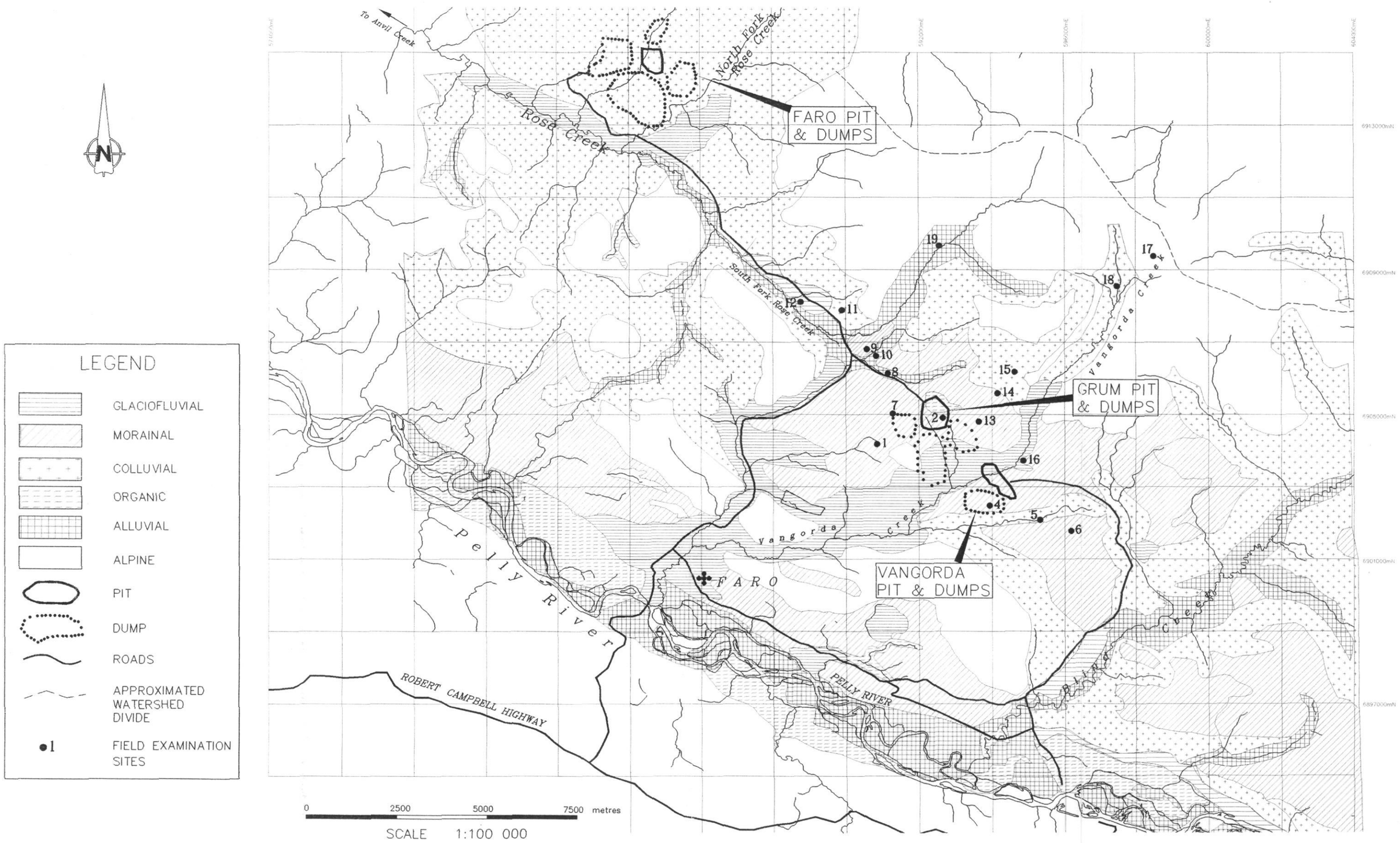

NOTE: Information obtained from drawing in Montreal Engineering Co. Ltd, 1976 – "Preliminary Engineering and Environmental Investigation".

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Anvil Complex Closure Plan

Regional Landform & Surficial Geology

PROJECT NO.	DATE	APPROVED	FIGURE
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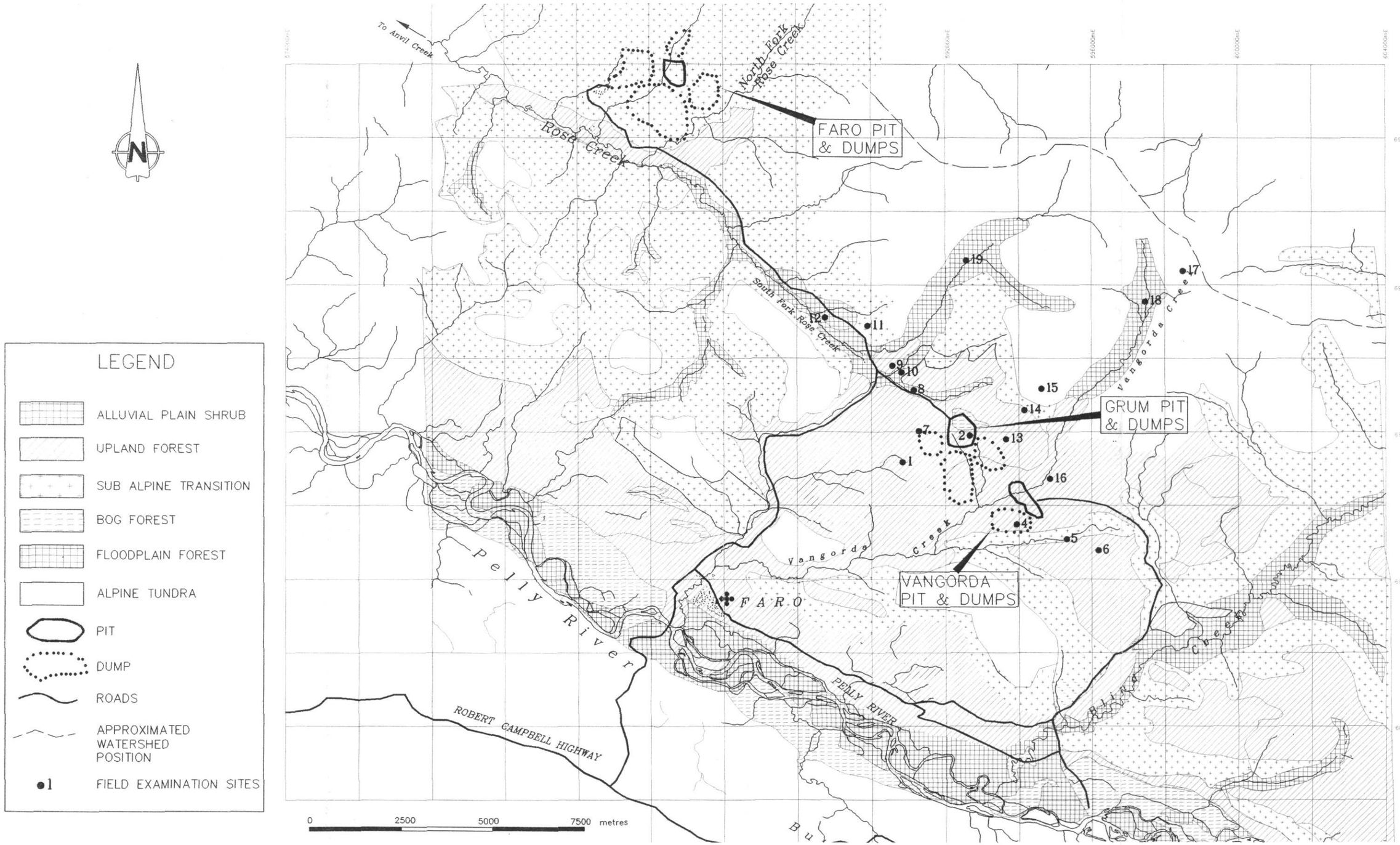

LEGEND

- ALLUVIAL PLAIN SHRUB
- UPLAND FOREST
- SUB ALPINE TRANSITION
- BOG FOREST
- FLOODPLAIN FOREST
- ALPINE TUNDRA
- PIT
- DUMP
- ROADS
- APPROXIMATED WATERSHED POSITION
- ●1 FIELD EXAMINATION SITES

SCALE 1:100 000

NOTE : Information obtained fro drawing in Montreal Engineering Co. Ltd., 1976 – "Preliminary Engineering and Environmental Investigation"

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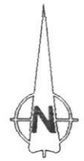
Anvil Complex Closure Plan

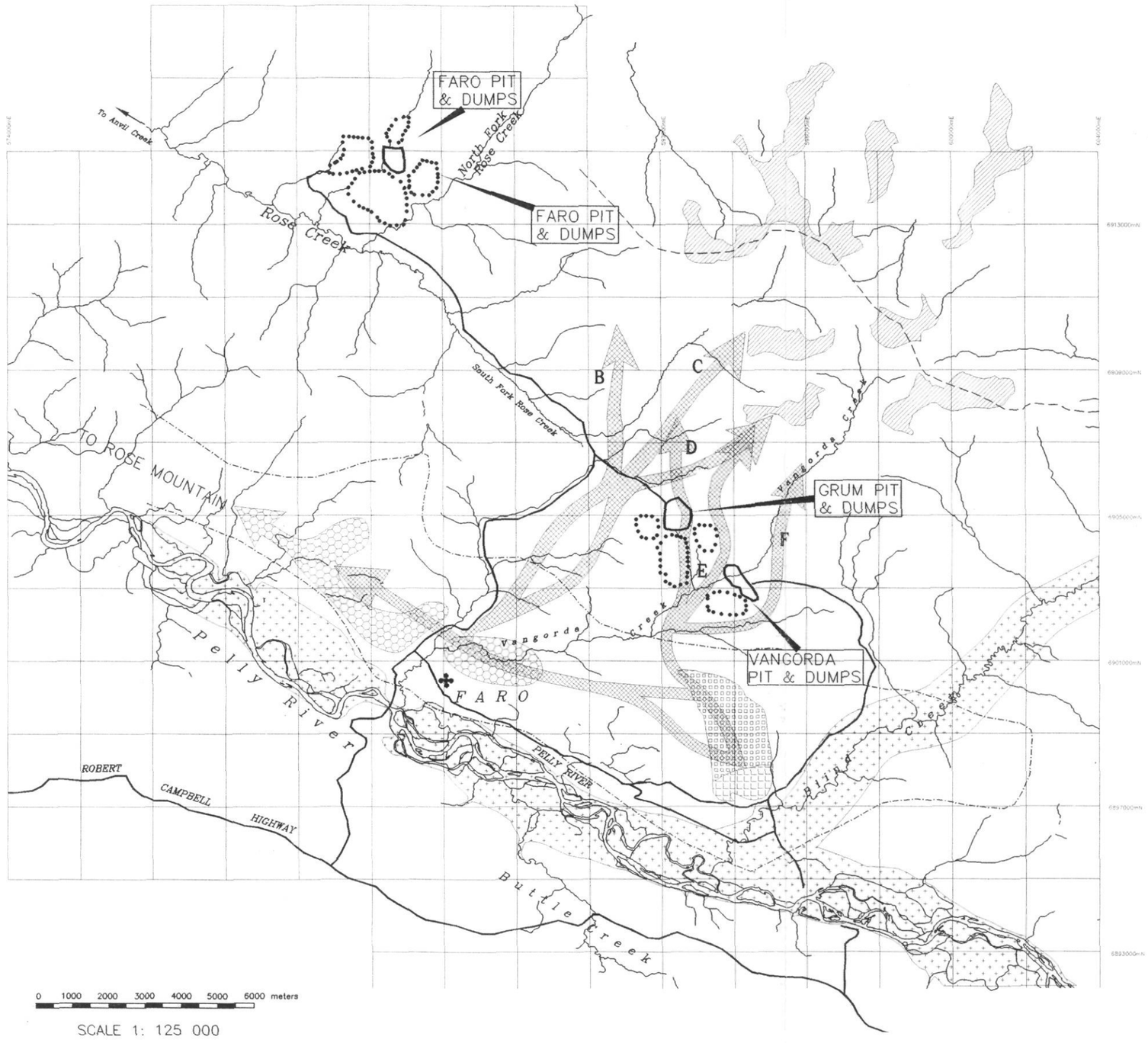
Regional Vegetation

PROJECT NO.	DATE	APPROVED	FIGURE
033001	Nov. 1996		3-7



LEGEND

- Ram Winter Range
- Sheep and Caribou – Summer Range (Alpine Habitat)
- Lambing Area
- Moose Winter Range – from local knowledge See Weinstein 1992
- Sheep Winter Range
- Probable Sheep Migration Routes – Routes A, B, C, D, E & F after McCleod (1981).
  Routes B and C remain unconfirmed in available literature, howerever, remain as most likely route for rams into Mt. Mye from known winter ranges above Faro (supported by local observation).
- Outline of Area burned in 1969 Fire
- Approximate Watershed Position
- Rivers
- Pit
- Roads
- Dump
- Approximated Watershed Position



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NOTE : Information obtained fro drawing in Montreal Engineering Co. Ltd., 1976 – "Preliminary Engineering and Environmental Investigation"

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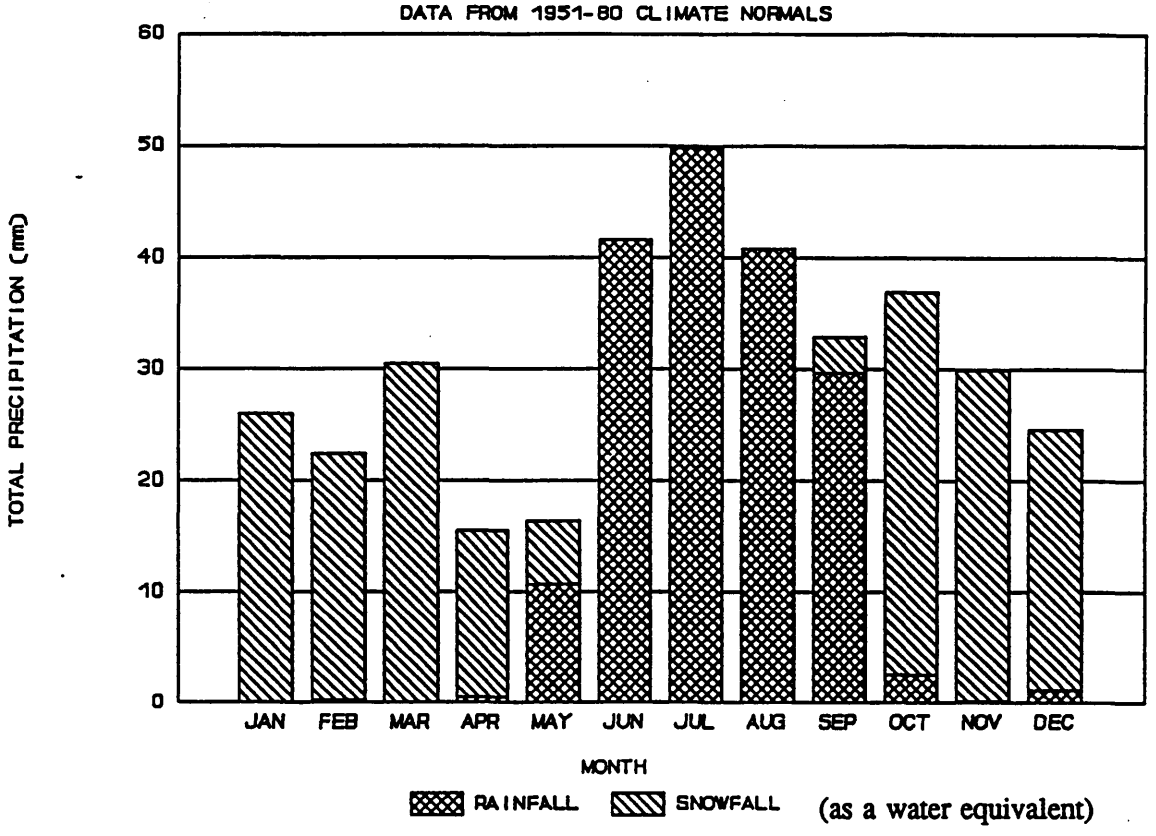
Anvil Complex Closure Plan

Wildlife habitat

PROJECT NO.	DATE	APPROVED	FIGURE
033001	Nov. 1996		3-8



NOTE: FIGURE TAKEN FROM SRK REPORT 60635 "DOWN VALLEY TAILINGS IMPOUNDMENT DECOMMISSIONING PLAN", APRIL 1991.

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Consulting Geotechnical and Environmental Engineers

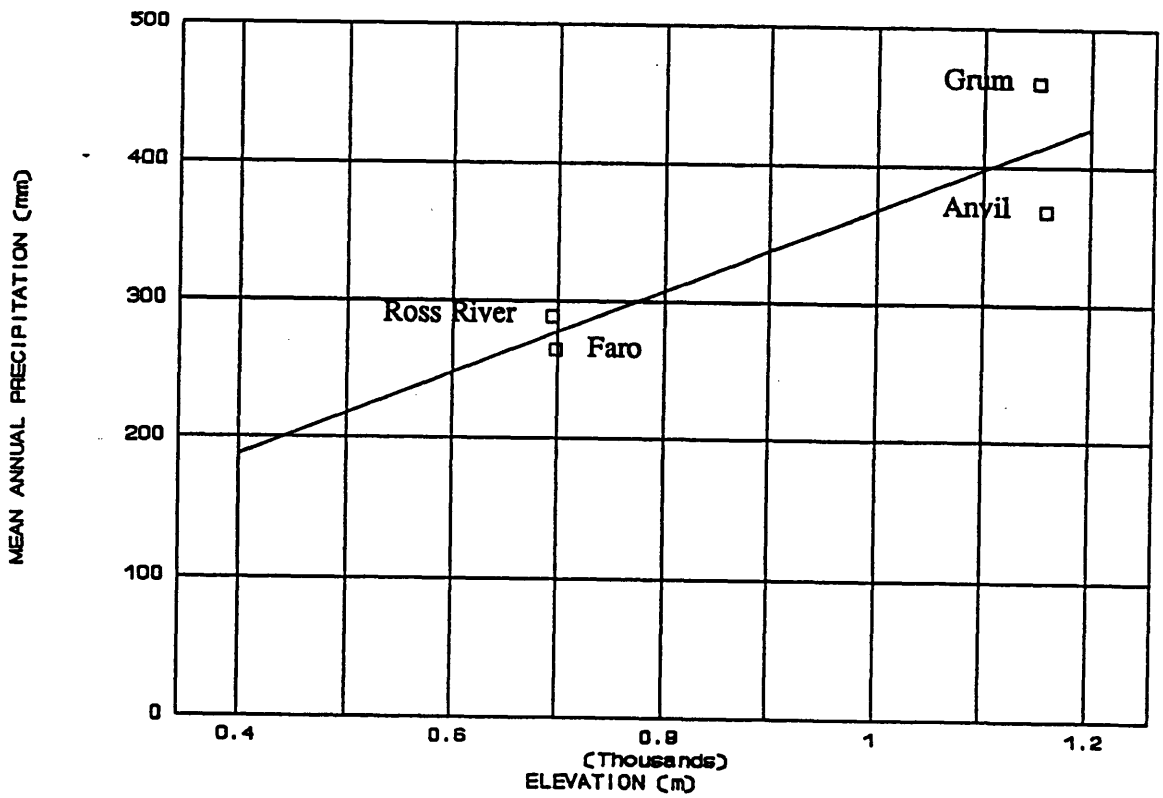
Anvil Range Mining Corporation

Anvil Complex Closure Plan

MEAN MONTHLY PRECIPITATION AT ANVIL CLIMATE STATION

PROJECT NO.	DATE	APPROVED	FIGURE
033001	Nov. 1996		3-9a

\FaroLane\ANVIL-PRECIP Fri Nov 22 13:14:26 1996 L. du Toit



NOTE: FIGURE TAKEN FROM SRK REPORT 60635 "DOWN VALLEY TAILINGS IMPOUNDMENT DECOMMISSIONING PLAN", APRIL 1991.

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Consulting Geotechnical and Environmental Engineers

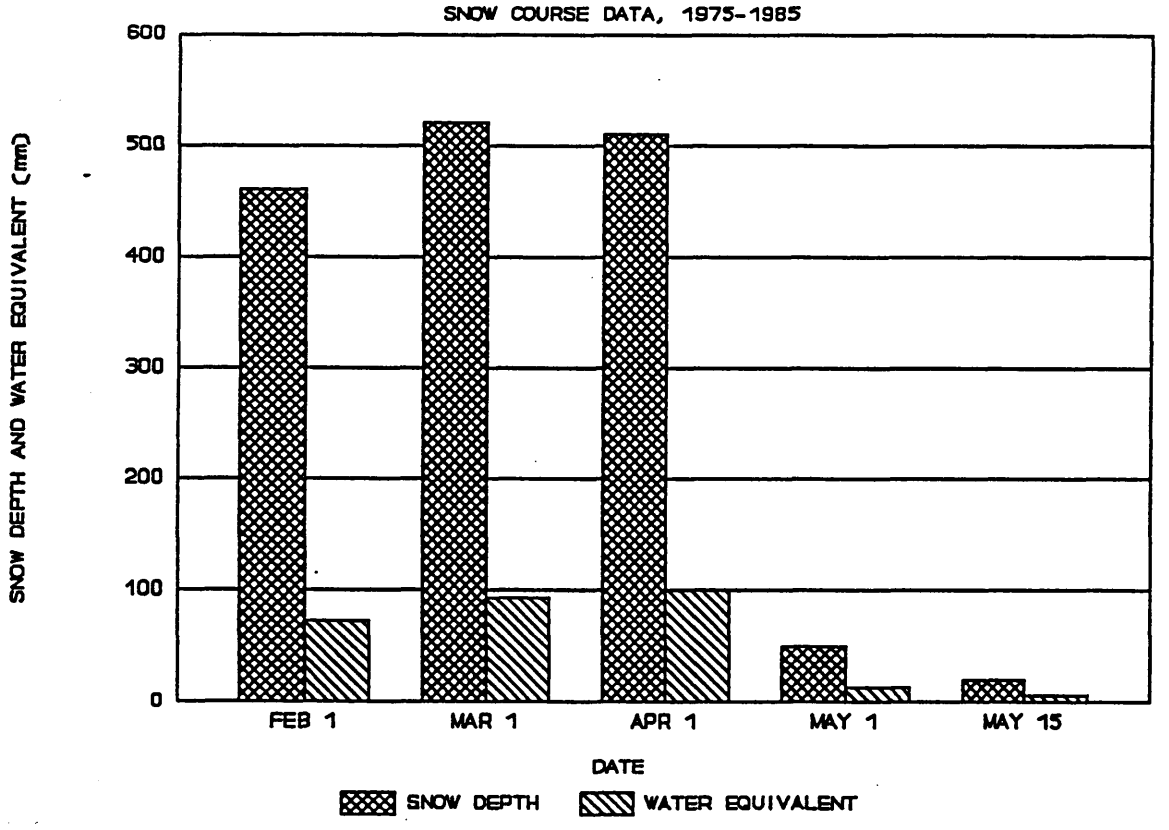
Anvil Range Mining Corporation

Anvil Complex Closure Plan

REGIONAL RELATIONSHIP BETWEEN MEAN ANNUAL PRECIPITATION AND ELEVATION

PROJECT NO.	DATE	APPROVED	FIGURE
033001	Nov. 1996		3-9b

\FaroLane\PRECIP-ELEV Fri Nov 22 13:15:36 1996 L. du Toit



NOTE: FIGURE TAKEN FROM SRK REPORT 60635 "DOWN VALLEY TAILINGS IMPOUNDMENT DECOMMISSIONING PLAN", APRIL 1991.

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Consulting Geotechnical and Environmental Engineers

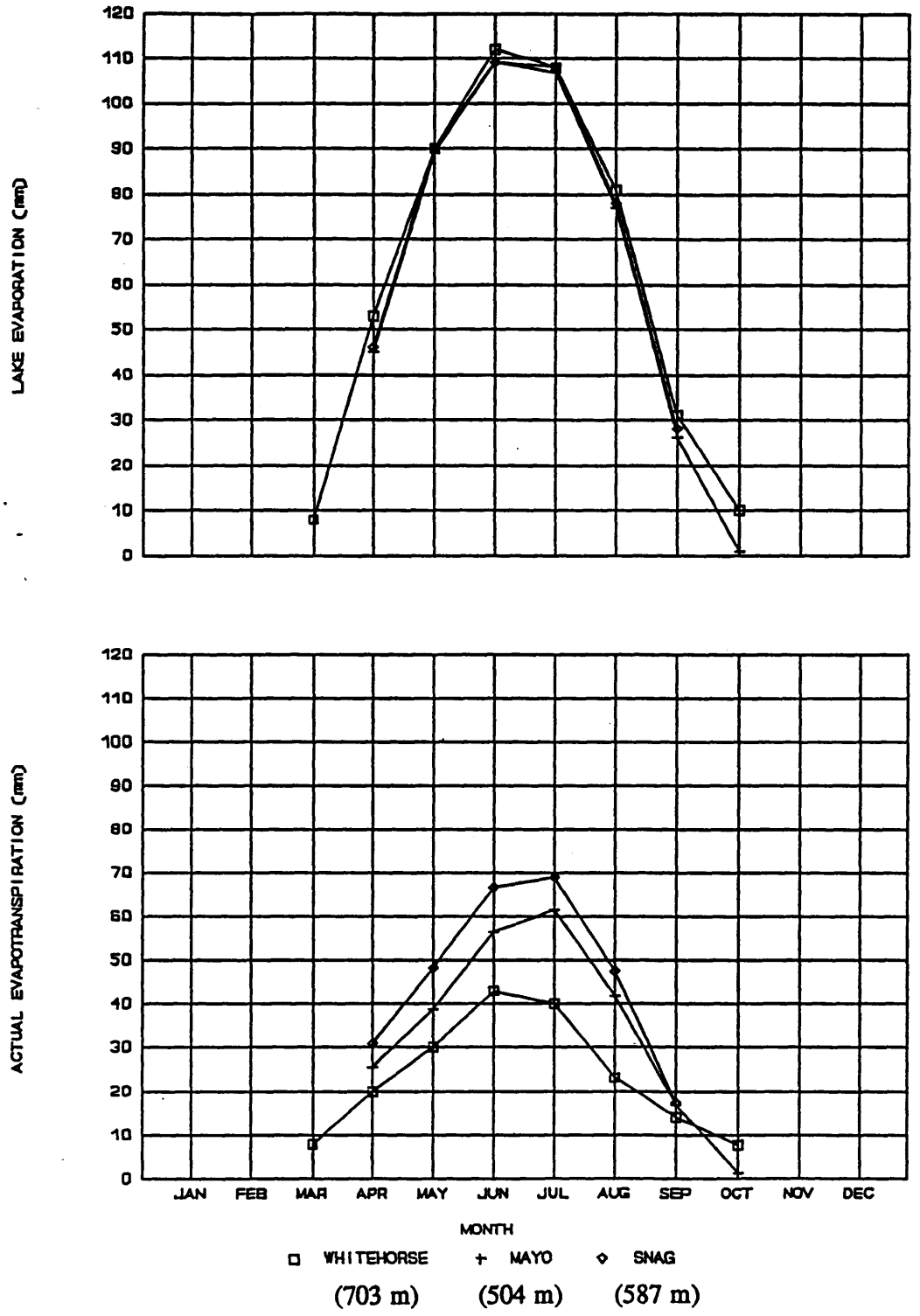
Anvil Range Mining Corporation

Anvil Complex Closure Plan

AVERAGE SNOWPACK AT ROSE CREEK SNOW SURVEY STATION

PROJECT NO.	DATE	APPROVED	FIGURE
033001	Nov. 1996		3-10

\FaroLane\SNOWPACK Fri Nov 22 13:17:36 1996 L. du Toit



NOTE: FIGURE TAKEN FROM SRK REPORT 60635 "DOWN VALLEY TAILINGS IMPOUNDMENT DECOMMISSIONING PLAN", APRIL 1991.

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Consulting Geotechnical and Environmental Engineers

Anvil Range Mining Corporation

Anvil Complex Closure Plan

ESTIMATED LAKE EVAPORATION AND ACTUAL EVAPOTRANSPIRATION AT REGIONAL CLIMATE STATIONS

PROJECT NO.	DATE	APPROVED	FIGURE
033001	Nov. 1996		3-11

\FaroLane\EVAPOTRANSPIRATION Fri Nov 22 13:23:36 1996 L. du Toit

Figure 3-12 Correlation Between Daily Flows at 29BC004 (Blind Creek) and 09BC005 (Tay River)

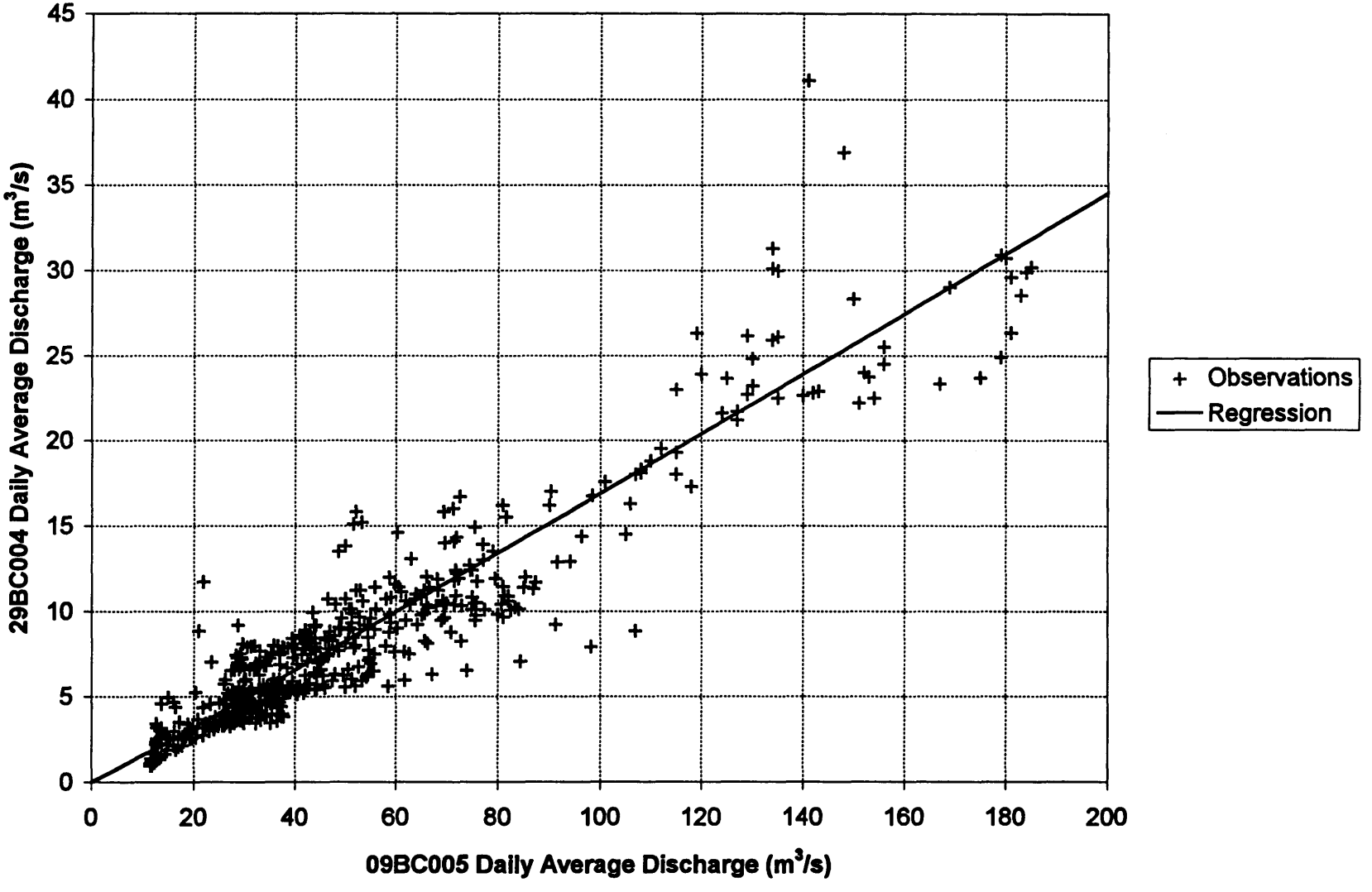


Figure 3-13 Daily Streamflow Record for Blind Creek at Station 29BC004

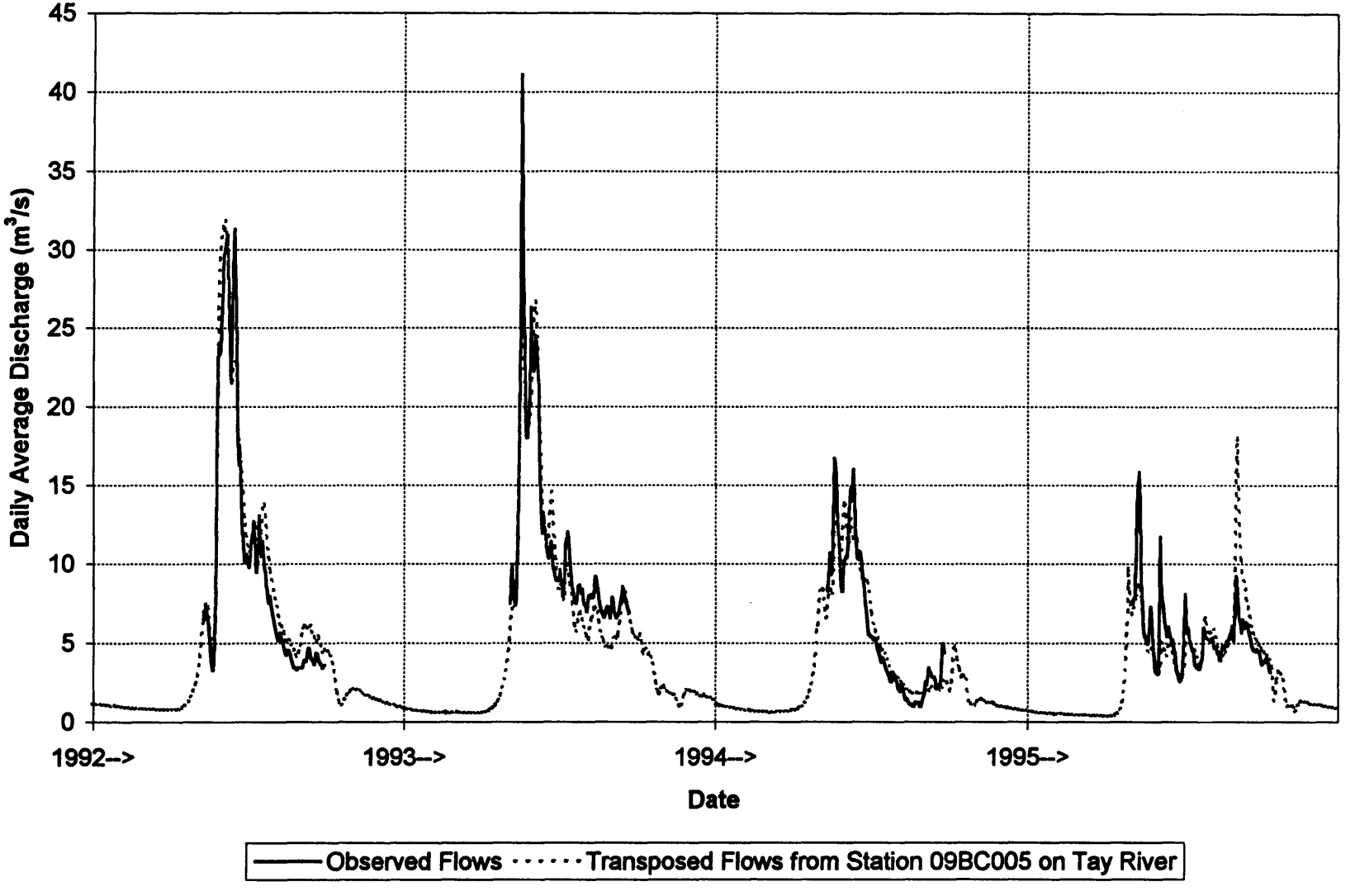


Figure 3-14 Stage-Discharge Relationship for Station X14

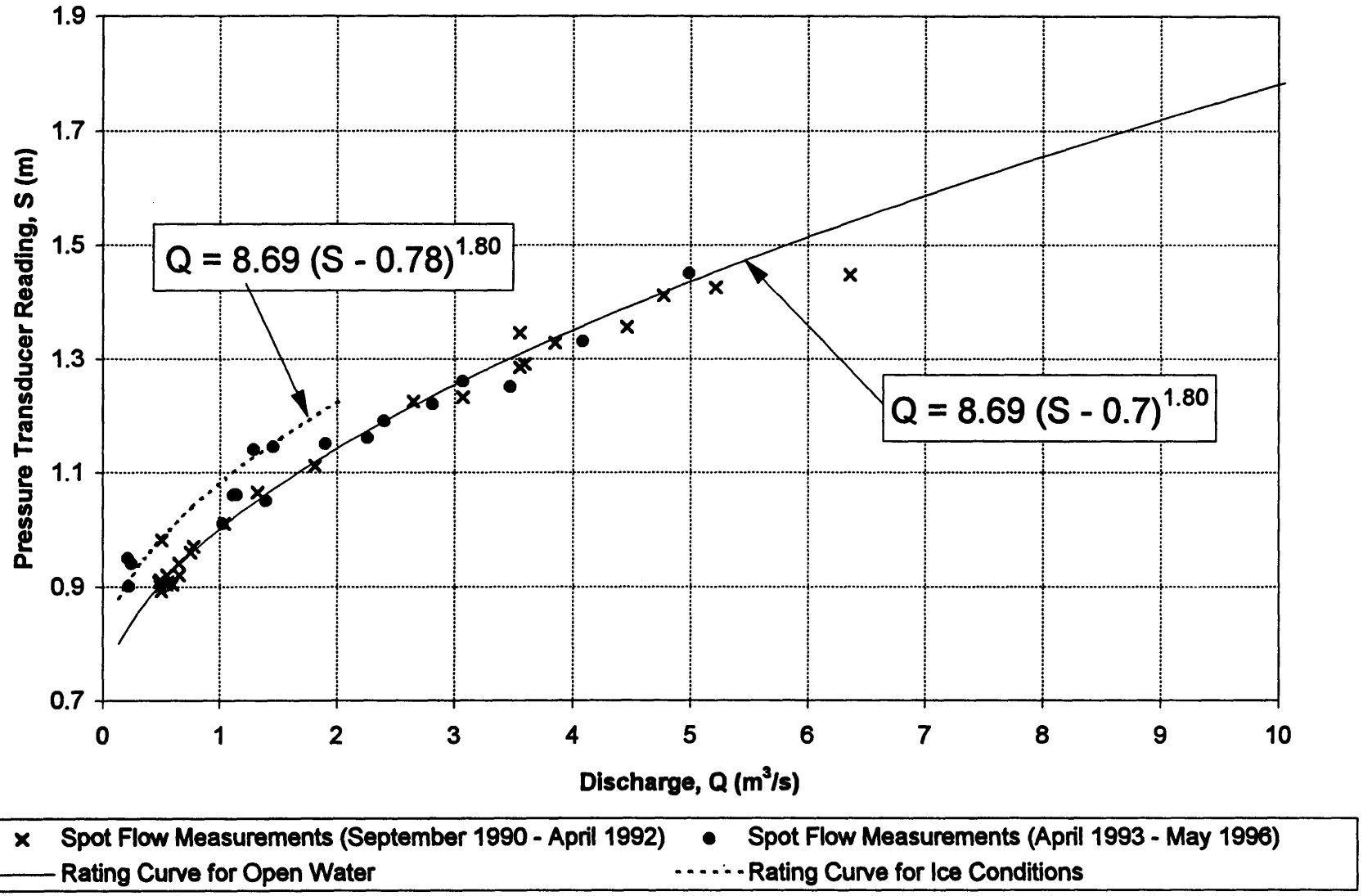


Figure 3-15 Patched 1990 Daily Streamflow Record for Station X14

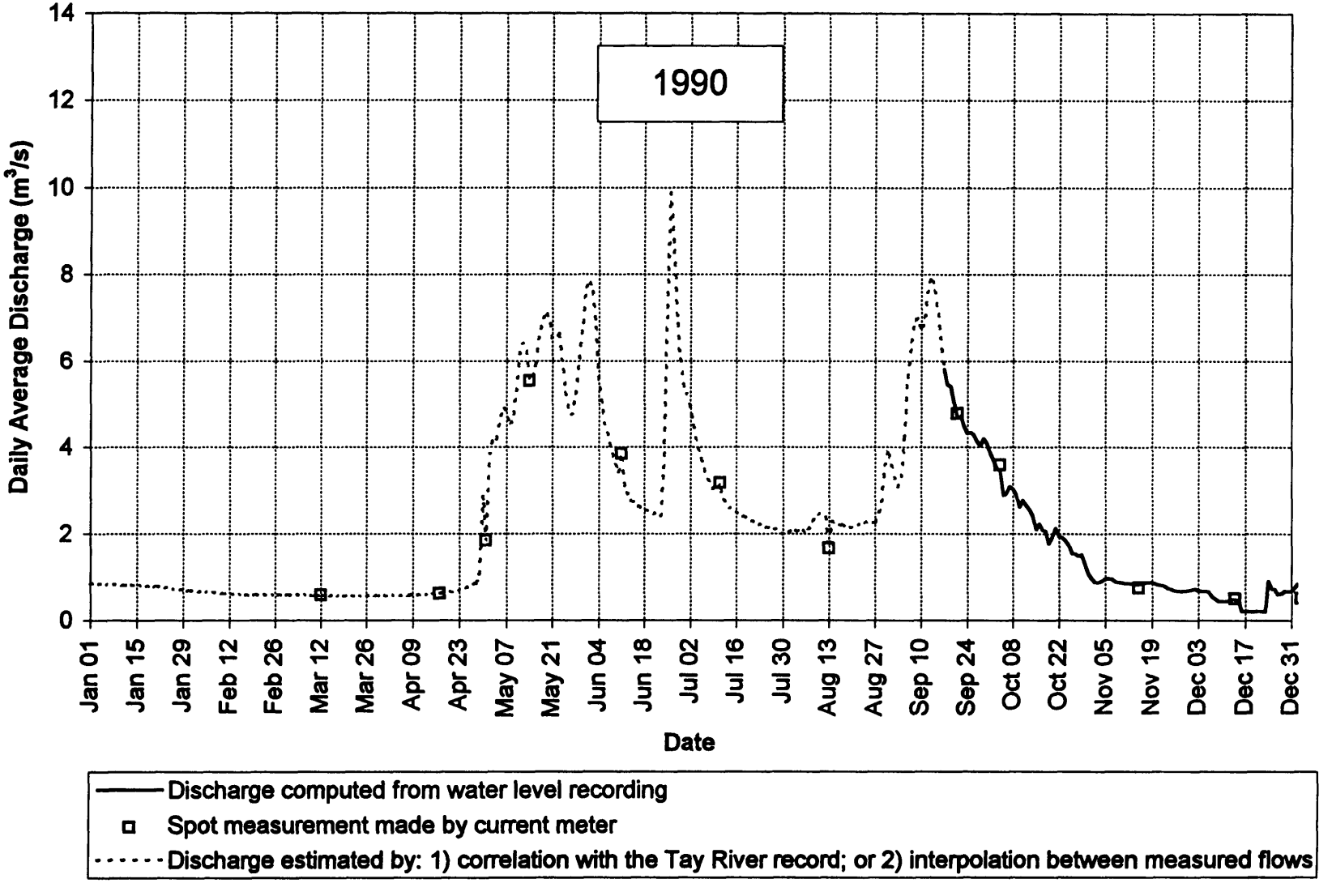


Figure 3-16 Regional Relationship Between Mean Annual Runoff and Catchment Median Elevation

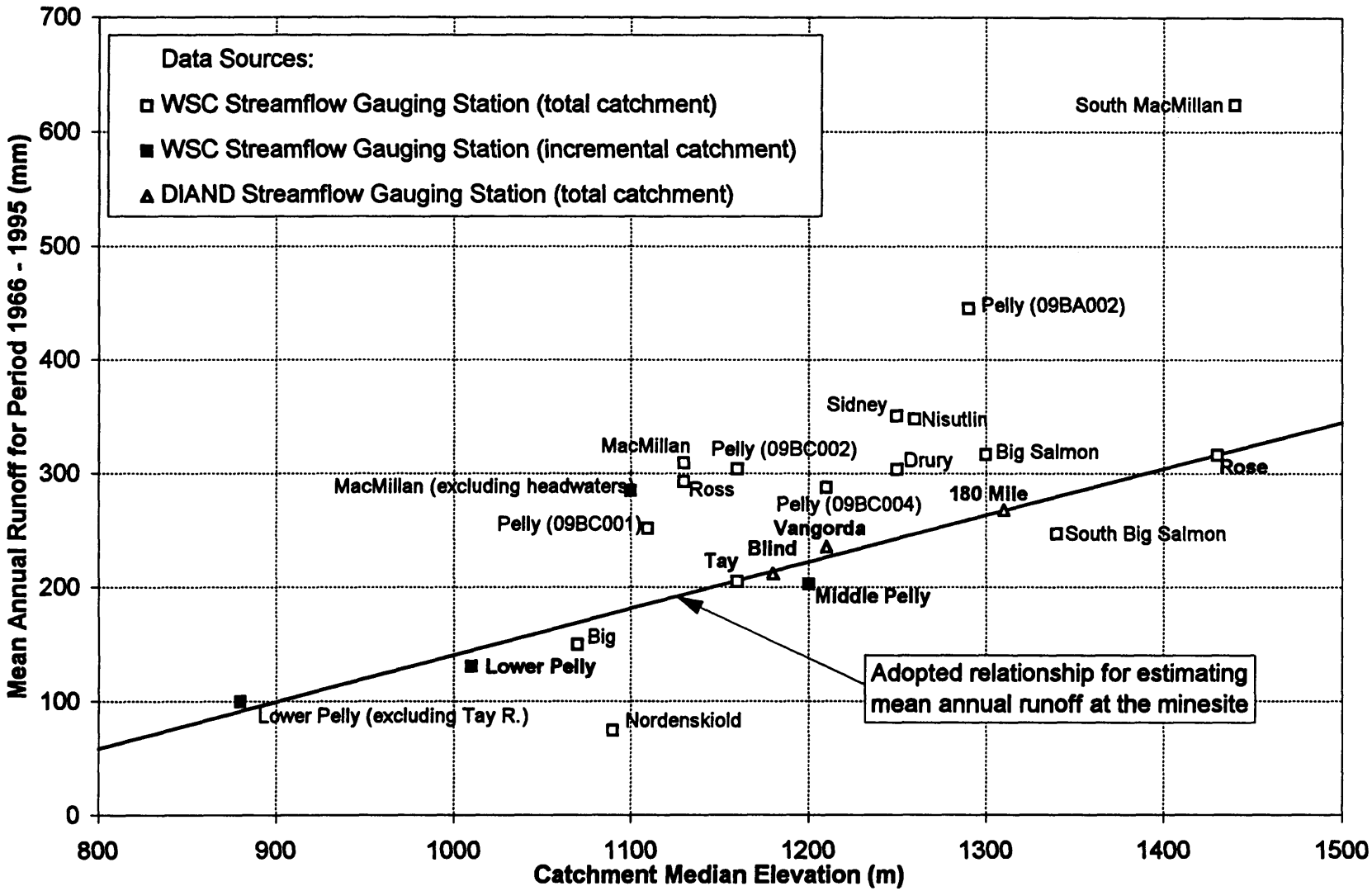


Figure 3-17 Average Monthly Streamflow Distributions for Regional WSC Stations

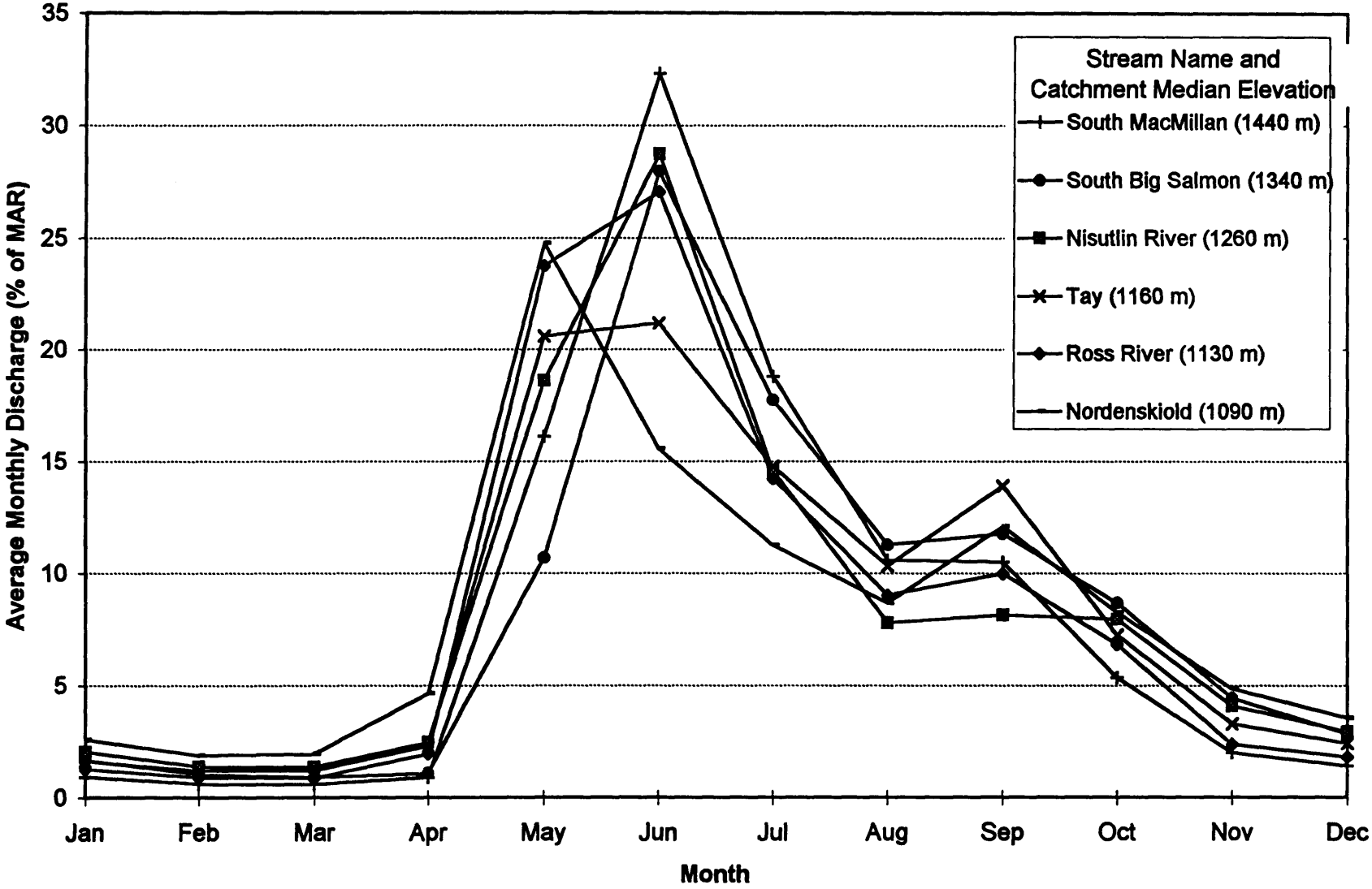
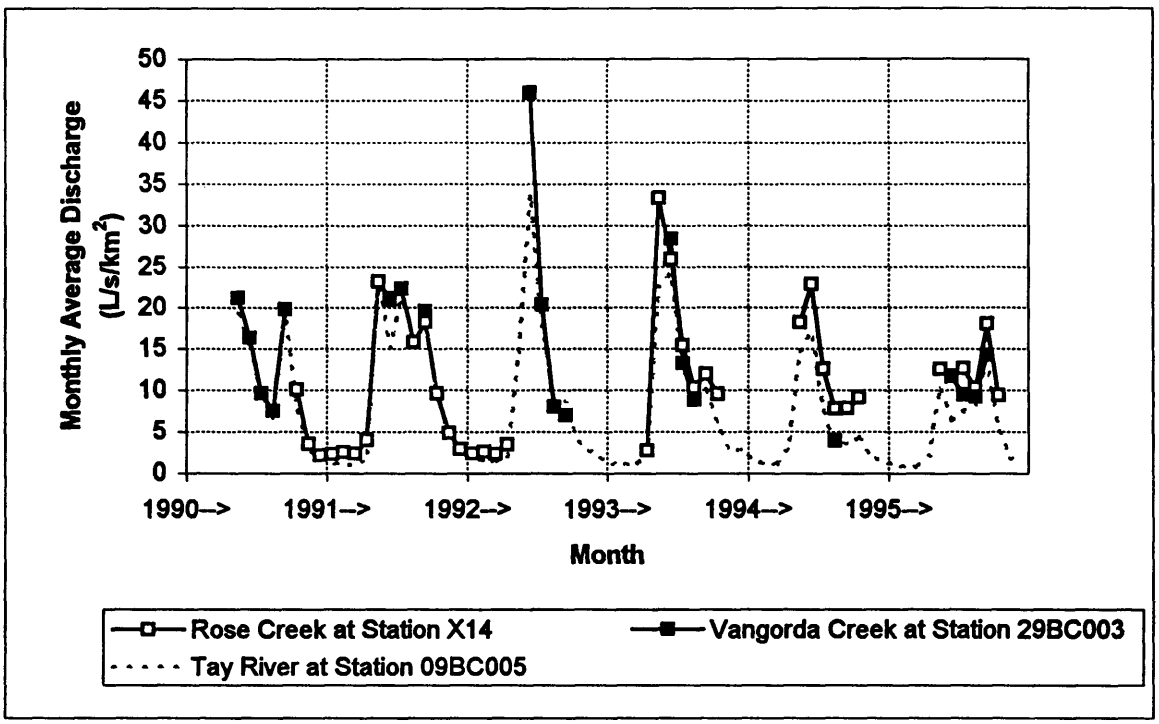
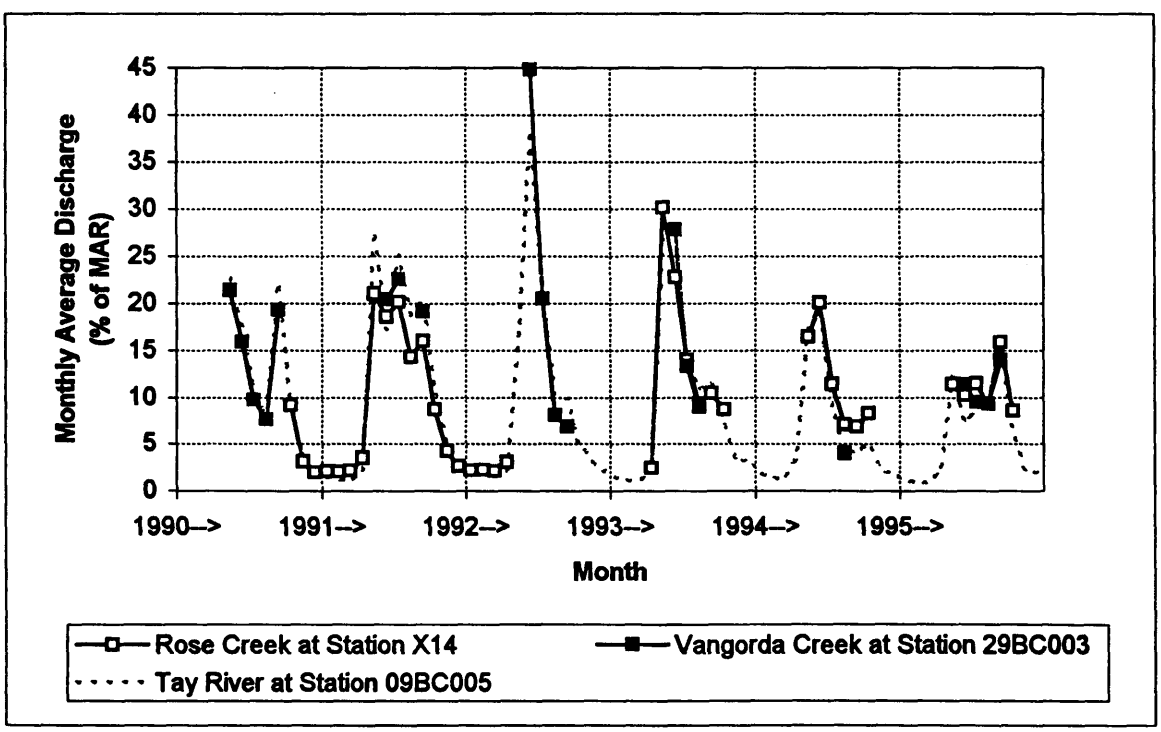
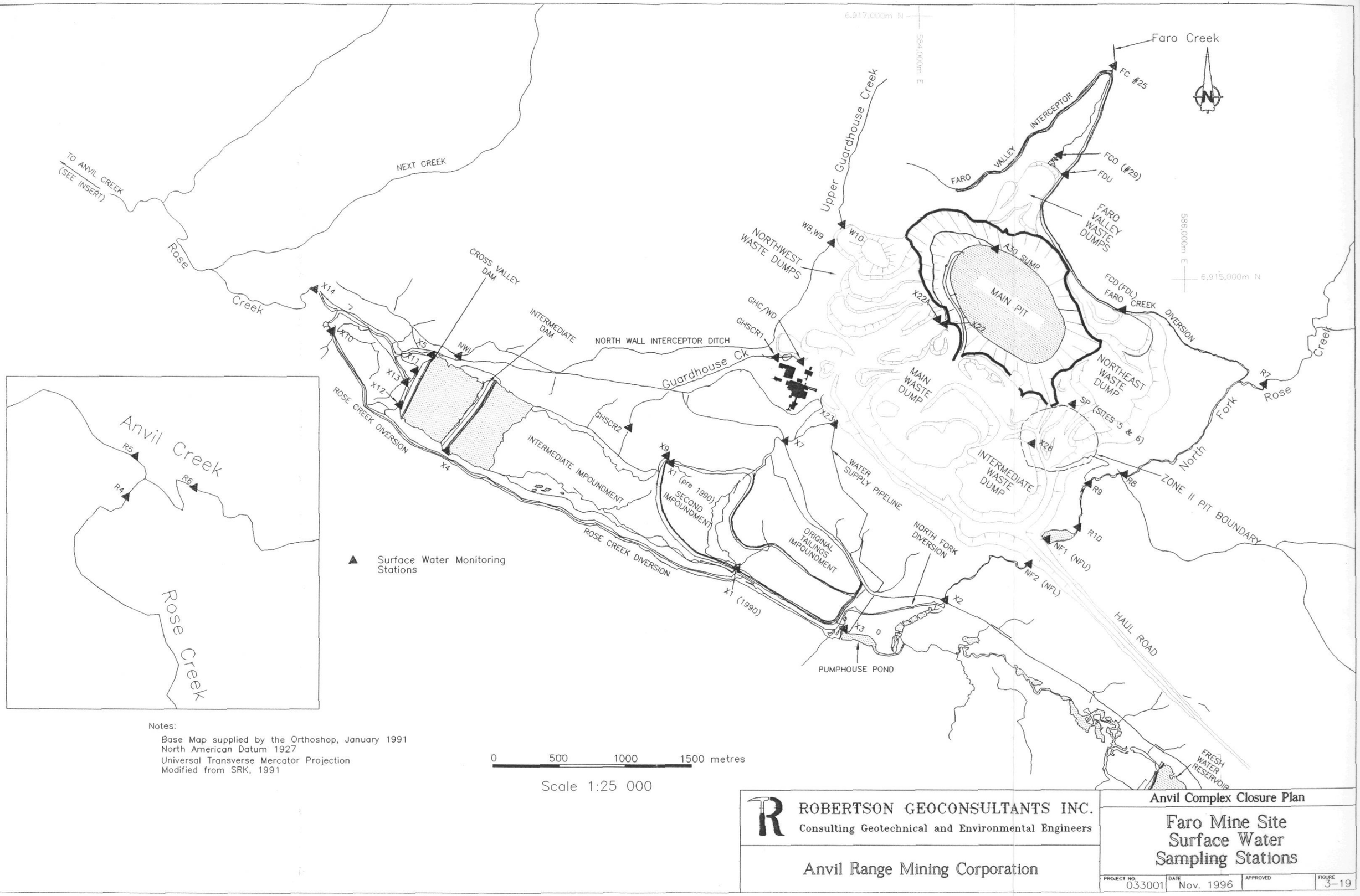


Figure 3-18 Comparison of Observed Flow Patterns of Rose Creek, Vangorda Creek and Tay River for Period 1990 to 1995







Notes:

Base Map supplied by the Orthoshop, January 1991
North American Datum 1927
Universal Transverse Mercator Projection
Modified from SRK, 1991

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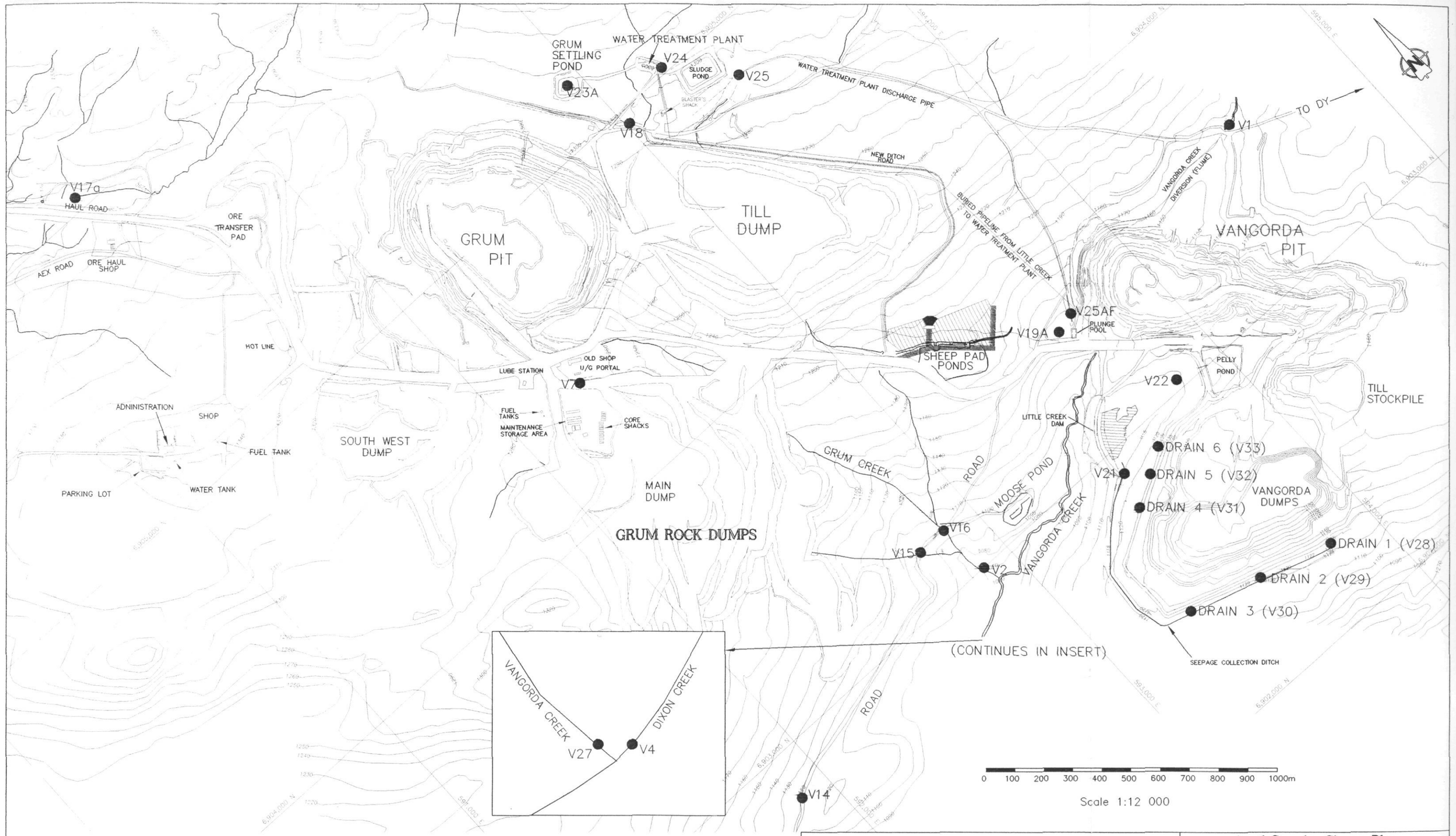
Anvil Complex Closure Plan

Faro Mine Site Surface Water Sampling Stations

PROJECT NO.	DATE	APPROVED	FIGURE
033001	Nov. 1996		3-19



Note:
Contours of Grum Pit and Dumps as of early Spring 1996.
Base Map supplied by Anvil Range Mining Corporation.
Elevations are relative to Mean Sea Level (NAD27)

Contour Interval 10 metres

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Anvil Range Mining Corporation

Anvil Complex Closure Plan

Vangorda Plateau Surface Water Sampling Stations

PROJECT NO.	DATE	APPROVED	FIGURE
033001	Nov. 1996		3-20

Figure 3-21 Total zinc time trend, Faro Creek above diversion channel

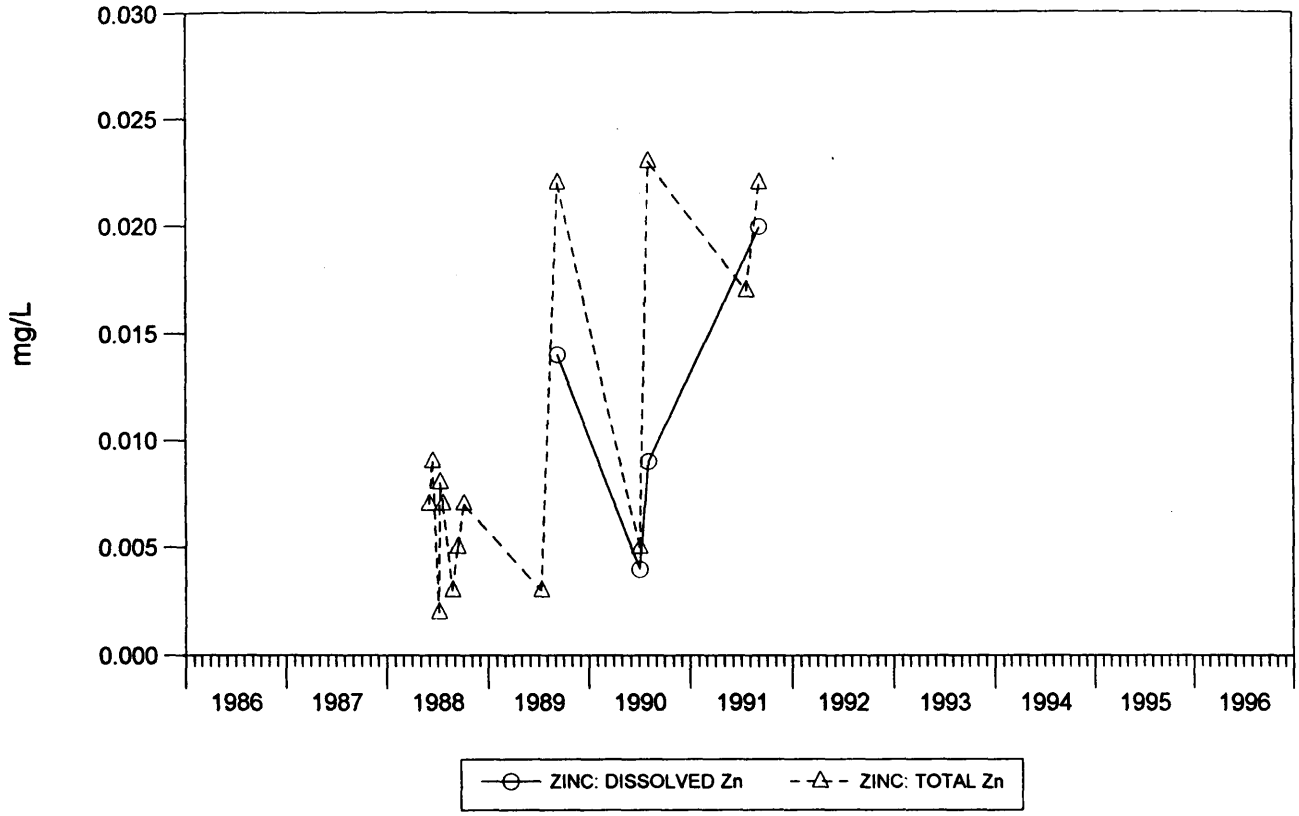


Figure 3-22 Total iron time trend, Faro Creek above diversion channel

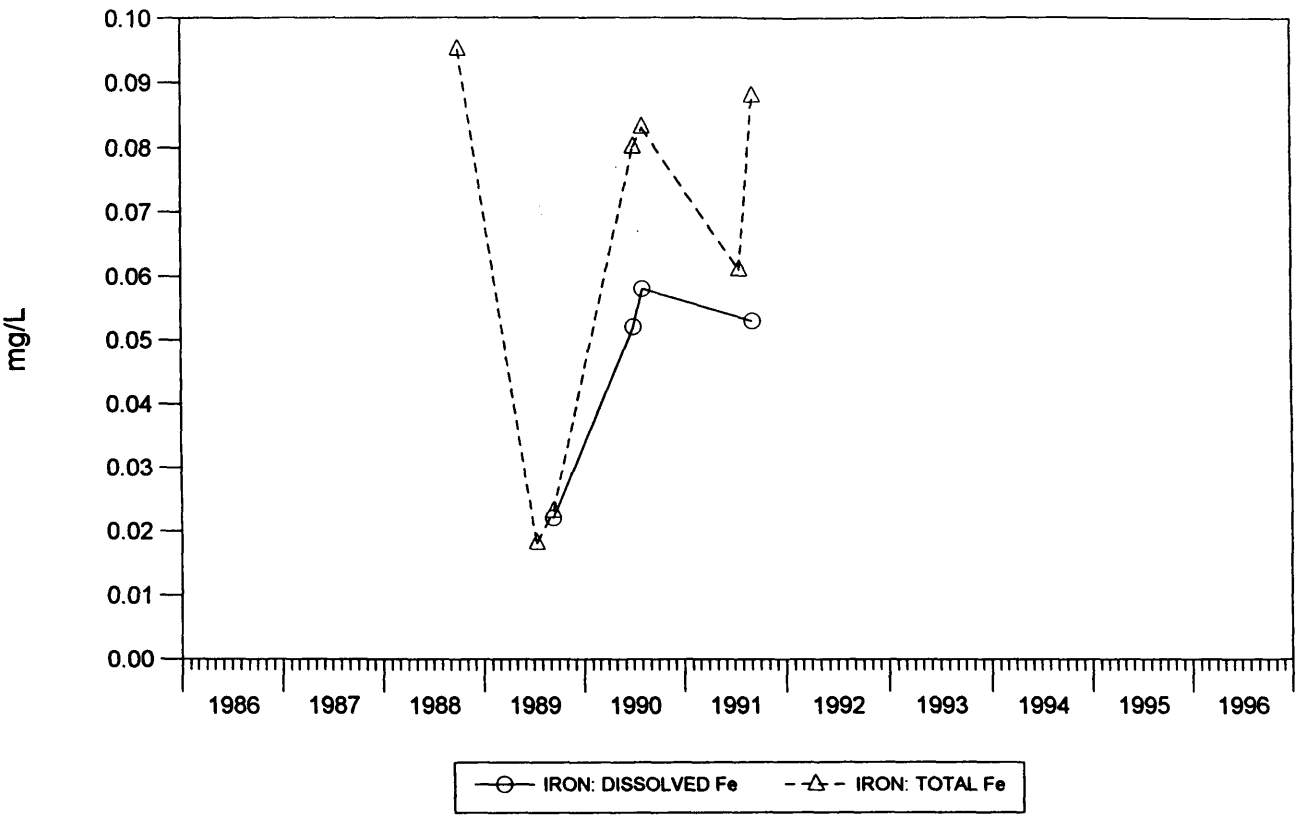


Figure 3-23 pH time trend, North Fork of Rose Creek above Faro Creek diversion

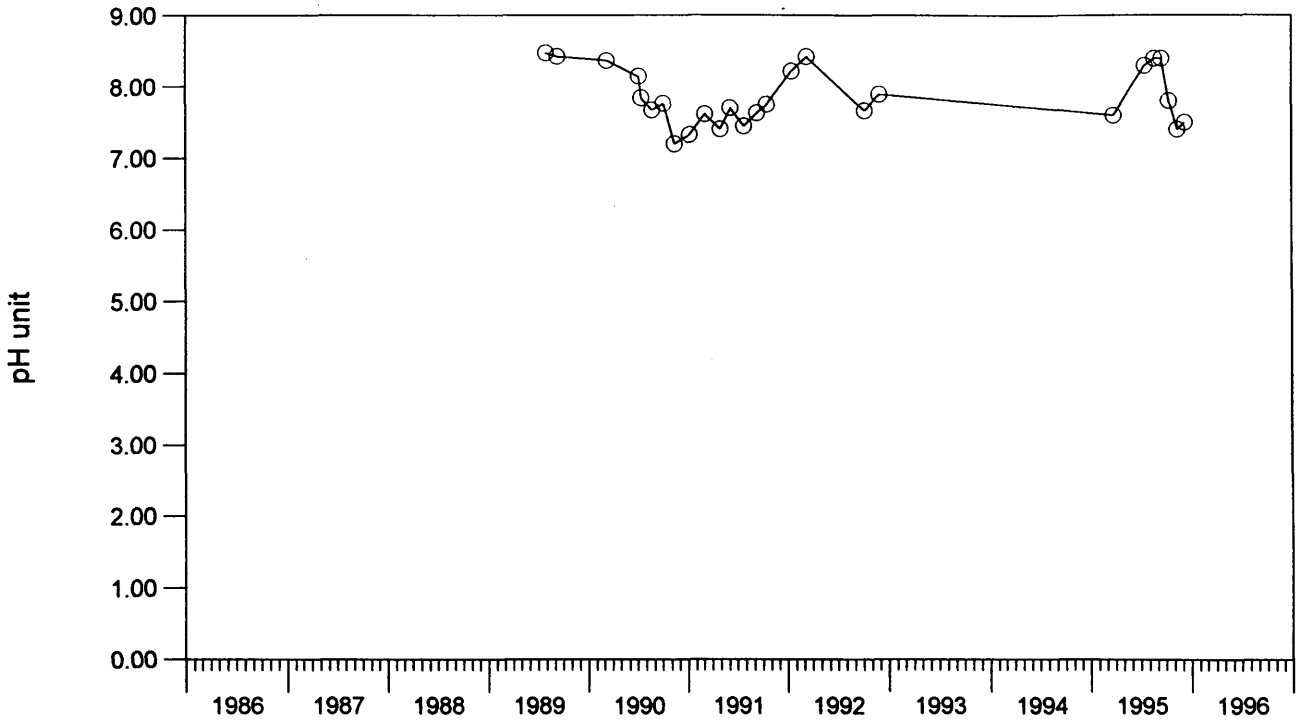


Figure 3-24 Total acidity and alkalinity time trends, North Fork of Rose Creek above Faro Creek diversion

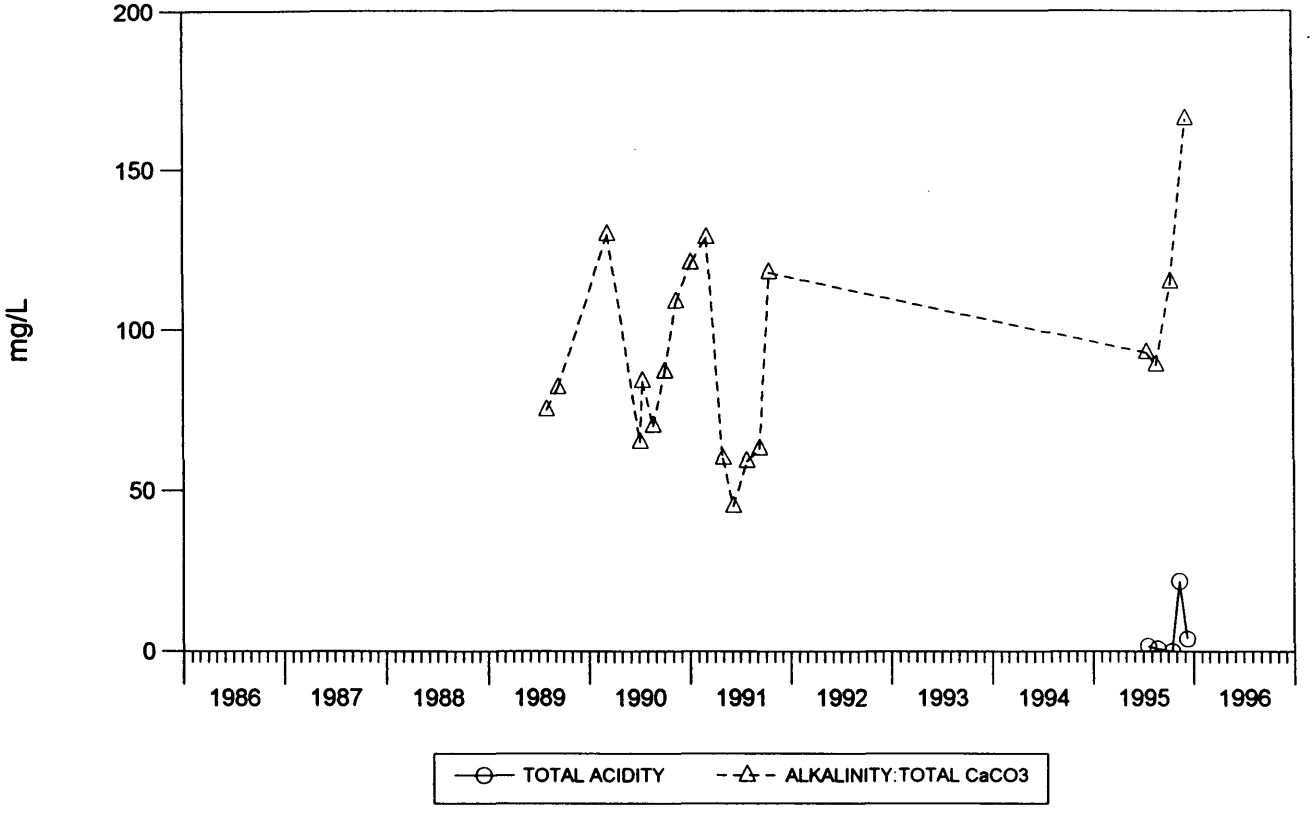


Figure 3-25 Total sulphate time trend, North Fork of Rose Creek above Faro Creek diversion

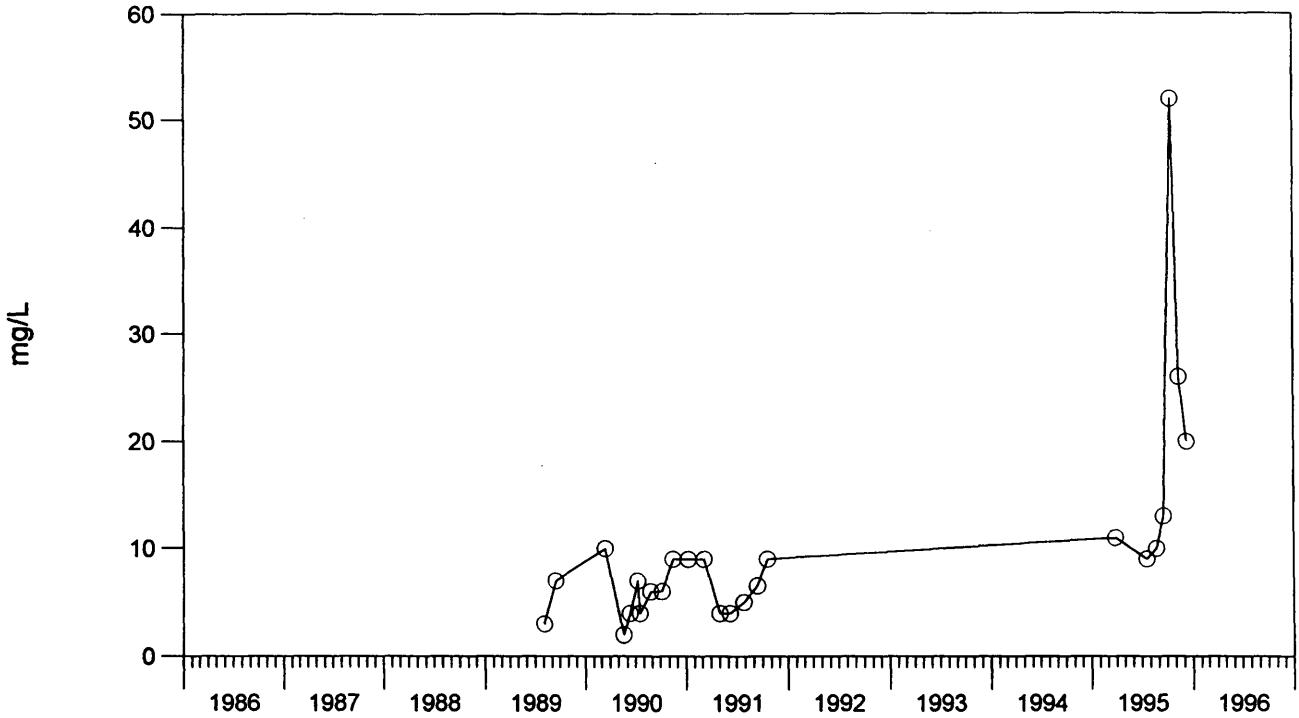


Figure 3-26 Total lead time trend, North Fork of Rose Creek above Faro Creek diversion

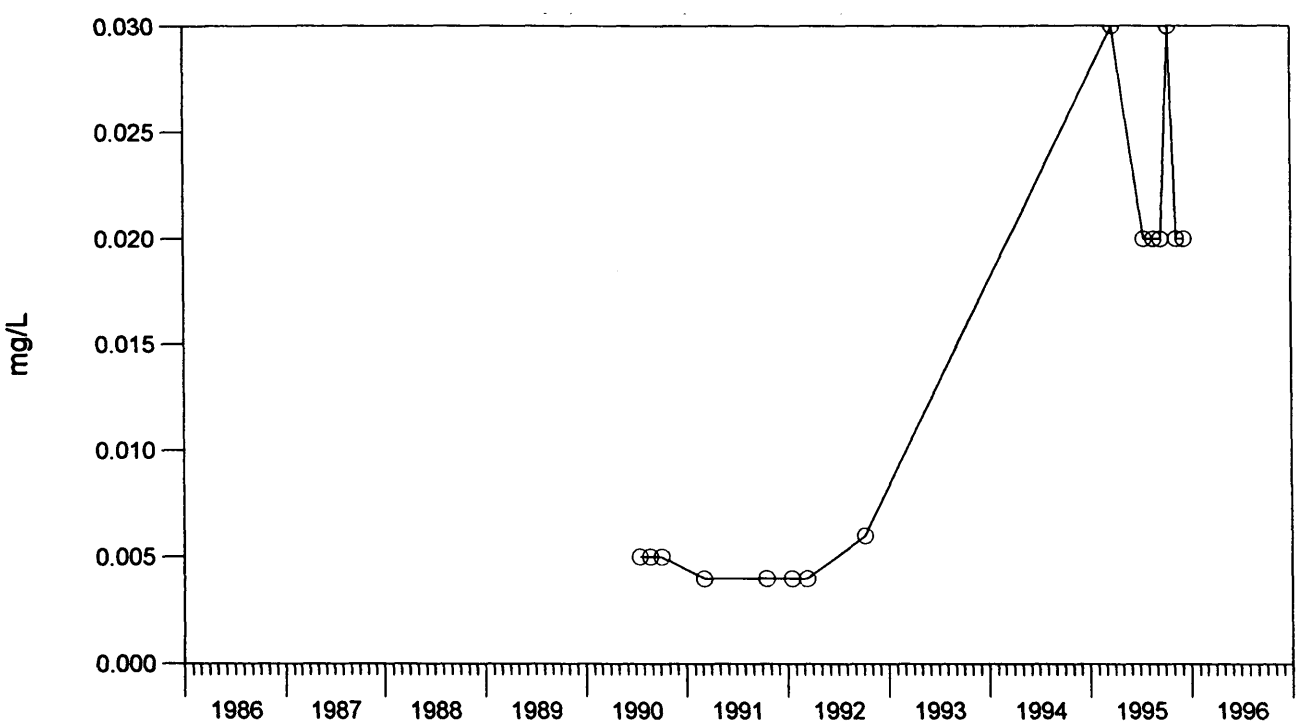


Figure 3-27 Total zinc time trend, North Fork of Rose Creek above Faro Creek diversion

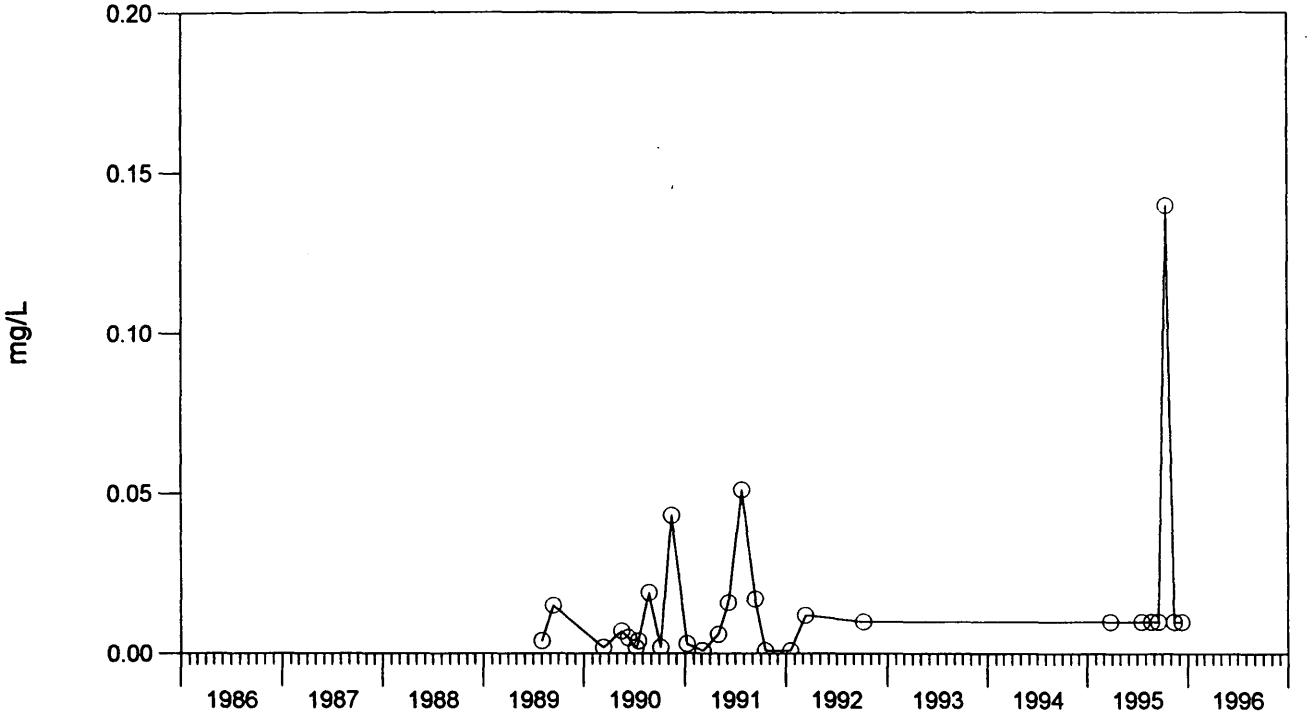


Figure 3-28 Total zinc time trend, Anvil Creek upstream of Rose Creek

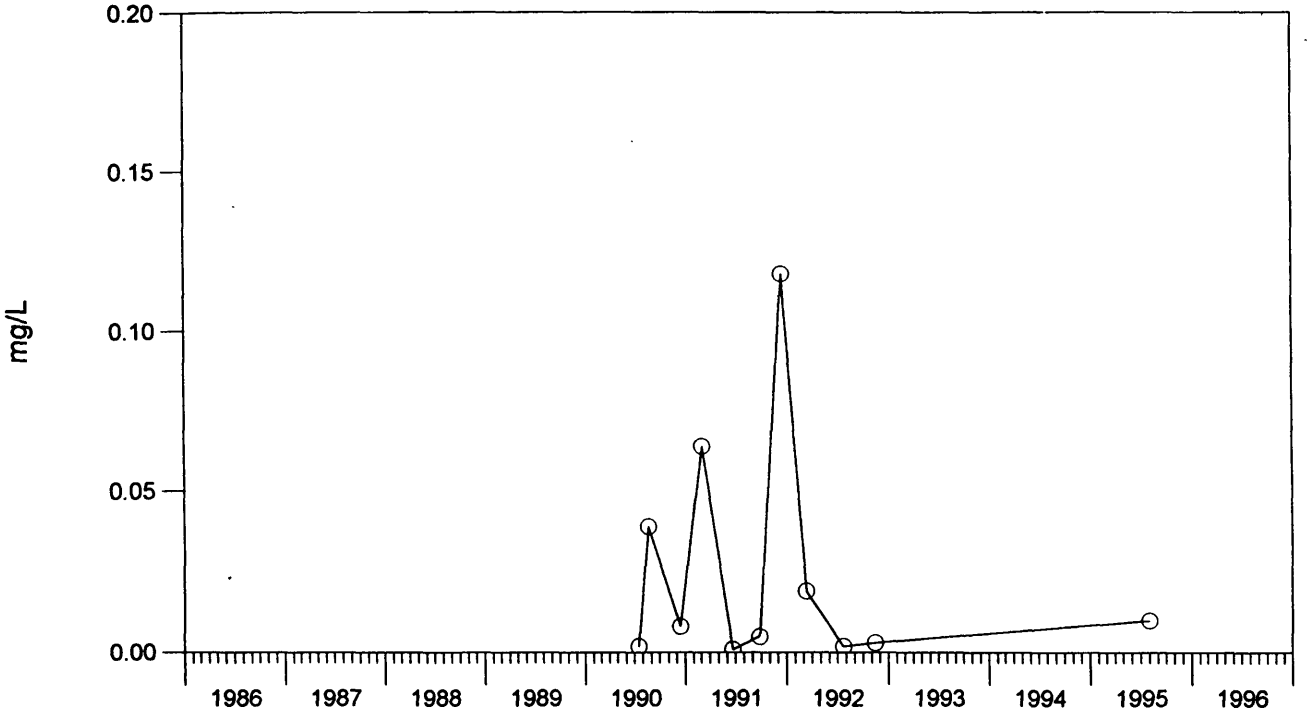


Figure 3-29 Background Stations - pH

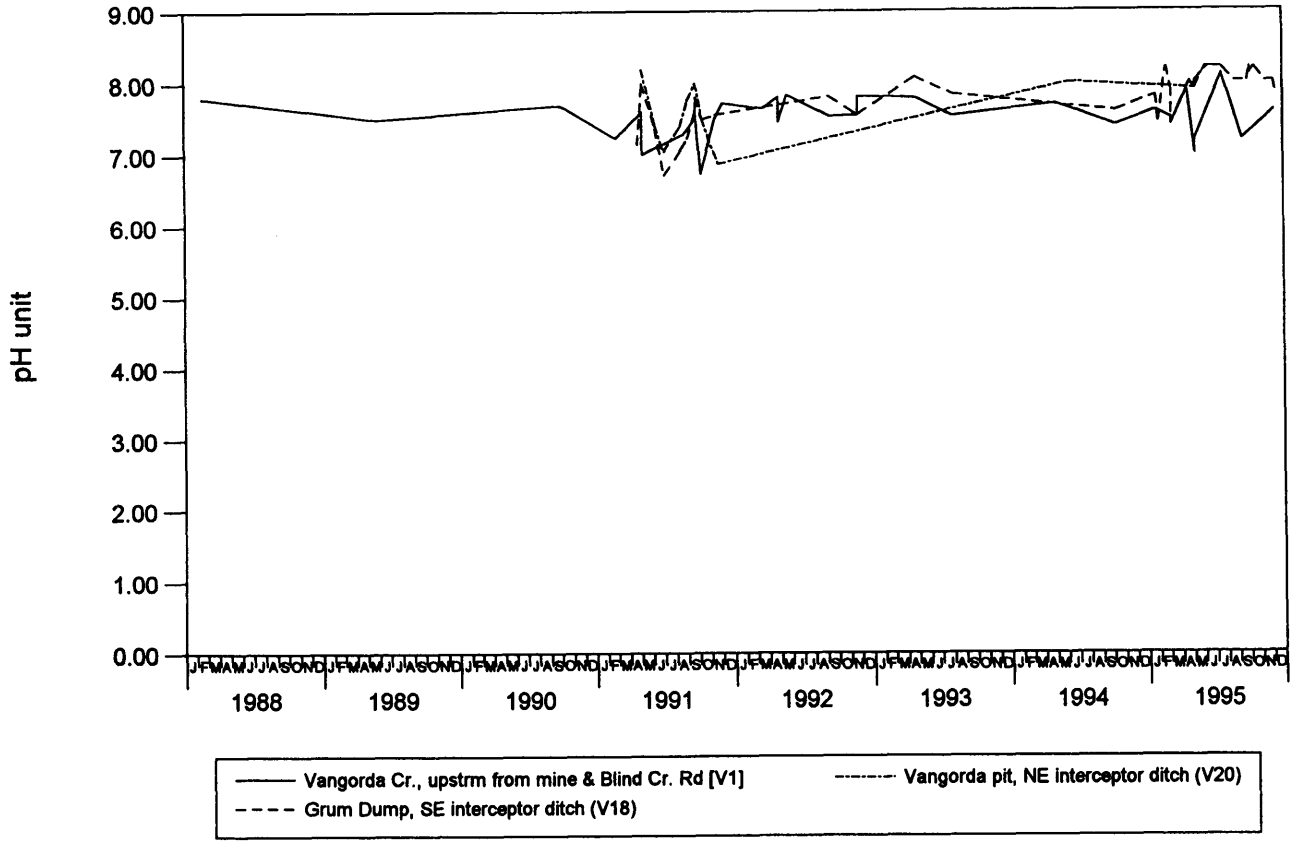


Figure 3-30 Background Stations - Alkalinity

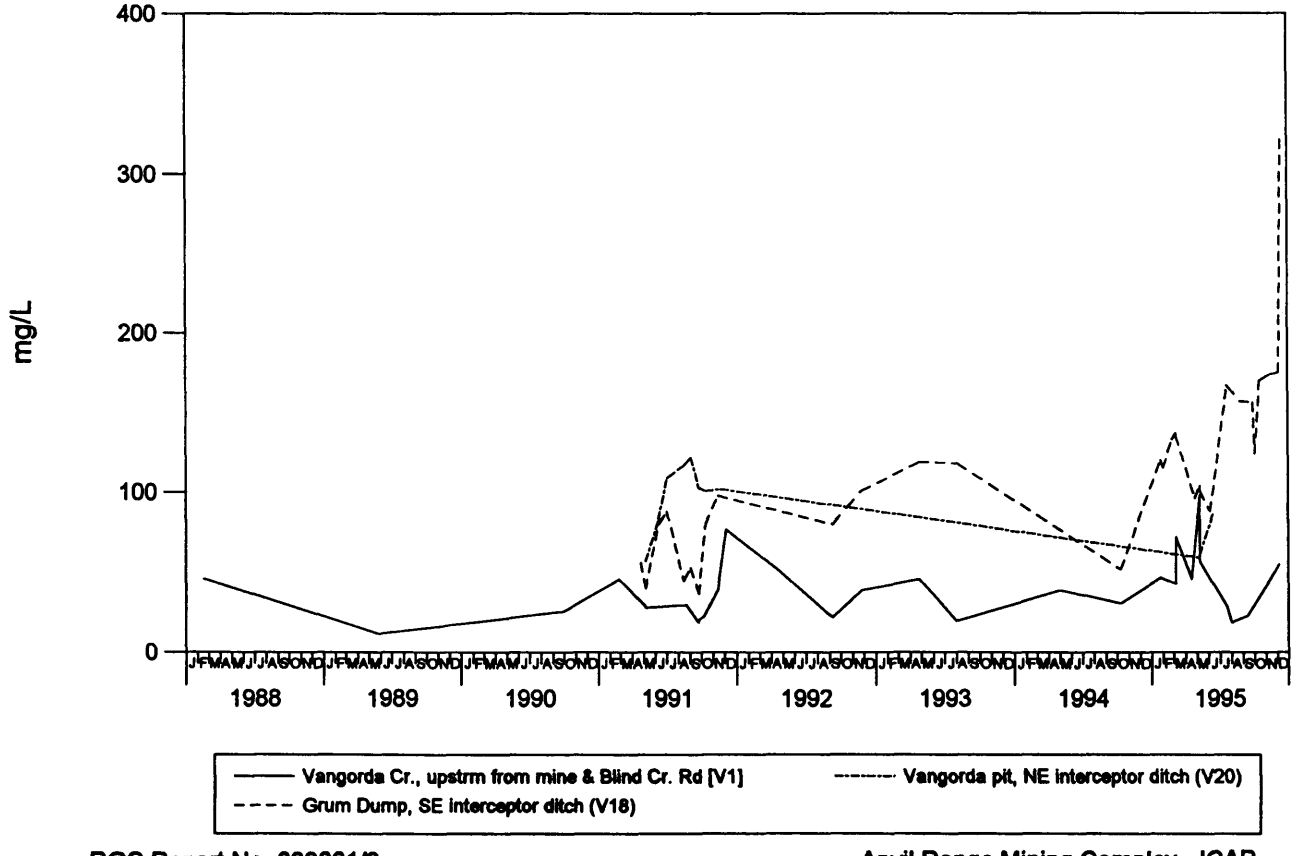


Figure 3-31 - Background Stations - Sulphate

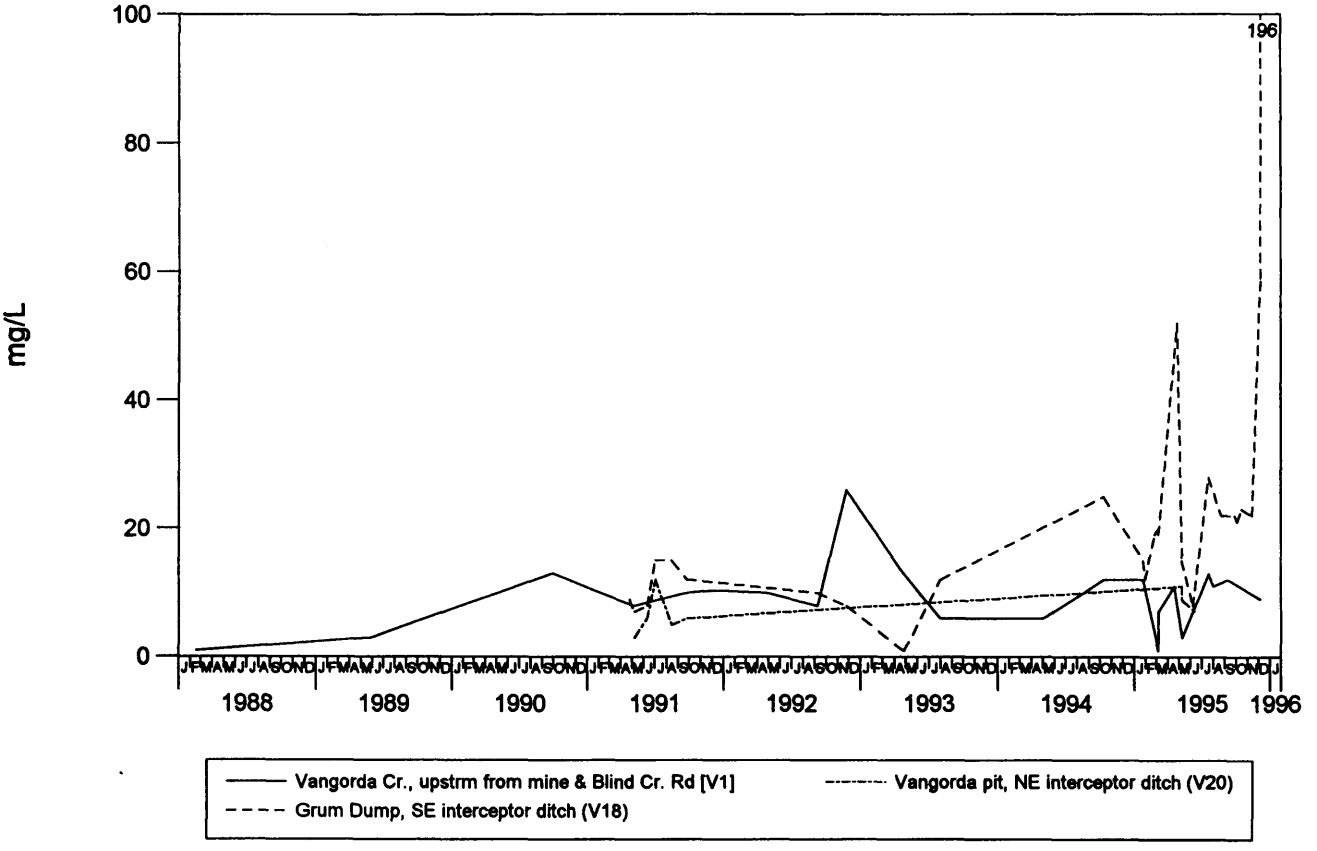


Figure 3-32 Background Stations - TSS

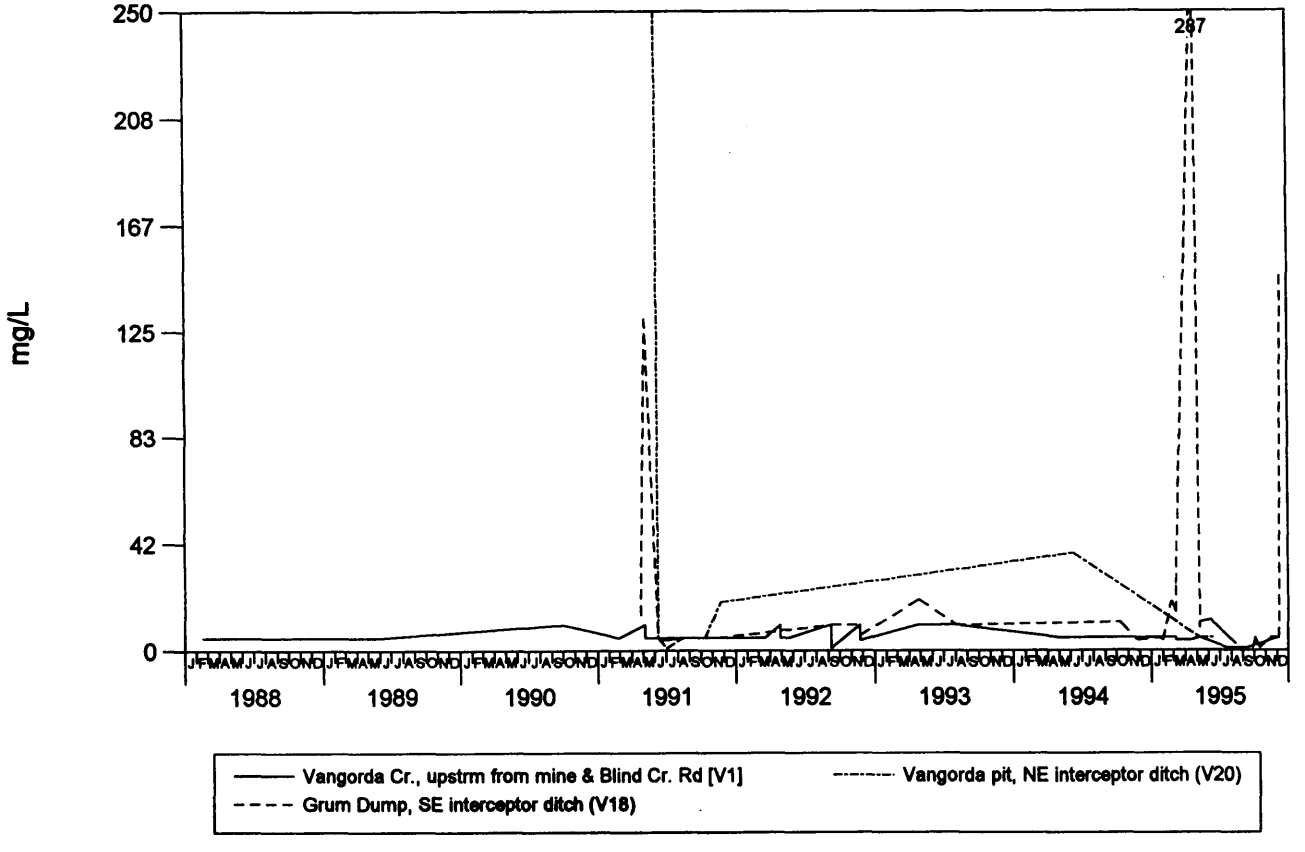


Figure 3-33 Background Stations - Total Iron

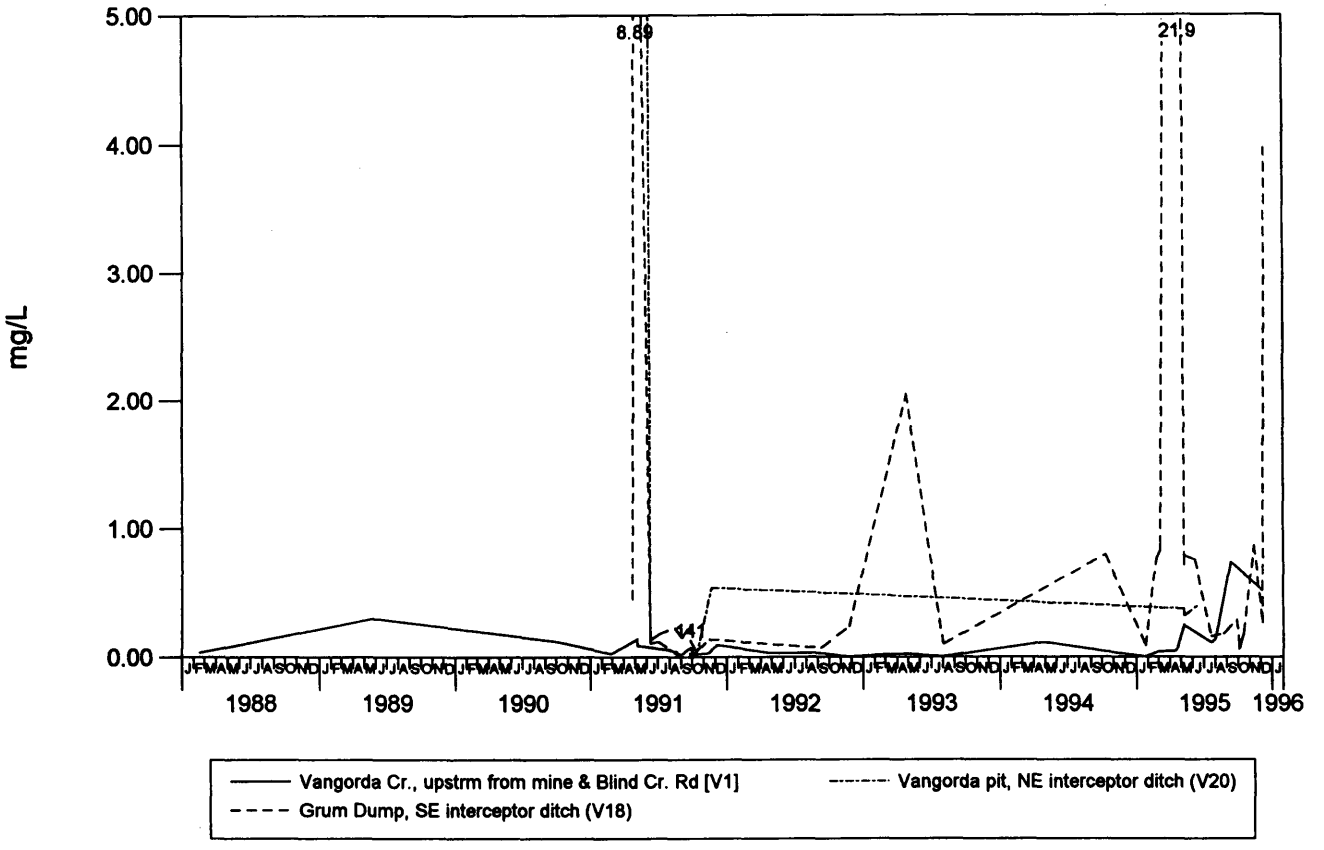


Figure 3-34 Background Stations - Total Zinc

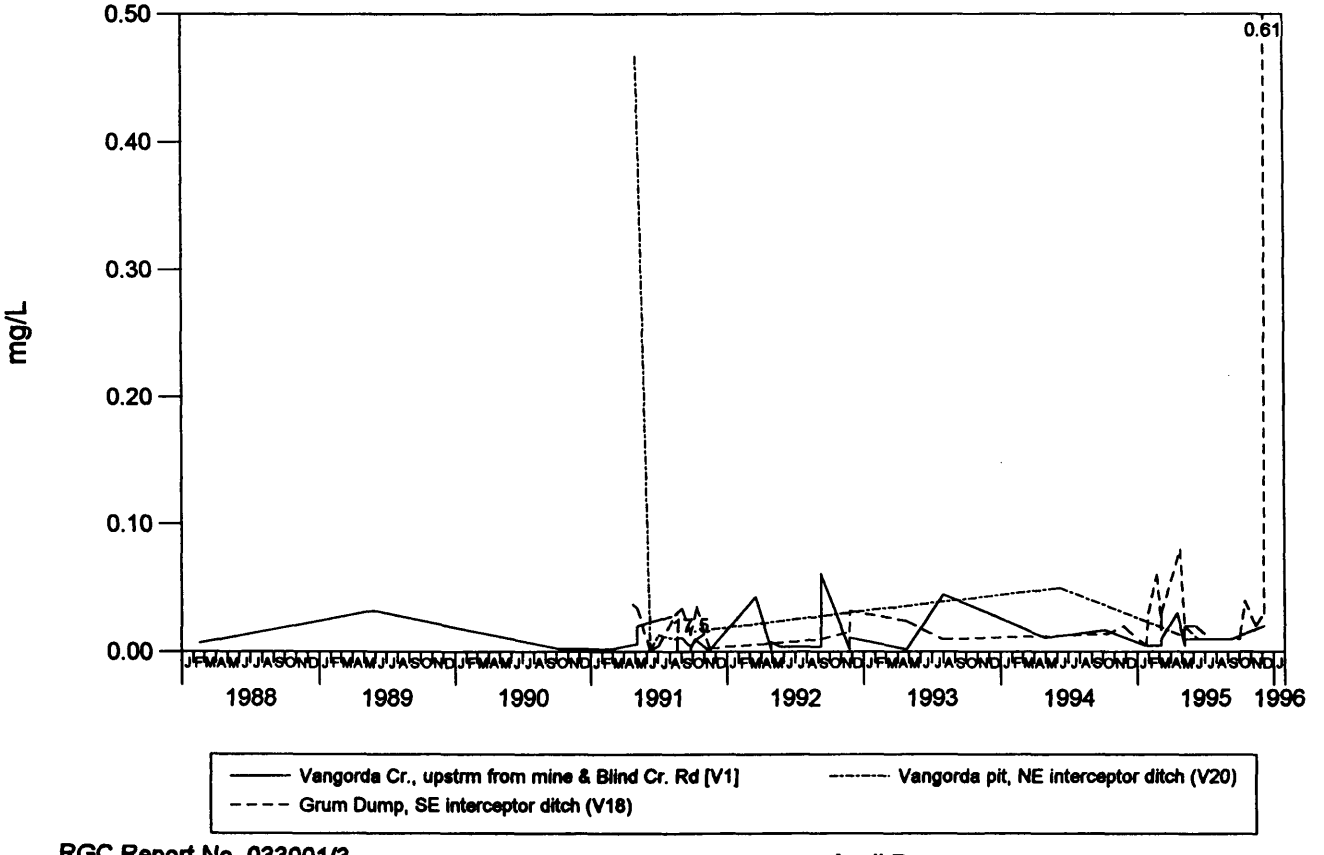


Figure 3-35 Vangorda and Shrimp Creek - pH

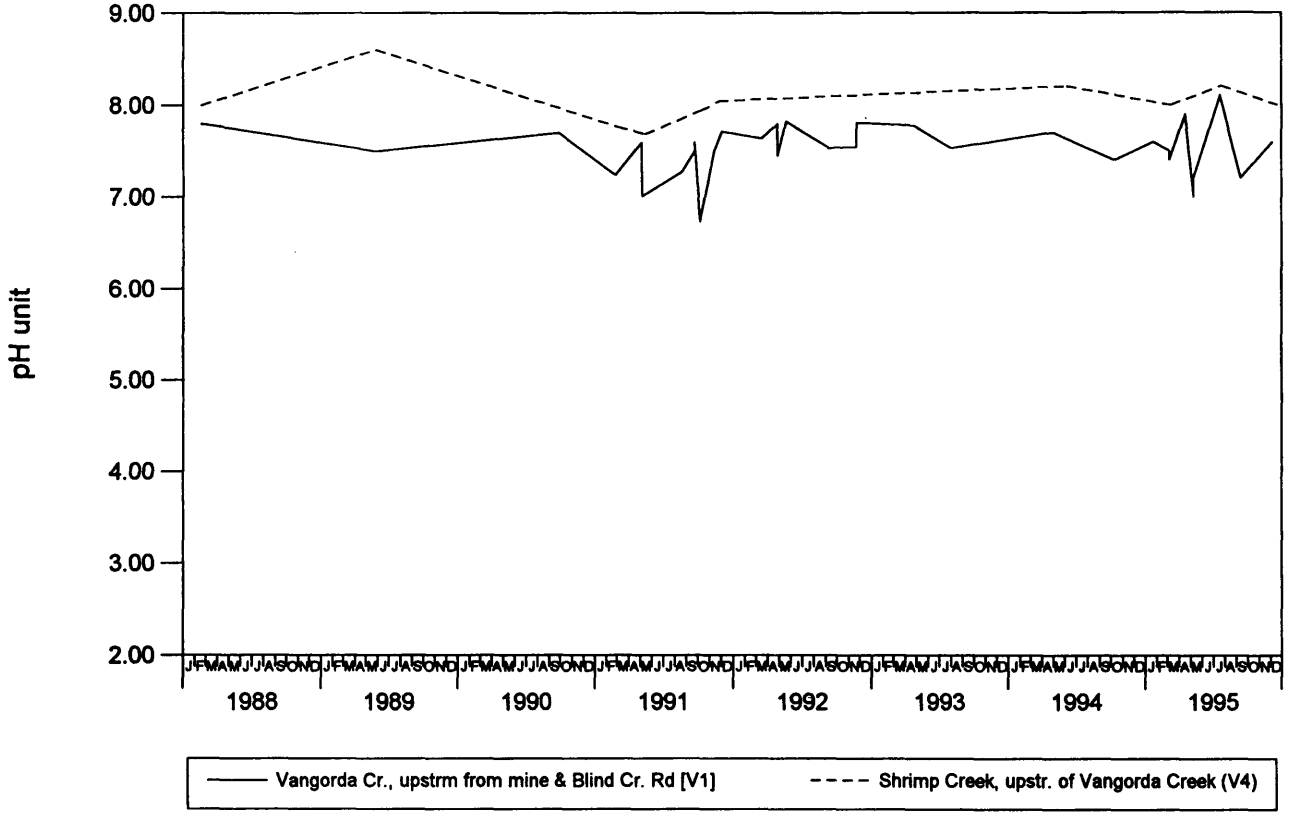


Figure 3-36 Vangorda and Shrimp Creek - Alkalinity

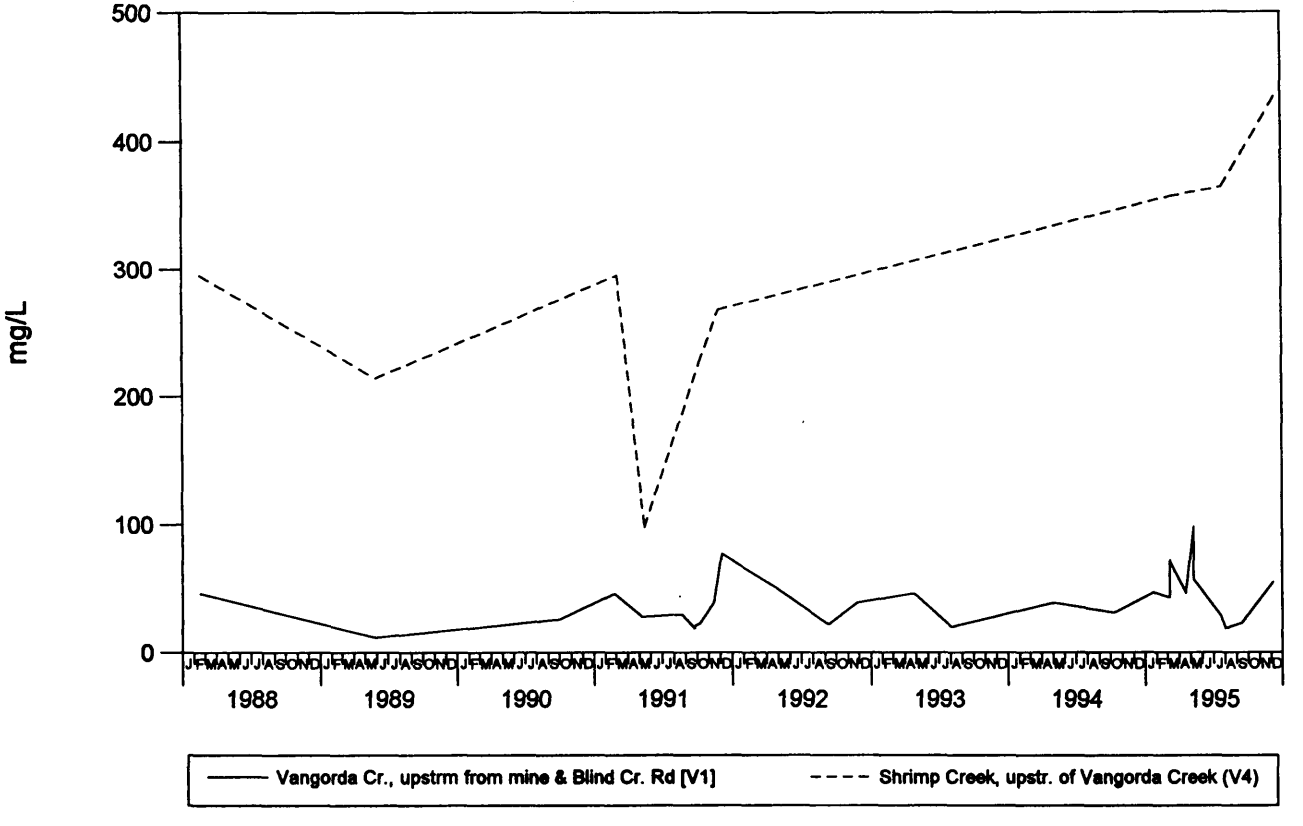


Figure 3-37 Vangorda and Shrimp Creek - Total Sulphate

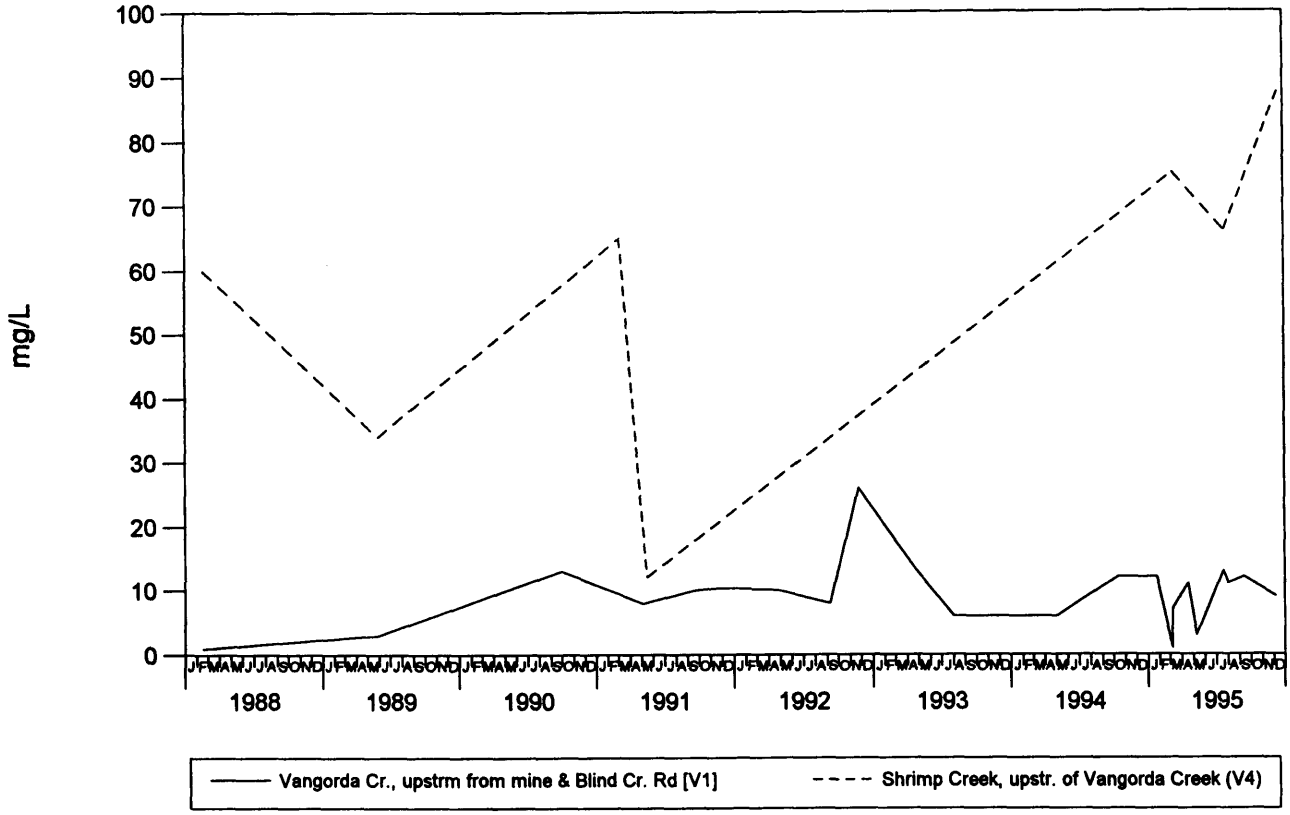
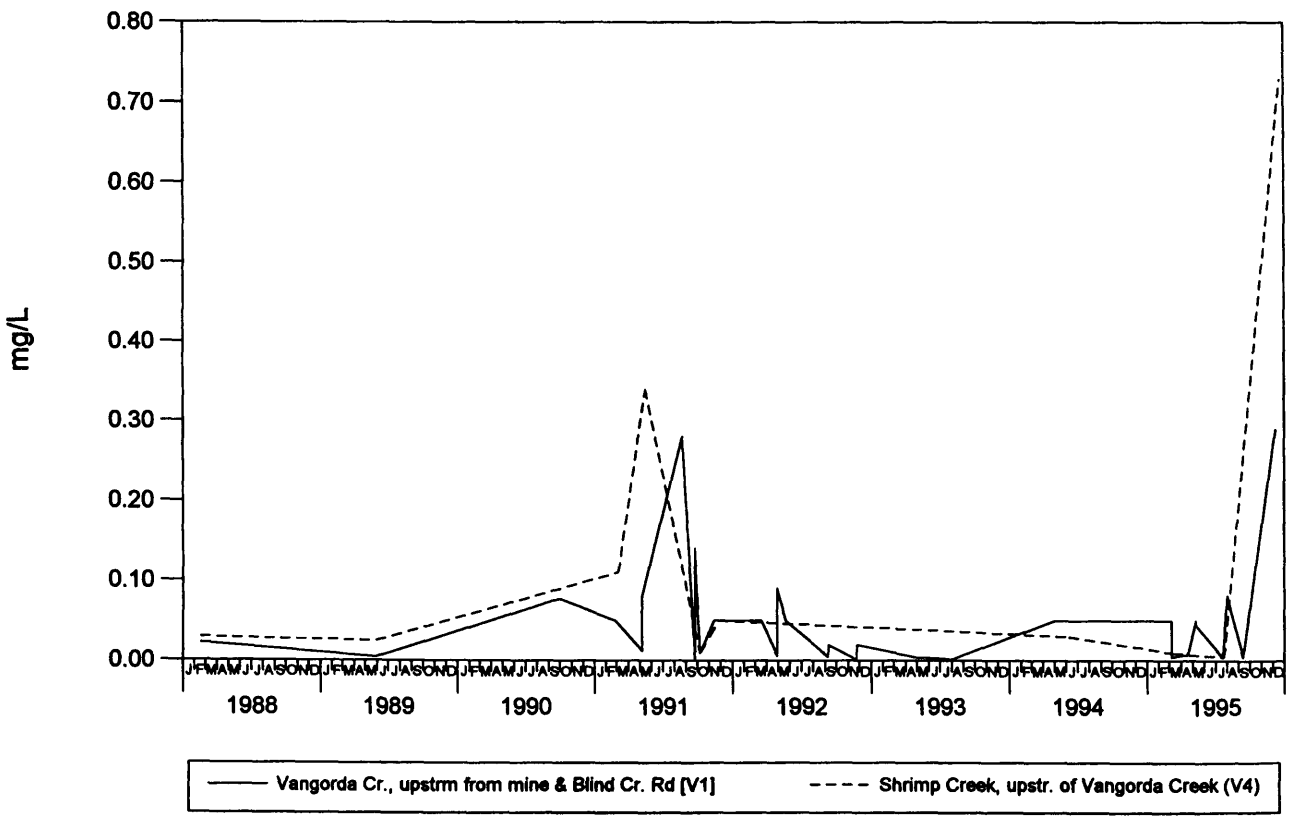
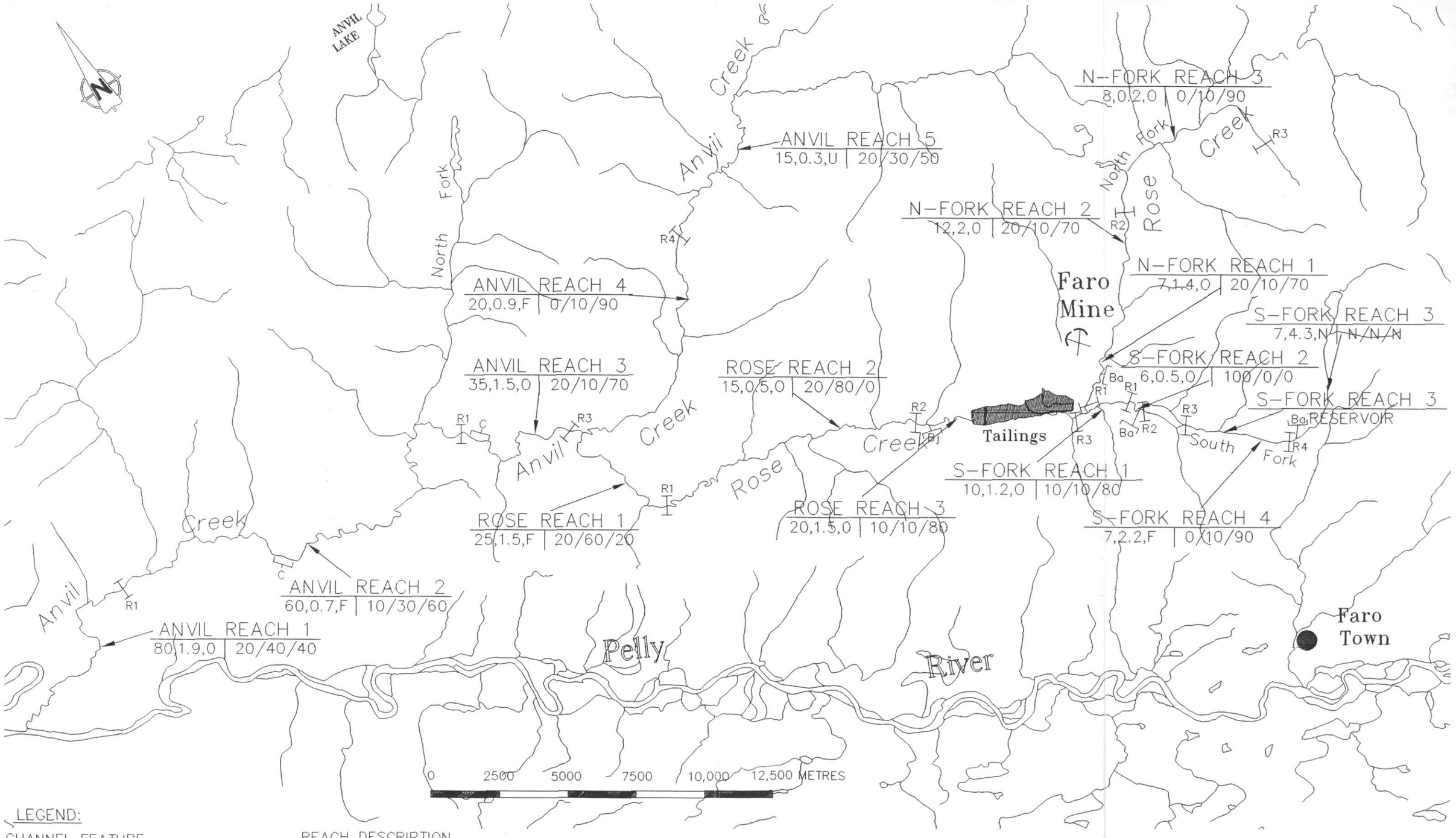


Figure 3-38 Vangorda and Shrimp Creek - Ammonia





LEGEND:

CHANNEL FEATURE

- Ba Barrier to Adult (a) and Juvenile (j) Migration
- C Constricted Area
- R Reach Break

REACH DESCRIPTION

1,1.2,3 | 10/20/30

- 1,1.2,3: Channel Width (m) / Slope / Channel Type
- 10/20/30: Large (%) / Gravel (%) / Fine (%)

N: Data not available
O: Occasionally Confined
F: Frequently Confined
U: Unconfined

Scale 1:130 000

Note: After Harder & Associates Ltd.

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Anvil Complex Closure Plan

ROSE/ANVIL CREEK
DRAINAGE
BIOPHYSICAL STREAM SUMMARY

PROJECT NO.	DATE	APPROVED	FIGURE
033001	Nov. 1996		3-39

ANVIL LAKE

North Fork

Anvil Creek

NORTH FORK REACH 3

1989	Harder & Assoc., 91	ag(2), ss(36)	

NORTH FORK REACH 3

1989	Harder & Assoc., 91	ag(1), ss(3)	

R3

NORTH FORK REACH 2

1989	Harder & Assoc., 91	ag(1), ss(19)	

NORTH FORK REACH 1

1989	Harder & Assoc., 91	ag(49), ss(34)	
1975	Baker, 79	ag(3)	

R4

R2

Rose Creek

ANVIL REACH 4

1990	Harder & Assoc., 91	ss(20)	
1989/90	Harder & Assoc., 91	ag(1/0), ss(31/20)	

ANVIL REACH 2

1976	Baker, '79	ch (1), ag(2), b(1)	

Faro Mine

SOUTH FORK REACH 5

1989	Harder & Assoc., 91	ag(9), ss(9)	

ANVIL REACH 2

1976	Baker, '79	ch (6), ag(14), rw(3), s(2), b(3)	

ROSE REACH 2

*1989	Harder & Assoc., 91	ag(8), ss(1)	

ANVIL REACH 3

1989/90	Harder & Assoc., 91	ss(11/26)	
1989/90	Harder & Assoc., 91	juvenille chinook	

R3

R2

Anvil Creek

R2

Tailings

R1

R1

R3

R2

R3 South Fork

R4

SOUTH FORK REACH 2

1989	Harder & Assoc., 91	ag(93), ss(104), b(5)	

SOUTH FORK REACH 4

1989	Harder & Assoc., 91	ag(13), ss(13), b(1)	

ANVIL REACH 1

1989	Harder & Assoc., '91	Chinook red	

ANVIL REACH 2

1989/90	Harder & Assoc., 91	ch78/3ag0/2ss9/10	

R1

Rose Creek

ROSE REACH 3

1989/90	Harder & Assoc., 91	ag(4/17), rw(0/1)	
1989	Harder & Assoc., 91	ag(3), ss(23)	
1975	Baker, 79	ag(3)	
1975	M.E.C., 16	ss(4)	
1974	Baker, 79	ag(4)	

ANVIL REACH 3

Possisble constraint to Upstream Migration
Juvenile fish, Harder & Assoc., 91

ROSE REACH 2

1989/90	Harder & Assoc., 91	Ø	
1989	Harder & Assoc., 91	Ø	
1975	Baker, 79	ag(2)	

SOUTH FORK REACH 1

1989	Harder & Assoc., 91	Ø	
1974/75/76	Baker, 79	ag(5/4/2), ss(3/1/0)	

ANVIL REACH 2

1990	Harder & Assoc., 91	Spawning Chinook Salmon	

R1

Anvil Creek

ANVIL REACH 1

1989/90	Harder & Assoc., 91	ch(18/32), ag(2/0), rw(6/7), ss(91/28), b(1/2), s(0/4)	
1974/75/76	Baker, 79	ch(0/1/1), ag(3/1/2), rw(0/16/0), ss(28/3/8), s(0/1/0)	

Faro Town

Pelly River

0 2500 5000 7500 10,000 12,500 METRES

Scale 1:130 000

LEGEND:

YEAR	REFERENCE	FISH SPECIES (NO. CAUGHT)

FISH SPECIES

ch = chinook salmon
ag = arctic grayling
rw = round whitefish
s = sucker
b = burbot
ss = slimy sucker
Ø = no fish
R = Reach Break

* = Combination of two sample sites from same year and source
For Reference list see Table
Note: After Harder & Associates Ltd.

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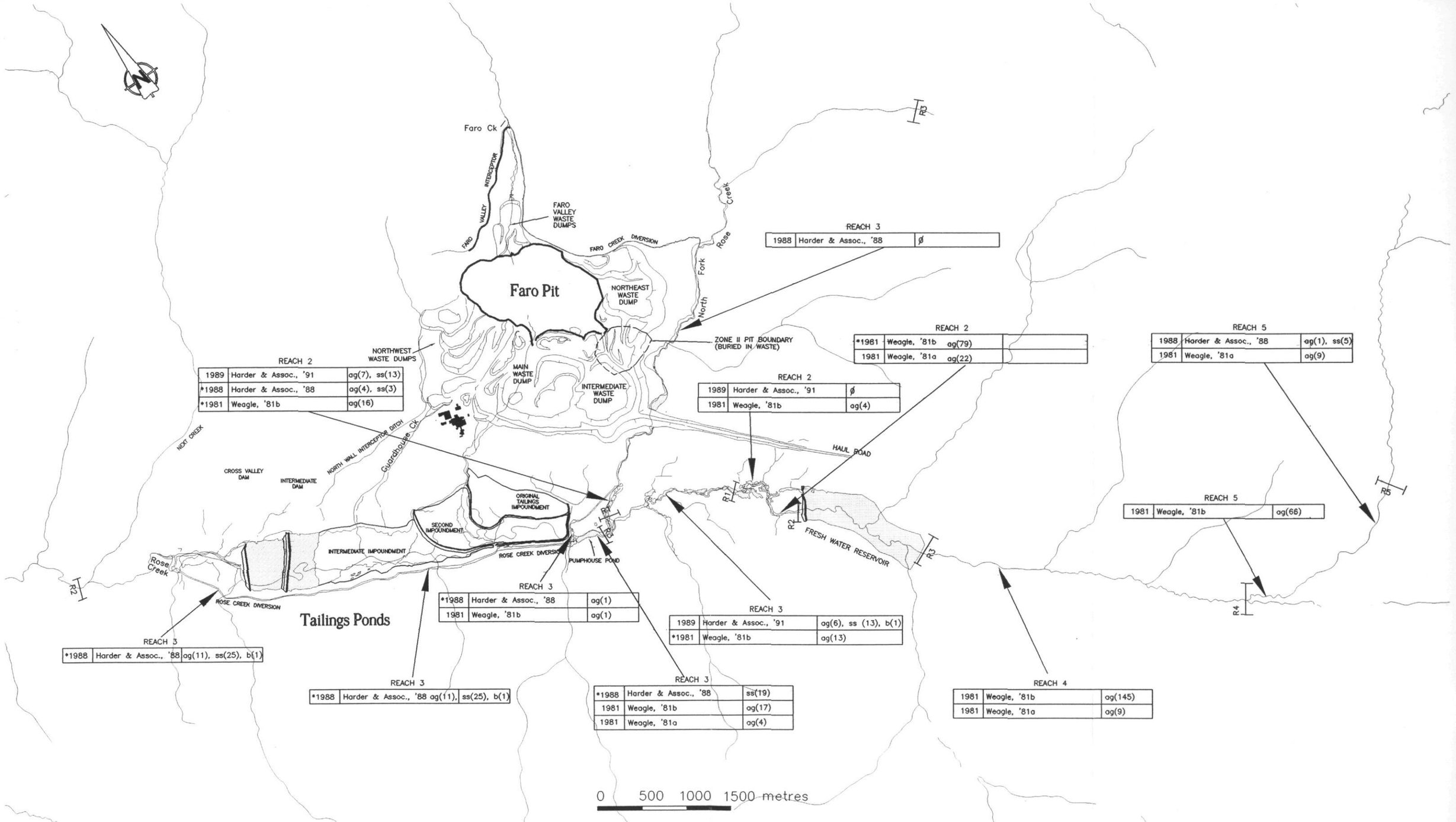
Anvil Complex Closure Plan

ROSE/ANVIL CREEK DRAINAGE FISHERIES SURVEY SUMMARY

PROJECT NO.	DATE	APPROVED	FIGURE
033001	Nov. 1996		3-40



LEGEND

YEAR	REFERENCE	FISH SPECIES (NO. CAUGHT)

FISH SPECIES

ch = chinook slamon
ag = arctic grayling
rw = round whitefish
s = sucker
b = burbot
ss = slimy sculpin
ø = no fish

R = Reach Break

* Combination of two or more sample sites from same year and source

SCALE 1:40 000

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ROSE CREEK AT FARO
MINE SITE
FISHERIES SURVEY SUMMARY

PROJECT NO.	DATE	APPROVED	FIGURE
033001	Nov. 1996		3-41

LEGEND:

CHANNEL FEATURES

W = Slump Bank
X = Debris
F = Waterfalls (m)
C = Culvert
R = Reach Break

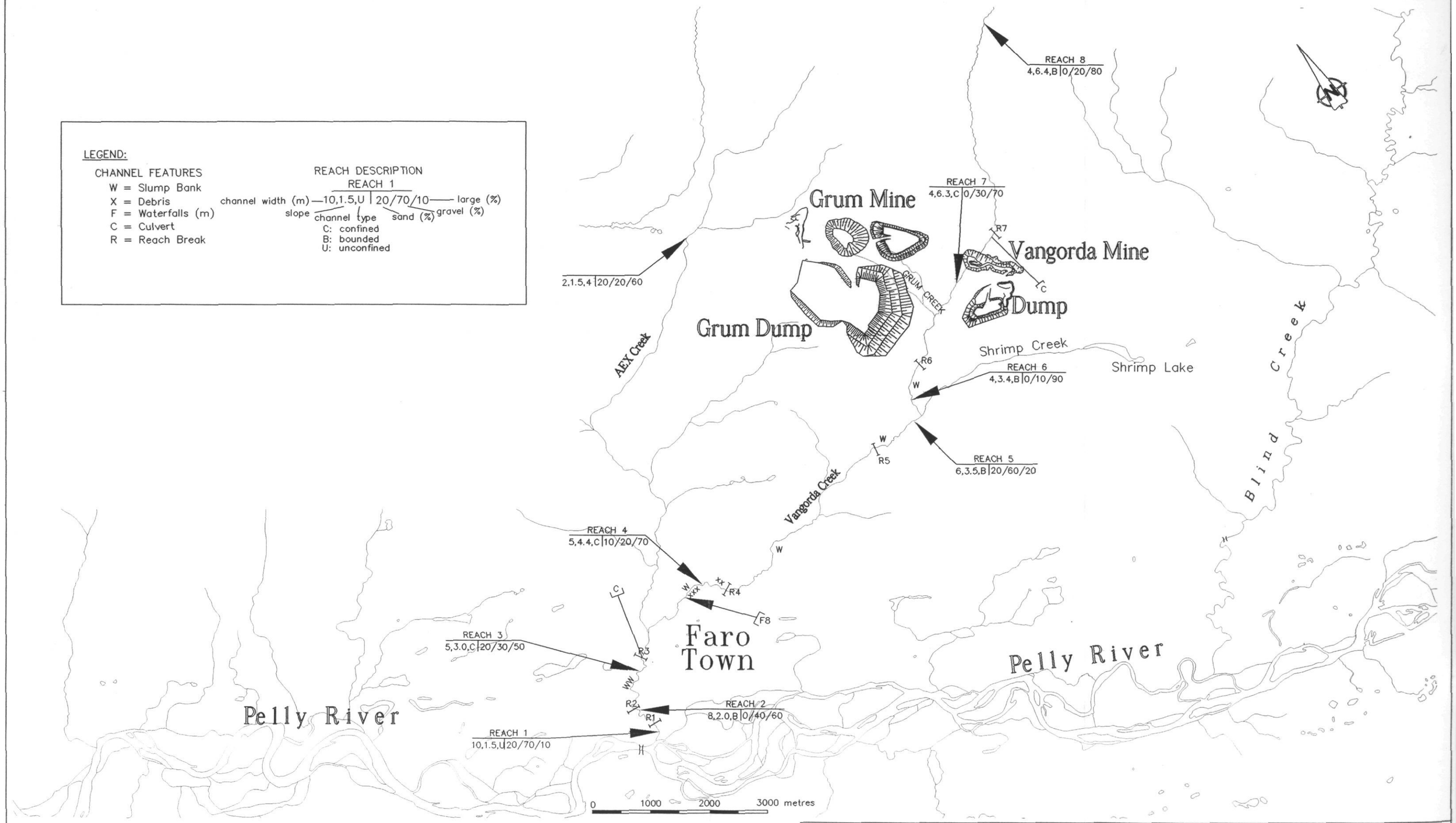
REACH DESCRIPTION

REACH 1

channel width (m) — 10,1.5,U | 20/70/10 — large (%)

slope | channel type | sand (%) | gravel (%)

C: confined
B: bounded
U: unconfined



Scale 1: 60 000

Note: After Harder & Associates Ltd., 1987

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Anvil Complex Closure Plan

VANGORDA CREEK DRAINAGE BIOPHYSICAL STREAM SUMMARY

PROJECT NO.	DATE	APPROVED	FIGURE
033001	Nov. 1996		3-42

LEGEND:

YEAR	REFERENCE	FISH SPECIES (NUMBER CAUGHT)

FISH SPECIES

ch = chinook salmon
ag = arctic grayling
rw = round whitefish
s = sucker
ss = slimy sculpin
Ø = no fish
b = burbot

R = Reach Break

For Reference list see Table 3.25

REACH 7

1987	Harder & Assoc., '87	Ø

REACH 8

1975	MEC, '76	Ø

Grum Mine

Grum Dump

Vangorda Mine

Vangorda Dump

GRUM CREEK

Vangorda Creek

R7

R6

Shrimp Lake

Blind Creek

R5

REACH 4

1987	Harder & Assoc., '87	Ø

REACH 3

1996	Harder & Assoc., '96	ch(3)
1990	Harder & Assoc., '92	ch(170), ss(18), rw(1)
1989	Harder & Assoc., '89	ch(320), ag(17), ss(20)
1987	Harder & Assoc., '87	ch(21)

REACH 4

1987	Harder & Assoc., '87	Ø

R4

Faro Town

R3

R2

R1

REACH 2

1996	Harder & Assoc., '96	ch(204)
1990	Harder & Assoc., '92	ch(107), ag(8), ss(32)
1989	Harder & Assoc., '89	ch(67), ss(32)

REACH 1

1996	Harder & Assoc., '96	ch(282), ag(1), other(5)
1990	Harder & Assoc., '92	ch(28), ss(1), ss(37), s(1), b(1)
1987	Harder & Assoc., '87	ch(57), ag(16), other (38)
1975	MEC, '76	Ø

PELLY RIVER

PELLY RIVER

0 1000 2000 5000 meters

Scale 1:60 000

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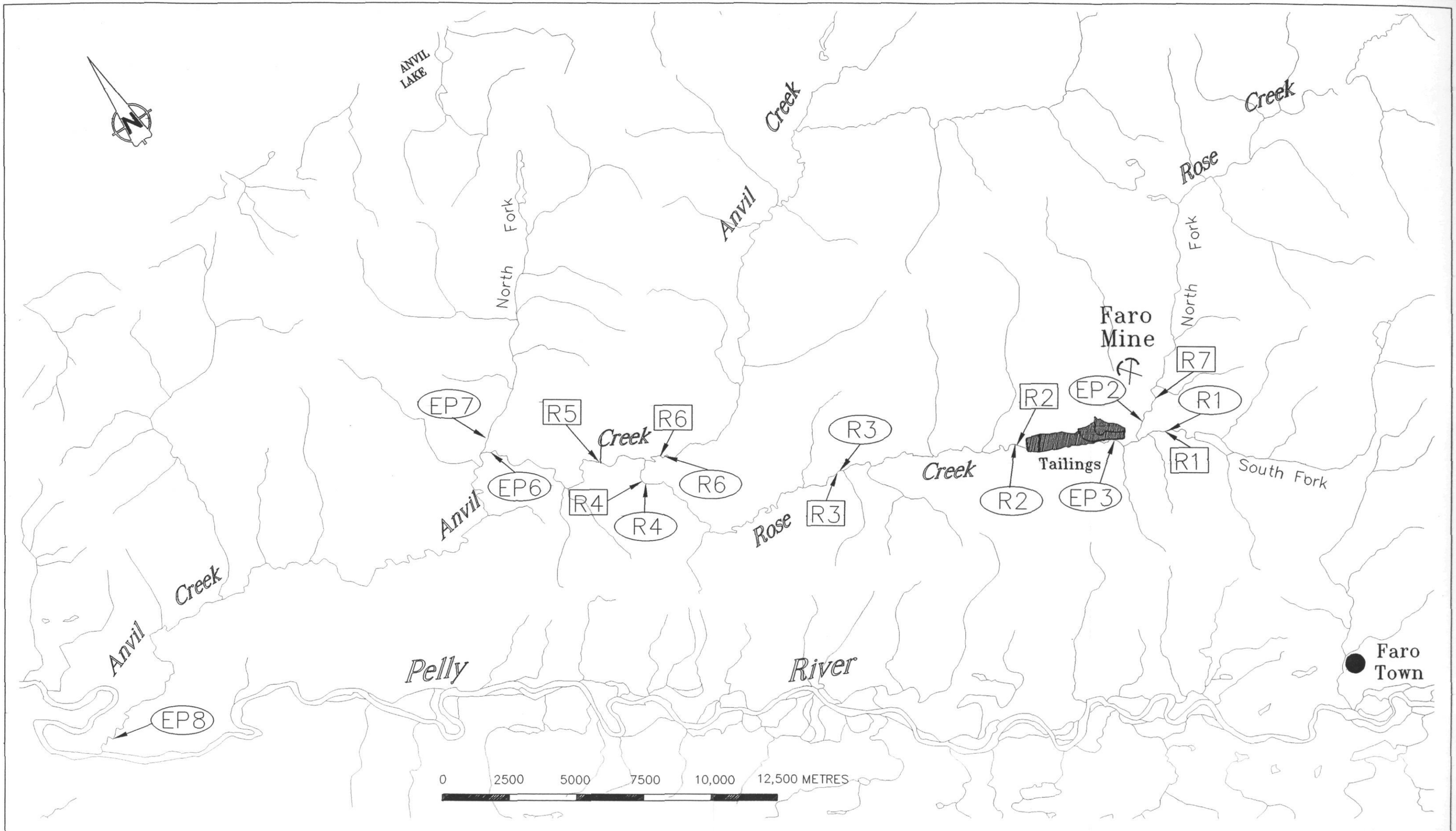
VANGORDA CREEK FISHERIES SURVEY

PROJECT NO.	DATE	APPROVED	FIGURE
033001	Nov. 1996		3-43



LEGEND

R1 Benthic Invertebrate Sampling Location

EP1 Sediment Sampling Location

Scale 1:130 000

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ROSE/ANVIL CREEK
BENTHIC INVERTEBRATE AND
SEDIMENT SAMPLING LOCATIONS

PROJECT NO.	DATE	APPROVED	FIGURE
033001	Nov. 1996		3-44

FIGURE 3-45 BENTHIC ABUNDANCE AT ROSE CREEK SITES 1973-1995

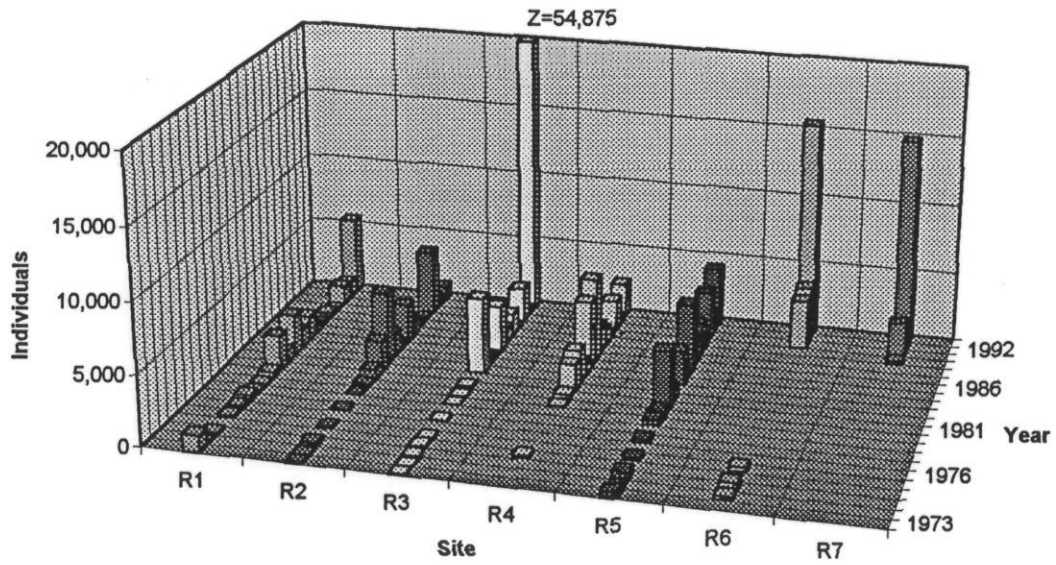
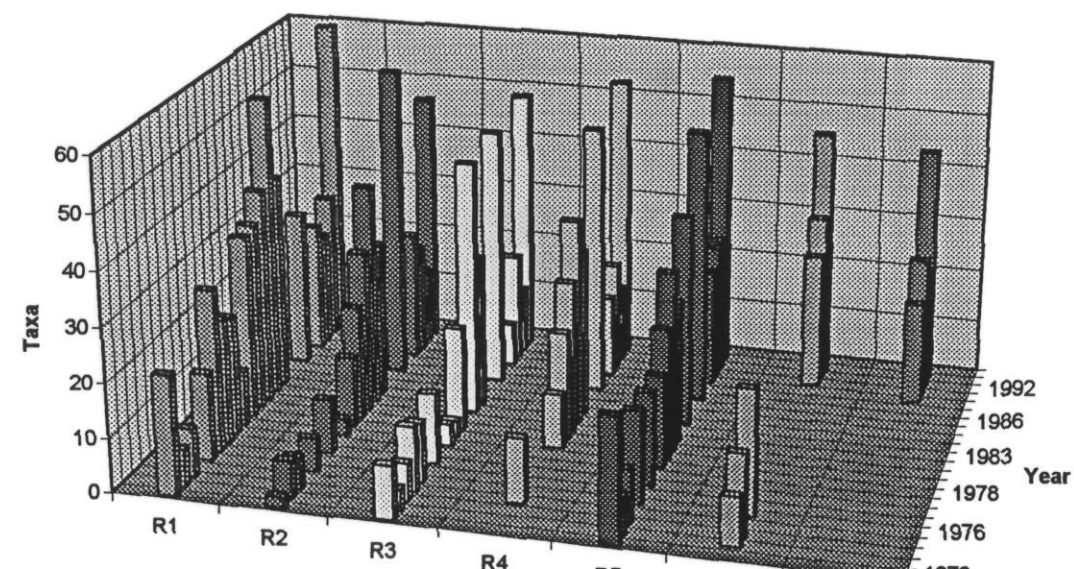


FIGURE 3-46 BENTHIC DIVERSITY AT ROSE CREEK SITES 1973-1995



LEGEND:

V8 — Benthic Invertebrate sampling location

(V8) — Sediment sampling location

Grum Mine

Grum Dump

GRUM CREEK

Vangorda Creek

Vangorda Mine

Vangorda Dump

Grizzly Deposit

Shrimp Lake

Blind Creek

V1

V1

EP6

V27

V27

V5

V5

Faro Town

V8

V8

PELLY RIVER

PELLY RIVER

0 1000 2000 3000 meters

Scale 1:60 000

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Consulting Geotechnical and Environmental Engineers

Anvil Range Mining Corporation

Anvil Complex Closure Plan

VANGORDA CREEK DRAINAGE
BENTHIC INVERTEBRATE AND
SEDIMENT SAMPLING LOCATIONS

PROJECT NO.	DATE	APPROVED	FIGURE
033001	Nov. 1996		3-47

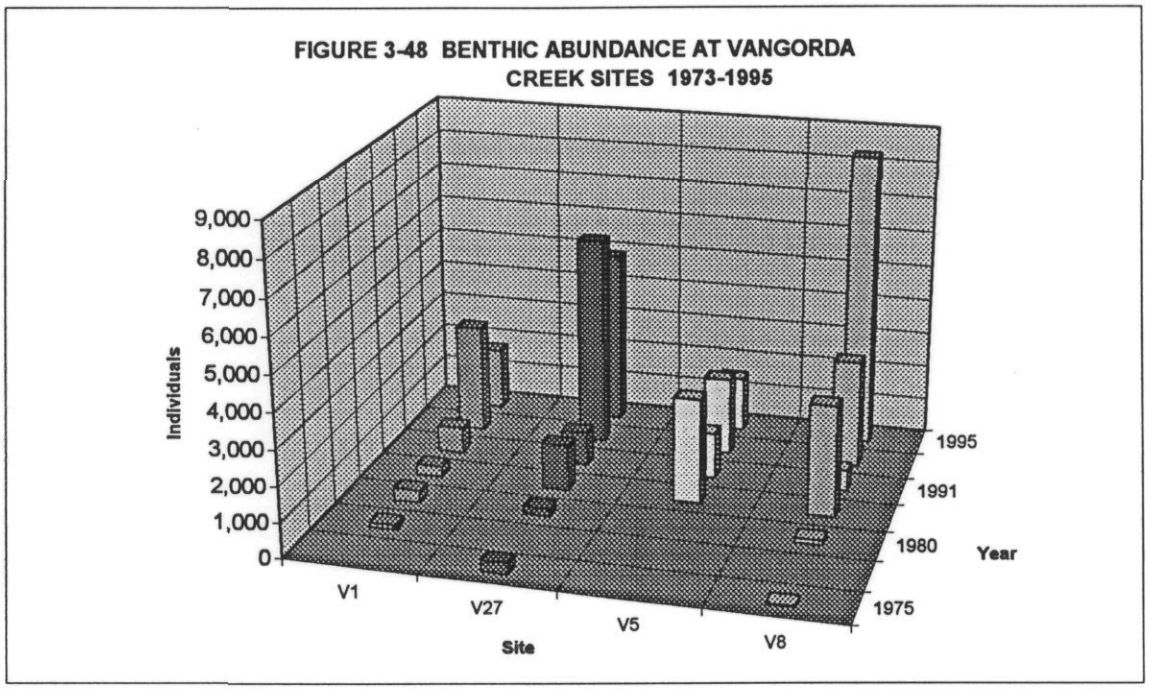

FIGURE 3-48 BENTHIC ABUNDANCE AT VANGORDA CREEK SITES 1973-1995

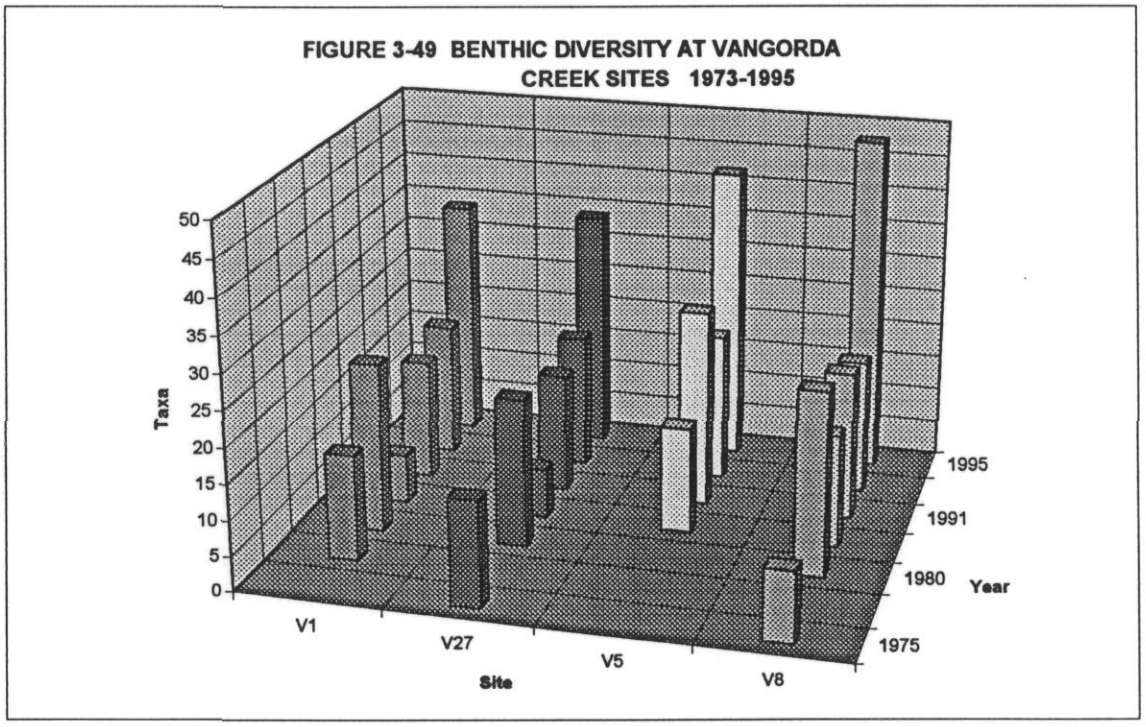

FIGURE 3-49 BENTHIC DIVERSITY AT VANGORDA CREEK SITES 1973-1995

FIGURE 3-50 COPPER CONCENTRATION IN SEDIMENTS AT ROSE/ANVIL CREEK SITES 1973-1983

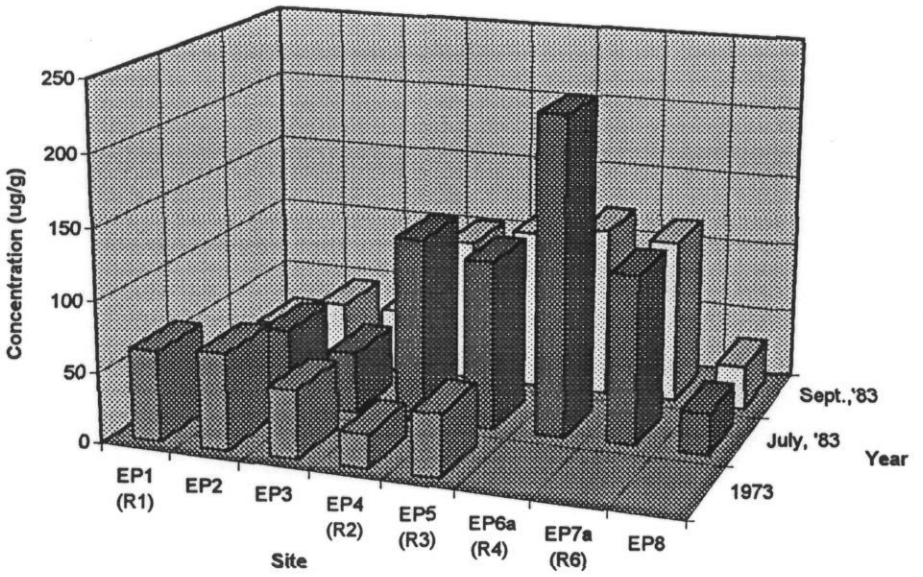

FIGURE 3-51 IRON CONCENTRATION IN SEDIMENTS AT ROSE/ANVIL CREEK SITES 1973-1983

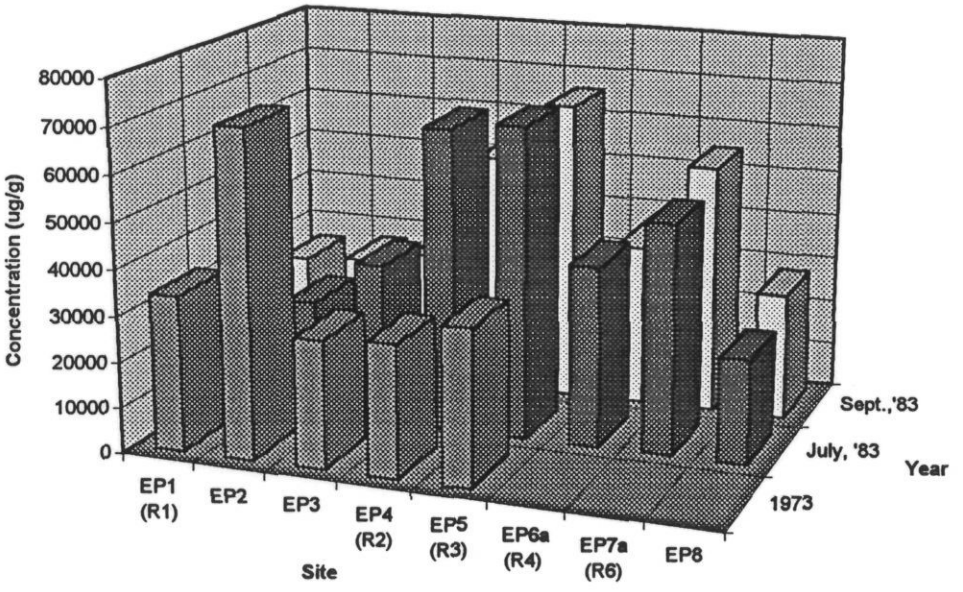

FIGURE 3-52 LEAD CONCENTRATION IN SEDIMENTS AT ROSE/ANVIL CREEK SITES 1973-1983

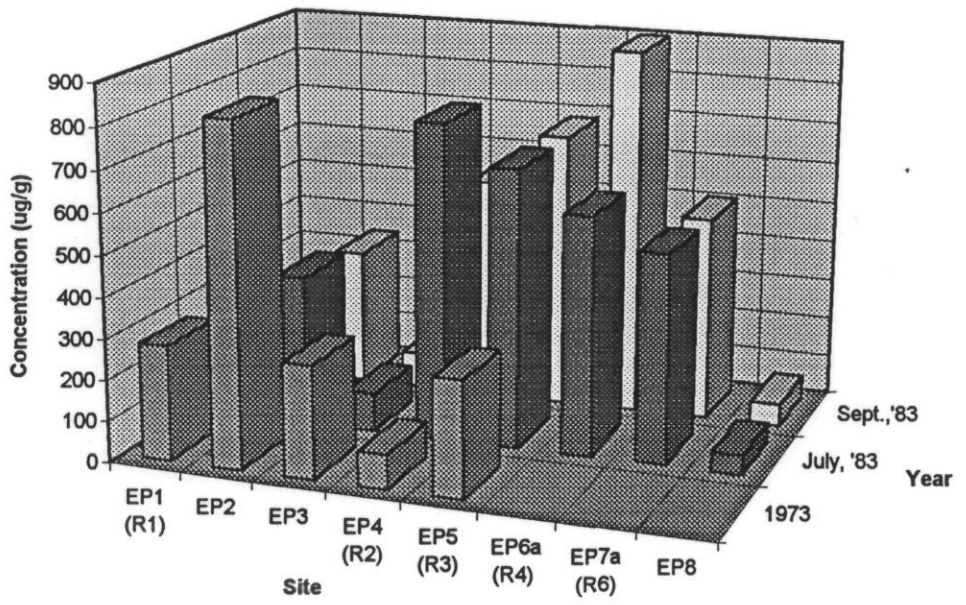

FIGURE 3-53 ZINC CONCENTRATION IN SEDIMENTS AT ROSE/ANVIL CREEK SITES 1973-1983

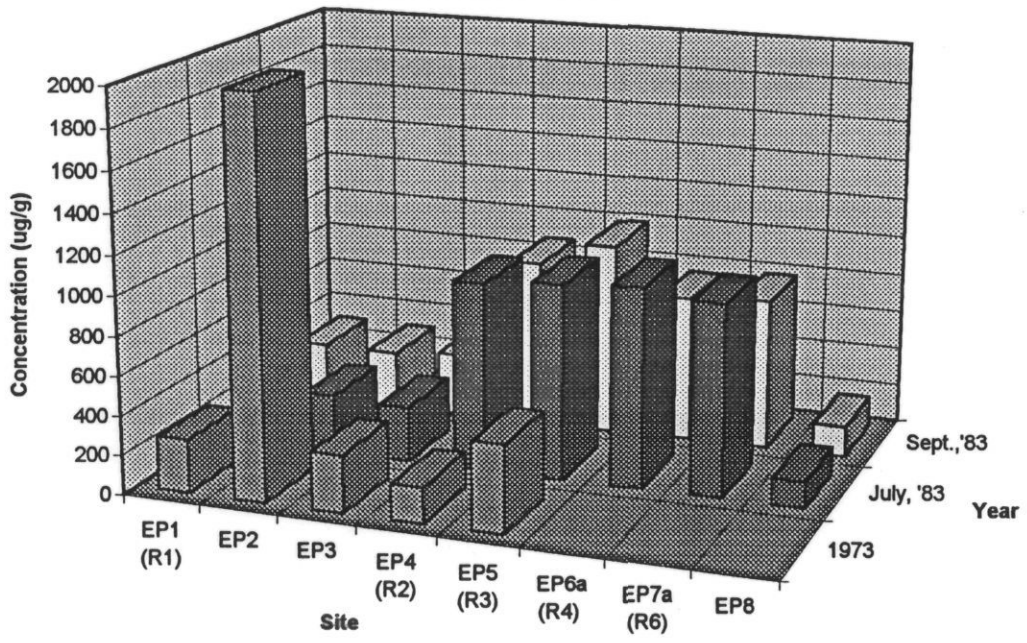

FIGURE 3-54 COPPER CONCENTRATION IN SEDIMENTS AT VANGORDA CREEK SITES 1991-1995

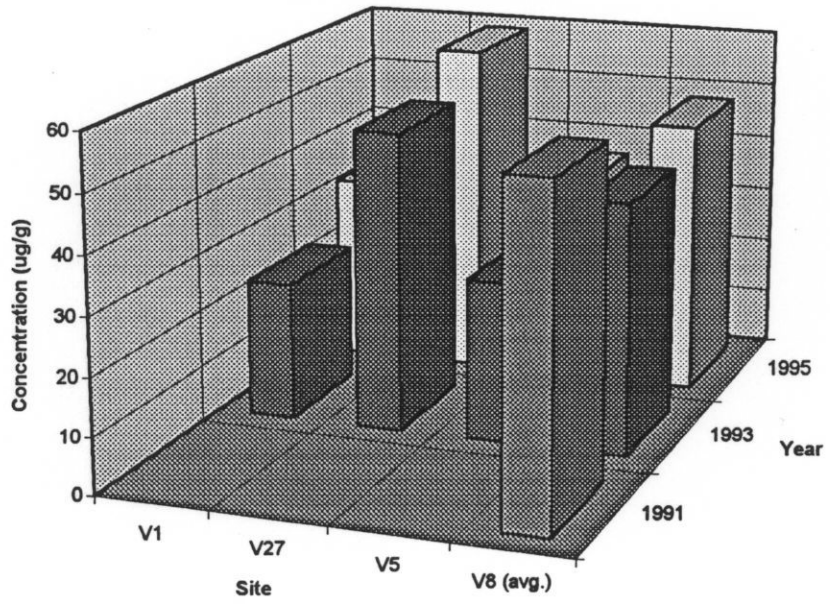

FIGURE 3-55 IRON CONCENTRATION IN SEDIMENTS AT VANGORDA CREEK SITES 1991-1995

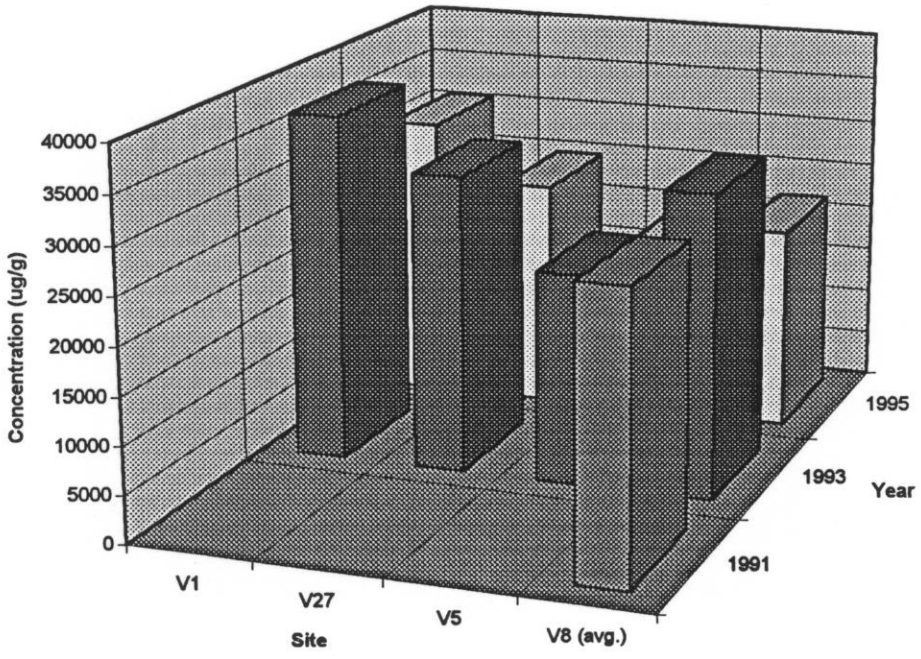

FIGURE 3-56 LEAD CONCENTRATION IN SEDIMENTS AT VANGORDA CREEK SITES 1991-1995

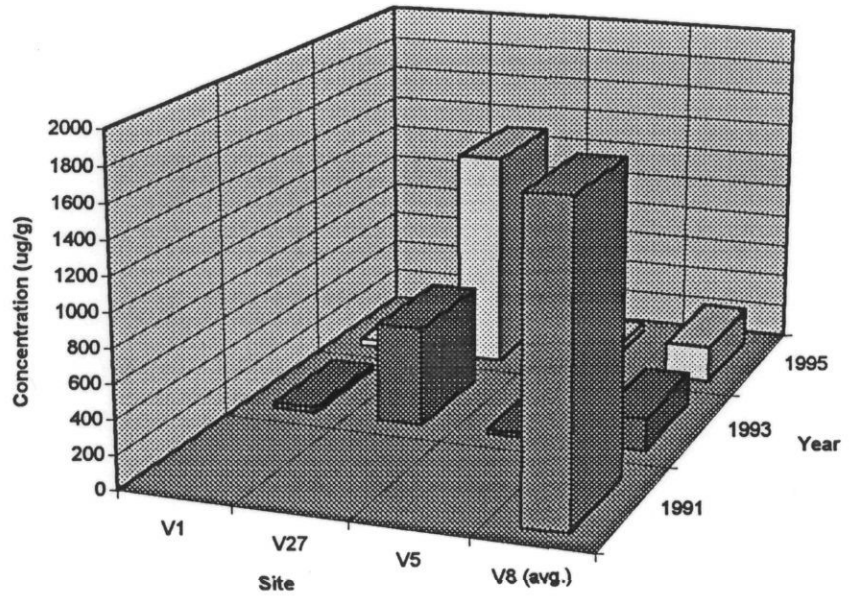

FIGURE 3-57 ZINC CONCENTRATION IN SEDIMENTS AT VANGORDA CREEK SITES 1991-1995