Planning for Stream Remediation Using Multiple-Account Analysis
Stoney (Topping) Creek, Trail, B.C.

L.B. Lawe
Water Quality Scientist, Golder Associates Ltd., 1000 – 940 Sixth Avenue Southwest,
Calgary, AB. T2P-3T1

J.C. Day Professor emeritus, School of Resource and Environmental Management, Simon Fraser University,
Burnaby, B.C. V5A 1S6

Abstract

In 1996, Stoney (Topping) Creek was identified as a significant contributor of zinc, cadmium, and arsenic to the Columbia River. The stream is located in Trail, B.C., north of the Cominco lead and zinc smelter. Mining operations leach toxins into the creek, notably zinc and cadmium, from an historic landfill, and arsenic from a storage site for this metal. Stoney Creek restoration is necessary for a variety of reasons: regulatory requirements, ethical motivations, potential ISO 14,001 certification requirements, and local and international stakeholder pressures.

Current ecosystem health is monitored in this study and restoration designs assessed to create and sustain the desired environmental quality in the degraded reach of Stoney Creek. Hydrology, water chemistry, and benthos were evaluated during the summers of 1998 and 1999. The relationships between aquatic insects and zinc, cadmium, and arsenic are quantified, in an effort to aid Cominco and government planners in choosing appropriate sustainability objectives. A multiple-account, cost-effectiveness study assesses five remediation options to control the toxins. These alternatives are groundwater interception, low-flow diversion, dilution in riffles and pools, dilution in riffles and pools with additional water, and purification in riffles and pools with phytoremediation.

Either groundwater interception or low-flow diversion is recommended as the preferred remediation option, and feasibility studies and related cost estimates are required to compare the costs of the two options. These two remediative techniques meet the cost-effectiveness criterion for water quality to remove toxins from the Stoney Creek watershed, and are relatively less expensive than other options with similar attributes. However, the construction of riffles and pools remediation option will provide many intangible environmental benefits that would not be attained by either the groundwater interception or low-flow diversion options. Thus, the construction of riffles and pools is also suggested to capture these intangible environmental benefits at Stoney Creek.

1. Stoney Creek Background

Topping Creek, locally known as Stoney Creek, lies directly west of one of the largest nonferrous lead and zinc smelters in the world, Cominco, in Trail, B.C. (fig. 1). In 1996, the creek was identified as a significant contributor of heavy metal contamination to the Columbia River due to toxic infiltration from Cominco-related activities. Local and international concerns for Cominco's impacts on the Columbia River heightened the need for restoration of this contaminated water body. Pollution from Cominco is principally due to zinc and cadmium leachate from an historic landfill and arsenic percolation from a disposal dumpsite for this metal.

Although the stream remains pristine in its western, upper reaches (fig. 2), industrial activities at Cominco severely degrade the eastern, lower part of Stoney Creek. Channelization, loss of riparian habitat, and heavy metal contamination impair the lower watershed. Expansive channelization below Thunder Road (fig. 3) contributes to flashy stream discharge. Fragmented vegetative cover affects temperature, erosion, and food supply for aquatic organisms. Heavy metal contamination is Cominco's largest environmental concern at Stoney Creek. Heavy metal pollution is compounded by drinking water extraction in the upper watershed by the City of Rossland. Thus, natural dilution in the contaminated, lower reaches is lessened by the

removal of nontoxic discharge from the upper watershed.

Remediation of Stoney Creek pollution has become a top environmental priority for Cominco, due to its heavy concentration of contaminants. Although a seepage collection system installed in 1997 removed a significant volume of heavy metals, stopping pollution at its source is only the beginning of freshwater restoration (Van der Vlugt et al., 1992). Rehabilitation of Stoney Creek requires a thorough planning process to identify Cominco's goals and to assess the economic and environmental aspects of potential remediation options.

This paper evaluates the environmental condition of lower Stoney Creek and potential remediation options. To do so it begins by outlining Cominco's corporate and political remediation incentives (section 2). Then stream health is evaluated based on quantitative analyses of hydrological, chemical, and biological variables (section 3). Various remediation options are then compared and the best alternative recommended using a multiple-account analysis in the concluding section (section 4).

2. Management Incentives and Goals

This section identifies the corporate and regulatory rationales for Cominco to reclaim Stoney Creek. ISO 14,001 certification is an important voluntary initiative promoting sustainable environmental practices. Regulatory pressures include provincial, federal, and international obligations. These details aid the development of applicable creek remediation goals and outcomes.

Cominco adopted an environmental management system (EMS) at the Trail Operations, a plan congruent with the globally recognized ISO 14,000 standardization system. In an effort to gauge environmental performance, the International Organization for Standardization (ISO) published a voluntary international standard, the ISO 14,000 series, in September 1996. ISO 14,001 represents this certification process. ISO regards environmental concerns as an integral part of daily operations, and emphasizes waste prevention (Boiral and Sala, 1998). The checking and corrective action management principles of ISO, where past wrongs are remediated, underlies the Stoney Creek restoration.

Three principal agencies are involved in regulation of Stoney Creek remediation: British Columbia (B.C.) Ministry of Water, Land and Air Protection (provincial); Environment Canada, and the Department of Fisheries and Oceans (federal); as well as international bodies.

Signatory provincial legislation protecting the Columbia River from tributary pollution is the *Waste Management Act* (1982). Taken together with the *Health Act* (1984), and the *Municipal Act* (1979), these statutes constitute the main powers to protect and manage freshwater in British Columbia (Affum 1994). The *Commission on Resources and the Environment* (CORE) *Act* (1995), which promotes sustainable social, ecological, and economic management, devolves planning responsibility to diverse stakeholders. Indeed, the *West Kootenay-Boundary Land-Use Plan*, the local document produced during this land use planning process, may ultimately influence new mining activities in British Columbia more than altering current industrial processes at Cominco (British Columbia, 1995).

Four legislative documents and one policy plan summarize the federal authority for fresh water management. The *Fisheries Act* (1856), the federal government's principal water quality legislation (Hunter, 1972), prohibits the discharge of deleterious substances into waters frequented by fish. The *Canada Water Act* (1970) allows a basin-to-basin method of pollution control, and the *Canadian Environmental Protection Act* (1999), legislates toxic substances. The *Inquiry on Federal Water Policy* (1985) and the *National Green Plan* (1990) outline federal doctrine on Canada's fresh water resources, although neither has been fully implemented.

Treaties and commissions between Canada and the U.S. are designed to manage shared water resources fairly and avoid disputes. The *Boundary Waters Treaty* (1909) is an international agreement between the two countries, to prevent

pollution, and changes to levels and flows in one country that could detrimentally affect the other. It is administered by the International Joint Commission (IJC). The treaty's purpose is to resolve disputes over water quantity and quality (International Joint Commission, United States and Canada 1990). If requested by both countries, orders of approval are issued by the IJC to regulate the use, obstruction, or diversion of waters that flow along or across a boundary, or if a natural use across the border is affected (International Joint Commission, United States and Canada 1990).

An important stimulus for Cominco to improve its water quality management practices stems from international public pressures. United States stakeholder concerns related to the State of Washington Department of Ecology, U.S. Environmental Protection Agency, Lake Roosevelt Water Quality Council, Tribes-First Nations, and public stakeholders are providing pressure for remediative action (Beatty, June 1999). Indeed, such stakeholder dissent has often been required to improve environmental management practices within many large corporations in B.C. and Canada.

In summary, motivation to remediate Stoney Creek at Cominco is a complex mixture of corporate and regulatory pressures. Voluntary initiatives, including ISO 14,001 certification, are being combined with regulatory requirements imposed by the Ministry of Water, Land and Air Protection, Environment Canada, and international bodies. Public pressure is also an important component of environmental reform. Operational objectives should be defined for the creek based on a clear identification of the regulatory context and Cominco's management objectives and incentives (U.S. Environmental Protection Agency, 1998). In this study, an evaluation of stream health, based on quantitative analyses of hydrological, chemical, and biological variables, was undertaken to develop operational objectives for Stoney Creek. This stream health study was completed at the request and expense of Cominco.

3. Biological State of Stoney Creek

Assessment endpoints are required to bring restoration objectives to the operational level, encompassing both long-term goals and daily management. These refer to ecological criteria and specific, desirable characteristics that should be sustained (U.S. Environmental Protection Agency, 1998). Endpoints must be tangible and operational to monitor success in achieving management objectives. Selecting appropriate assessment endpoints can be difficult until a goal is broken down into multiple management components (U.S. Environmental Protection Agency, 1998).

At Stoney Creek, a physical, chemical, and biological health assessment is used to aid Cominco and government planners to identify appropriate assessment endpoints for the watershed. Stream hydrology, water chemistry, algal communities, and aquatic insect communities were evaluated during the summers of 1998 and 1999 at Stoney Creek. The assessment endpoint selected is to maintain aquatic insects at Stoney Creek at 100 percent of control-site abundance in the degraded sites. Heavy metal concentrations required to maintain 100 percent benthic survival are identified as 17 µg/l zinc, 0.47 µg/l cadmium, and 2 µg/l arsenic (Brewer, 2000). Cadmium is critical to aquatic invertebrate survival at Stoney Creek (Brewer, 2000). Remediation options that meet this target, 0.47 µg/l cadmium, are evaluated in section 4.

4. Multiple-Account Framework

What is the best method to compare assorted stream restoration options? Each remediative technique has monetary costs and nonmonetary environmental benefits. Multiple accounts are a system of comparison among options that use dollar values to quantify the monetary aspects of projects, while qualifying environmental considerations. Multiple-account evaluation is similar to the traditional economic cost-benefit analysis in that monetary aspects of a project continue to be quantified in this way. The multiple-account framework at Stoney Creek has two components—expenses, and environmental aspects. The cost side method measures project aspects that have directly observable market

prices. There is growing recognition that not all costs and benefits should be calculated monetarily; and those environmental aspects that cannot be monetized are assessed qualitatively (Field and Olewiler, 1994).

In the Stoney Creek analysis, two accounts are used to evaluate the remediation options— an environmental and an economic account. The environmental account has two subaccounts: (1) meeting the cost-effectiveness criterion, and (2) qualifying intangible environmental benefits. The primary importance in cost-effectiveness is to meet a predetermined standard or guideline. This guideline represents the minimum environmental quality that must be achieved by a restoration option for that technique to be considered as a valid remediation alternative at Stoney Creek. Remediation options that do not meet the cost-effectiveness criterion are considered inadequate to achieve primary restoration needs.

The intangible environmental benefits subaccount cannot be measured quantitatively, and thus are treated separately. These environmental benefits are qualitatively assessed, forming the second subaccount of the environmental account. The economic account is evaluated using the present value of the costs (PV_C) as the evaluative criterion. The benefits are evaluated separately in the environmental subaccounts. The expenses for the remediation options are ranked accordingly by these costs, forming the economic account of the multiple-account framework.

Application to Cominco In order to choose a cost-effectiveness target, a thorough assessment of remediation incentives and creek health is required. Management targets are outlined based on the ethical, ISO 14,001, provincial, federal, and international incentives outlined in section 2. In section 3, the principal Stoney Creek cost-effectiveness goal is then identified as 100 percent benthic abundance, or 0.47 µg/l cadmium. This concentration is used as the cost-effectiveness criterion in this study.

In summary, each remediation option is assessed to determine if the cost-effectiveness criterion, 0.47 µg/l cadmium, is met. This information forms the cost-effectiveness subaccount of the environmental account. Then, each remediation option is assessed qualitatively to determine whether additional environmental benefits would occur. This analysis forms the intangible environmental benefits subaccount. Finally, the costs of the remediation options are assessed quantitatively in the economic subaccount.

4.1. Remediation Options

Zinc, cadmium, and arsenic concentrations at Stoney Creek must be low enough for aquatic invertebrates to survive. To remediate the stream, heavy metal concentrations must be either reduced, or diluted. Dilution is an important consideration since water is extracted in upper Stoney Creek to supply drinking water for the city of Rossland. This water would have diluted toxins naturally in lower Stoney Creek. Potential options for addressing heavy metals range from extraction, to diversion, to dilution, and in-stream treatment. There are five leading options: (1) groundwater interception, (2) low-flow diversion, (3) dilution in riffles and pools, (4) dilution in riffles and pools with additional water, and (5) purification in riffles and pools with phytoremediation.

Groundwater Interception (SC)

Contaminated seeps were treated previously at Stoney Creek using groundwater collection. This option reduces metal contamination by physically removing toxins from the creek. Heavily contaminated water is intercepted before reaching the creek via diversion pipes in a drainage system, and is transferred to the effluent treatment plant for lime precipitate treatment. Additional contaminated seep collection (SC) may reduce metal concentrations in the creek to below the cost-effectiveness criterion.

Low-Flow Diversion (LC)

Diverting the entire stream into a low-flow channel (LC) during exceptionally toxic flows would also maintain the cost-effectiveness guideline. Biological life survives in the creek during the spring freshet, when contaminated seepage water is diluted in the spring, as snow from surrounding areas starts to melt. The heavy metal concentrations are reduced by this input of fresh water, allowing aquatic life to thrive at this time. Conversely, metal pollution is concentrated

during summer when stream discharge declines because of increased evapotranspiration, and reduced precipitation and freshet inflow. Stream life is destroyed during this period as a result of toxic metal contamination levels.

To avoid this annual disruption, the creek could be diverted to the effluent treatment plant for lime precipitate treatment during periods of exceptionally toxic flows. But when cadmium concentrations are below the cost-effectiveness criterion, 0.47 µg/l for 100 percent benthic abundance, the creek would continue to flow in its natural channel. In summer, the creek discharge is almost entirely based on groundwater flows, as surface runoff ceases. Creek flows are lethal at these times to all stream life. When this occurs, the entire creek discharge would be diverted for treatment and precipitation of toxic pollutants at the effluent treatment plant.

Dilution in Riffles and Pools (R)

Riffles and pools (R) re-establish the natural morphology of rivers by storing water in-stream, and providing dilution at critical times for aquatic life. Riffles are areas of increased stream velocity, usually over rocky surfaces and, therefore, pools form downstream increasing creek depth. This channel morphology dilutes discharge, by increasing water volume in the creek. If dilution is sufficient during the critical low-flow periods to maintain the cost-effectiveness criterion, aquatic insect and algal life are prolonged.

Dilution in Riffles and Pools with Additional Water (RW)

If dilution were inadequate to sustain metal concentrations below the cost-effectiveness guideline using the riffles and pools alternative, extra dilution could be achieved through water importation (RW). Additional water could be stored in the upper watershed for release during critical times. This influx of nonpolluted water would dilute metal concentrations during the low-flow season. There are three proposed methods of diluting Stoney Creek discharge in late spring and summer: (1) releasing stored water, (2) stopping drinking water extraction, and (3) importing water from local streams.

A reservoir would capture water throughout the rainy, spring season and stores it for slow release in lower Stoney Creek, particularly when dilution is critical to aquatic insect survival. Altering Rossland drinking water consumption practices, so that stream flow is not diverted during late summer, may augment insect abundance. Meeting water demands in Rossland is often difficult at this time, however, as Rossland relies on Stoney Creek flows to satisfy pressing supply demands. Although implementation of the water importation option may prove difficult for ecological reasons, diverting water from nearby streams, such as Hanna and Murphy Creeks, could also dilute toxic metals at critical times to aid aquatic insects.

Purification in Riffles and Pools with Phytoremediation (RP)

Riffle and pool construction could be combined with phytoremediation (RP), the use of green plants to remove, to collect, or to detoxify metal pollutants (Burke, 1993). An experimental phytoremediation passive treatment system with four cells was built in Trail, B.C. to purify Stoney Creek wastewater. Ninety-six to 98 percent of the zinc, cadmium, and arsenic (Duncan and Mattes, 1998) were removed using an anaerobic digester and perennial plants for phytoextraction. Creating in-situ phytoremediation pools among the constructed riffles and pools might be a viable remediation option for Stoney Creek to reduce metal concentrations below the cost-effectiveness guideline.

4.2. Environmental Account: Meeting Target Concentrations

The cost-effectiveness guideline, 0.47 µg/l cadmium, can be achieved with each remediative technique except the dilution in riffles and pools (R) and dilution in riffles and pools with additional water (RW) options (Brewer, 2000). In 10- to 40-minutes for the status quo, and in no more than 1.5-hours with the addition of riffles and pools, concentrations in the creek meet levels that sustain only 50 percent of the benthos. This minor extension of time with dilution in riffles and pools, one hour, is inadequate for Cominco goals. This is because during low-flows, contaminated groundwater degrades stream quality over several months. Although dilution in

riffles and pools with additional water could also sustain 50% of aquatic invertebrate abundance, the cost effectiveness criterion would not be met with either of these options (table 1).

4.3. Environmental Account: Intangible Environmental Benefits

Environmental benefits that are additional to meeting the cost-effectiveness criterion and the midpoint goal are discussed below. The first environmental subaccount, meeting the cost-effectiveness criterion, was reviewed in the previous section. The second environmental subaccount, quantifying intangible environmental benefits for each remediation technique, are outlined next for each remediation option.

Seep Collection

Reduced terrestrial and fluvial metal pollution to the surrounding ecosystem, and temporally consistent habitat, are the principal intangible environmental benefits associated with this option (table 1). Heavy metals diverted from seep collection are permanently removed from the Stoney Creek and Columbia River systems, and are precipitated out for use as sludge in cement production. Impacts downstream and in the terrestrial ecosystem are mitigated due to this removal of heavy metals. Additionally, habitat for periphyton, aquatic invertebrates, and fish is present throughout the year. This occurs with all options except low-flow diversion, when the creek bed is dry during a portion of the summer, at the time that the stream is diverted.

Low-Flow Diversion

A low-flow channel has two significant intangible environmental benefits: reduced terrestrial and fluvial contamination. A low-flow channel physically removes heavy metal contamination from the riparian and in-stream ecosystem, when metal concentrations in the creek exceed the cost-effectiveness criterion. Therefore, further detrimental impacts of these toxins within the watershed and to the Columbia River are mitigated.

Dilution in Riffles and Pools

Varied intangible environmental benefits are associated with riffles and pools. Riffles and pools reduce stream flashiness, oxygenate the water, create amenable aquatic habitat, persist longer than other remediative techniques, and diminish risk to aquatic life. However, pollution of the Columbia River is not mitigated with this option. With riffle and pool construction, the creek hydrology is restored to a predisturbance state. Riffle and pool stream structures restore natural flow patterns, and because of enlarged storage capacity, decrease the variability of stream discharge, or stream flashiness.

Riffle substrate was the single most important element in positively influencing benthic macroinvertebrates (Austin, Lang, and Pomery, 1981). Fish habitat was enhanced by the creation of new riffle structures, which provide holding and resting areas for fish (Newbury and Gaboury, 1993). Numbers of cutthroat trout (*Oncorhynchus clarki*) increased significantly with augmented pool volume (Fausch and Northcot, 1992). Rabeni and Jacobson (1993) suggested that such hydraulic adaptations are low-cost, highly efficient methods to restore fish communities. Trout (*Oncorhynchus sp*.) exist in upper Stoney Creek and colonization downstream is a function of both amenable habitat and water quality.

The life span of riffle and pool construction is longer than for other remediation options. As the hydrology in a stream with riffles and pools closely resembles predisturbance discharge patterns, natural hydrological forces tend to reinforce riffles and pools. Thus, the life span of the project is extended. Also, risk of unintentional toxic contamination is reduced with riffles and pools. A slump from erosion due to a large storm, or clogged drainage lines, could cause the seepage collection system or a low-flow channel to fail. In a few hours, metal contamination to the creek would increase enough to destroy the aquatic insects that required months or years to establish. This risk is unrelated to riffle and pool installation, but is a common concern with other remediation options.

Metal pollution continues to enter the Columbia River. The intensity of water pollutants that enter the Columbia River from Stoney Creek reduces suitability of the dilution option. Except for a cursory analysis performed by Aquametrix Research Ltd. (1994), cumulative impacts to the

Columbia River are unknown. Due to this continued heavy metal pollution, this option is unsuitable at Stoney Creek.

Dilution in Riffles and Pools with Additional Water

This remediative technique has the same intangible environmental benefits as the dilution in the riffles and pools option. No significant intangible environmental benefits, that exceed meeting guidelines for water chemistry, are associated with additional water to augment dilution in riffles and pools.

Purification in Riffles and Pools with Phytoremediation

Reduced pollution to the Columbia River, and the benefits associated with riffle and pool construction, are the main intangible environmental benefits of phytoremediation. Phytoremediation is also less invasive and is easier to implement than traditional site restoration. Potential for terrestrial recontamination limits the suitability of phytoremediation. Pollution released to the Columbia River is lessened because toxins are hyperaccumulated in metal-tolerant plants. Riffles and pools are implemented at the same time as phytoremediation, so that the intangible environmental benefits of dilution in riffles and pools are identical to those of phytoremediation.

Terrestrial recontamination is also associated with this option. Heavy metal infested leaf litter may recontaminate the stream, and the toxins may bioaccumulate throughout the food chain (Schnoor et al., 1995). Macrophytes hyperaccumulate metals as a physiological response to control pathogens and insects (Watanabe, 1997). Bioaccumulation and biomagnification in the food chain are likely results. Contaminants may also collect as allocthonous input in the leaves released from riparian vegetation, or as fuel wood (Schnoor et al., 1995), recontaminating the steam. The potential for recontamination must be assessed when evaluating the suitability of this remediation option.

4.4. Economic Account

An economic account was tabulated for each project using present value of the costs (PV_C) to compare among the options. A 7-percent discount rate was used, and the life span for each remediation project was estimated at twenty years. When costs are less predictable, a sensitivity analysis was conducted, which estimates high- and low-cost variability. A sensitivity analysis was performed for every option except for dilution in riffles and pools, as costs for this treatment are relatively invariable. For other remediation techniques, scenario one is depicted as a low-cost option, and scenario two represents a higher cost variation. Complete calculations for each option are displayed in Brewer (2000).

5. Conclusions

A holistic assessment of management goals, stream health, and remediation alternatives is required prior to the development of a restoration plan for a contaminated watershed. This requires identifying the voluntary and regulatory remediation incentives, evaluating ecological needs that should be met by restoration, and thoroughly assessing costs and benefits of the proposed remediation alternatives.

A multiple-accounts framework aids planners to weigh the benefits and costs of each remediation option. The 100 percent benthic abundance goal, represented by 0.47 µg/l cadmium, represents the cost-effectiveness target for water quality. Intangible environmental aspects and economic components are evaluated separately. The achievement of sustainability goals for water chemistry, the inclusion of intangible environmental benefits, and a comparison of costs are summarized for each restoration option.

The multiple-accounts analysis outlines the benefits and costs of each remediation option suggested for Stoney Creek (table 1). Based on this analysis, several recommendations are suggested. 1) Neither dilution in riffles and pools (R), nor dilution in riffles and pools with additional water (RW) is recommended as the primary restorative technique for Stoney Creek because the cost-effectiveness target is not met with either option. 2) Phytoremediation (RP) is

not recommended as the primary restoratation alternative because of the potential effects of bioaccumulation, and due to the higher costs of this option when compared to the seep collection (SC), or low-flow diversion (LC), options. 3) A detailed cost estimation and feasibility study should be conducted to determine whether the seep collection, or the low-flow diversion option, is the lower cost alternative. Based on the results of this analysis, one of these 2 options should be chosen as the primary restoration option for the creek. 4) Riffles and pools (R) should be implemented at Stoney Creek, in addition to either seep collection (SC) or low-flow diversion (LC), due to the myriad of environmental benefits that this option affords.

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Table 1. Summary of the multiple-account analysis for five remediation options

ACCOUNT	SC	LC	R	RW	RP
Environmental:					
(a) Meeting Cost-Effectiveness Target					
Cost-effectiveness criterion: Cadmium < 0.47 µg/l	√	√			√
Environmental:					
(b) Qualifying Intangible Benefits					
Reduced pollution: Columbia River	√	√			√
Reduced pollution: terrestrial	√	√			
Habitat present longer, temporally	√		√	√	√
Reduced flashiness			√	√	√
Increased oxygenation			√	√	√
Increased periphyton and benthic habitat			√	√	√
Possible fish colonization			√	√	√
Longer life span of project			√	√	√
Reduced risk			√	√	√
Economic:					
Quantifying Costs					
PV_C					
Scenario 1 (lower-cost)	$60,468	$862,804	$201,168	N/A	$1,603,037
Scenario 2 (higher-cost)	$2,500,000	$1,236,636	-	-	$3,004,906

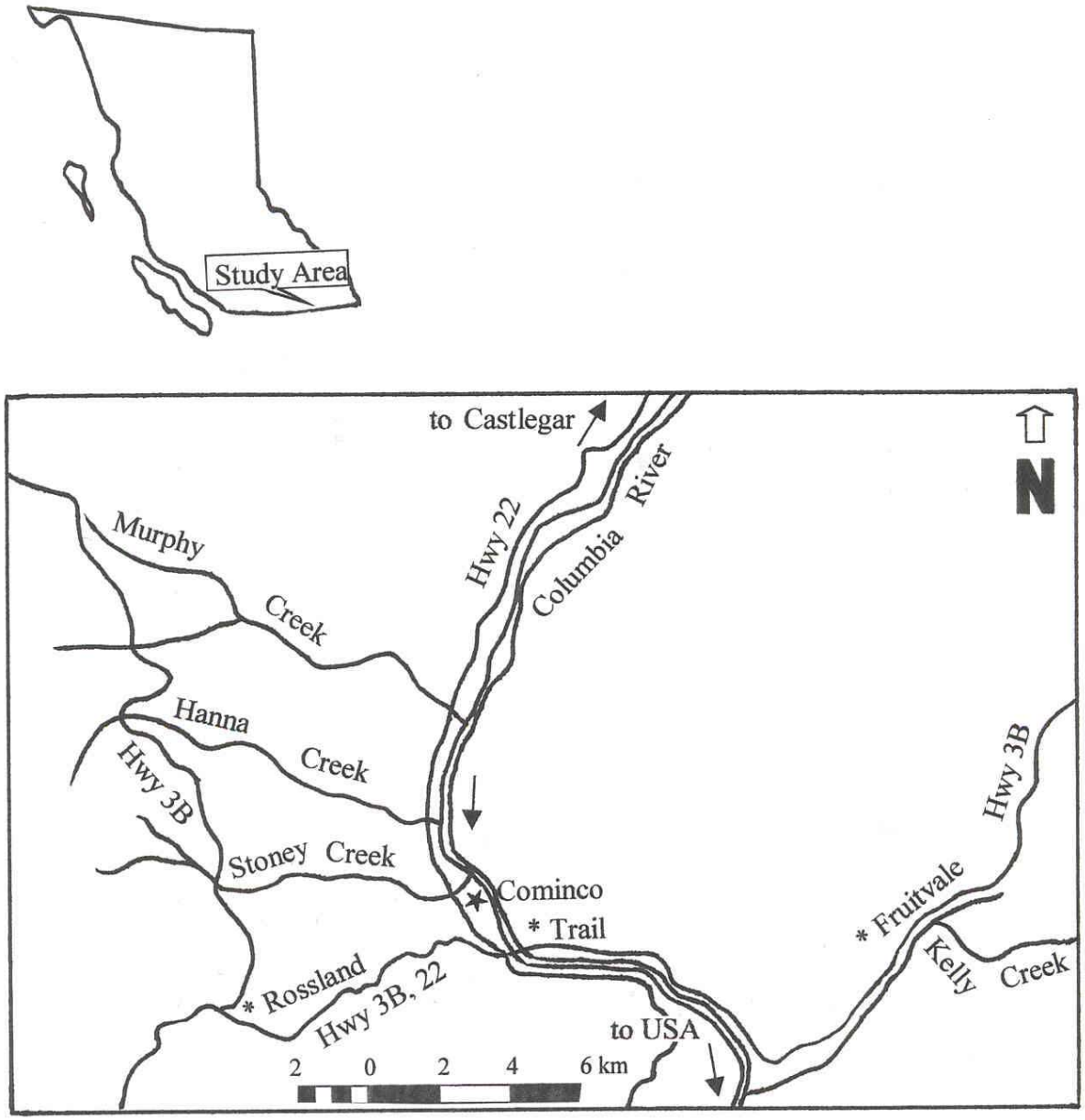

Figure 1. Location of Stoney Creek, near Trail and Rossland, BC

Figure 2. Upper Stoney Creek in August 1999, which provides part of the water supply for Rossland, BC

Figure 3. Lower Stoney Creek, located west of Cominco in Trail, BC in August 1999