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Department of Landscape Architecture

The University of British Columbia
Vancouver, Canada

Date April 27th 2001
Abstract

This thesis has two intentions: 1) to examine different options for the Remediation of the former Britannia Beach Copper Mine and select a scheme for the Remediation of the site which is contaminated by more than 80 years of intensive mining activity and 2) to examine how the elements of this scheme could be organised to improve the spatial layout of the community and designed to provide opportunities for interpretation, education and an improved sense of heritage.

This thesis document critiques several potential Remediation options available to deal with the Remediation of Britannia Beach and recommends the implementation of a single scheme, using a system of anaerobic wetlands as the principal element. Design factors affecting the implementation of such a system are discussed such as sizing, plant materials, layout, and land availability.

A second portion of this study, the graphic component, focuses on the design of the second portion of this thesis – how the design of the chosen passive Remediation scheme could be used to improve the spatial organisation and aesthetics of the community while providing opportunities for interpretation, education and history. Copies of this document, including reduced versions of the design drawings are available at the Department of Landscape Architecture Office.
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- Terry Johnson, Manager, Mining Museum of British Columbia
- Yale Simpson, Resident
- Pa'n Tattersfield, Elected Representative, City of Squamish

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And of course my family and friends - I love you all very much.
INTRODUCTION

The goal of this thesis is to examine different options for the Remediation of a mine site contaminated by more than 80 years of intensive mining activity and develop a design scheme allowing the Remediation of the site be expanded to improve the organisation, aesthetics of the community, while also providing opportunities for this design to educate and inform visitors about the history of the site and the Remediation of the site itself. Research will focus on a particular location, Britannia Beach, British Columbia.

Britannia Beach was once a prosperous community of 750 mining workers and their families located in two town sites. It was also the site of what was once the largest copper mine in the British Commonwealth. Today, the mine is closed and community of Britannia Beach town barely exists, its total population reduced to just over 300 residents. A mining museum, a few dilapidated buildings, and rotting machinery and infrastructure are all that remains. Today the community's legacy is a badly degraded landscape of chain link fences, asphalt and a spate of environmental problems.

*Figure 1: BC Min. of Crown Lands - 1992 TRIM Data*
Site History

Large-scale copper mining operations were first put in place in 1904-05 and had a daily capacity of 200 tons of concentrate. Concentrate and high-grade ore were originally smelted in Nanaimo. In 1908, both smelting and mining operations were merged to form the Britannia Mining and Smelting Co., Ltd. In 1913, the company moved smelting operations from Nanaimo to the American Smelting and Refining Company in Tacoma, Washington. Britannia Beach Mining and Smelting CO. operated the mine from 1905 to 1963\(^1\)

Between 1911 and 1941 production rose steadily from less than 100,000 tones per year to nearly 2,000,000 tones per annum by 1941. The years up to the and following World War II were the most productive. In 1963 the mine was sold to Anaconda where it continued to operate until 1974. Mining activity was ceased because of a depressed world market for Copper and the exhaustion of economically available ore\(^2\). Approximately 47 million tones of ore were shipped for smelting over its seventy-six year history\(^3\)

---

What is ARD?

The formation of Acid Rock Drainage is primarily a function of the geology and hydrology of the site, it is a natural process which is accelerated by human activity such as mining which bores large holes into the bedrock, exposing large quantities of pyritic-rich parent material to the open air and elements. ARD occurs when rock containing parent rock is exposed to aerobic conditions and oxidisation of iron sulfide minerals such as pyrite occurs. A by-product of this process is the formation is two moles of acid, which becomes soluble in water. ARD is common to mining operations, as they tend to expose large quantities of parent material. The resulting water is usually high in acidity and dissolved metals. The metals stay dissolved in solution until the pH rises to a level where precipitation occurs.

Although there are several different chemical reactions that typically lead to the formation of ARD, the following reaction is the most common and is a good sample illustration of what is occurring at Britannia:

\[
4 \text{FeS}_2 + 15 \text{O}_2 + 14 \text{H}_2\text{O} \rightarrow 4 \text{Fe(OH)}_3 \downarrow + 8 \text{H}_2\text{SO}_4
\]

Pyrite + Oxygen + Water \rightarrow "Yellowboy" + Sulphuric Acid

The first reaction in the weathering of pyrite includes the oxidation of pyrite by oxygen. Sulphur is oxidised to sulphate and ferrous iron is released. This reaction generates two moles of acidity for each mole of pyrite oxidised.\(^4\)

Site Description

Location

The site of the former Britannia Mine is located approximately 48 km north of Vancouver, British Columbia, adjacent to the fjord of Howe Sound.

Catchment Area

There are two catchment basins in the area. One is Britannia Creek (29km$^2$), the other Furry Creek (54km$^2$). Both flow westward into Howe Sound. Most the mining activities took place within the Britannia Creek catchment basin (principally in the Jane and Mineral Creek tributaries). Therefore it is the area most affected by ARD. No historical stream flow data exists for these sites, but analysis has been carried out since the 1990s (see next section).

Climate

A weather station was in operation from 1913 to 1974. The station was located just above the Britannia Beach Community, at an elevation of 49 meters. According to this data, average annual precipitation levels were 2,164mm with 96% falling as rainfall. The greatest precipitation levels were typically recorded between October and March. More than 174 days showed measurable precipitation. Upper elevations get significantly more precipitation with a greater proportion as snow. An additional 200-3000mm of annual precipitation is estimated with every 100 meters of ascent.\(^5\)

Geology

The ore bodies mined were located in Mineral Ridge, the east-west divide between Britannia Creek to the north and Furry Creek to the south, which rises to an altitude of 4,600 feet (1,400 m) from Howe Sound (NTS map 92G/11, 1981). Ore bodies were located in Mineral Ridge,

which rises to an altitude of 4600 feet (1400 m) from Howe Sound. The primary minerals present on Mineral Ridge were chalcopyrite (copper-iron sulphide), sphalerite (zinc sulphide) and extensive occurrences of pyrite (iron sulphide).  

Analysis of the geology and geochemistry of ore and waste rock indicates sources and the potential for ARD, impacts on water quality and the future pattern of acid generation. The principal mineral of economic value derived largely from quartz mineralisation, mostly in the form of pyrite (iron sulphide), but also with concentrations of chalcopyrite (copper-iron sulphide) with concentrations of sphalerite (zinc sulphide). Minor concentrations of galena, tennanite, tetrathyedrite and siderite also exist in smaller concentrations.

There are 7 major ore deposits in the mine area, all are located in a steeply sloping sheared band of metamorphosed sedimentary and volcanic rock. These deposits form what is referred to as a "roof pendant" that is two miles wide and 7 miles long. The minerals are have three sources: as massive sulphide ore bodies, disseminated sulphide and concentrations along bedding planes.

The ore bodies mined were located in Mineral Ridge, the east-west divide between Britannia Creek to the north and Furry Creek to the south, which rises to an altitude of 4,600 feet (1,400 m) from Howe Sound (NTS map 92G/11, 1981).  

---

Figure 2: Britannia Mine File

<table>
<thead>
<tr>
<th>Mining Division</th>
<th>Name</th>
<th>NTS</th>
<th>Status</th>
<th>UTM</th>
<th>Latitude</th>
<th>Longitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vancouver</td>
<td>Britannia</td>
<td>092G11E</td>
<td>Past Producer</td>
<td>10 5495200</td>
<td>49 36 41 N</td>
<td>123 08 23 W</td>
</tr>
</tbody>
</table>

Deposit Types: G06: Noranda/Kuroko massive sulphide Cu-Pb-Zn.
Commodities: Copper and Zinc
Terranes: Gambier Plutonic Rocks.


Open Pits

Until the last few years of the mine's existence, most of its operations were underground, but as copper deposits became harder via the mine's extensive tunnel network, Anaconda decided it would be more economical to mine surficial deposits on Mount Sheer. Five open pits were dug to facilitate this.

This has compounded the ARD problem as the open-pits towards the top of the mountain act like a funnel for rain and meltwater. This water collects in these pits and funnels into the underground workings of the mine.

This means that Britannia has about the worst possible conditions for the production of ARD.¹⁰

2200 Level Adit

The 2200 level adit, is the highest portal and source of the highest levels of contaminants and ARD flow. A cementation plant at Mount Sheer once treated discharge from the 2200 portal discharge. This plant is no longer in operation, however and the elevated copper flows currently drain untreated into Jane Creek, which is a tributary of Britannia Creek.

Attempts were made to divert the 2200 Level flow inside the mine to lower levels, away from the portal, but these measures appear to be currently ineffective. Even though the copper (40 to 100 mg/l) and other metal concentrations in the 2200 Level portal discharge are now less than 10% of concentrations reported by the United States Bureau of Mines in 1935, they remain an environmental hazard, and are the major contributor to the concentration of copper (typically 0.5 to 3 mg/l) (Figure 1) in Britannia Creek at its discharge to Howe Sound (monitoring station at Town site Bridge)."\(^{11}\)

*Figure 3: Flow from 2200 Level Adit*

Source: A Tour of the Britannia Mine in Pictures [http://www.direct.ca/ntbc/frames.html](http://www.direct.ca/ntbc/frames.html)

**4100 Level Adit**

Located approximately 60 m above Britannia Beach, the 4,100 level adit served as the principal haulage tunnel for the mine. Running 6 kilometres into the mountainside, the adit was served by a railway, which brought workers and equipment in and out of the mine, transported the mined ore to the refinement building and connected with the gravel pit nearby.\(^{12}\)

The 4100 portal is plugged about 1,500 feet from the entrance gate, with the Acid rock drainage (ARD) entering a pipe that runs below the floor of the tunnel. The discharge flows through this submerged pipeline to an outfall 40 m below the surface of Howe Sound.

---


Copper Can Plant

The ARD issues at the mine are also not news. Throughout the life of the mine the ARD problem was not only well known, it was an integral part of the mining operation. Drainage from the mine was so acidic and so laden with copper that it was run through two can plants to recover extra copper. These plants were simply concrete trenches filled with shredded tin cans. As the copper-laden mine drainage ran through the trenches, it replaced the iron in the old cans. In the 1930s, copper recovery from these can plants reached a high of over 450,000 kg per year.
Furry Creek

The 4100, 2200 and 2200 portals are not the only portals in the area. There is a portal at Furry Creek, located on the south side of Mineral Ridge, but their discharge rate and metal concentrations are not nearly as high as the 2200 and 4100 Level Portal discharges. The portal at Furry Creek (also known as Beta Portal) is located near the Furry Creek Development and ARD levels were not considered high enough to prevent the selling of the land for redevelopment.

Assessment of ARD in Britannia Watershed

Since the mine's closure, most of the surface drainage has been diverted into the underground mine workings. Drainage now enters these workings via open pits and gloryholes at the 4150 level. This drainage is routed through the underground workings and discharges at the 4150 Level portal just above the town site. This was done in order to minimize ARD flow into the drainage basin. This does not stop the ARD as water continues to oxidise with exposed pyrite rock in the open pits and in the underground workings of the mine.

Flow from the 4100 level travels down to an inlet at the 4100 level where it enters and outflow pipe at the 4150 level, which runs into Howe Sound and releases the ARD laden water at a depth of 40 meters. In times of high flow rates or when copper levels exceed 15mg/l, the water is supposed to be treated via a cementation plant, however the plant is no longer in operation.

At the 2200 level, ARD laden flows out of the 2200 level portal and into Jane Creek during large rain events. This lowers pH and increases metal concentrations in Britannia Creek.

---

The abundance and diversity of aquatic organisms near Britannia Creek, one of the outflows from the site, are low compared to other areas in Howe sound. The lower reaches of Britannia Creek could be potential habitat for salmon and trout, but these areas are devoid of aquatic life. Studies have shown that the mine effluent is harmful to mussels, brine shrimp and salmon; copper concentrations in Britannia Bay surface waters are well in excess of the toxic levels for most marine organisms. Surface water from Britannia creek is highly toxic to young salmon. When Chinook salmon smolts were held in cages near Britannia creek, they all died in less than 48 hours.

Preventing ARD generation is impossible given the vast quantities of exposed pyrite. This necessitates some sort of mechanism to treat the runoff before it comes in contact with aquatic life. Over the past couple of decades, a number of studies have been conducted to look into treatment options for the Britannia site. The most likely option is a lime-based chemical treatment plant with a landfill for the by-product sludge.

Open Pits

The gloryholes at the base of Mt Sheer funnel massive amounts of rain and meltwater through the mine. The water that is trapped in the gloryholes travels more than 6 km laterally and 3km horizontally through the workings, provide extensive contact with pyritic material. this means that Britannia has about the worst possible conditions for the production of ARD. Much discussion has centred on the feasibility of diverting flow from the gloryholes and into the tributaries that flow into Britannia Creek. This could potentially reduce the amount of pyritic (i.e. acid-forming) material that rainwater comes into contact with, thereby reducing the amount of dissolved metals and net acidity of the water.

However, this solution has significant implementation problems. The steep slope of the site could prevent the design of a system that would divert the water and capping the gloryholes would be prohibitively expensive, as the entire open pit would have to be lined and filled in. This solution would also have to be strong enough to withstand the accumulated weight of water that would fill the basin during large rain events.

4100 Level

With mine closure in 1974, all the portals were blocked off and all discharge routed to the 4150 level portal where it bypasses the creek and enters Howe Sound via a pipe whose outflow is located 40m below sea-level. Although this has improved the creeks and tributaries, ARD now flows directly into Howe Sound. Because the fresh water of Britannia Creek and the outfall pipe are of a lower density than the saline waters of Howe Sound these flows are drawn to the surface of Howe Sound. The pH of both Britannia Creek and the 4100 Level discharge to the outfall are lower than the pH of the Sound, resulting in some neutralisation of the flows and precipitation of copper hydroxides. Precipitates within flows are often visible as plumes.

All the runoff from the open pit drains into the underground workings, some of which emerges out of the 2200 Level Portal, while the majority continues westward and downward through the extensive tunnel network to the 4100 Level portal (77). At the 4100 Level it reaches a bulkhead 100 metres from the portal entrance. At this point the water is funnelled into 3 pipes (4", 6" and 10"). Varying the flow of the pipes can control the flow of water.19

The system was originally designed to take the water and run it through a series of splitter boxes, pipes, channels, launders and settling ponds and eventually into Britannia Creek and later, into an outflow pipe in Howe Sound 40 meters below sea-level. The system has been in disrepair since 1992, however, so water now flows unimpeded through the bulkhead and is put

19 Sierra Legal Defence Fund. May 1998.
into an underground pipe system and carried directly to the outflow pipe. The launders that were once lined with tin cans to reduce copper concentrations during peak flow event are no longer in use. The water that flows down them today is simply run-off, not mine water.

The mineral elements Al, Ca, Fe, Mg, and Si are all major elements in ARD. The presence of these mineral elements indicates that calcite, dolomite and aluminosilicates have all been weathered hastening the onset of ARD. The major ore mineral elements Cu, Fe and Zn are major elements in ARD also. ARD from the 4100 level portal typically contains:  
- 12 to 28 mg/L of copper and zinc
- 0.1 mg/L cadmium
- 30 mg/L of iron and aluminum
- 1200 to 1800 mg/L Sulphate
- Redox is typically +300 to +550 mV
- pH of 3 to 4.

**2200 Level**

Drainage at the 2200 level is a lower and more variable flow than the 4100 level portal, with 0 to 10,000,000 litres per day passing through depending on the seasonal variations in precipitation and snowfall. This drainage has been known to contain contaminants in the following concentrations:
- 120 mg/L of copper
- 50 mg/L zinc
- 0.4 mg/L cadmium
- 60 mg/L of iron
- 74 mg/L of aluminum

---

- Sulphate levels ranging from 200 to 2000 mg/L with a pH of 2 to 4

However, according to Chris Mills, a UBC PEng who has written extensively on the level of contamination at Britannia Creek,

"the 2200 drainage is of particular concern because it drains directly into a freshwater creek (Jane Creek) which in turn feeds Britannia Creek, raising the copper level of both to levels toxic to fish. (4100 drainage exits directly into the basin of Howe Sound, bypassing local creeks and streams)."

*Figure 7: Jane's at 2200 Level*

![Image](image1.jpg)


*Figure 8: ARD at 2200 Level*

![Image](image2.jpg)

Attempts were made to divert the 2200 Level flow inside the mine to lower levels, away from the portal, but these measures appear to be currently ineffective. Even though the copper (40 to 100 mg/l) and other metal concentrations in the 2200 Level portal are lower than have historically been reported, they still contribute significantly to the heavy metal concentrations in Britannia Creek.23

Groundwater Contamination at Britannia Beach

Recently Golder and associates undertook a study of groundwater contamination at Britannia Beach. Nearly a century of industrial activity has had a significant impact on the soil quality of the area. This represents a significant problem environmental problem apart from acid rock drainage.

The South Area Foreshore (the area surrounding the concentrator) has particularly high levels of contaminants, indicating that it is likely materials and refuse from the cementation process that has contributed to groundwater contamination.

Figure 10: Britannia Creek Ground Water Analysis

Ground Water Analysis

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>South Area Foreshore (MW-01,02,04)</th>
<th>North Area Foreshore (MW-05,06,07)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow</td>
<td>l/s</td>
<td>4.6</td>
<td>24.3</td>
</tr>
<tr>
<td>Flow</td>
<td>(m$^3$/day)$^1$</td>
<td>400</td>
<td>2100</td>
</tr>
<tr>
<td>Cu</td>
<td>mg/l</td>
<td>15.1</td>
<td>1.1</td>
</tr>
<tr>
<td>Zn</td>
<td>mg/l</td>
<td>14.7</td>
<td>1.2</td>
</tr>
<tr>
<td>Ca</td>
<td>mg/l</td>
<td>0.06</td>
<td>0.01</td>
</tr>
<tr>
<td>Cu loading</td>
<td>kg/day</td>
<td>6 to 88</td>
<td>2 to 5</td>
</tr>
<tr>
<td>Zn Loading</td>
<td>kg/day</td>
<td>6 to 85</td>
<td>3 to 5</td>
</tr>
<tr>
<td>Ca loading</td>
<td>kg/day</td>
<td>0.02 to 0.035</td>
<td>0.02 to 0.03</td>
</tr>
</tbody>
</table>

Conventional Remediation Options

The province is set to announce that an agreement has been reached between the
province and federal government, Price Watterhouse Coopers, the citizens of Britannia
Beach and the Sunshine Coast Regional District to implement a lime-based treatment
facility. This is welcome news to the community as well as landowners and developers
who have a significant interest in redeveloping the area. It is also good news for the
overall health of Howe Sound. Hopefully, this will signal an important first step in the
effort to clean up the pollution problems that plague the Sound.

However, there are significant problems associated with this technology.

First, it is extremely costly to build a lime-based treatment plant. According to the
Ministry of Environment, Lands and Parks, it will cost an estimated $12 million to build
and $1 million to maintain. Because the timeline for the treatment of ARD is measured
in the thousands of years, this treatment option is extremely costly, particularly over the
long term.

Second, a by-product of lime treatment plants is large amounts of sludge production. It
is estimated that for every 1 litre of water cleaned by a lime treatment plant, 1.4 litres of
sludge is produced. The removal of the sludge is a large component of the cost
estimate. Aside from being costly sludge removal requires a disposal site and constant
trucking of the sludge between the facility and the disposal site. It has been
recommended in the past that a landfill be built at the 2200 level to accommodate the
sludge production.

---

Another problem with conventional treatment is that although water will enter Howe Sound at drinking water quality, ever expanding amounts of toxic sludge will accumulate in perpetuity at the top of the 2200 level. This scheme essentially assures that the area will never be truly remediated. As a result the treatment facility will also have to run permanently – at a cost of $1,000,000 per year. It is interesting to point-out that there are nearly 40 mines either in operation or decommissioned in BC. Even a small percentage of these requiring similar treatment systems would represent a substantial permanent cost to the province. Other concerns surrounding the conventional treatment/landfill option include the noise and emission pollution caused by dozens of large trucks travelling between the treatment facility and the landfill. The accumulation of untreated trace materials in the sludge end-product as well as what happens when the landfill inevitably becomes full and the environmental impact of an accident or rupture in the liner of the landfill.
Limitations of a Passive System
The goal of this thesis is to develop a concept for a system that could improve water quality using passive Remediation technologies. It should be acknowledged at the outset that Britannia Beach is one of the most difficult of all environments for passive Remediation, for a variety of reasons.

Had rock mines containing Pyritic Copper deposits have not as widely studied for the application of passive Remediation because most of the research to date has centred in the Eastern United States (particularly Pennsylvania) where the majority of mines are open pit coal mines.

Also, the site constraints, particularly regarding a lack of suitable terrain (steep slope, shallow delta) and high concentrations of dissolved metals such as Aluminum and Cadmium also present a significant obstacle in passive Remediation.

Perhaps the greatest problem concerns the very high flow rates due to the large volume of meltwater and run-off on the site.

For these reasons, it is acknowledged that a passive Remediation concept is unlikely the best short-term option for Britannia Beach. This is a very young technology with many more hurdles to be overcome before it can be applied to Britannia Beach – if ever. The massive scale of the problem, combined with many particular site constraints may make such an option unworkable or prohibitively costly.
However, given the multiple problems and massive large-scale problems associated with most conventional technologies, it is worthwhile examining alternatives. Although a conventional treatment facility will be required in the short term, it is important to begin to look at passive technologies and how they can be integrated into a hybrid system that incorporate both passive and conventional technologies. The long-term goal will ultimately be developing a system that can do more than just manage the pollution problem over the long-term, but actively treat and ultimately reduce the Acid rock drainage in a way that does not have all of the negative consequences of conventional treatment technologies.
Landscape Benefits of Passive Remediation

Even if passive Remediation technology is never capable of dealing with the problem of ARD at Britannia, there are many reasons why a conventional system would be enhanced by the presence of such a system. Although not a natural system in itself, a passive system incorporates itself into the natural environment. A constructed wetland is not a purely natural element, but it certainly appears to be. This has obvious aesthetic benefits over a conventional treatment system, which usually takes the form of a warehouse structure on concrete surrounded by a chain-link fence. A passive system can be easily incorporated into the landscape as part of an open space system that can provide opportunities for education, recreation and heritage interpretation. For these reasons a passive system would be a perfect element for Britannia Beach given the presence of the mining museum and the its recreation potential.

The landscape of Britannia Beach is particularly eroded. The community has suffered the steady erosion of its tax base as its population has declined and also suffers from being an unincorporated community, essentially owned by Price Waterhouse Cooper and the BC Museum of Mining. Because Britannia Beach is not an official municipal area its infrastructure and services are lacking and many of the buildings are in disrepair. Although the area has a spectacular setting and an equally inspiring heritage and built environment, everything man-made is in decay. No money is being invested in beautification or public environment. As a result, the area is a hodgepodge of chain link fences, crumbling buildings and asphalt. Though classified by the federal government
as a National Historic Site, the area receives no funding from that level of government and only a small grant from the province. 25

Aesthetics are crucial not only for the community but also in the larger context of the region. Located right on the Sea to Sky Highway, that links Vancouver with the world class Whistler/Blackcomb Ski Resort, the area is passed by a massive number of tourists. In general, the highway is an inspiring scenic drive with an abundance of tourist destinations.

The aesthetic and pollution problems at Britannia Beach not only create a competitive disadvantage relative to the other more scenic attractions along the sea to sky highway, it detracts from the overall scenic quality of the corridor. These two problems associated with the mine have the potential to negatively impact upon tourism in general within the area and perhaps upon the Vancouver/Whistler 2010 Olympic bid.

25 Interview with Kirsten Clauson, Curator BC Museum of Mining. March 16th, 2001
Remediation Concept

Many people assume that passive Remediation is not applicable at Britannia Beach. They say that the flow rates and dissolved metal concentrations are so high that a systems far too large would be required. Given the present drainage pattern of meltwater through the mine itself, this is likely true. Given the problems associated with conventional Remediation and the ancillary benefits of passive technologies, it is a worthwhile endeavour to test the claim that passive Remediation could not be applied to Britannia Beach.

This thesis project will attempt to show that although land constraints are significant, metal concentrations and flow rates are very high, and pH levels very low, it is not inconceivable that a passive or hybrid passive/conventional scheme could be applied. It is important to stress that this is only at a conceptual level. The modelling that has been done would need to be replicated on a much greater level of detail. An in-depth site analysis, to look at issues like grading, surficial geology, removal of problematic metals, such as Aluminum would all need to be undertaken.
The Scheme

In attempting to determine how a passive system could conceptually be applied to the watershed, a few schemes were investigated. The first involved a Remediation system at the base of the town-site. This would have been preferable as it would have kept the entire system in a more manageable area. However, it was immediately evident that the lack of available land would be a problem. A brief look at the modelling data showed that given the flow rates and level of contamination the network of wetlands required for such a project would be at least 5 kilometres wide assuming a 20m wetland width.

The next option was to divert drainage from the gloryholes and back into the watershed. Plugging the gloryholes and building a channel to take meltwater down to the flatter topography of Jane's Creek, where the water could then be treated, would do this. The problem with this scheme was the grade of the slope where the gloryholes are located and the difficulty and cost of building and maintaining a channel system that would be in perpetual danger of falling due to earth movement.

The third option also involved redirecting flow to the Jane's Creek Flats Area. During heavy rain events, water frequently overflows the mine-workings and flow spills out an adit at Jane's Creek. It is this seasonal overflow that accounts for the high levels of ARD in Jane's Creek. In this scheme, mine water would still enter the gloryholes on Mount Sheer, but instead of running the 6km of run and 1km rise to Britannia Beach, flow would be re-directed through the Jane's Creek portal. This proposal would use the existing mine architecture to carry the run-off to the Jane's Creek Area. This was the proposal that seemed to the most viable.
In order to determine if this scheme would be viable a significant amount of research would have to be undertaken. First, the chemistry of the contamination would need to be analysed and a model developed to determine the amount of area required to accommodate a passive system. Second, an in-depth study of the feasibility of the architecture of the mine workings would also need to be undertaken to determine if the mine water could be diverted through to the 2200 level (Jane’s Creek). And, third, a GIS analysis would need to be undertaken to determine if enough land was available at a relatively gentle slope (preferably under 5%) to accommodate the system.

Of these three requirements, only enough information was available to tackle the first requirement – chemistry and sizing. As for the second research problem relating to the mine architecture, plans of the mine workings as well as a detailed analysis would be required. With regards to the third problem, significant fieldwork as well as topographical analysis using aerial photography and GIS would need to be made available in order to understand land availability.
System Design

Analysis of Chemistry

In order to develop an effective passive system, it is first necessary to look at the type of contaminants found at Britannia Beach.

Figure 11: Site Contaminants and Flow Rate

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Min</th>
<th>Max</th>
<th>Avg.</th>
<th>Removal Rate (g/m²/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow</td>
<td>l/s</td>
<td>42</td>
<td>160</td>
<td>101</td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>su</td>
<td>3.2</td>
<td>4.5</td>
<td>3.85</td>
<td></td>
</tr>
<tr>
<td>Cu</td>
<td>mg/l</td>
<td>14</td>
<td>31</td>
<td>22.5</td>
<td></td>
</tr>
<tr>
<td>Zn</td>
<td>mg/l</td>
<td>22</td>
<td>27</td>
<td>24.5</td>
<td></td>
</tr>
<tr>
<td>Al</td>
<td>mg/l</td>
<td>20</td>
<td>32</td>
<td>26</td>
<td></td>
</tr>
<tr>
<td>Ca</td>
<td>mg/l</td>
<td>122</td>
<td>465</td>
<td>293.5</td>
<td></td>
</tr>
<tr>
<td>Fe</td>
<td>mg/l</td>
<td>2</td>
<td>34</td>
<td>18</td>
<td>20</td>
</tr>
<tr>
<td>Mg</td>
<td>mg/l</td>
<td>73</td>
<td>96</td>
<td>84.5</td>
<td></td>
</tr>
<tr>
<td>Si</td>
<td>mg/l</td>
<td>12</td>
<td>17</td>
<td>14.5</td>
<td></td>
</tr>
<tr>
<td>SO₄</td>
<td>mg/l</td>
<td>1140</td>
<td>1900</td>
<td>1520</td>
<td>12</td>
</tr>
<tr>
<td>Acidity</td>
<td>mg CaCO₃ eq./L</td>
<td>305</td>
<td>558</td>
<td>431</td>
<td></td>
</tr>
</tbody>
</table>


The measurements found in this table are aggregate numbers taken at a variety of locations and times. Most of these tests took place near at the 4150 level, where water has passed through the entire length of the mine. Obviously the dissolved metal content is very high. The following is a brief summary of the contents.
**Aluminum**
High concentrations of Aluminum is a significant problem for many wetlands that inhibits the operations of other passive Remediation technologies such as anoxic limestone drains. Adequate removal rates for aluminum were not available, but it is assumed that some removal would occur with the reduction of sulphates. Although the presence of aluminium is a problem, concentrations are not high enough to threaten a large passive system.

**Zinc**
High levels of Zinc are also present (22-27 mg/l). It is also assumed that some quantities of Zn will be absorbed by the wetland. As is the case with aluminum, Zn requires a very high pH (10-11) for it to become soluble as Zinc hydroxide. The presence of Zinc poses less of a threat to wetland design.

**Iron**
Generally, dissolved iron does not exist in an aerobic environment. Therefore, even small quantities of Fe are indicative of significant water pollution problems. However, Fe settles out quickly once the pH is increased. The puddles of orange-coloured water are telltale signs of iron settlement and are frequently found around the Britannia Creek watershed. Variations in pH accounts for the wide range in dissolved Fe content in the ARD analysis.

**Calcium and magnesium**
Calcium and magnesium are weathered carbonaceous material that play an important role in keeping acidity low and the presence of sulphates at or below 2000mg/l. Unfortunately, the geology of the large amounts of seasonal rainfall combined with the geology of the area ensure that a limited amount most of these materials are quickly
weathered away once exposed, limiting their ability to off-set ARD and ensuring higher acidity and SO₄ rates.

Because of the high amounts of SO₄, a sulphate reducing treatment system will be required. This means that an anaerobic wetland would be required. An anaerobic wetland forcing microbes to consume the sulphates. Sulphates are consumed in such a system because a anaerobic systems are O and N deficient, forcing microbes to consume materials such as sulphates instead of O and N. Anaerobic systems therefore have higher redox rates and can consume contaminants such as sulphates more efficiently. Such a system would incorporate a series of detention basins, limestone channels, anaerobic wetlands and settling ponds. Water would be piped into a detention pond where limestone is added, then slowly forced through the substrate of an anaerobic wetland (essentially a reed-bed - usually *typhus latifolia*).

**Wetland Size**

Sizing appropriate wetlands needs to take into account both chemical and hydrologic factors. In order to determine the type and size of wetland system required, it was first necessary to analyse contamination levels. The first step in is to determine which metals the wetland will be sized for. Generally, wetland size is based on the contaminant with the largest load (measured in mg/second). In the case of Britannia, the high concentration of sulphates (1520 – 1900 mg/l) that determine amount of wetland area required.

Typically, the more time water can spend in a wetland, the more efficiently the wetland will treat the wastewater. As retention time increases, so does the precipitation of
soluble materials. Ideally, such a system would be sized for 3 days worth of retention. However, where size is a consideration or other treatment options are available (such as conventional or hybrid treatment systems) shorter residence times can be considered (1 day minimum).

Sulphate loads are determined by multiplying available flow and concentration data. Average flow rate is 101 l/s and average loading is 1,520 mg/l for a total load of 153,520 mg/s (153 g/s). This translates 8,726,400 litres per second and a total of 1,330,000 grams per day.

Finally, the surface area can be calculated by dividing the total load by the removal rate of sulphates in g/m$^3$/day. The removal rate for SO$_4$ is 12 g/m$^3$/day. The total area required for adequate sulphate removal is 1.11E+06 m$^2$. This is a massive number. A 50-meter wide wetland would need to be more than 11 km long for Remediation based on only one day's worth of retention. On the surface, this would lead one to the belief that there would not be nearly enough land available for Remediation.
Figure 12: Wetland Sizing

Sizing Treatment Pond for SO$_4$ Removal

<table>
<thead>
<tr>
<th></th>
<th>Avg. Values</th>
<th>Min Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO$_4$ load</td>
<td>153520 mg/s</td>
<td>47880 mg/s</td>
</tr>
<tr>
<td></td>
<td>153.52 g/s</td>
<td>47.88 g/s</td>
</tr>
<tr>
<td>Total SO$_4$ load</td>
<td>1.33E+07 g/day</td>
<td>4.14E+06 g/day</td>
</tr>
<tr>
<td>Retention time</td>
<td>1 Days</td>
<td>1 Days</td>
</tr>
<tr>
<td>Total SO$_4$ load</td>
<td>1.33E+07 g/day</td>
<td>4.14E+06</td>
</tr>
<tr>
<td>SO$_4$ removal rate</td>
<td>12 g/m$^2$/day</td>
<td>20 g/m$^2$/day</td>
</tr>
<tr>
<td>Surface area req'd</td>
<td>1.11E+06 m$^2$</td>
<td>2.07E+05 m$^2$</td>
</tr>
<tr>
<td>Assumed depth</td>
<td>2.0 M</td>
<td>2.0 M</td>
</tr>
<tr>
<td>Assumed width</td>
<td>50 M</td>
<td>20 M</td>
</tr>
<tr>
<td>Length</td>
<td>11053 M</td>
<td>5171 M</td>
</tr>
</tbody>
</table>

Source: By Author. March, 2001

Initially, it would be assumed that the wetland system would be sized only to accommodate minimum flows, but could be expanded in the future. Because wetland systems are new technology, removal efficiencies are steadily being improved. It is hoped that eventually either the system could be gradually expanded (if the land base allows) or the removal rates improved to the point where the even maximum flows could be handled with an entirely passive system.
Physical Wetland Design Considerations

**General Considerations:**
Once the size and type of wetland has been determined, it is necessary to look at the specific design perimeters for each wetland cell. The following general siting factors need to be considered in the location of a constructed wetland system:

- Land cost.
- Topography.
- Slope.
- Soil Type.
- Prevailing Winds.
- Right of Way/Land Use Considerations.
- At least 1 km from development (recommended due to smell and bugs).

All constructed wetlands have a basic layout:

- A detention pond for water storage during high and low water periods.
- An adjustable inlet system that controls flow in to the wetland.
- A diversion system that allows flow to by-pass the wetland during flood events.
- A filter system to prevent garbage and large debris from passing through the system.
- An adjustable outflow system that controls flow out of the wetland.

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26 Wood, A. "Constructed Wetlands for Wastewater Engineering and Design Considerations" in Cooper, A. *Constructed Wetlands and Water Pollution Control*. International Association of Water Pollution Control. 1990.
It is also important not to use heavy vehicles on the wetland subsoil during the construction process. Temperature variations between 0 and 25 degrees seem to have little impact on effluent quality as plant cover on surface has an insulating effect on the system.

The following site considerations also need to be considered:

- One to eight percent slope (on steeper ground, design to fit along contours).
- Plastic liner (.05mm)
- Root penetration zone (1 – 2 m)
- Screens to trap sediment (changed regularly)
- Zone 1m wide along influent area filled with stones (.6 – 1mm dia) to prevent accumulation of organic matter.
- Water flow should be introduced evenly along the entire influent area.
- Embankments 500mm above substrata to accommodate sludge accumulation and storm events (slope between 1:2 and 1:3)
- Fringes should be filled with soil-cement, grassing, stone pitching...

*Form:*
Constructed wetlands are not natural in appearance. They do not have coves or islands, but regularly shaped channels of uniform dimensions. Generally, they are rectangular in shape and are longer than their width by a factor of ten to one. This shape is most efficient for uniform water flow through the system. Irregularly shaped wetlands or wetlands with too much width become prone to developing pockets where flow is impeded. To function effectively and provide the greatest Remediation benefit it is crucial that wetlands draw water through their entire surface area at a uniform rate.
**Substrate:**
The substrate of anaerobic wetlands is crucial because the water is treated there instead of above the surface as with aerobic wetlands. The substrate must provide a stable surface area for microbial attachment, an environment that encourages vigorous plant growth and the opportunity for lots of chemical and physical reaction with water as it is drawn through. Obviously, the substrate material must be permeable, so gravel, river sand and waste ash are ideal substrate bases, but clay loam, silty clay and silty clay loam are also acceptable. Hydraulic conductivity must be between 10^-3 m/s and 10^-5 m/s. Initially, permeability will be much lower as the vegetation needs time to grow, establish its rhizosphere.

**Remediation:**
There are three species of plants that are best suited for wastewater Remediation. Care must be taken to ensure that the desired plants take hold and to prevent invasives and other undesirables from taking hold. Plants take only 6 months to develop but 3-4 seasons to establish a rhizosphere. Cutting, seeding and even fertilising and pest control will be necessary. The three types of plants are:

- *Phragmites australis* (Common Reed) has a deep root bed (1.5m deep) and forms a large rhizosphere.
- *Typha latifolia* (Cattail) does not have as deep a root system but provides the best environment for sulphate sedimentation.

**Maintenance:**
There has always existed a myth that passive Remediation is superior because it lasts forever, without any maintenance. As previously mentioned, constructed wetlands are not natural and do require periodic maintenance. However, the amount of maintenance
required is definitely less than a conventional system, particularly when transportation and disposal of sludge is taken into consideration. Regular harvesting, cutting and selective seeding is necessary to control species development, particularly when first established. Periodic herbicidal treatment may also be necessary to control weeds. Wetlands also have a finite life span in that sludge will accumulate. However, proper management of the plant community and occasional dredging will maximise the operating life span and removal efficiency of a wetland. Dredging will be required to remove sludge and straw accumulation (15 – 25mm per year).

The museum once had an outdoor path through which traveled from the parking lot North of the Dinner 99er to the museum building next to the concentrator, but this part of the museum was discontinued due a lack of funding. The path was an elevated wooden structure through the trees with occasional views over Howe Sound and it showcased a variety of mining equipment.

An enhanced open space plan would re-open this trail and make it part of a larger museum trail that would pass through the refurbished concentrator and allow visitors to appreciate the impressive concentrator, the spectacular view from above. The trail would also connect with the trail through the wetlands system, ultimately forming a larger loop that would connect the entire community.
Wetland System

The proposed wetland scheme will resemble a kind of pipeline that will keep ARD-laden water separate from the Jane and Britannia Creek and for the most part, out of the pyritic environment of the mine itself, hopefully reducing the levels of contaminants in the water supply and increasing the ability of a wetland system to remedial. The system will start at the 2200 level, near the confluence point of Jane and Britannia Creeks. Because it is an anaerobic system, it will work its way down the watershed as a series of detention and settlement basins, and anaerobic wetland strips all connecting by an extensive pipeline network, which keeps water flowing in an anaerobic environment.

The wetlands will be a significant component of the overall open space system. It will provide hiking opportunities through not landscape that is both spectacular and historic. The wetland system will require that a road be maintained for maintenance purposes. The presence of this flat, stable surface will allow a variety of users who do are normally able to experience rugged natural environments such as elderly and disabled to use do so.

The wetland system will also be a crucial interpretative and educational element. Visitors will be able to access a variety of information panels designed to explain the cause and significance of the ARD problem and how the role that the open space system plays in remediating it.

Fittingly, the system will terminate at the foot of the concentrator building – symbolic source of the area’s polluted history – as a park that doubles as an doubles as a large retention pond that separates the heritage main street of the community from the mining
museum. This powerful space improves aesthetics and bringing interpretative possibilities to the community, while demarcating the museum space. The museum would contribute to the quality of the open space by incorporating it into its museum tour. The museum currently provides an excellent tour of the facilities which begins in the central yard, takes visitors on a train through the mine and terminates inside the spectacular interior of the concentrator building, but there are no current exhibitions of the mine system. An enhanced tour would follow an expanded path to bring visitors through the rejuvenated landscape, past the treatment plant and wetlands both at the base of the community and at the plateau the top of the concentrator building.

Figure 13: Wetland System Overview

Source: By Author
Conclusion

This essay has attempted to examine the different options for passive Remediation of Acid rock drainage at Britannia Beach. The results of this research indicate that passive technology may be a viable application in certain specific areas. It is not a panacea, however and is unlikely to be able to effectively deal with the high levels of flow, acidity and dissolved metals that occur at Britannia Beach. It is likely that a conventional treatment technology such as a lime-based facility will be necessary.

However, there are still opportunities for passive Remediation, perhaps as part of a hybrid system that incorporates conventional treatment. Integrating passive technologies has many positive spin-offs:

- Improved aesthetics of a degraded environment that still has significant tourism and recreation potential given its location.
- Improved research of ARD at Copper Mines.
- Interpretative and educational potential for visitors.
- Opportunities for art and interpretation in the landscape.

The application of passive Remediation provides benefits that go beyond the science of Remediation. They are important symbols in the landscape of our ability to heal the places that resource extraction has degraded.
Bibliography and Personal Communications


