ABSTRACT

For the purpose of treatment plant design, the hydrology of the Britannia Mine area was investigated. Precipitation data were collected from four precipitation gauges near the Britannia Mine and flow data were collected from the two major outflow points of the mine. The data were analyzed to determine the relationship between precipitation and flow rate. In addition, return period analysis was performed to determine the treatment plant design flow rate. The possibility of storing water inside the mine to attenuate the peak flows and decrease the treatment plant design flow rate was examined.

The precipitation/outflow relationship indicated that a complex routing mechanism exists in the mine workings. Groundwater appeared to contribute a significant portion of the total flow rate. Flow peaks were delayed for up to one week before exiting the mine. Forty-two years of record were available to generate return period graphs for mine outflows and precipitation events. There was a strong relationship between the annual precipitation volumes and the annual mine outflow volumes over the period of record. Calculations indicated that the treatment plant design flow rate may be reduced to nearly half of the average annual maximum flow if the mine workings are used as a storage reservoir.

INTRODUCTION

In 1902, mining operations began at Britannia Beach. Since then there has been acid rock drainage (ARD) from the Britannia Mine workings at an average rate of 13,000 cubic meters per day. The outflow contains elevated levels of copper and zinc, as well as other metals and its pH is approximately 3. The mine's outflow poses a risk to its receiving waters, Britannia Creek and Howe Sound.

In 1991, Stephen, Robertson, and Kirsten Inc. (SRK) prepared a report for the Ministry of Energy, Mines and Petroleum Resources which evaluated the acid rock drainage at Britannia and identified remediation options. Price, Schwab, and Hutt, (1995) included findings from reconnaissance level surveys of the terrestrial disturbance and water quality impacts and summarized the SRK findings. Currently, a water treatment plant which will neutralize the pH and reduce the metals concentrations in the mine's outflow is being designed. For a suitable design, the hydrology of the mine area needs to be determined.
BACKGROUND

Water enters the Britannia Mine by infiltration and through raises which emerge in open pits at the top of the ridge between Britannia Creek and Furry Creek. The majority of the drainage exits the mine through two portals, the 2200 and 4100 levels. The flow measurements at the 2200 level are made at a rectangular weir. At the 4100 level, the tunnel was plugged by a 6 meter thick wall of concrete pierced with three pipes (4", 6", and 10"). A valve was installed on each pipe to allow the flow rate to be regulated. The flow is measured downstream of the plug in two Parshall flumes. Partial blockage of the mine shafts and tunnels at numerous locations controls the flow rate as does the rectangular weir at the 2200 level and the pipe/valve system at the 4100 level. Jane Creek drains 50 ha near the open pits and is representative of the snowmelt and runoff characteristics of the area. Like the 2200 level outflow, flow in Jane Creek is measured by a rectangular weir.

Data for both precipitation and flows are incomplete with numerous gaps throughout the monitoring period. Precipitation data were collected at four stations:
- Squamish A CS (Squamish airport, Elevation: 59 m)
- Britannia Beach Furry Creek station (Elevation: 9 m)
- Cypress Bowl - West Vancouver CS (Hwy. #1, Elevation: 850 m)
- 2200 level station (Elevation: 640 m)

PRECIPITATION - FLOW RELATIONSHIPS

For the period October 24 to November 28, 1997, precipitation was recorded hourly at the Squamish, Cypress, and 2200 level stations. Figure 1 shows the relationship between flows and precipitation for this period. Jane Creek responds rapidly to precipitation events. A spike in Jane Creek flow follows each precipitation event recorded at the 2200 level station. The catchment area of Jane Creek was determined from a topographical map to be approximately 0.50 km². Multiplying this value by the average annual precipitation at the Furry Creek gauge (1960 mm) yields a total annual precipitation volume of 0.98x10⁶ m³. The total annual volume from measured flows in Jane Creek was 1.79(10⁶) m³, a value almost twice that of the calculated precipitation volume. This discrepancy can be attributed to both a precipitation gradient between the Furry Creek precipitation gauge and the Jane Creek basin and the fact that Jane Creek is fed by groundwater flow. The groundwater flow in Jane Creek is believed to be seepage from the mine workings as it contains elevated metals concentrations (Price, Schwab, and Hutt, 1995).
The 2200 level portal flow is not as responsive to precipitation events as the Jane Creek flow. The spikes in the 2200 level portal flow do correspond to precipitation events. However, the spikes are much smoother with smaller precipitation events being attenuated and therefore not causing a rise in flow. The flow out of the 2200 level portal appears to be routed through a form of reservoir. The mine workings and rectangular weir combine to cause this attenuation. Like Jane Creek, the 2200 level portal does not dry up and is also most likely fed by groundwater. Its base flow, however, is approximately half that of Jane Creek.

The 4100 level portal flow shows very little response to precipitation events. Individual precipitation events combine to increase the flow much more gradually. Detention in the upper levels of the mine and
behind the plug smoothes out the inflow peaks making a precipitation-flow relationship visually imperceptible.

For the 1996-97 period, precipitation, flows, and temperatures were recorded on a daily basis. Figure 2 shows that the relationships observed in Figure 1 hold for the most part, however, snowmelt and snow accumulation alters the flow response.

In Figure 2, the response of the 4100 level portal flow is more apparent. High intensity and long duration precipitation events cause large spikes in the flow as can be seen at the end of 1996 and beginning of 1997. Medium precipitation events cause the flow to increase, however, the peak flows trail the precipitation peaks by days. Smaller precipitation peaks alone do not cause spikes in the 4100 portal level flow. Complicated routing and storage mechanisms along with snow accumulation are responsible for these observations. All three flows exhibit a recession flow during the summer period, characteristic of snowmelt dominated flow with precipitation peaks appearing as short-lived spikes on the flow curve. The largest 4100 level portal flow in June 1996 is a result of the combination of snowmelt and rainfall events.
Before 1996, flows were only measured at the 2200 and 4100 level portals. Measurements were taken once a week from the time the 4100 level concrete plug was installed (1978) until 1993, with numerous gaps in the data. Valves on the three pipes that carry the flow through the plug were regulated throughout this period. For a particular year between 1978 and 1993, the same precipitation events would result in differing outflows from the 4100 level portal today than the flows recorded in that year. This is because the valves were not all open during those years as they are now. Nevertheless, Figure 3 shows the relationship between the precipitation at Squamish and 4100 level portal outflow for a typical four year period.

Figure 3. 4100 Outflow and Squamish Precipitation vs. Time - 1990 to 1993

Squamish precipitation was chosen because it was more complete than the other precipitation record available for this period (Cypress). The vertical line in Figure 3 indicates the point at which all three valves were opened. The 4100 outflow follows the same pattern for the entire sixteen year period. The flow peaks twice during the year, once in the fall and once in the late spring or early summer. The spring peaks are the highest as they are a combination of snowmelt and rain. The fall peaks vary from year to year.
year as a function of temperature and precipitation. Low temperatures cause snow accumulation and therefore a lower peak flow in the fall.

Semi-monthly flow measurements were taken at the 2200 level portal between 1930 and 1956. As the Britannia Mine was still being developed during this period, the 2200 level portal outflows may not be representative of the mine behavior today. It is still worthwhile to examine these flow records for general trends. For this period, only Furry Creek gauge records were available. The same patterns as were observed in the 4100 outflows can be seen in Figure 4. The peak flows occur in the late spring or early summer, often during periods of low precipitation. The second annual peak, most often lower than the spring peak, occurs in the fall.

Figure 4. 2200 Outflow and Furry Creek Precipitation vs. Time - 1952 to 1956

Because the route the water takes through the mine is unknown, it is difficult to measure the catchment area for either the 2200 or 4100 level portal flows from a topographical map. Instead, total annual flow volumes and total annual precipitation values were compared. The ratio of total annual 4100 flow volume to total annual precipitation at the Squamish gauge remained constant over 20 years. The ratio of total
annual 2200 flow volume to total annual precipitation at the Furry Creek gauge varied slightly between 1930 and 1956 due to mining activity.

**RETURN PERIOD ANALYSIS**

All available Furry Creek gauge precipitation data and all 2200 and 4100 level portal outflow data were compiled to develop return period plots. A Normal distribution was used for analysis of total or average values and a Gumbel distribution was used for maximum values. Both precipitation and flow data were divided into years starting at the beginning of September and ending at the end of August. This division is preferred over a calendar year division since summer flows are actually driven by melting snow which accumulated during the late fall and winter of the previous year. Average and maximum 2200 and 4100 level portal outflows were analyzed with respect to return period. Furry Creek gauge precipitation data was analyzed because it has the longest record and its location is nearest to the Britannia Mine catchment. The Furry Creek data can be multiplied by a factor to give estimates of Squamish or Cypress precipitation values. Total annual precipitation and 24-hour maximum precipitation was analyzed with respect to return period. The values of the flows and precipitation for a number of return periods are listed in Table 1.

Table 1. Flows and Precipitation Values for Various Return Periods

<table>
<thead>
<tr>
<th>Return Period</th>
<th>Mean</th>
<th>10 years</th>
<th>20 years</th>
<th>50 years</th>
<th>100 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual average 4100 flow (CMS)</td>
<td>0.136</td>
<td>0.160</td>
<td>0.166</td>
<td>0.174</td>
<td>0.179</td>
</tr>
<tr>
<td>Annual maximum 4100 flow (CMS)</td>
<td>0.326</td>
<td>0.413</td>
<td>0.451</td>
<td>0.499</td>
<td>0.536</td>
</tr>
<tr>
<td>Annual average 2200 flow (CMS)</td>
<td>0.0131</td>
<td>0.0190</td>
<td>0.0207</td>
<td>0.0226</td>
<td>0.0239</td>
</tr>
<tr>
<td>Annual maximum 2200 flow (CMS)</td>
<td>0.0273</td>
<td>0.0371</td>
<td>0.0413</td>
<td>0.0467</td>
<td>0.0508</td>
</tr>
<tr>
<td>Total annual Furry Cr. precipitation (mm)</td>
<td>2100</td>
<td>2480</td>
<td>2580</td>
<td>2700</td>
<td>2780</td>
</tr>
<tr>
<td>Annual 24 hour maximum Furry Cr. precipitation (mm)</td>
<td>74</td>
<td>97</td>
<td>107</td>
<td>120</td>
<td>129</td>
</tr>
</tbody>
</table>

**STORAGE CAPACITY**

The storage volume of the Britannia Mine between the 4100 level and the next level above with a tunnel that emerges, the 3250 level, is estimated at 200,000 cubic meters. This value was calculated by
measuring the length of tunnels and shafts: and multiplying it by a cross-sectional area of 10.5 square meters (the area of the 4100 tunnel at the plug). Plan views were not available for four small levels which appeared on the cross-sectional view of the mine and were therefore not taken into account. Also, any cavities in the mine where ore was removed were not accounted for. This additional volume may be slightly offset by the exaggerated cross-sectional area (10.5 m²) used in the calculation and by any material that may have slumped in from higher levels. The value of 200,000 cubic meters is believed to be very conservative. The maximum required storage, using the 10 year return flow design year and a treatment plant flow of 0.18 CMS (646 cubic metes per hour), will be 645,000 cubic meters. This value is over three times the calculated mine volume. Based on experience with mines of Britannia's type, this volume would not be unreasonable given the extensive excavated volume of the slopes (Simons, 1998). With the available storage capacity, the peak flows could be attenuated, allowing a much lower treatment plant design flow arid possibly a constant flow throughout the year. Storage would also allow the plant to shut down for maintenance or in case of emergency without having to spill untreated water.

**PRECIPITATION - FLOW MODELLING**

Attempts using simple snow budget and linear reservoir models failed to accurately describe the 4100 and 2200 level outflows. The UBC Watershed model (Quick, 1995) was applied with greater success. The model was developed to describe the behavior of streams in mountainous areas. Applying it to flow through a mine is justified because it has the ability to model groundwater flow and flow through a series of reservoirs. The main purpose of using the UBC Watershed model was to estimate the relative quantities of fast runoff and slow groundwater flow. It was also used because of its ability to model snow accumulation and melt using only precipitation and maximum and minimum temperature as input. Figure 5 shows an output of the model comparing the observed and calculated flow from the 4100 level portal.

**CONCLUSIONS**

The mine acts to attenuate the outflows from the 2200 and 4100 level portals. Inflows due to snowmelt and precipitation enter the mine at various rates: as fast speed runoff into shafts, as medium speed fracture flow, and as slow speed infiltration. Regional groundwater table elevations also contribute to both inflow (during high groundwater table periods) and outflow (during low groundwater table periods). The flow that enters the mine workings undergoes a complex form of routing as a result of the network of shafts and tunnels, small dams, concrete plug, and valves. A more complex model is needed to describe the routing characteristics of the mine workings.
In order to determine accurate mine storage capacity for a more cost-effective treatment plant design, the volume needs to be calculated by performing a pressure test. During this test the valves on the 4100 level portal pipes should be closed and the pressure recorded as the mine working flood. Assuming constant inflow for the duration of the test, mine volume could be calculated as a function of pressure and therefore as a function of water surface elevation behind the concrete plug.

Figure 5. Output of the UBC Watershed Model

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REFERENCES


