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Case Study of Non-Mining Prediction and Control of Acid Rock Drainage — The Vancouver Island Highway Project

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ABSTRACT

The Vancouver Island Highway Project (VIHP) was a $CAD 1.2 billion expenditure by the Province of British Columbia to improve travel safety and relieve traffic congestion between Victoria and Campbell River on Vancouver Island. In the section of highway between the Tsolum River and Oyster River, on the Inland Island Highway portion of the VIHP, over half of the rock to be cut and filled was found to be net acid generating. The Tsolum River has been impacted by metal leaching and acid rock drainage (ML/ARD) for decades from an upstream closed minesite.

Geochemical testwork indicated:

1. over half of the rock along this section of highway was potentially net acid generating based on a site-specific SNPR (=NP/SAP) criterion of 1.5;
2. some core samples were already acidic;
3. pyrite occurred in disseminated framboidal and gel forms;
4. the rate of acid generation was not high;
5. measured neutralisation potential (NP) provided some lag time for the onset of net acidity; and
6. non-carbonate neutralising minerals prevented low pH (<4.0) from appearing in the humidity cells.

These predictions led to ML/ARD controls involving:

1. realignment of the highway;
2. elevation control to minimise the volume of disturbed rock;
3. encapsulation of blasted-rock fills within the highway, surrounded by low-permeability till and covered with asphalt; and
4. diversion of water away from cut faces.

Internal pipes drained any water reaching the fills into external ditches and ponds, where the water could be monitored and, if necessary, treated. Water from the cuts was also captured in ditches and carried to monitored ponds.

Elevated aqueous sulfate concentrations in several ponds confirmed that sulfide minerals were oxidising, but the lack of both acidic pH and increasing trends in concentrations demonstrated that ML/ARD was controlled. Contingency plans for any pond that may become acidic include water treatment, which predictive testwork has shown would not require substantial amounts of limestone or lime.

INTRODUCTION

The 250-km-long Vancouver Island Highway Project (VIHP) was a $CAD 1.2 billion undertaking to improve travel safety and relieve traffic congestion between Victoria and Campbell River on Vancouver Island, British Columbia (Figure 1). The VIHP included 150 stream crossings, $CAD 10 million for environmental assessment and monitoring, and tens of millions of dollars on special mitigation and enhancement. The drainage courses and rivers on the east coast of Vancouver Island provide critical spawning habitat for the salmon fishery. As a result, stringent environmental conditions were imposed on the VIHP by the federal environmental authority, Fisheries and Oceans Canada, on any work that may adversely impact the fish habitat.

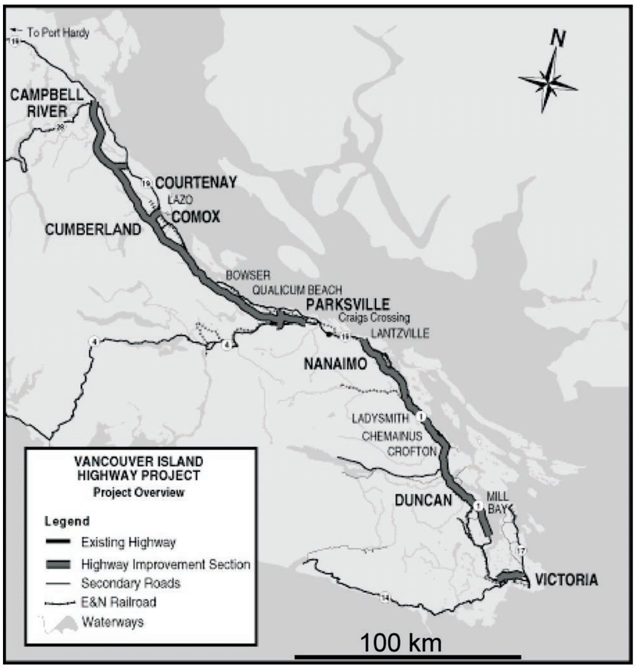

FIG 1 - Map of the Vancouver Island Highway Project (VIHP).

One of the VIHP crossings was the Tsolum River, located on the Inland Island Highway portion of the VIH (Figure 2). The salmon fishery on the Tsolum River was virtually eliminated decades ago as a consequence of metal leaching (ML) and acid rock drainage (ARD) from the closed Mt Washington minesite (Golder Associates Ltd, 1989; Galbraith, 1990; Morin and Hutt, 1997 and 2001). Since the mine closed, efforts by government and environmental organisations have considerably improved the Tsolum's water quality and the fish habitat.

The VIHP staff was acutely aware of the need to protect the Tsolum River and nearby drainage courses from degradation as a result of the new highway. Thus, a study of the section between the Tsolum River and Oyster River (Figure 2), where numerous rock cuts were required, was conducted to assess the ML/ARD potential and to recommend mitigation measures for the highway design. This study addressed both the highway 'cuts', where relatively intact bedrock was exposed along the sides of the highway, and the 'fills' where blasted rock from the cut areas was filled into depressions. This process of cutting and filling provided a relatively smooth grade to the highway.

The Government of British Columbia has issued a policy, guidelines, and a draft prediction manual for ML/ARD (Price and Errington, 1998; Price, 1998; Price *et al*, 1997). These recommend a series of complementary geochemical tests, sometimes called the 'Wheel' approach (www.mdag.com/case_studies/cs11-99.html; Morin and Hutt, 2001 and 1997), which were implemented for the prediction and control of ML/ARD around the Tsolum River portion of the VIHP.

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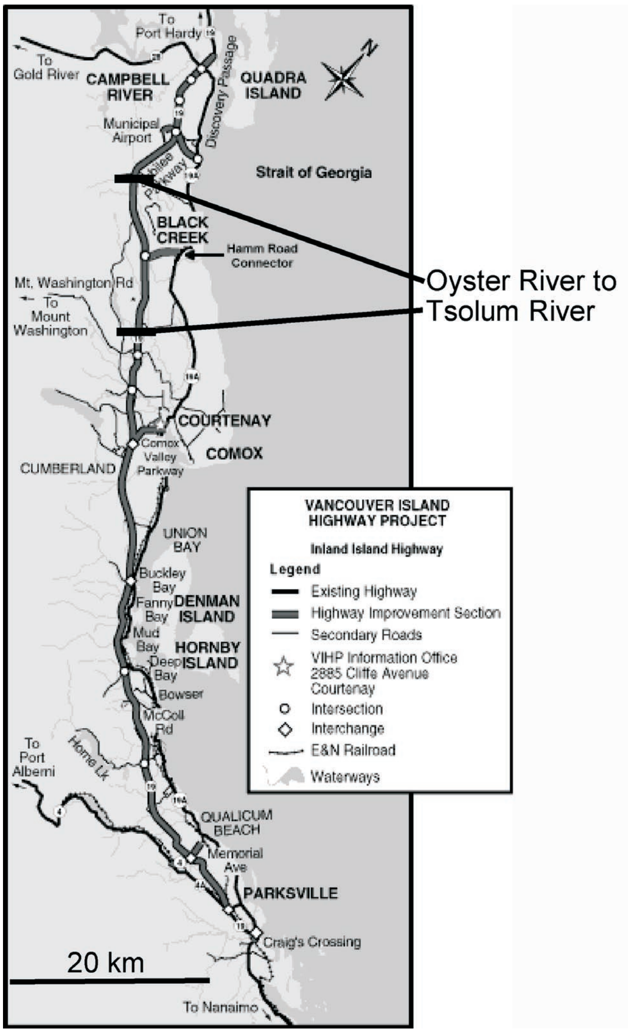

FIG 2 - Map of the Inland Island Highway Section of the VIHP; the Tsolum River to Oyster River Section is to the east (downstream) of the closed Mt Washington Minesite.

PREDICTION OF ML/ARD

The preliminary design for the crossing of the Tsolum River involved excavation of a high cut along the approach to the proposed bridge, and placement of the blasted rock fill on the river banks for the bridge abutments. Cores of the rock showed significant iron staining at shallow depths, leading to a suspicion of possible ARD. Twenty-five samples of these cores were then submitted for standard-Sobek expanded acid-base accounting (ABA) and total-metal contents (Morin and Hutt, 1998 and 1999). This showed that much of the measured total sulfur was acid-generating sulfide, which produced net acidity (acidic paste pH) in four of the 25 samples. Bulk neutralisation potential (NP) indicated that much of the measured neutralisation potential (NP) was carbonate-based, but there was insufficient NP to neutralise all acid potential. Therefore, 21 of the 25 samples were predicted to be net acid generating in the long term, and there were no major geochemical trends by lateral location or depth in the cores. Additional work indicated:

1. the rock was of sedimentary origin;
2. the rock was relatively porous to air and moisture; and
3. the sulfide occurred as disseminated framboidal and gel pyrite, which are among the most reactive forms of pyrite.

These conclusions from the first round of sampling highlighted the critical need to have ML/ARD controls in place before excavation of the rock began. Also, as a consequence of this initial assessment, the highway alignment was shifted laterally and vertically to eliminate the rock cut and fill at the bridge crossing.

These initial findings led to additional testwork to refine ML/ARD predictions and control plans, including more ABAs, laboratory-based testing using standard-Sobek humidity cells, and in-field monitoring. The ABA database grew to 79 rock samples, which showed:

1. most of the rock contained detectable sulfur as acid-generating pyrite and some of the samples were already acidic (Figure 3);
2. unavailable NP was as much as 10 kg $CaCO_3$ equivalent/t and thus had to be subtracted from measured NP (Figure 4); and
3. roughly 58 - 76 per cent of the rock would be net acid generating some day (Sulfide Net Potential Ratio <1.0 or <2.0 in Figure 5), depending on exact values of unavailable NP.

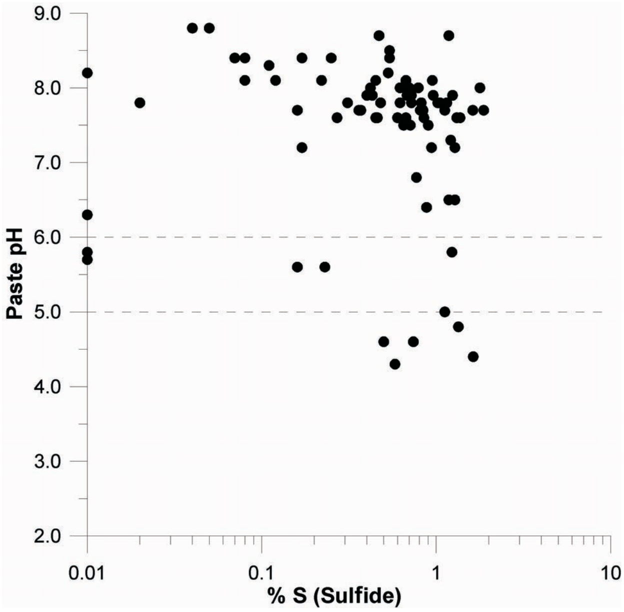

FIG 3 - Paste pH versus sulfide content from acid-base accounting (ABA) [acidic paste pH is typically considered to be less than pH 5 to 6, as marked by dashed lines].

The net-acid-generating rock was initially expected to generate ARD quickly and strongly, because of the very fine-grained form of the pyrite and because some samples were already acidic. However, the two standard-Sobek humidity cells showed that some initial expectations were incorrect (Figures 6 and 7). The pyrite was not as reactive as expected, and the acidic samples were apparently the result of decades or centuries of oxidation in the ground rather than from recent oxidation after coring. Comparisons of these rates of acid generation, acid neutralisation, and metal leaching to the International Kinetic Database (Morin *et al*, 1996; www.mdag.com\ikd.html) showed the rates were near average within their pH ranges.

After acidic conditions appeared in one cell (MR97-12), other minerals continued to partially neutralise acidity, so that pH did not fall to strongly acidic values (only as low as pH 4.1). This was consistent with ABA results which showed that some of the measured NP was associated with slow-neutralising non-carbonate minerals.

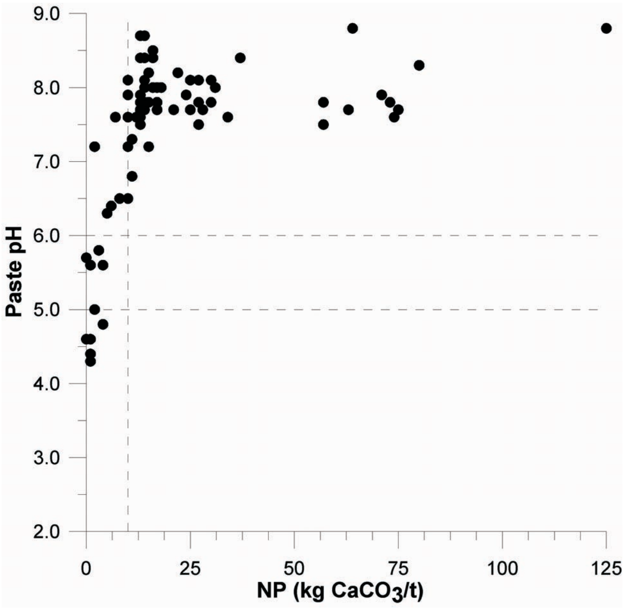

FIG 4 - Paste pH versus Standard-Sobek neutralisation potential (NP) from acid-base accounting; unavailable NP initially estimated at 5 - 10 kg/t [acidic paste pH is typically considered to be less than pH 5 to 6, as marked by horizontal dashed lines; paste pH decreases towards acidic values around NP = 10 kg/t].

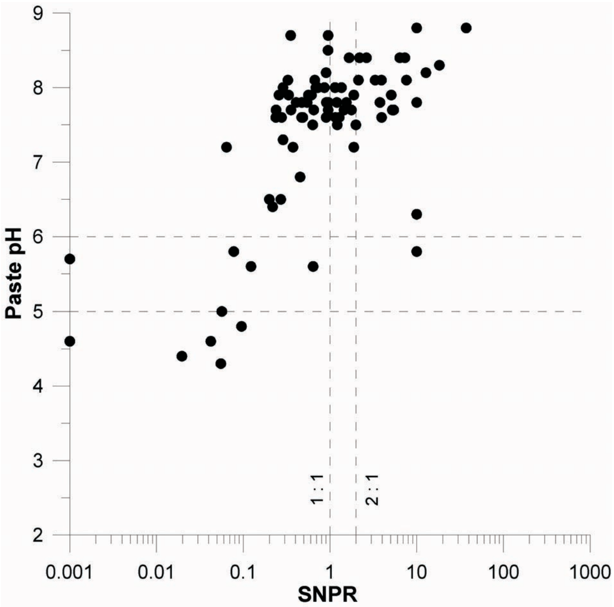

FIG 5 - Paste pH versus sulfide net potential ratio [SNPR = NP/(per cent S-sulfide * 31.25)]; values less than 1.0 - 2.0 are often considered net acid generating, but site-specific testwork for this study yielded a criterion of 1.5 [acidic paste pH is typically considered to be less than pH 5 to 6, as marked by horizontal dashed lines; SNPR = 1.0 and 2.0 marked by vertical lines].

One cell became acidic only after all of its measured NP was depleted, and the other cell when terminated was still near-neutral with remaining NP around 4 kg/t. Thus, the initially estimated unavailable NP of up to 10 kg/t based on ABA (Figure 4) was actually around zero based on the cells. Also, the near-neutral cell indicated the appropriate criterion to distinguish net-acid-generating from net-acid-neutralising rock was a Sulfide Net Potential Ratio of 1.5 (Figure 5).

In general, at least half of the rock mass that was to be blasted or exposed along this section of highway was predicted to eventually generate some net acidity and ML/ARD. This led to the implementation of ML/ARD control techniques that were optimised for the highway construction.

CONTROL OF ML/ARD

Highway construction involved the process of cutting and filling of rock to create a relatively smooth grade, producing 'cuts' where relatively intact bedrock remained exposed along the sides of the highway and 'fills' where blasted rock from the cut areas was filled into depressions. Thus, control techniques for ML/ARD had to be developed and optimised for both fills and cuts, with the recognition that the fills had greater exposed surface areas per unit weight and thus were a greater concern.

Initial steps in ML/ARD control involved realignment of the highway right-of-way and fine adjustments to its elevation along the Tsolum River portion. This minimised the amount of net-acid-generating rock that had to be exposed and moved.

ML/ARD control for the highway fills

After consideration of several options, the selected primary control technique involved encapsulating the fill rock within the highway itself (Figure 8). This typically involved laying a 1-m-thick low-permeability till layer on the original surface, placing the blasted rock along the centerline of the highway, installing approximately 3 m of till along the sides of the blasted rock covered by granular fill, laying 0.5 m of till over the rock, then installing the highway bed including a relatively impermeable asphalt surface.

For monitoring purposes and as a contingency in case water treatment was needed, drainage pipes were installed at low elevations in the fills. These pipes drained the bed of the highway into a series of lined ponds where water chemistry was periodically monitored. Fine-grained limestone was stockpiled nearby should any pond exhibit a substantial decrease in pH, allowing time for more elaborate treatment plans to be developed.

ML/ARD control for the highway cuts

The cuts remaining after the highway was constructed were less of a concern than the fills, because the cut rock is relatively intact with less exposed surface area per unit weight. Nevertheless, road cuts elsewhere can reportedly lead to significant ML/ARD (BC Ministry of Transportation, 2001) and thus potential ML/ARD from these VIHP road cuts was given due attention.

Upgradient water flowing towards and through the cut faces was diverted away from the faces where possible. The ditches along the bases of the cuts were augmented with about one per cent limestone for short-term control if drainage pH became acidic. Finally, the drainage ditches fed to a series of ponds, some shared with the fills discussed above, where water chemistry was periodically monitored and water could be treated if necessary.

MONITORING

The highway ponds, as well as additional upstream 'background' flows, were monitored for several years during and after highway construction (Morin and Hutt, 2000, 2002). Through 2001, in comparison to the background sites, the highway ponds typically had notably higher pH and higher levels of some parameters and metals, like hardness (roughly 100 mg $CaCO_3$/L on average versus 9 mg/L), total dissolved solids, total suspended solids, bicarbonate and total alkalinity, sulfate, calcium, iron, and magnesium. Conversely, several background locations were producing elevated metal concentrations for reasons apparently not related to the highway.

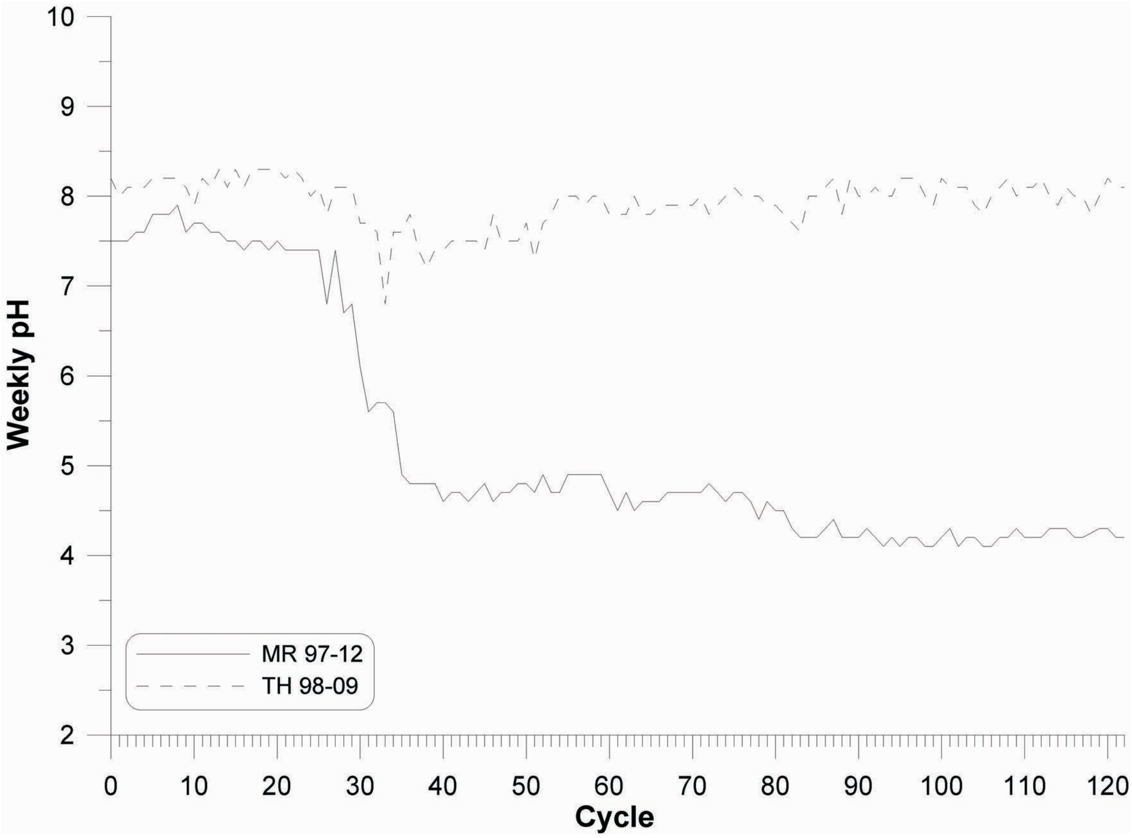

FIG 6 - Aqueous pH through weekly cycles in the two VIHP Standard-Sobek humidity cells.

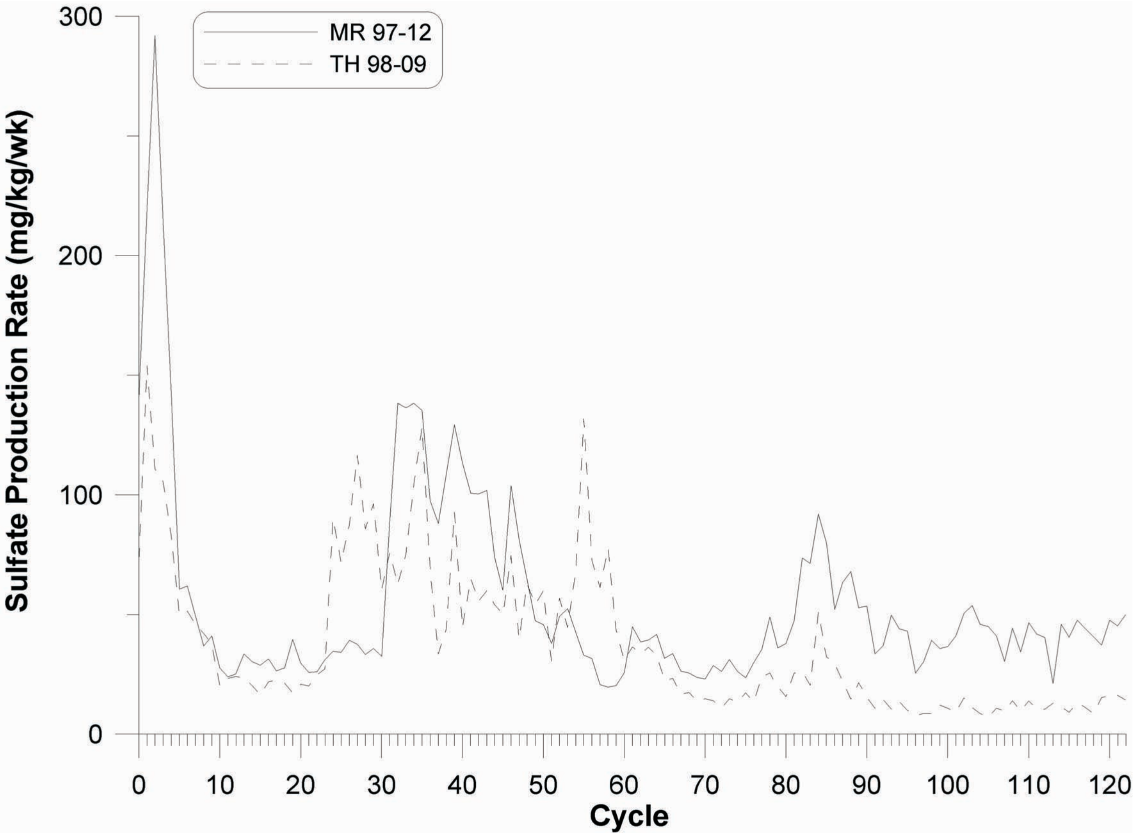

FIG 7 - Sulfate production rate through weekly cycles in the two VIHP Standard-Sobek humidity cells.

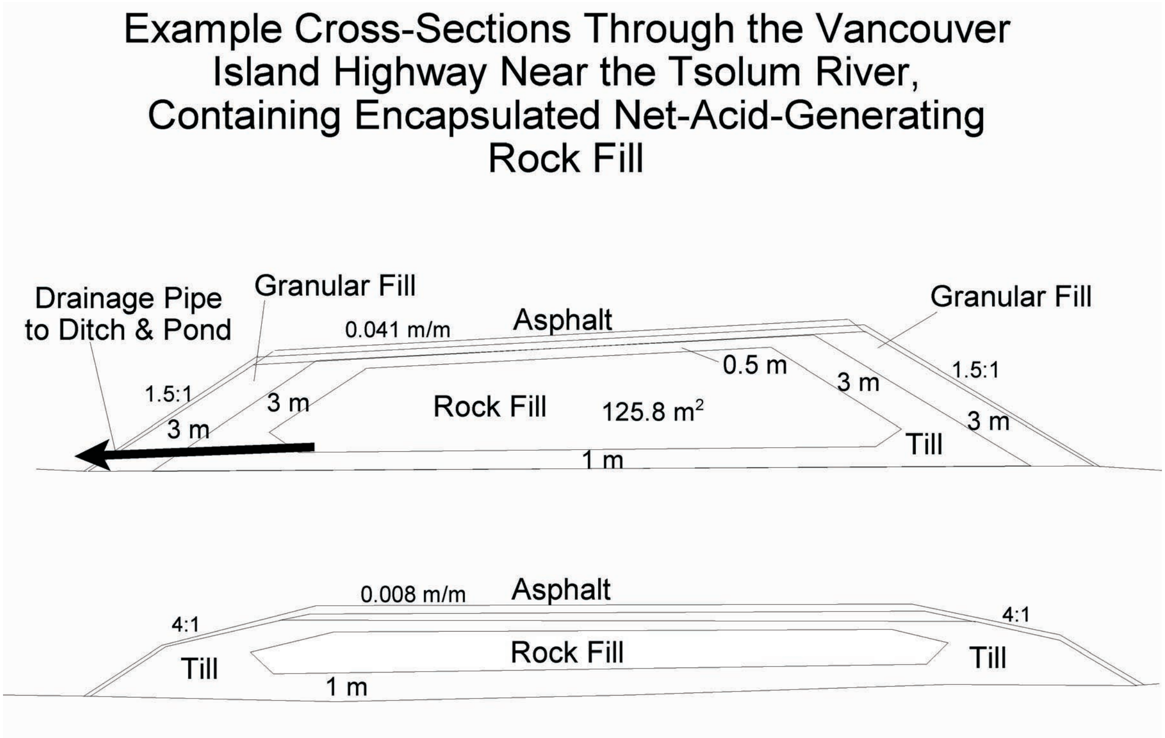

FIG 8 - Example cross-sections of highway fills encapsulated within the highway.

The elevated aqueous sulfate in the highway ponds indicated pyrite was reacting in the rock fills and cuts, but the near-neutral pH confirmed the generated acidity was still being neutralised internally at all locations (Figure 9). Also, the sulfate correlated reasonably well with other parameters like pH, conductivity, and calcium, indicating the pyrite-reaction rate and subsequent neutralisation within the rock affected the levels of these other parameters. This also meant that conductivity measurements provided rapid in-field indications of high sulfate concentrations.

The concentrations in some ponds draining the highway fills were notably higher than other ponds (Figure 9). Also, the higher concentrations occurred at irregularly spaced locations along the highway. As a result, each pond and highway segment behaved somewhat differently geochemically, suggesting differing predictions for each pond (see Potential Water Treatment below).

A comparison of water-quality data to British Columbia provincial approved and working (non-approved) guidelines showed that both pond waters and background waters exceeded several guidelines. The only parameters which exceeded guidelines much more frequently in the ponds than in background were: nitrate, total suspended solids, total cobalt, and total iron (primarily due to the suspended solids).

Overall, there have been no indications of impending ARD or accelerated metal leaching, because of the continuing near-neutral pH, low levels of acidity, and general lack of increasing sulfate and metal concentrations. Thus, self-neutralisation by the highway fills and cuts continues to control the chemistry of water draining from them.

POTENTIAL WATER TREATMENT AT THE MONITORING PONDS

It is difficult to predict any potential treatment requirements for each segment of highway and its associated pond, because the predictions depend on factors like the amount of water eventually seeping through the asphalt and the encapsulated rock, and the exact percentages of net-acid-generating and net-acid-neutralising rock in each segment. This type of detailed information is not available, and thus monitoring of the ponds continues.

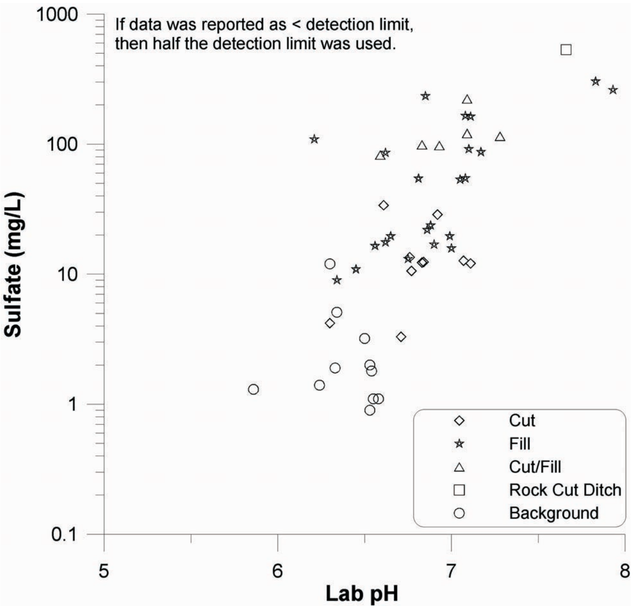

FIG 9 - Aqueous sulfate versus pH from monitoring of water in the highway drainage ponds and in background waters.

Based on the predictive humidity cells, the acidity production in the rock is relatively low and thus most monitoring ponds would require, at most, a few cubic metres of limestone or lime a year if pond water became acidic. Also, active pyrite oxidation and any accelerated metal leaching are expected to cease within several decades, and any water treatment would end soon after. An exception would be the cut walls if fresh, reactive rock continued to be exposed over the decades.

CONCLUSION

On the Inland Island Highway portion of the VIHP, over half of the rock to be cut and filled in the vicinity of the Tsolum River was found to be net acid generating with disseminated framboidal and gel pyrite. Despite the reactive forms of pyrite, the rate of acid generation was not high, measured NP provided some lag time for the onset of net acidity, and non-carbonate neutralising minerals prevented low pH (<4.0) from appearing in the humidity cells.

This led to ML/ARD controls involving:

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