# INTERNAL HYDROGEOLOGIC MONITORING OF AN ACIDIC WASTE-ROCK DUMP AT WESTMIN RESOURCES' MYRA FALLS OPERATIONS, BRITISH COLUMBIA[1]

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**Abstract:** Planning for closure at Westmin's Myra Falls Operations (British Columbia) began indirectly in the early 1980's with hydrogeologic and water-chemistry studies downstream of the primary waste-rock dump and mine workings. The hydrogeologic investigation was expanded significantly in 1988 and again in 1990, culminating in a Decommissioning Plan submitted in 1992. The Plan and its supporting technical documentation defined strategies to minimize acidic drainage and metal leaching in waste rock, underground workings, and pit walls. A primary target for decommissioning was Waste-Rock Dump #1.

Dump #1 contains approximately 10 million metric tonnes (mt) of coarse-to-fine pyritic waste rock. This dump was built against a valley wall and is approximately 800 m long parallel to the wall by approximately 300 m wide at the base. It reaches a maximum measured height of 42 meters. Sixty-five boreholes have been drilled into the dump since 1988. Over 230 rock samples have been submitted for acid-base accounting, providing stratigraphic data on sulfide and neutralization potential.

Five boreholes contain multilevel gas ports for a total of 25 ports to monitor internal levels of oxygen and carbon dioxide. One year of monitoring data showed that oxygen could vary from essentially zero to full atmospheric level at any particular depth and lateral location within the dump. Overall, sulfide-mineral oxidation within the dump was not oxygen limited.

Four boreholes contain thermistor strings for a total of 20 thermistors. These thermistors have transmitted temperature data to dataloggers every 12 h for the last three years. The temperature data show a maximum value of 51.6°C at intermediate depths. During precipitation and subsequent infiltration events, the upper and intermediate temperatures are cooled by the infiltration, but the deeper temperatures are raised by the infiltration because it has warmed to a maximum of 52°C.

A total of fifty-one 0.75-inch-diameter and five 2-inch-diameter piezometers have been installed within and below the dump. Four of the 2-inch wells contain pressure transducers which have transmitted groundwater levels to dataloggers every 12 h for the past three years. Fluctuations of up to 4 m have been recorded during intense storm events of approximately 10 cm of rain in 12 h.

Infiltration events from individual storms were tracked downward through the dump by their effects on internal temperature and basal water-table levels. This tracking shows that infiltration can pass through up to 45 m of waste rock within 12 h, based on initial temperature responses, to 36 h, based on midpoints of water-table responses.

**Additional Key Words:** waste rock, hydrogeology, groundwater, subsurface temperature, poregas composition

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## Introduction and Objectives

Westmin Resources' Myra Falls Operations are located in Strathcona Provincial Park, near the geographic center of Vancouver Island in British Columbia (fig. 1). The minesite contains several base-metal ore zones, which are mined and processed on-site primarily for zinc and lead with minor amounts of other metals including gold. Mining is currently conducted from underground workings, but initial mining was in an open pit excavated into a valley wall.

Myra Falls Operations recently celebrated their 25th anniversary of mining, and some estimates have extended the mine life to another 25 yr. Nevertheless, closure and decommissioning are inevitable, and thus several years ago Westmin Resources initiated detailed monitoring of several mine components. These components included several levels of underground workings, the former pit area, and the primary waste-rock dump known as Dump #1. All results to the end of 1991 were used in the design of the initial Decommissioning Plan (C.E. Jones and Associates 1992, Northwest Geochem 1992); however, results up to mid-1993 are now available.

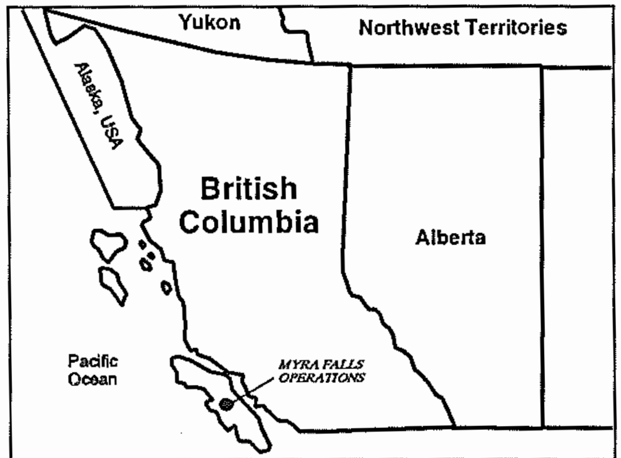


**Figure 1. Location of Westmin Resources' Myra Falls Operations in British Columbia.**

The primary objective of this paper is to describe the monitoring network for Dump #1 and some of the monitoring results, which probably form one of the largest hydrogeologic databases currently available for a waste-rock dump (Morin et al. 1991). Monitoring has included solid, gas, and water phases as well as internal temperatures and water chemistry below the water table, but length restrictions preclude presentation and justification of much of the database here. A second, more focused objective of this paper is to track the infiltration of water during two storm events from the top of the dump to the water table, over a distance of up to 45 m and a time period of several days. Another, indirect objective is to show (1) the sporadic damage to monitoring equipment that can occur on a dump that continues to undergo active disposal and contouring and (2) the compromises that must be made to data collection in order to accommodate active mining.

## Layout of the Myra Falls Operations and Dump #1

The Myra Falls Operations lie in a narrow valley where Myra Creek flows over floodplain and colluvium sediments consisting predominantly of sand and gravel. The valley walls are composed of intact fractured rock, covered in places by talus or debris-avalanche deposits, and rise up to mountain peaks that are capped by snow throughout most of the year. The minesite consists of several components including a tailings impoundment built on the floodplain, a mill, the Lynx Pit excavated laterally into the north valley wall, and waste-rock dumps.

Dump #1 is the primary, active dump at the minesite, containing an estimated 10 million ($10^7$) mt, and is located along the north valley wall (fig. 2). Dumps #2, #3, and #4 are relatively minor and are not discussed here. The Lower Lift of Dump #1 is located laterally adjacent to the tailings impoundment and in fact is mostly buried by tailings. Within a year, the tailings are expected to cover the Lower Lift entirely. The Middle Lift extends laterally from the south end of the dump half-way to the northern end. This lift has been partly covered by recent waste-rock dumping. The Upper Lift is comprised of rock slopes rising tens of meters above the other lifts. The top of the Upper Lift is used for storage and disposal of mine equipment, rock core, and waste oil. A diversion ditch along the northwest perimeter of this lift carries water from the slopes above the dump to Myra Creek below the dump. This ditch is lined in places above the dump and is shotcreted adjacent to the dump.

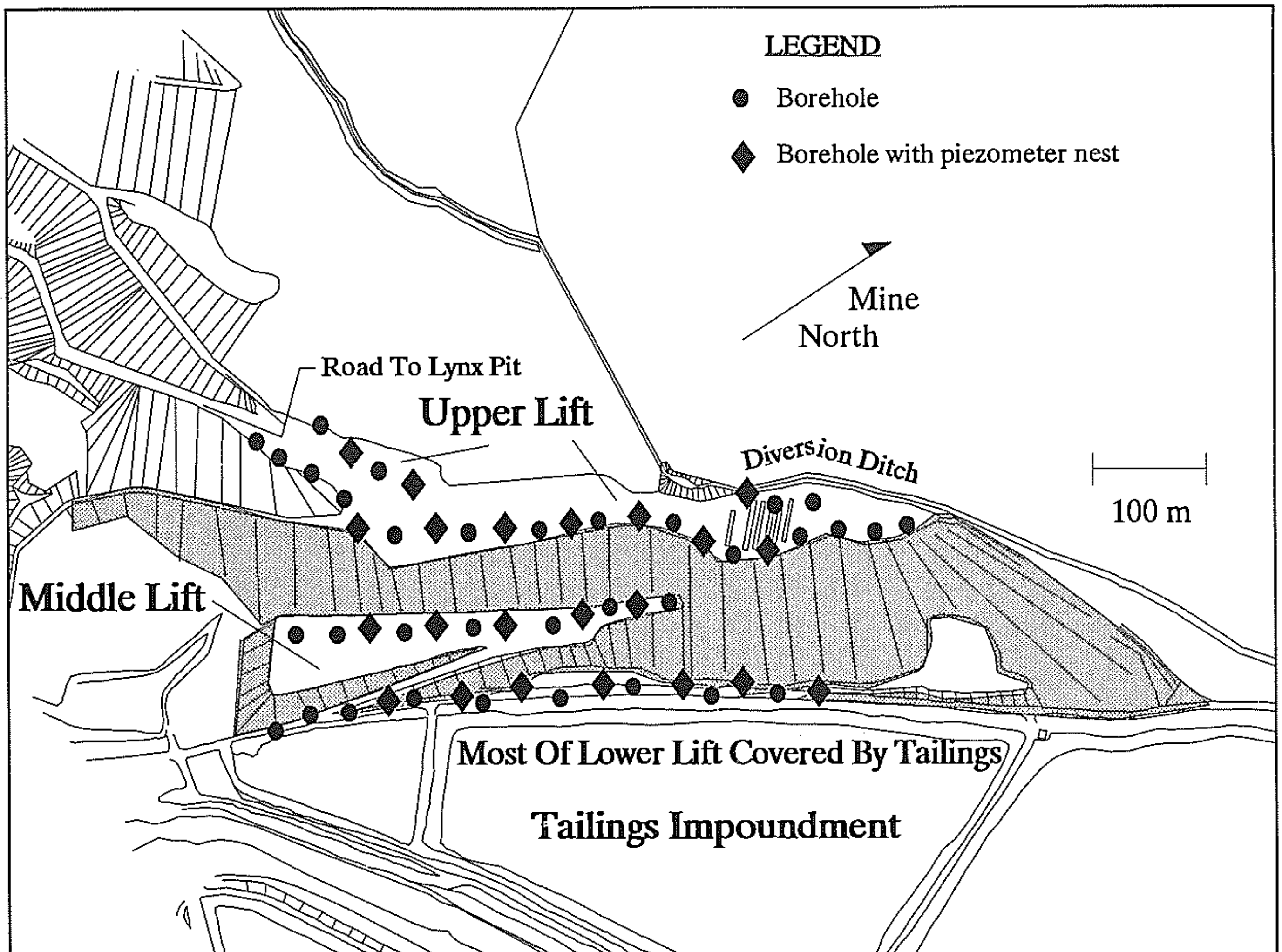


**Figure 2. Physical layout of Dump #1 and locations of boreholes drilled in 1988.**

## Stratigraphy and Acid-Base Accounting of Dump #1

In 1988, 57 boreholes were drilled into the three lifts of Dump #1 (fig. 2), using tricone and downhole-hammer techniques (Northwest Geochem 1990). A total of 1,642 m were drilled and sampled for acid-base accounting (ABA) analysis and the delineation of stratigraphy. During this drilling program, up to three 0.75-inch-diameter piezometers were installed in 22 boreholes to monitor groundwater levels and water chemistry below the water table.

The upper and middle portions of the dump were found to vary from coarse boulders to fine-grained rock. The fine-grained layers may reflect surfaces across which heavy equipment moved during delivery and dumping of the rock, and have implications for perched water tables (Morin et al. 1991). The lowest portions of the dump consist of fine-grained waste rock mixed with other materials including wood and brown-colored "sludge". The underlying bedrock could not often be differentiated from the deepest waste rock through the drilling techniques, and thus the presence of peat, soil, or timber was often the indicator used for top of bedrock.

Based on contour interpolation of waste-rock thickness, the Upper Lift rises 26 to 32 m above the original land surface, reaching a maximum of 42 m near the center of the dump and a minimum of a few meters where it drapes onto the valley wall. The Middle Lift is approximately 20 to 30 m thick. The Lower Lift is generally less than 16 m thick, but much of this thickness at the toe is covered by tailings.

ABA is a common static test used in the prediction of acidic drainage. In its basic form, it consists of measurements of paste pH, Neutralization Potential (NP), and total sulfur, which is mathematically converted into an Acid Potential (AP). A sample's ability to generate acidic drainage at some point in time is then assessed through the evaluation of NP:AP ratios or values of Net Neutralization Potential (NNP = NP - AP). This evaluation should be performed on a site-specific basis, rather than through universal criteria (e.g., Morin and Hutt 1994a).

During the 1988 drilling program, 236 samples were collected for ABA of waste rock (179 samples), bedrock (40 samples), basal organic layer (11 samples), and alluvium (6 samples). The results showed that the waste rock on average was considered a potential acid generator, and paste pH confirmed net acid generation in some samples (table 1). This was not unexpected as Dump #1 has been a known source of acid drainage for almost 20 yr.

Table 1. Summary statistics of waste-rock ABA analyses for Dump #1 (179 samples)

| Parameter | Mean | Minimum | Maximum |
|---|---|---|---|
| Paste pH | 7.23 | 4.00 | 8.16 |
| AP . . t $CaCO_3$/1000 t | 108 | 0.63 | 438 |
| NP . . t $CaCO_3$/1000 t | 23.2 | 1.74 | 50.4 |
| NNP . t $CaCO_3$/1000 t | -84.8 | -424 | 25.7 |
| NP/AP | 0.99 | 0.01 | 42.1 |

The ABA results for individual boreholes revealed stratification of ABA parameters with depth. For example, values of paste pH showed that the entire thickness of waste rock can be acidic where the thickness is smallest: at the toe and in the Upper Lift against the valley wall. For the remainder of the Upper Lift, boreholes were either (1) essentially pH-neutral, but generally capable of generating net acidity at a later time, (2) acidic from the top down to depths of roughly 8 to 15 m, or (3) acidic only within distinct zones at depth. Values of other ABA parameters in individual boreholes revealed other trends, such as pyrite-rich and NP-rich layers at distinct depths.

## Internal Gas Monitoring

Following the 1988 drilling program, a second drilling program in 1990 involved nine boreholes with 235 m of rock drilled with a downhole hammer. Various combinations of 2-inch-diameter monitor wells, thermistor strings, and gas ports were installed in these boreholes (fig. 3). For monitoring of internal gas composition, two gas-port stations were installed in the Lower Lift (G1 and G2), one in the Middle Lift (G3), and two in the Upper Lift (G4 and G5). Each gas port at a station consisted of a continuous, individual length of flexible polyethylene tubing, which terminated at a specific depth to a maximum of 30 m.

Over a period of nearly a year, gas concentrations of oxygen and carbon dioxide were measured on four occasions with an in-line pump and gas analyzer. Results of oxygen measurements depicted a transient system with oxygen concentrations often ranging from nearly atmospheric to nearly zero at most depths throughout the year (e.g., fig. 4). Based on these results, the dump was found to be open to sufficient oxygen at all depths to allow sulfide-mineral oxidation, although occasional periods of oxygen limitation occurred. No further monitoring of gas concentrations was conducted.

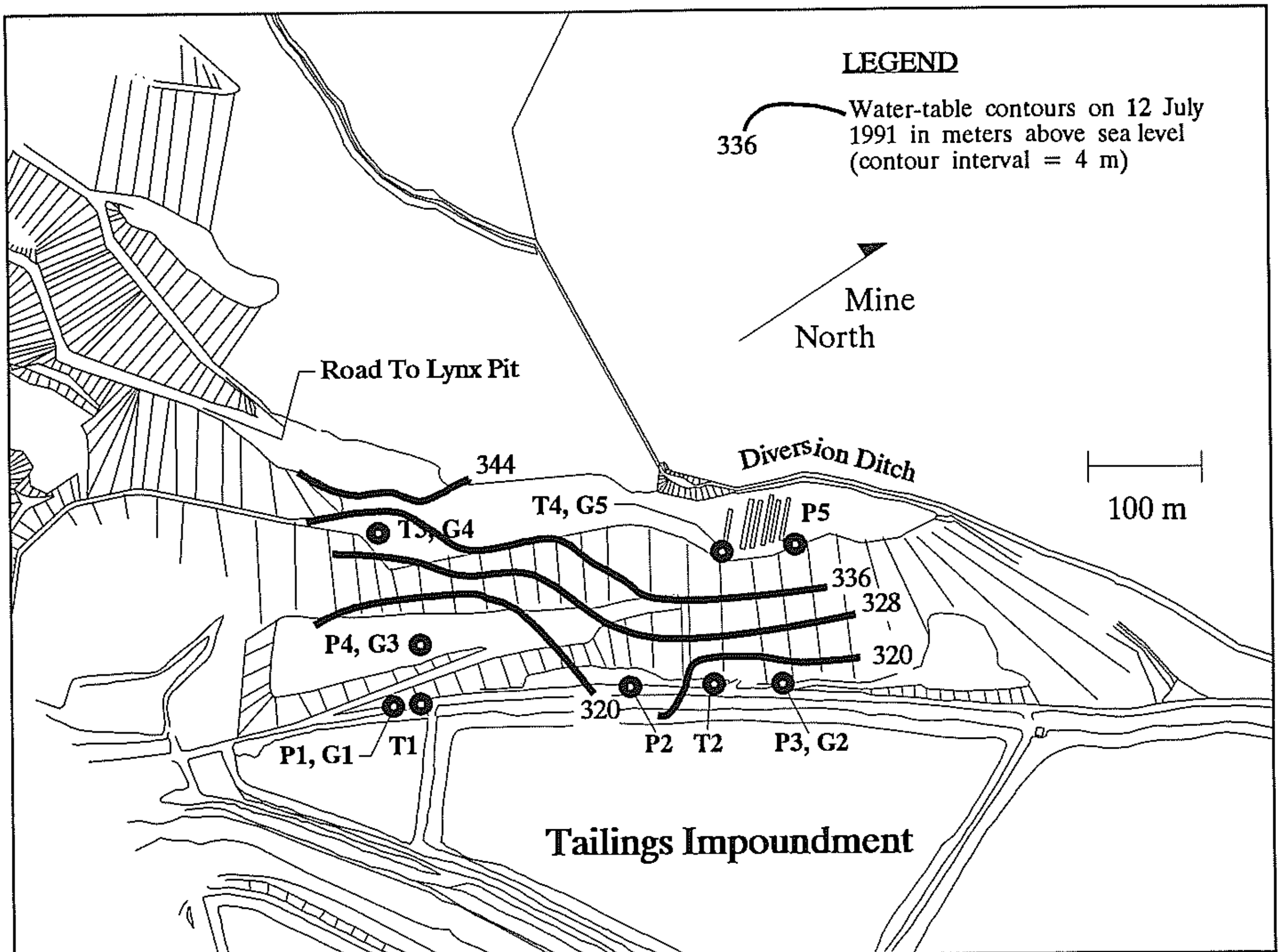

Figure 3. Locations of boreholes drilled in 1990 and a typical map of the Main Water Table.

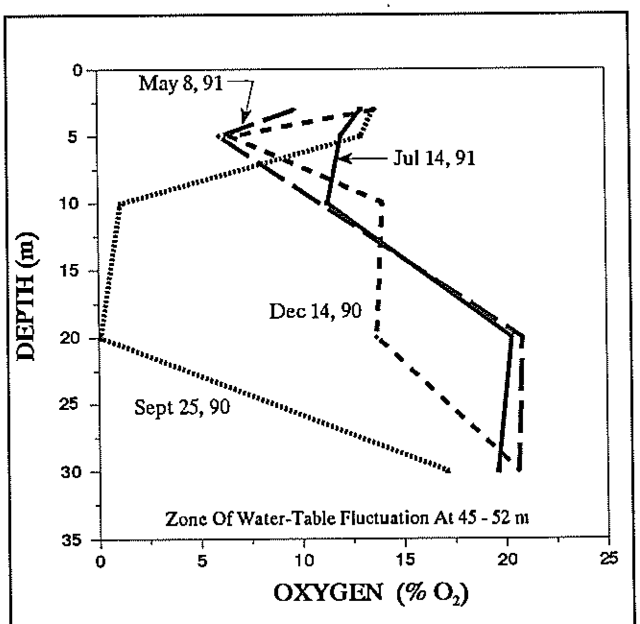

Figure 4. Oxygen profiles at G5.

## Internal Temperature Monitoring

In 1990, four thermistor strings ("T" prefix, fig. 3) consisting of commercially supplied thermistors were installed in two boreholes on the Lower Lift (T1 and T2) and two boreholes on the Upper Lift (T3 and T4). The number and depth of the individual thermistors depended on the location of the borehole; all thermistors were connected to dataloggers which recorded temperature every 12 h. These thermistors were installed to identify the lateral and vertical extent of significant heat generation resulting from sulfide-mineral oxidation.

The results at T1, T2, and T3 indicated that temperatures at most depths only slightly exceeded the average annual surface temperature. However, the temperature at T4 near the northern end of the Upper Lift (fig. 3) showed elevated temperatures above the average annual value (fig. 5), reflecting significant heat production and transmission. The maximum measured temperature was 51.6°C at T4 at a depth of 10 m. This is consistent with an acidic zone identified in this area by ABA (discussed above) to a depth of 26 m. T4 will be used in the following section to track infiltration through the Upper Lift during storm events.

The significant gaps in data caused by datalogger failures have plagued interpretations due to the incomplete records (fig. 5). However, these data gaps were not caused by internal failures, but by external events. Because Dump #1 is still active, there is traffic movement across all lifts on most days. This traffic carries fresh waste rock and used equipment from the mines and mill. Also, there is road maintenance and, during winter months, road plowing. Such activity has resulted in the crushing or covering of instrumentation and piezometer nests and in the cutting of cables attached to the dataloggers. All of this work is part of normal mine operation and cannot be eliminated without great expense. As a result, the gaps in the data cannot be easily eliminated and controlled, and must be taken as part of the normal problems encountered at an active mine. In turn, interpretations based on these data must recognize the limitations that an active dump places on data availability. In any case, Dump #1 is evolving through time as old rock weathers and new rock is added, and thus the physical and chemical hydrogeology of Dump #1 could change significantly through time from current conditions. The intermittent records from the dataloggers will reveal how this evolution occurs.

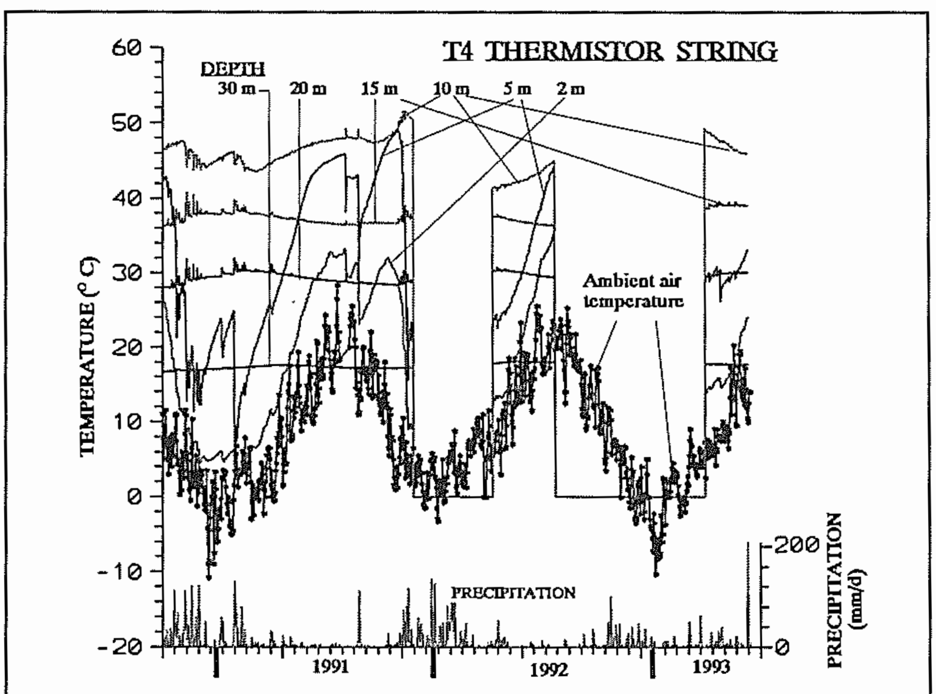


**Figure 5. Temperature data from T4 and average daily temperature at Myra Falls.**

## Water-Table Fluctuations in Dump #1

Five 2-inch-diameter monitor wells were installed in the lifts of Dump #1 ("P" prefix, fig. 3). All except P2 contain pressure transducers, which have transmitted water levels every 12 h to dataloggers.

All P-series monitor wells are installed in the "main" or "basal" water table near the base of the dump. This water table passes through waste rock or bedrock, depending on location, as it extends from the valley wall to the floodplain and tailings impoundment (fig. 3). In addition to the main water table, there are other, perched water tables within the dump. These perched tables affect the movement, chemistry, and timing of infiltrating water in a dump (Morin and Hutt 1994b, Morin et al. 1991).

The hydraulic gradient of the main water table is approximately 0.2 to 0.3 towards the east, and the groundwater thus flows towards the tailings where it is intercepted at the toe (now buried with tailings) by the Inner Drain (van Dyk 1987). This subsurface drain was specially designed to intercept dump seepage and to carry it to the treatment plant.

Based on single-well-response tests, the hydraulic conductivity of the bedrock and basal waste rock ranges from $10^{-5}$ to $10^{-8}$ m/s. With a porosity of 5% from the relative fluctuations of precipitation and groundwater level, groundwater beneath the main water table requires at least a few weeks to travel from the top end of the dump to the Inner Drain.

Mass-balance calculations have shown that approximately 10% of total annual groundwater flow beneath the main water table is derived from infiltration directly through waste rock, while the remainder is background groundwater from behind the valley wall (Northwest Geochem, 1992). Despite its relative unimportance on an annual basis, most infiltration through the dump occurs during the wet season from October to March and periodic storm events carry acid-generation products downward through the dump to the water table, affecting the chemistry of the Inner Drain water (Northwest Geochem 1990, Northwest Geochem 1992). Concepts behind such flushing of waste-rock dumps are discussed in Morin and Hutt (1994b) and Morin et al. (1994).

The results of 12-h measurements along the south-end flowpath from P4 to P1 (fig. 3) show a relationship in which water levels rise roughly 2 m during storm events. This response is more dramatic along the north-end flowpath (P5 to P3) in which P3 has fluctuations up to 4 m during storm events (fig. 6). These fluctuations can carry major implications for oxygen pumping within the dump (discussed above). When a storm event of roughly 10 cm causes a water table response of 2 to 4 m, mass-balance relationships indicate porosity of the rock would be around 2 to 5%, which is used above in groundwater-velocity calculations.

Instead of examining the entire database of water levels, a detailed examination of water-level responses to individual storm events is more informative. For this paper, the storm events that occurred around February 1, 1991 and August 29, 1991, and their resulting effects at T4/P5 in the Upper Lift (fig. 3) and at T2/P3 in the Lower Lift, will be highlighted. During the 12-h period centered around 00:00 on January 31, 1991, precipitation began falling and increased to roughly 7 cm in 12 h by 00:00 on February 1, 1991 (fig. 7). Within 12 h, this storm event caused a rapid decrease in temperature at T4 to depths of 10 m. Since the highest measured temperatures occur at 10 m, the corresponding responses at greater depths occurred as increases in temperature as the warmed infiltration passed through within the 12 h. There was no temperature response at the 30 m depth.

The water table at this location with a depth of approximately 45 m, however, did not respond to the storm event for nearly 24 h, with the midpoint of the response at 36 h (table 2). The discrepancy between this delayed response of 36 h and the temperature responses in less than 12 h to depths of 20 m suggests either (1) there is a perched zone between 20 and 45 m which slows infiltration or (2) the temperature responds to an initial, minimal amount of initial infiltration, whereas the water table reflects the response to volume. A storm event three days later produced similar results.

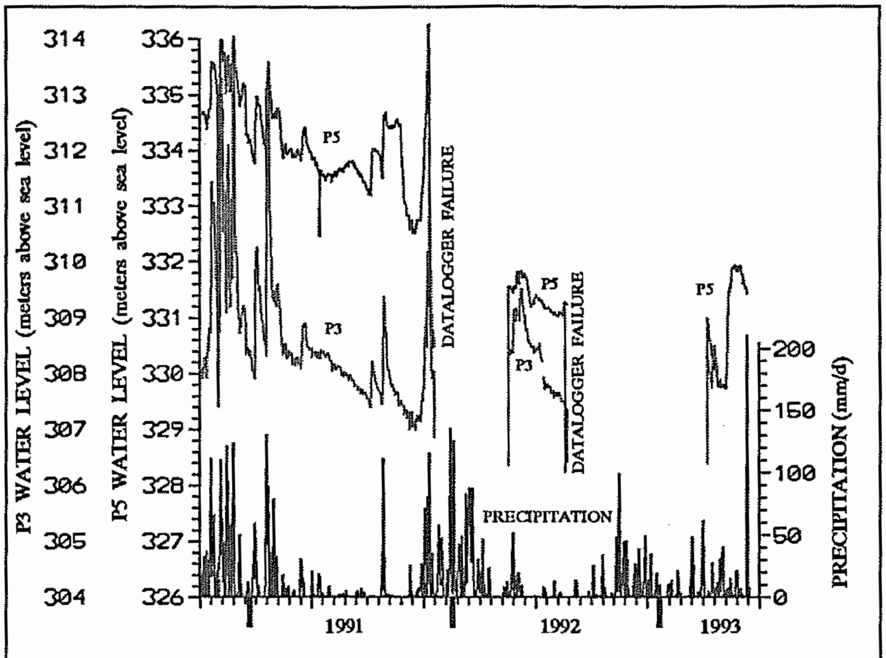


**Figure 6. Water levels at P5 and P3, and average daily precipitation.**

At T2 and P3 (fig. 8), temperature responses could only be clearly seen at depths of 5 m (in 12 h) and at 12 m (in 24 h). The water-table response at a depth of approximately 16 m had a midpoint response at 36 h (table 2). Because of the greater thickness at T4/P5, the similar time lags at the water table indicate infiltration passes through a unit depth at T2/P3 more slowly.

The storm event during the 12-h period centered at 12:00 on August 29, 1991 generated similar, but generally more rapid, responses at both locations (figs. 9 and 10; table 2). The more rapid responses could be the result of the precipitation that occurred during the prior 36-h period. In any case, a significant storm event at Myra Falls is capable of initiating infiltration through the dump to depths of 45 m within 12 h to 36 h based on temperature and water-table response, respectively.

Table 2. Time delay between the start of a storm event and the midpoint response of temperature and water level.

| Station AND DEPTH | STORM EVENT | | STATION AND DEPTH | STORM EVENT | |
|---|---|---|---|---|---|
| | 1 FEB 91 | 29 AUG 91 | | 1 FEB 91 | 29 AUG 91 |
| T4 - 2 m | < 12 h | < 12 h | T2 - 2 m | ? | ? |
| T4 - 5 m | < 12 h | < 12 h | T2 - 5 m | 12 h | < 12 h |
| T4 - 10 m | < 12 h | none | T2 - 8 m | ? | < 12 h |
| T4 - 15 m | < 12 h | none | T2 - 12 m | 24 h | < 12 h |
| T4 - 20 m | < 12 h | none | P3 (16 m) | 36 h | 12 h |
| T4 - 30 m | none | none | | | |
| P5 (45 m) | 36 h | 24 h | | | |

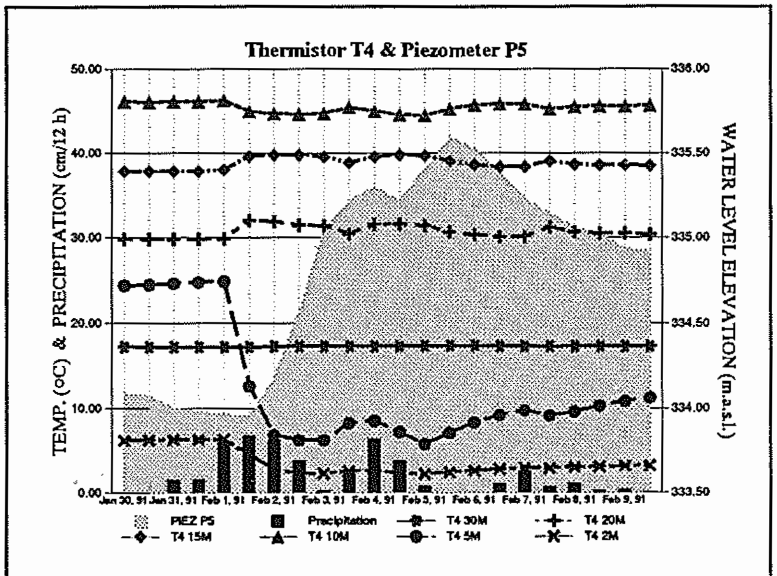


Figure 7. Response of T4 and P5 to the storm event around February 1, 1991.

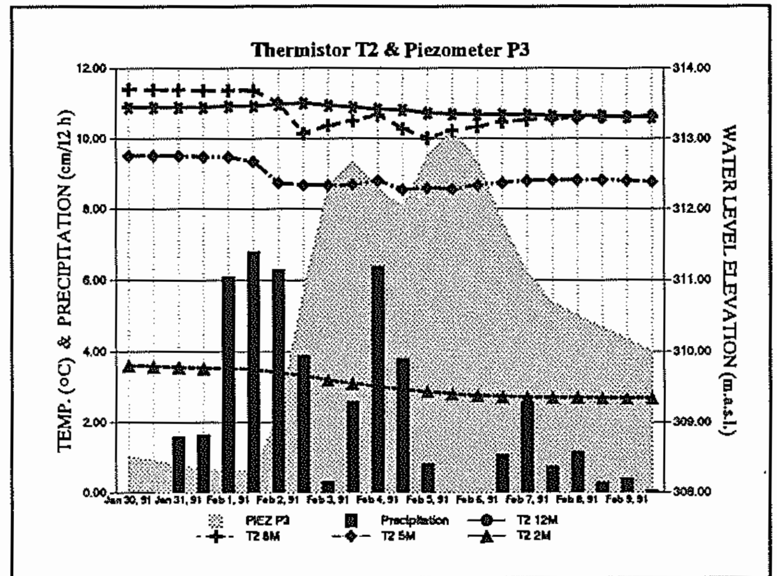


Figure 8. Response of T2 and P3 to the storm event around February 1, 1991.

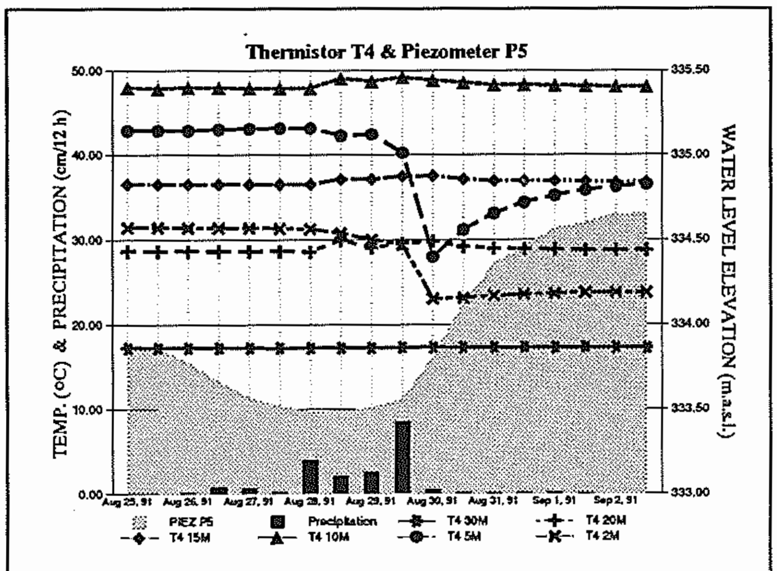


Figure 9. Response of T4 and P5 to the storm event around August 29, 1991.

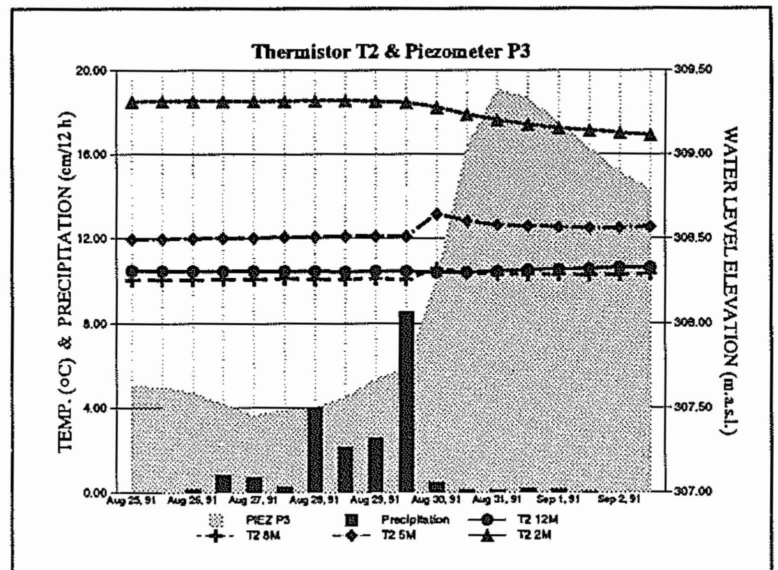


Figure 10. Response of T2 and P3 to the storm event around August 29, 1991.

## Conclusion

This paper has presented the monitoring program for Dump #1 at Westmin Resources' Myra Falls Operations in British Columbia. The database consists of data on solid, gas, and water phases as well as internal temperatures and water chemistry below the water table.

The monitoring of Dump #1 is providing valuable information from which to select decommissioning options (Northwest Geochem 1992). For example, shotcreting of the dump surface appears viable (Wong et al. 1993). However, in a more general sense, the monitoring database also provides valuable information from which to draw empirical correlations and to test theoretical relationships on waste-rock dumps.

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