

# **REMEDICATION OF COAL WASTE PILE IN UNION BAY, B.C.**

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## **ABSTRACT**

During the late 1800's to early 1900's, a coal processing plant operated in the community of Union Bay on Vancouver Island. Waste coal was deposited onto the foreshore and today this waste pile occupies approximately 13 hectares of leased Crown Land on the waterfront. The waste pile is also bounded on one side by a fish-bearing creek, with an environmentally sensitive buffer zone along its length.

Under oxidizing, moist conditions, acid may be produced by sulphides in coal waste materials and can cause heavy elements and low pH conditions to be released into groundwater. Concerns have arisen over the acid generating potential of the Union Bay waste pile, its potential impacts on foreshore and aquatic ecology, and the selection of appropriate mitigating options that will address the concerns of multiple stakeholders. Over the years, the waste pile has become a popular community park and a renowned destination for biking enthusiasts. The future land use of the pile has thus become an important and sensitive community issue.

Through the collaboration of SEACOR Environmental Inc. (SEACOR), SRK Consulting (Canada) Inc. (SRK) and KSW Resources (KSW), work has been undertaken to characterize the waste coal, to identify the contaminants of concern, potential receptors of concern and to determine the endpoints for an ecological risk assessment. Based on the results of a problem formulation and detailed site investigation, a plan has been developed to remediate the Site for urban park/residential land use and to return the lease to the province (Land and Water BC).

The coal waste was assessed through acid base accounting and laboratory kinetic tests. The primary contaminants of concern include heavy metals and polycyclic aromatic hydrocarbons and results indicated that contaminant concentrations in soil, groundwater, sediment and surface water currently exceed the applicable environmental standards at most locations. A detailed hydrogeologic assessment was completed to evaluate the basic parameters controlling the flow of groundwater through the pile, to develop a conceptual water balance, to quantify the potential flux of contaminants of concern to receiving environments and to assist in the development of a remediation plan for the Site. Investigations beyond the pile limits included sampling and toxicity testing of sediments from various zones within the foreshore and creek, surface water and groundwater, shellfish tissue sampling and analysis of subtidal sediment cores collected by divers.

It was concluded that acidification of near surface waste has already occurred, while the material at depth remains relatively fresh. However, an acid-generating front is expected to move downward through the pile over time. As a result, if left as is, increased leaching



Environmental investigations conducted at the Site indicate that contaminant concentrations in the waste coal exceed the applicable environmental standards. In addition, the geochemistry of the pile indicates that acid rock drainage (ARD) is occurring. Acid generation occurs when minerals containing sulphide and elemental sulphur are exposed to the weathering effects and microbial activity in the presence of oxygen and water. Acidity is generated primarily from the oxidation of sulphur. ARD occurs when the resulting acidity is entrained by water (Price et al., 1998).

The owner of the Site wishes to return the land to the province but is first required to obtain a Certificate of Compliance from the BC Ministry of Environment (MOE). To do so, the Site must be remediated to a condition considered satisfactory by the BC MOE. The proposed future land use for the Site is urban park/residential.

Evaluation of remedial approaches for the waste coal pile has indicated that placement of a cover (cap) on the pile is the most effective way to achieve remedial objectives. Due to the advanced stage of oxidation and existing stored acidity within the pile, it was determined that remedial measures should focus on limiting water infiltration rather than controlling oxygen. Placement of a cover on the pile will reduce infiltration and result in a reduction of contaminant loadings to the aquatic receiving environment.

## **ENVIRONMENTAL INVESTIGATIONS**

Environmental investigations were conducted to characterize the waste coal and underlying groundwater, to delineate the extent of waste coal on adjacent properties and in the adjacent marine and freshwater environments (Baynes Sound and Hart Creek, respectively), and to develop a remedial plan for the Site.

Samples of waste coal/soil, groundwater, sediment and surface water collected from the Site were submitted for analysis of potential contaminants of concern (PCOCs). PCOCs associated with the waste coal include metals, polycyclic aromatic hydrocarbons (PAH), nitrate, nitrite, sulphate, sulphite and pH. Additional characterization of the waste material included acid base accounting (ABA), kinetic testing and analysis of related geochemical parameters.

### **Waste Coal Pile**

Numerous boreholes were advanced across the waste coal pile. A groundwater monitoring well was installed at each borehole location. A summary of the Regulatory exceedances indicated by the chemistry results for the waste coal, native soil and groundwater is provided below.

#### *Waste Coal/Native Soil*

Chemical analysis of the waste coal indicated that concentrations of metals, namely arsenic and copper, and two PAHs, naphthalene and phenanthrene, are in excess of the Regulatory standards. Concentrations of metals and PAHs in the waste coal generally decrease with depth in the pile and concentrations in native soils underlying the waste coal were below the applicable standards.

### *Groundwater*

Concentrations of dissolved metals, including cadmium, cobalt, copper, nickel and zinc, and sulphate in groundwater were in excess of the marine and/or freshwater standards. Elevated concentrations of aluminum, iron and manganese were observed in the majority of wells; however, these metals are not regulated in groundwater for the protection of aquatic life in BC. Concentrations of PAHs were below the applicable standards.

### **Baynes Sound**

Evidence of waste coal is visible throughout the intertidal and subtidal zones to depths more than 9 m below zero elevation. Observations recorded during a subtidal survey indicate that a waste coal slope is present to approximately 30 m offshore. Beyond this slope, the offshore is typical of shallow subtidal marine areas in coastal BC with soft sediment and evidence of abundant infauna.

Two iron stained areas are present on the marine foreshore, one to the east of the waste coal pile and one to the north. The staining on the north side is localized (estimated area of 60 m<sup>2</sup>) and limited to the intertidal zone. Iron stained sediments on the east side of the pile cover an area of approximately 500 to 700 m<sup>2</sup> and extend into the subtidal zone. The observed iron staining is located in areas where groundwater from the pile is discharging and is related to the precipitation of iron from groundwater upon discharge and mixing with seawater.

### *Intertidal Sediments*

The chemistry results for intertidal sediments indicate that concentrations of PAHs, including acenaphthene, acenaphthylene, anthracene, chrysene, fluorene, 2-methylnaphthalene, naphthalene and phenanthrene, are in excess of the applicable criteria. Concentrations of arsenic, copper and/or mercury in select samples also exceed the criteria. Waste coal was evident in intertidal sediments to depths up to 3.0 m below surface, above native grey sand; concentrations of contaminants in the underlying native sediments were below the criteria.

### *Subtidal Sediments*

The chemistry results for subtidal sediment cores indicated that concentrations of the same PAHs encountered in the intertidal sediments were in excess of the applicable sediment criteria in one or more samples collected from each core. Contamination was encountered from depths of 0.3 m to > 0.8 m in each core. Although larger (sand or pebble) sized waste coal fragments were not observed in cores collected beyond the waste coal slope, the chemistry suggests that the grey silt substrate observed at these locations contains fine waste coal.

### *Seep Water*

Seep water samples were collected from groundwater breakout areas on the foreshore during low tide events. Concentrations of metals, including aluminum, cadmium, cobalt, iron, manganese, nickel and zinc have been measured in excess of applicable surface water guidelines; however, concentrations were approximately ten times lower than those measured in groundwater samples collected from the waste coal pile. This suggests that

some dilution of impacted groundwater occurs prior to discharge to the receiving environment.

### Hart Creek

Based on the chemistry results for sediment and surface water samples collected from Hart Creek and the limited presence of waste coal along the creek channel, limited impacts to the creek have occurred. Contaminant concentrations (PAHs and metals) in one sediment sample marginally exceeded the applicable sediment criteria and concentrations in surface water samples were below the applicable guidelines.

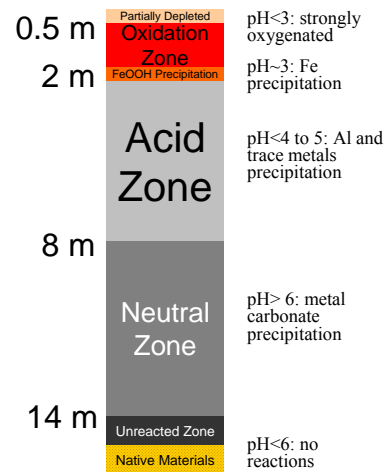
### Geochemistry

Geochemical characterization of the waste coal was conducted by SRK Consulting (Canada) Inc. (SRK) to evaluate the acid generating potential of the material. Both static (i.e. acid base accounting) and kinetic (i.e. humidity cell) testing of the waste coal was conducted. Acid base accounting allows for a comparison of the potential for the material to generate acid to the potential for the material to consume acid. The acid potential (AP) is estimated from the sulphide sulphur content of the waste coal. The neutralization potential (NP) is determined directly by acid addition to the sample. The humidity cell tests consisted of a weekly cycle where a 1-kg sample was aerated for six days and then leached with 500 mL of water. The resulting leachate was analyzed for pH, conductivity, oxidation-reduction potential (ORP), sulphate, acidity and dissolved metals. The tests were run for 26 weeks and provided information about the rate of acid generation and the timing of the onset of acid generation if NP is present.

The geochemical evaluation indicated that the majority of the waste coal is strongly potentially acid generating and is already acidic. The humidity cell tests indicated that exposure to unlimited oxygen supply resulted in immediate rapid oxidation of sulphide and generation of acidic leachate containing elevated concentrations of aluminum, cobalt, copper, iron, manganese, nickel and zinc.

Vertical zonation of sulphate sulphur and pH was noted within the pile and comprised a near surface partially leached zone (0.5 m), a zone of active sulphide oxidation (2 m) where precipitation of iron is occurring, an acidic zone extending to 8 m and a zone of acid consumption under pH neutral conditions extending to 14 m. Below 14 m some of the waste coal is unreacted and is relatively fresh. As depicted in Figure 3, the lowest pHs ( $\leq 3$ ) were observed at surface extending to a depth of approximately 2 m. From 3 to 8 m, pHs increased to 4 to 5. Below 8 m, pHs were greater than 6.

Under the existing conditions, acidification of the pile is expected to continue in the future as the oxidation layer continues to produce acid that will leach the underlying waste coal. As a result, secondary minerals are continually



**Figure 2.** Geochemical profile of the waste coal pile (courtesy of SRK).

leached and re-precipitated as low pH conditions advance further into the pile. Contaminant loading spikes in groundwater may occur as acidic fronts penetrate the base of the pile. The time frame for complete acidification of the pile is in the order of decades to a century, but elevated loadings would be expected to continue for many centuries without intervention.

### **Hydrogeology**

A detailed hydrogeological assessment has been undertaken to evaluate the local hydrogeologic setting and basic parameters controlling groundwater flow through the waste pile. The investigations included an evaluation of climate data, the completion of infiltration tests, hydraulic conductivity tests, monitoring of water levels and analysis of physicochemical groundwater chemistry including pH, temperature, dissolved oxygen, redox and conductivity. A conceptual water balance was subsequently developed with the aid of the numerical software HELP. The hydrogeology study has been integral to development of the remedial action plan and for the prediction of pore water chemistry in the risk-based problem formulation.

#### *Hydrogeology Program Scope*

A monitoring well network was established in the borings used to characterize the waste coal and underlying native materials. Well placement included nested installations to assess vertical gradients and potential groundwater recharge/discharge characteristics at hydraulic boundaries formed by Hart creek and the foreshore area. Extended monitoring of water levels was conducted seasonally using dataloggers and the spatial effects of tidal influence on groundwater were mathematically filtered to assess the hydraulic gradient and the direction of groundwater flow within the pile.

Soil samples were collected at regular intervals throughout the stratigraphic profile during both the summer and winter drilling programs. Using laboratory derived values for residual soil moisture content, soil moisture profiles were generated for both the winter and summer seasons.

The upgradient third of the pile is unsaturated at the base. The transition into saturated waste material is coincident with the location of the former shoreline and is consistent with the depositional history of the pile. As a result, groundwater recharge occurs only in the downgradient two-thirds of the pile within a relatively narrow wedge of saturated waste material that is thickest (approximately 2 metres) adjacent to the foreshore. The waste material here has been reworked by tidal action into a complex, interlayered sequence of waste coal and native sediments.

Monitoring of physicochemical groundwater parameters indicated that groundwater within the base of the pile was neutral to slightly acidic, between pH 5.1 and 7.2. Redox conditions were positive and conductivity measurements were generally low to moderate indicating that tidal influence on-site may be manifested primarily through the propagation of inland pressure waves with only localized impacts on groundwater chemistry near the foreshore environment.

Bail-down tests were performed in several wells for the purpose of calculating *in-situ* hydraulic conductivity estimates within the saturated waste coal and the underlying native soil. In general, the hydraulic conductivity values measured in the native silty sand and gravel were an order of magnitude lower than the overlying waste coal. This suggests that groundwater flow within the saturated coal tailings is significantly faster than in the underlying native material and that contaminated seepage likely propagates along this interface.

Infiltration tests were conducted using an ASTM standard (No. D-3385-94) dual ring infiltrometer. Tests were conducted at surface and approximately 0.20 metres below surface. Both compacted and uncompacted areas of the pile were assessed with the apparatus.

#### *Hydrogeology Investigation Results*

The primary findings from the hydrogeology investigations are summarized as follows:

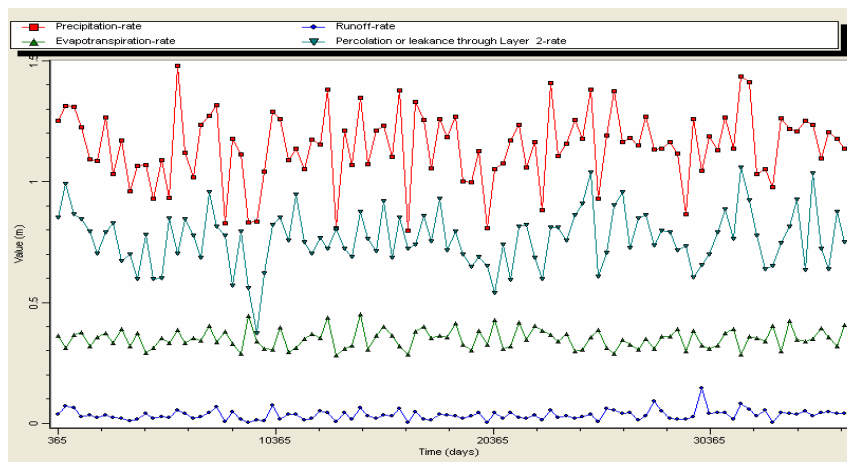
- Maximum tidal fluctuations in waste material adjacent to the foreshore were approximately 1.5m. Extrapolation of the data indicated that tidal influence extends approximately 400 metres inland near the southwest edge of the pile. Intrusion of saline water beneath the pile was only locally observed within 75 metres of the foreshore.
- Hart Creek was dry during the summer investigation, with isolated ponding of water. Coarse, alluvial materials were observed beneath the west edge of the pile beside Hart Creek. During the winter, water from the creek may recharge some portion of the pile along the west side. However, winter monitoring indicated that recharge from the creek does not occur within the upgradient third of the pile.
- Infiltration rates at typical surface locations on the pile were approximately 5 times slower than at 20 cm depth due to compaction in the top few centimetres of waste coal material. In a relatively small portion of the pile where dense compaction of the waste coal has occurred due to frequent recreational vehicle traffic, the infiltration rate was an order of magnitude lower than at typical surface locations.
- The average hydraulic conductivity of the waste coal material at the base of the pile was approximately  $7 \times 10^{-4}$  m/sec. The hydraulic conductivity in the underlying native stratigraphy averaged  $8 \times 10^{-5}$  m/sec, approximately one order of magnitude lower. The mean annual gradient was relatively flat at approximately 0.02 % to 0.03 % to the northeast, towards Baynes Sound.
- Using an estimated porosity value of 0.3 and the mean hydraulic conductivity data, the average linear groundwater velocity within the waste coal was estimated to range from approximately 100 to 150 metres per year. The groundwater velocity within the underlying native material was estimated to be approximately 15 to 25 metres per year.

### Water Balance

A conceptual water balance was developed to provide an understanding of the movement of groundwater and contaminant discharge through the waste coal pile. In general, precipitation falling on the pile will either become runoff across the surface of the pile, infiltration as groundwater recharge to the pile, or evaporation. These three processes form the external portion of the water balance. Within the pile, infiltrating groundwater may go into storage in the waste coal pore space, become discharged as lateral seepage near the edges of the pile, or contribute to baseflow via groundwater flow below the water table. Soil moisture as groundwater storage within the waste coal was approximately 15 to 25% by volume during the summer compared to 15 to 35% observed during the winter. In general, maximum infiltration is expected to occur during the winter months with only minor recharge occurring during the summer. Transpiration was considered to be negligible due to the lack of vegetative cover on the pile.

The Hydrogeologic Evaluation of Landfill Performance (HELP) model was used to assist with quantifying the water balance components such as the pre-remediation infiltration rates and to assist in the subsequent evaluation of pore water chemistry predictions. The HELP computer program is a quasi-two-dimensional hydrologic model used for evaluating the movement of water across, into, through and out of landfills. The model utilizes climatologic and soil data to evaluate surface storage and runoff, infiltration, percolation, evapotranspiration, soil moisture storage and lateral drainage. The model can also be used to evaluate alternative barrier cover designs when dealing with climatological data that covers a large time frame.

The HELP model results indicated that the net annual recharge to the waste pile is approximately 75,000 m<sup>3</sup>/yr while the estimated runoff is approximately 5,000 m<sup>3</sup>/yr. The hydrogeology investigations indicated that an additional 15,000 m<sup>3</sup>/yr of groundwater recharge the pile from upgradient each year. Figure 2 presents the HELP model results for a 100 year projection of the annual unit rates for precipitation, infiltration, runoff and evapotranspiration at the waste coal pile under pre-remediation conditions.



**Figure 3.** HELP Model Predicted Annual Unit Rates for Precipitation, Infiltration, Runoff and Evapotranspiration.

## PROBLEM FORMULATION AND SCREENING LEVEL RISK ASSESSMENT

A Problem Formulation (PF) and Screening Level Risk Assessment (SLRA) was conducted to identify and evaluate the potential for immediate threat to human health and to define assessment endpoints for ecological risk assessment; the PF and SLRA have been conducted based on current (pre-remediation) conditions. A comprehensive risk assessment will be conducted following remediation of the waste coal pile.

### *COPC Screening*

Chemicals of potential concern (COPCs) retained for evaluation included those chemicals identified in the various environmental media as exceeding the applicable standards/criteria/guidelines. A summary of the COPCs is presented in Table 1.

Medium	Chemicals of Potential Concern (COPCs)
Waste Coal/Native Soil	arsenic, copper, naphthalene, phenanthrene
Groundwater	cadmium, cobalt, copper, nickel, zinc, sulphate
Marine Sediment	acenaphthene, acenaphthylene, anthracene, chrysene, fluorene, 2-methylnaphthalene, naphthalene, phenanthrene, arsenic, copper, mercury
Marine Surface Water	aluminum, cadmium, cobalt, copper, iron, manganese, nickel, zinc
Freshwater Sediment	naphthalene, phenanthrene, arsenic
Freshwater Surface Water	none

**Table 1.** COPCs identified in various media at the Site. Human and ecological receptor exposure to the COPCs was evaluated in the PF and SLRA.

### **Human Health**

A human health SLRA was conducted to evaluate potential risks to Site users under the current conditions. Exposures and associated risks to recreational Site users via incidental ingestion, dermal contact and inhalation of fugitive dusts were estimated. Non-cancer and cancer risk estimates were below the applicable risk-based standards of 1E+00 and 1E-05, respectively. Exposures and risks to seafood consumers were also estimated using measured shellfish tissue concentrations; risks were below the applicable risk based standards.

### **Ecological Risk Assessment**

Based on the results of the environmental investigations, the widespread deposition of waste coal in the intertidal and subtidal sediments and the measurement of elevated COPC concentrations in seep water draining from the pile, marine aquatic species are considered to be the primary ecological receptors of concern at the Site. Other potential receptors of concern include terrestrial plants, soil invertebrates and wildlife.

Assessment endpoints for ecological risk assessment were identified as follows:

- Qualitative review of species composition and habitat quality in contaminated areas in various intertidal zones;
- Examination of partitioning of the COPCs in the ecosystem, with primary focus on sediments and aquatic biota;
- Assessment of adverse effects to benthic and pelagic species using laboratory bioassays; and,

- Measurement of COPC concentrations in shellfish tissue (e.g. clams and oysters).

Preliminary evaluation of the above endpoints has been conducted to identify the potential for immediate impacts to ecological receptors of concern and to identify areas requiring further evaluation.

Although variations in species composition were observed during biological surveys conducted for Baynes Sound, the differences are suspected to be related to varying substrates and salinities, as well as zonation. Marine flora and fauna have colonized the intertidal and subtidal zones, including an extensive eelgrass bed.

Sediment toxicity testing was conducted for two organisms, the amphipod *Eohaustorius estuarius* and the polychaete *Neanthes arenaceodentata*. The tests measured amphipod survival and test-end reburial, and polychaete survival and growth. No toxicity was observed for *E. estuarius*, however, sublethal and lethal toxic effects were observed for *N. arenaceodentata* in one sample collected during the initial testing; the toxic sample was collected from the iron stained area located on the east side of the waste coal pile. No toxicity was observed for the polychaete in a second round of testing, which included samples from the iron stained areas. An additional round of testing is currently being conducted to further evaluate potential effects to benthic invertebrates. The results to date suggest that although elevated iron concentrations may be toxic to benthic organisms, the elevated concentrations of PAHs and metals (arsenic, copper and mercury) in the marine sediments are not toxic and are not bioavailable. This is supported by the available literature (Bender et al., 1987).

Groundwater and seep water toxicity testing is currently being conducted for three organisms including, topmelt (*Atherinops affinis*), sand dollar gametes (*Dendraster excentricus*) and oyster spat (*Crassostrea gigas*). Preliminary results for the dilution series tests indicate that lethality was observed for *A. affinis* at the lowest concentration tested (6% of the original sample). Further testing for each of the organisms is being conducted using a lower dilution series. Based on the available literature, the observed toxicity is likely related to elevated iron concentrations in the groundwater and seep water.

The results of the shellfish tissue sampling program indicated elevated concentrations of cadmium in one sample collected north of the waste coal pile. As cadmium was identified as a COPC in groundwater, a second round of tissue sampling is currently underway to determine whether the observed cadmium is related to the Site or representative of background concentrations.

Site-specific groundwater remedial targets for the protection of marine aquatic life are currently being derived; the results of the laboratory toxicity testing, along with the available literature, will be used in the derivation of the targets. The final remedial design for the waste coal pile will be based on the groundwater remedial targets.

## **REMEDICATION PLAN**

A remediation plan encompassing the waste coal pile, the shoreline and adjacent low-lying areas was developed by SEACOR, SRK and KSW Resources. SEACOR is the lead consultant on the project and has conducted the environmental investigations and risk assessment; SRK has provided input on the geochemistry of the pile and has assisted in the development of the remediation plan for the pile; and, KSW has designed the re-alignment of Hart Creek. When considering remedial options, preference was given to alternatives that provided permanent solutions to the maximum extent practical. Consideration was given to the potential for adverse effects on human health and the environment, technical feasibility, the cost and risks associated with alternative options and the potential for economic benefits.

The waste coal was subdivided into four different zones for the purpose of remediation planning. These zones include the main pile, the tidal zone deposit, the Hart Creek deposit and the submarine deposit. Overall Site remediation would have to take into account all of these zones; however, their distinctive characteristics indicated that different strategies would need to be adopted. This paper discusses the remedial strategy proposed for the main pile only.

The main pile is a distinctly convex shaped dome covering a surface area of approximately 13 ha and containing approximately 1.1 to 1.2 million m<sup>3</sup> of waste coal. The material is a matrix of gravelly silts and clays. In most places the pile surface is covered by a well-compacted crust, probably mostly associated with frequent use of the pile by recreational motorcycle and all terrain vehicle (ATV) users. Pools of standing water establish for short periods of time in low-lying areas of the pile during the rainy season; however, for the most part the pile appears to be well drained through a naturally established dendritic erosional type drainage pattern. There are no signs of severe erosion gulleys over the undulating surface areas of the pile; however, significant erosion gulleys on the steep perimeter side slopes attest to accumulated volume runoff, which suggests that the compacted crust likely sheds significant amounts of water.

The coarse nature of the waste material is probably resulting in a net downward flux of water. However, it is considered reasonable to assume that all surface runoff that comes into contact with the waste coal should be considered contaminated. Currently all this runoff enters either the ocean or Hart Creek in an uncontrolled fashion.

There are substantial precipitates present on the over-steepened perimeter slopes of the waste coal pile, indicating that evapo-concentrated salts could occur should a net upward flux at the surface be present. The cementation in these slopes is probably a result of the release and precipitation of iron produced by oxidation of sulphides in the host rock. As the pile turns acidic over time this cementation may degrade, resulting in a destabilization of the slopes.

The waste pile is predominantly un-vegetated, probably in part as a result of the bulk of this pile being frequented by recreational vehicles. Based on the physical and hydraulic properties of the waste coal, the preliminary geochemical data and demonstrated nutrient

deficiencies, direct re-vegetation as a remediation alternative is not sustainable and would not achieve the remedial objectives.

### **Contaminant Release Mechanisms**

Various transport mechanisms have been identified by which contaminants may be released from the Union Bay waste coal. These include:

- Wind dispersion of the waste coal solids;
- Leaching of metals by infiltrating water and runoff;
- Leaching of metals by tidal effects;
- Shore erosion by wave action within the tidal and subtidal zone, and
- Shore erosion by stream flow in Hart Creek.

It is technically most challenging to control oxidation and leaching of the waste coal and therefore the evaluation of remediation alternatives was focussed to specifically address these issues. The erosion pathway is also of concern and requires consideration in the remediation plan.

The waste coal is acidic or is potentially acid generating. Under the current Site conditions, acidification of the pile is expected to continue into the future as the oxidised layer continues to produce acid. Possible control measures to reduce metal loadings from the waste coal could include:

- Alkaline amendment to offset excess AP.
- Measures to control oxygen ingress into the pile.
- Reduction or elimination of infiltration of water.

The first 2 options were considered to be impractical. Oxidation of the coal waste is considered to be advanced. An oxygen barrier would reduce the rate of oxidation, however stored leachable acidity in the waste coal is already sufficient to cause the pile to acidify in the absence of oxygen. As a result, control of oxygen in the waste coal pile is only being considered in conjunction with other remedial measures.

Reduction of infiltration of water is considered to be beneficial since it reduces the volume of water moving through the waste coal and consequently the loadings of acidity and contaminants. This is based on the expectation that concentrations of contaminants leaching from the oxidation zone are limited (i.e. concentrations are fixed). Several factors can limit concentrations, including solubility of the metal salts indicated by thermodynamics, sorption processes and the kinetics of dissolution. The highly acidic conditions in the surface waste coal indicate that solubility is extremely high. Nonetheless, moderately acidic conditions deeper in the pile suggest that precipitation of metals will occur and acidity and metal loadings will depend on the infiltration rate.

Based on these considerations, an infiltration barrier will result in a reduction of contaminant loadings. However, the reduction in loading is not expected to be in direct proportion to the reduction in infiltration (e.g. 80% reduction in infiltration will not

reduce loading by 80%). The actual reduction in loading will be based on the type of barrier selected.

The main waste coal pile is already acid generating throughout the exposed surface and for the purposes of evaluating remediation goals, the following assumptions have been made:

- Release of contaminants through wind blown dust should be minimized.
- Release of soluble oxidation products to the surface and groundwater environment as a result of acid generation should be minimized.
- The waste coal pile must be restored to a final land use, suitable for residential/urban park use.

Based on the above, the selected remediation alternative for the waste coal pile is the placement of some form of physical cover (or cap) on the pile. The effectiveness of this approach would depend on the ability to effectively cut-off oxygen and water access on all sides (i.e. not only the top surface). There are a number of different cover (capping) technologies that can be used to achieve this goal. The primary cover design considerations and alternatives are discussed below.

### **Cover Design Considerations**

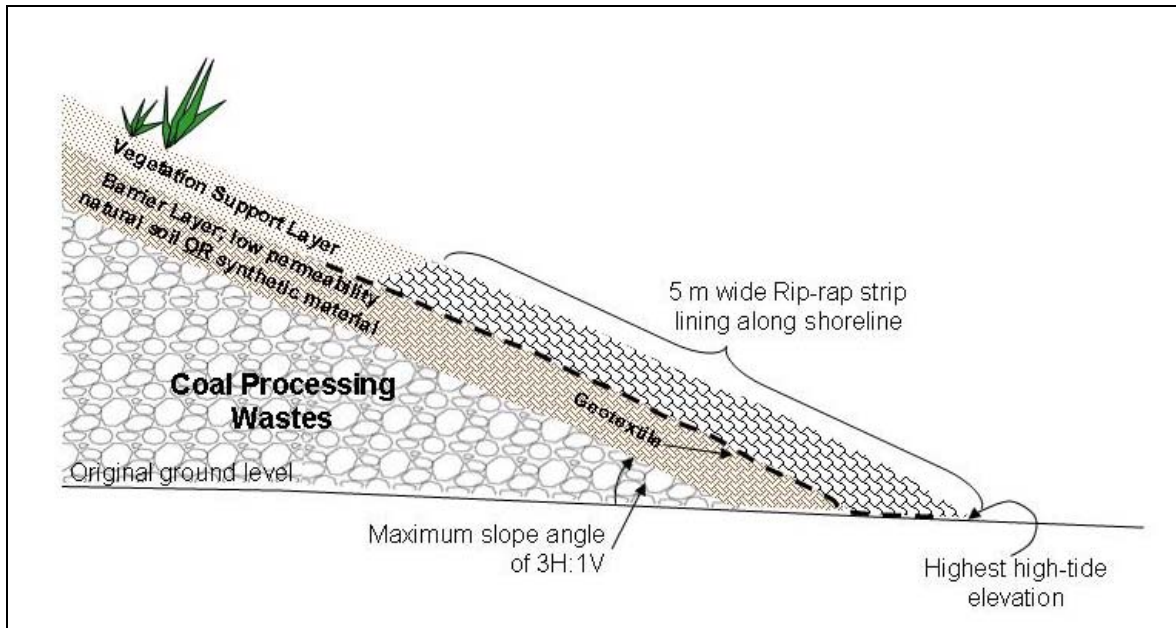
The Site climatic water balance is usually the first indicator of the appropriate cover approach to use. If the climatic water balance is net positive, low permeability barrier type covers are usually the most effective, provided suitable low permeability material is readily available. In contrast, in net negative climates, store-and-release type covers may also be effective. This Site has a net positive water balance.

The physical integrity of low permeability barrier type covers is extremely susceptible to freeze/thaw and wet/dry cycles, which reduces their effectiveness over time. The main risk of a low permeability cover at Union Bay would be desiccation due to wet/dry cycles during the summer when the water balance is substantially negative. This can be overcome by increasing the cover thickness and/or introducing surface protection layers, typically in the form of gravel or vegetation substrate layers.

The final cover design will need to consider the environment on which the cover would be constructed. Existing steep slopes, such as around the perimeter of the waste coal pile need to be re-graded to appropriate slopes and the construction completed in the dry summer period. The cover will need to be designed to accommodate residential and urban park use with special design considerations to manage contact areas with roadways and building foundations. Puncture of the cover will be inevitable and therefore, careful drainage and plug designs will be required to mitigate against these potential minor flaws in the cover.

A significant portion of runoff will be generated at the waste coal pile, and this runoff must be managed to ensure that it does not erode the cover soils and ultimately expose the underlying waste or synthetic covers if such covers are ultimately used. Shoreline

protection measures will be required in the tidal zone and at Hart Creek. Protection measures will include reshaping of the perimeter slopes of the pile to at least 3H:1V, and lining the face of the slopes with suitably sized rip-rap to provide a permanent erosion protection barrier. A schematic of the proposed cover design details at the perimeter of the waste pile is presented in Figure 4.



**Figure 4.** Schematic showing proposed cover design details at waste pile perimeter (courtesy of SRK).

### Cover Design Alternatives

Barrier covers work on the principle of limiting and/or preventing infiltration. This can be accomplished through the use of an impermeable barrier such as High Density Polyethylene (HDPE) liner, Low Density Polyethylene (LDPE), bituminous liner, Geosynthetic Clay Liner (GCL), using a layer of low permeability natural soil, or amending the surface layer of coal wastes to achieve a low permeability layer. In most cases effective moisture limiting barrier covers can also function as effective oxygen limiting covers for acid generating wastes. Based on geochemical modelling, it would appear that limiting oxygen ingress would be of less benefit since oxidation in the pile is already advanced to the point that stored levels of sulphate will continue to generate acid and leach metals for decades. The primary remediation objective has thus been identified as limiting the infiltration of meteoric water.

It is clear that only a barrier cover is likely to fully meet the remediation objectives for the waste coal pile. The four preferred cover design alternatives for the pile are:

- Alternative A – Natural soil low permeability barrier cover
- Alternative B – Synthetic barrier cover using a HDPE/bituminous liner
- Alternative C – Synthetic barrier cover using a GCL
- Alternative D – Store and release cover

There are a number of uncertainties that would impact the selection of any of these alternatives or combination of alternatives as the final choice. These include; (a) availability of suitable natural low permeability soils, (b) availability of a vegetation substrate, (c) final adopted remediation design life, (c) final adopted land use, and (e) overall cost effectiveness.

In addition, risk-based groundwater remedial targets are currently being derived for the area. These targets will be considered in the final selection of the cover type and the overall cover design.

## **SUMMARY**

The cover design will be finalized once the site-specific groundwater remedial targets have been determined. Although not described here, the remediation program for the Site also includes the realignment of Hart Creek to eliminate communication of groundwater between the creek and the waste coal pile. The upper reaches of Hart Creek were rechannelled in September 2005. Work in the lower reaches will be conducted in conjunction with the re-grading and capping of the waste coal pile, which is scheduled for summer 2006.

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