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RECLAMATION RESEARCH AT HIGHLAND VALLEY COPPER

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ABSTRACT

The reclamation program is an integral part of the mining and mine decommissioning activities at Highland Valley Copper. The reclamation program comprises three related components: planning, operations and research. The planning components of the mine reclamation program include scheduling areas available for future reclamation, identifying site preparation requirements and reclamation objectives. Operational reclamation activities include mine decommissioning work, supervision of site preparation, and seeding and planting sites prepared for reclamation. Reclamation research activities include assessment and monitoring programs and programs to identify specific techniques to facilitate future reclamation planning and reclamation activities. Highland Valley Copper takes a leading role in the reclamation planning/scheduling and mine decommissioning activities. C.E. Jones and Associates provides consulting and supervisory services in the operational and research components of the reclamation program at Highland Valley Copper. This paper provides a brief overview of the reclamation research program and the integrated approach to mine reclamation at Highland Valley Copper.

INTRODUCTION

Highland Valley Copper operates one of the larger base metal mining complexes in North America, producing approximately 370 million pounds of copper and 4 million pounds of molybdenum annually. The mine site is located in the southern interior of British Columbia, approximately 80 km southeast of Kamloops. The mine encompasses approximately 5900 ha of disturbance and extensive reclamation activities were initiated on the site during the 1980's.

Highland Valley Copper has undertaken a research program to provide quantitative measure of the reclamation success of specific reclamation activities and to identify and implement specific techniques to improve reclamation success. The program addresses routine monitoring of reclaimed sites to determine productivity, assess species composition, assess foliar nutrient status, measure foliar metal concentrations, determine tree and shrub survival and growth performance, and to monitor aquatic productivity of lakes and ponds. Additional studies have been initiated to define site preparation and recontouring requirements to reclaim waste rock sites, identify suitable overburden materials for capping mine waste, examine the success of inoculating grass species with nitrogen-fixing bacteria, and to develop a passive wetland system for aqueous metal removal. Regional studies have also been conducted including vegetation productivity and soil and vegetation trace element assessments which have specific implications for site reclamation. The

following discussion will present an overview of the reclamation research programs and their application to planning and operational reclamation at Highland Valley Copper.

RECLAMATION RESEARCH

Reclamation research provides the foundation for successful reclamation planning and operational reclamation at Highland Valley Copper. The reclamation research program consists of assessment and monitoring programs and "predictive" studies. The assessment and monitoring programs are designed as on-going programs to measure and assess the performance of reclaimed sites. In addition, the reclamation research program includes "predictive" studies designed to address specific areas of concern and to provide data that can be used to facilitate future reclamation planning and mine decommissioning.

Assessment and Monitoring Programs

The reclamation research program at Highland Valley includes assessment and monitoring programs to evaluate and quantify the status and success of reclaimed sites. The assessment and monitoring programs include measurement of site productivity, and species composition. In order to assess changes in each of these parameters, an initial assessment is performed on all sites after the establishment of a vegetative cover and while the site is receiving maintenance fertilizer. These data are used to establish a baseline condition which can be compared to data collected after maintenance fertilizer applications are discontinued. A second assessment of the site is conducted three years after maintenance fertilizer is withdrawn.

Additional assessment and monitoring programs include determination of foliar nutrient status, foliar sampling to evaluate metal concentrations in reclaimed vegetation, measurement of native tree and shrub growth performance on reclaimed sites, and aquatic monitoring of mine lakes and ponds.

Productivity

Productivity sampling provides a measure of biomass production that is used to assess the performance of reclaimed sites and is one measurement to determine when sites become self-sustaining. Gradual changes in productivity are expected to occur in response to changes in species composition over time and in response to annual weather fluctuations. However, a sudden decrease in productivity following withdrawal of maintenance fertilizer may indicate a lack of ecological stability.

Productivity sampling is conducted on each reclaimed site using a systematic grid based sampling design with multiple random starts. In addition, two research sites are monitored annually: Lornex Southeast waste

rock dump (seeded 1990) is monitored to assess possible effects of weather conditions on biomass production; and, Lornex South waste rock dump (seeded 1987) is monitored to compare plant biomass production on fertilized and unfertilized exclosures. Biomass sampling has continued on Lornex South waste rock dump since 1991. Grass biomass is greater on the fertilized site than on the unfertilized site, and has declined slightly on both the fertilized and unfertilized sites from 1991 through 1995. Legume biomass has been greater on the unfertilized site than the fertilized site since 1991. Legume biomass has decreased slightly over the monitoring period on the unfertilized site. The results indicate that the biomass of legumes has remained relatively constant on the unfertilized site, while grass biomass has reduced over the monitoring period.

In addition to site specific evaluations of plant productivity on reclaimed sites, regional studies of plant productivity have been undertaken on sites in the Highland Valley adjacent to mining areas. The purpose of these assessments has been to determine baseline values for comparison with productivity on reclaimed sites.

Species Composition

Assessments of species composition provide a measure of species diversity and are used to evaluate the self-sustaining capacity of vegetation on reclaimed sites. Species composition assessments utilize measurements of percent cover to provide information on the total number of species and the relative abundance of species present on a site. This information is used to refine seed mixtures for reclamation areas and to assess changes in the species composition over time.

The composition of species established on a reclaimed site provides valuable information to infer the stability of the vegetation. Ideally the vegetation cover should contain a strong component of legumes and a diversity of grasses. Legume species fix atmospheric nitrogen and improve the mine soil's nitrogen content. A diversity of grass species, particularly in the first few years after seeding suggests that the site is capable of sustaining good plant growth and is relatively stable. Species composition may change over time and often a single species will dominate the cover after a few years. Other grass species should still be present, but may occur at lower cover values.

Assessments of species composition are conducted using a grid based sampling design. Sampling densities are determined to provide adequate sampling of variations in species cover on the site. At each sampling point, species composition is assessed along a line transect 5 metres in length.

The vegetative cover on many waste rock dumps has been found to be composed of a dense to moderate cover of alfalfa, a dense to low cover of alfalfa, fescue and timothy, or a dense to low cover of timothy and fescue. Soil assessments of these site have indicated that areas dominated by a low cover of grasses have low available water storage capacity resulting from a high coarse fragment content of the waste material or from a shallow depth of a coarse textured overburden capping. The slope angle has also been found to effect the species composition of sites, but this factor is also influenced by mine soil characteristics which effect available water storage capacity.

Foliar Nutrients

Assessments of foliar nutrients have been conducted on all reclaimed sites. These data have provided information regarding the requirements for maintenance fertilizer applications (amount and composition) and data necessary to assess the stability of vegetation on sites where maintenance fertilizer applications have been discontinued. The collection of foliar nutrient samples has recently been redesigned to follow the same monitoring schedule established for productivity and species composition assessments.

Sampling is conducted during the middle of the growing season. Composite samples of each plant type (grass and legume) are collected from each site, and submitted for analytical determination of macronutrient and micronutrient concentrations. The foliar nutrient sampling program provides the data required to recognize possible nutrient deficiencies, and boron and zinc deficiencies have been detected on some reclaimed sites. To correct these deficiencies, the maintenance fertilizer formulation is supplemented with zinc and/or boron on a site specific basis.

Metal Uptake

Plants grown on mine waste may have tissue concentrations of metals that exceed background levels. At Highland Valley Copper, molybdenum and copper are the metals of concern; specifically the potential for molybdenum to produce toxicity in ruminants. Prior to 1992, limited sampling of metals in vegetation was conducted on selected waste rock and tailings sites. Due to the high variability observed in the foliar concentrations, a detailed sampling strategy was developed. The metals which have been studied include molybdenum, copper and sulphur, due to concern regarding the forage suitability of these elements for ruminant consumption. A related study has been initiated by Highland Valley Copper and Agriculture Canada to conduct a cattle grazing experiment on molybdenum rich pastures at Bethlehem Main tailings.

In 1992, a study of metal variability in vegetation grown on reclaimed waste rock sites indicated that a

systematic grid sampling program with a sampling density of 6 samples per hectare was required to adequately sample the variability in molybdenum concentration of the vegetation on reclaimed Lornex Southeast waste rock sites (Jones *et. al,* 1995). This methodology was incorporated into the sampling design of subsequent programs. To date, four reclaimed waste rock sites and three reclaimed tailings sites have been included in this sampling program. Sampling has been conducted using a rigorous grid based sampling design similar to that used for productivity assessments. The results of these programs indicate that sample densities of 4 to 6 samples per hectare on the waste rock areas and 2 samples per hectare on tailings areas should be adequate to sample the variability in the concentration of molybdenum growing on reclaimed sites. At each sample site, samples of a single grass and single legume are collected and submitted to a laboratory for analysis.

Vegetation established on these waste materials demonstrated a much higher variability in molybdenum concentration than in other elements such as copper or sulphur. The data evaluation indicates that legumes display the greatest variability and highest concentraitions of molybdenum compared to grasses. These data also indicate that the spatial variability of molybdenum is generally greater on waste rock material compared to tailings. A comparison of the mean concentration and variability of molybdenum on each of the sampled sites indicates that each site is unique. Assessment of the spatial variability and the mean concentration provide a useful measure to assess the molybdenum concern on a site specific basis.

Growth Performance of Native Trees and Shrubs

Assessments of growth performance have been conducted on selected operationally planted areas of Bethlehem, Highmont, Lornex and Valley. Assessments of growth performance on operationally planted sites have been conducted since 1992; growth monitoring is conducted two years following planting. In addition to measurement of growth characteristics, site characteristics including material type, slope and aspect were collected to determine if any differences in growth might be attributable to these factors. To date, the variation in the site characteristic data has been insufficient to facilitate a statistical comparison of growth performance and site specific factors. It is anticipated that after several years of monitoring different sites, these data can be used to evaluate the overall growth performance on a diversity of sites. Based upon the results of these assessments, lists of preferred species have been determined for various waste rock and tailings sites. At Lornex waste rock sites, preferred species include: alder, prickly rose, Saskatoon, trembling aspen, willow and wolf-willow. For Bethlehem overburden capped sites the preferred species include: chokecherry, Saskatoon, shrubby pentstemon, trembling aspen, willow and wolf-willow. The preferred species for Trojan tailings sites include: red-osier dogwood, willow and wolf-willow.

Prior to 1992, native shrub and tree species were planted within operationally seeded areas. In 1992, several open sites were planted with native shrubs and trees in areas that had not been seeded. Monitoring provided a comparison of operationally planted sites on open (unseeded) areas and seeded areas. These data suggested that shrubs planted on open areas performed better that those planted on seeded sites. The enhanced survival and growth was attributed to the lack of competition with grasses and legumes on the open areas. Beginning in 1993, the operational planting of shrubs and trees has been conducted within unseeded islands. These islands are interseeded with legume mix applied at a low rate in the year following planting. Assessments of growth performance on these sites indicates that the establishment and growth of the native trees and shrubs is enhanced by minimizing competition with grasses and legumes during the first year of growth.

In addition to assessments of operationally planted areas, survival assessments have been conducted annually on a research trial established on the Valley Northwest waste rock dump. This trial was established in 1991 to evaluate species performance for future reclamation of the Valley area. Based upon the results of the survival assessments, a species mix of buffalo-berry, chokecherry, lodgepole pine and/or ponderosa pine, prickly rose, Saskatoon, trembling aspen, willow, and wolf-willow is planted on similar waste rock sites at Valley.

Aquatic Monitoring of Mine Lakes and Ponds

Monitoring activities were initiated at selected mine ponds in 1992 to better understand peak summer growth conditions of some of the tailings ponds, pit ponds and seepage ponds, and the influence of mine drainage on natural ponds on the mine property. The purpose of this work was to assess the potential of the ponds to perform passive biological removal of metals and to develop an aquatic sampling schedule that would enable measurement and characterization of the biological state of mine ponds. The aquatic monitoring program includes physical and chemical sampling to determine oxygen and temperature profiles and aquatic nutrient balance, collection and analysis of aquatic plants and sediments, plankton tows to determine species compositions and density measurements, and collection of chlorophyll-a measurements as an indicator of algae growth.

Predictive Studies

Directed research programs have been initiated at Highland Valley Copper to address specific aspects or concerns of the reclamation program. These research programs vary in duration and scope, yet provide valuable data that can be used to facilitate future reclamation planning and mine decommissioning. Programs initiated include a study to define site preparation and resloping requirements to reclaim waste

rock sites, identify suitable overburden materials for capping mine waste, examine the success of inoculating grass species with nitrogen-fixing bacteria, and develop a passive wetland system for aqueous metal removal. Regional studies have also been conducted to assess soil and vegetation trace element concentrations which have specific implications for site reclamation.

Site Preparation and Resloping Requirements for Waste Rock

In 1990 a study was initiated on the Lornex waste rock dump slopes to assess the relationship between specific site conditions and vegetation cover establishment. A research trial was established on two waste rock dump slopes. On each waste rock dump, trials were developed using two site preparation methods. In one treatment, the entire slope was regraded to 21°; in the other treatment, the dump slope was rounded such that the upper portion of the slope was regraded to 20° to 25° and the lower portion of the slope was left at angle of repose. The findings of the study indicated that the mean total cover was significantly greater on the Lornex Northwest resloped and rounded slopes of the waste rock dumps than on the Lornex Southeast waste rock dumps.

Assessments of vegetation cover and species composition were conducted on additional areas of the large Southeast waste rock dumps in 1992. The areas assessed included level areas, shallow slopes (<30°) and steep slopes (>30°). The vegetation data were evaluated to identify associations with slope position. Mean vegetation cover was significantly greater on resloped and rounded portions of the waste rock dump compared to angle of repose slopes. Slope position was not related to specific vegetation associations present, but was related to the percentage of plots characterized by low cover (less than 20% total vegetation cover). For shallow slopes approximately 35% of the plots were characterized by low cover compared to 55% low cover plots noted on steep slopes. In contrast, only 5% of the plots assessed on level areas were characterized by low cover. These data indicate that site preparation techniques are important to ensuring the reclamation success of sites.

Evaluation of Reclamation Suitability of Overburden Material

Substantial overburden deposits associated with the development of the Valley pit represent potentially useful material to enhance the reclamation capacity of some sites on the mine. Valley pit overburden has been used as a capping material to improve growing conditions on selected Bethlehem waste rock sites and all Valley waste rock sites. Sampling of overburden material has indicated that coarse texture and/or elevated molybdenum concentrations limit the suitability of some overburden materials for reclamation. Studies pertaining to the reclamation suitability of Valley overburden material were initiated in 1989 and

included greenhouse studies, field and laboratory studies. The geochemical data were evaluated statistically to identify cutoff concentrations of molybdenum in overburden that could yield vegetation within the standard acceptable for cattle forage. The geochemical data were also correlated to Valley overburden stratigraphie units to identify those units that might consistently achieve the reclamation criteria. Based upon the findings of this study, geochemical and textural criteria were developed to identify overburden material suitable for use as a reclamation capping material on selected Bethlehem and Valley sites. Related field studies were undertaken to determine the optimum overburden capping depth to ensure successful site reclamation.

Influence of Mine Soil Materials on Vegetation Establishment

Field observations indicated that the vegetative cover supported on reclaimed sites was often variable, despite apparent similar growing conditions. A field program was undertaken to evaluate surface and subsurface factors that may influence the success of vegetation cover development on reclaimed sites. The program included sites at Lornex where vegetation was established directly on waste rock material, and sites reclaimed at Bethlehem on an overburden cap. The mine soil's moisture holding capacity, determined by the soil texture, soil depth and coarse fragment content was found to be the most important factor influencing the reclamation potential of the site. For sites with an overburden capping, a minimum depth of 40 cm of overburden was recognized as important for the establishment of vegetation (Bloodgood *et. al,* 1995). The results of this study indicate that material characteristics are critical to the development of successful reclamation sites, and suggest that the final material placed on the surface of the dump should have an adequate fine particle component with a minimum coarse fragment content to optimize the water storage capacity of the soil. Typical depth of rooting suggests that these material characteristics are especially important for the upper one metre of the reclaimed site.

Grasses Inoculated with Nitrogen Fixing Bacteria

A research program was initiated in 1995 to assess the ability of nitrogen-fixing bacteria *(Azospirillum brasilense)* to supply nitrogen to various inoculated grass species. The bacterial inoculum has been reported to improve water and mineral uptake by grass. By supplying nitrogen to grass, the inoculum could potentially reduce the need for chemical fertilizer applications to low fertility mine soils. The research trial was conducted with the participation and support of the BC Ministry of Agriculture. The trial was designed to test the performance of inoculated and non-inoculated treatments on fertilized and unfertilized waste rock and tailings sites. Future monitoring will evaluate the productivity and species cover on these trials.

Aqueous Metal Removal Using a Passive Wetland System

Highland Valley Copper has examined various alternatives utilizing natural processes to reduce metal concentrations in certain discharge waters. A relatively low maintenance treatment option may be provided by biological treatment utilizing aquatic plants and sulphate reducing bacteria in a wetland setting. Monitoring results of various ponds on the mine site has indicated that bioaccumulation of molybdenum in plant tissues and sediments is occurring. In July 1994, design and construction of a biological treatment pond was initiated in order to better define the metal removal capabilities of a wetland system. A site was selected adjacent to a seepage pond in the Highmont tailings area. This location was chosen because water monitoring data indicated higher molybdenum concentrations than the other monitored seepage ponds; the seepage pond provided source water for testing the system.

Construction of a closed system, with controlled inflow and outflow was deemed essential to determine the limitations of the wetland system. To achieve this principal design criteria, a 49,000 litre steel tank was modified to simulate a pond. To optimize biological activity, several elements were required. Sulphate reducing bacteria provide the backbone of the biological treatment system and are the mechanism by which soluble molybdenum sulphate in water is reduced to non-soluble molybdenum sulphide. Three physical conditions are required to promote this reaction and include a coarse granular substrate to provide a large surface area for the reactions to occur, the presence of sulphate reducing bacteria, and anoxic conditions. A substrate of coarse pea gravel was placed in the tank to a depth of approximately 0.8 to 1.0 metre. Sulphate reducing bacteria present in the shallow sediments of the S2 seepage pond were collected and added to the treatment pond. Duckweed, a free floating aquatic plant was used to provide a biological cover for the tank and induce anoxic conditions. Results of the 1995 monitoring program were very positive and indicate that the system is effectively reducing molybdenum concentrations based upon comparison of the aqueous molybdenum concentrations of inflow and outflow samples. Future monitoring will focus on determining the quantity of mine water that can be treated effectively using this system.

Regional Studies of Trace Elements in Soil and Vegetation

In 1992, a preliminary assessment was conducted of metal concentrations in various plant species collected in forest and grassland areas in the area of the Valley pit. These data identified foliar concentrations of molybdenum elevated over those which have been suggested to cause molybdenosis in cattle. During 1993 and 1994 this program was expanded to assess metal concentrations of soil and various plant species in several areas adjacent to Highland Valley Copper. Due to the variability of molybdenum uptake by different species the molybdenum content of the sampled vegetation was evaluated by species. The results of the

program detected elevated concentrations of molybdenum in vegetaition; it is inferred that the findings are indicative of geochemical anomalies expected in mineralized zones. These data suggest that the detected concentrations are likely to be attributed to regional soil geochemistry within the periphery of the Guichon Creek batholith, host to the Highland Valley Copper mineral deposit.

SUMMARY

Highland Valley Copper has undertaken a reclamation research and monitoring program to support the long range reclamation and mine decommissioning activities. This approach has provided valuable data to identify successful reclamation techniques and facilitate reclamation planning and implementation. Reclamation research and monitoring activities in the future will continue to provide essential data to quantify the performance of reclaimed sites and methods to achieve the reclamation objectives developed by the mine.

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