THE DEVELOPMENT OF AN AQUATIC ECOSYSTEM IN TROJAN TAILINGS POND, HIGHLAND VALLEY COPPER

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ABSTRACT

Trojan Tailings Pond at Highland Valley Copper developed in only 15 years from a biologically inactive water body into a productive lake with a well established aquatic ecosystem and fishery. After a further 8 years, the Trojan system remains sustainable with small annual nitrogen additions. There were two compatible goals in this work; improving tailings water cover quality by biochemically modifying the sediment-water interface, and making the pond productive for wildlife and fish. This transformation was achieved using a few simple and inexpensive procedures including fertilization and introduction of essential organisms. The success at the Trojan Pond has encouraged the use of similar techniques in other water bodies on the mine site.

LOCATION & HISTORY

Highland Valley Copper operates one of the world's largest open pit copper mines. The mine is located approximately 210 kilometers northeast of Vancouver and 75 kilometers by road southwest of Kamloops, in British Columbia (Fig. 1). Large scale mining began in the valley with the commissioning of the Bethlehem Mine in 1960. This was followed by the start-up of Rio Algom's Lornex mine in 1972 and Teck's Highmont Mine in 1982. Cominco began mining the Valley deposit in 1983, initially using the Bethlehem concentrator to process the ore.

In 1986, Cominco and Rio Algom combined their Highland Valley assets to create Highland Valley Copper. In 1988, Teck and Highmont Mining Corporation added the Highmont Mill to the partnership

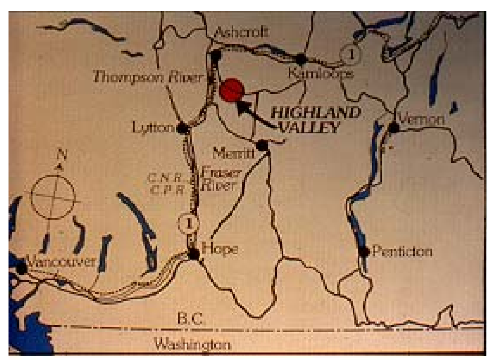


Figure 1. Location Map of Highland Valley Copper

BACKGROUND INFORMATION ON TROJAN TAILINGS FACILITY

The Trojan Tailings facility is bound by natural topography on three sides and contained to the south by Trojan Dam. Trojan Dam was completed in 1988 to its final elevation of 1441.5 m. Tailings placement ceased in June 1989. Reclamation efforts began in the early 1990's. The majority of the surface has been successfully reclaimed with a mixture of agronomic species and native shrubs.

Figure 2 shows the tailings pond bordered by the various reclamation plots covering the dam and spigotted tailings photographed in 2000 and a similar view from 2007. Please note the improved vegetation cover on the dam capped with overburden in 2005 and the recent devastation by mountain pine beetle in the Trojan watershed.

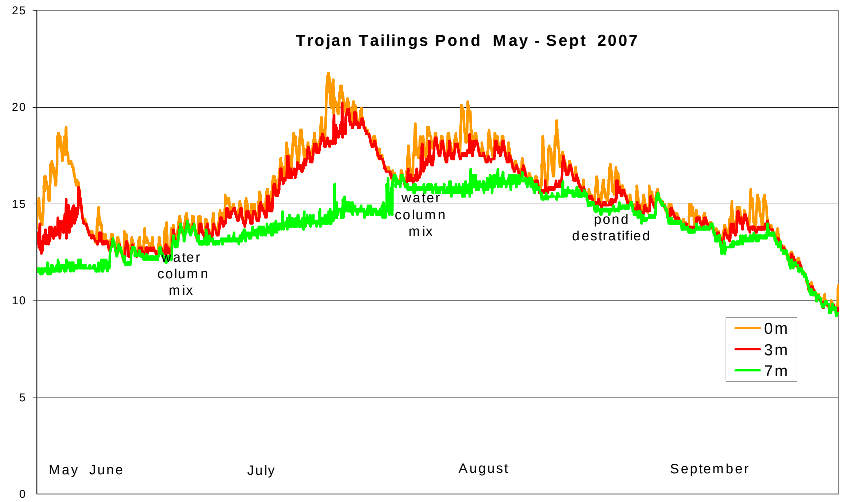
Figure 2: Aerial Photographs of Trojan Tailings Pond 2000 and 2007

POND LIMNOLOGY

The water level of a decommissioned tailings facility is fixed by other concerns and reclamation works with what is left by operations as opposed to embarking on large-scale modifications of the tailings pond. Trojan Tailings Pond has a surface area of 26 hectares, an average depth of 4 m and a maximum depth of 8 m at the estimated average water elevation of 1433 m (Wong & Lo, 1996). Trojan's water elevation was 1436 m in 1991 and since then has oscillated downward between 1434 and 1432 m after seepage return ceased in 1996. Inflows consist of surface runoff from the surrounding area and from a surge pond on Trojan Creek constructed to provide constant flow for a spawning channel. The estimated inflow and the measured seepage approximate a flushing time of two years for the pond. Water levels drop between 0.5 to 1.5 meters each summer/fall before being recharged by snowmelt and spring rainfall.

Originally Trojan tailings pond was 9-10 m deep and it stratified from May to August with periodic mixing during wind storms. Approximately 10 % of the pond volume became anaerobic at the base of the thermocline during a stratified summer. With stratification, decomposition activities in the sediments caused low dissolved oxygen concentrations in the bottom water. In recent years, low water levels encouraged water column mixing and stratification became infrequent (Fig. 3). Anaerobic conditions at the sediment-water interface were confined to the brief periods of stable summer weather.

Figure 3: Trojan Tailings Pond 0 m, 3 m & 7 m Thermistor Data, 2007



TECHNIQUES USED TO RECLAIM TROJAN TAILINGS POND

Today, Trojan tailings pond has a thriving aquatic ecosystem that also performs gradual removal of aqueous metals. Aquatic plants and algae create a "conveyor belt" delivering adsorbed metals to the sediments as they die. Their adsorption of metals are often far in excess of aqueous and sediment concentrations. The range of biochemically active surfaces is large. HVC does not attempt to control the type of microflora in its tailings ponds – they create a variety of habitats and rely on microfloral diversity. Trojan's transformation from a tailings facility into an ecosystem was achieved using fertilization and a sequence of native species introductions, detailed below.

1. Fertilizing

Fertilizer is usually required to accelerate the transformation of a tailings pond into an aquatic ecosystem. In many cases, wash-in from terrestrial reclamation surrounding the pond was sufficient to stimulate initial algae growth.

Trojan tailings pond nutrient sources include inflowing water, nutrient recycling from the sediments and reclamation activities in its immediate watershed. Left alone, inorganic nitrogen and phosphorus losses exceed gains in Trojan due to:

- Large N losses as nitrogen gas via denitrifying bacteria (they develop in large numbers in basic ponds)
- Large nutrient losses via particulate transfer to the sediments
- P binds to humic color compounds from Trojan inflows and are not available (Lee et al., 1980)
- Donations of nutrients from Trojan Creek dropped by more than 50% in recent years
- Organic acids contributed by Trojan Creek with logging activity in recent years depress nitrifying bacteria activity (the bacteria consume 10 – 40% of a lake N budget).
- Sediment nutrient releases into the bottom water are much larger under prolonged anaerobic conditions and they only occur in years with high water levels.

The sum of all these factors created a nutrient deficit that starved the algal base of the food chain. On-going fertilizer additions are needed at Trojan. While it is almost impossible to perform trials or bench tests to predict the algae that will be produced, some generalizations are possible:

Timing The timing of fertilizer additions is based on the type of algae that dominate over the growing season. Fertilizing in late winter/early spring promotes diatoms, early summer encourages greens, and early to late summer tends to promote blue-green (cyanobacteria), while the hardy protozoan algae occur in all seasons.

Amount For Trojan, the amount of fertilizer required was calculated based on the amount of nitrogen (N) and phosphorus (P) needed to bring one pond volume of distilled water into the range of adjacent productive lakes. This calculation was then doubled to allow for sediment adsorption. In general, fertilizer application rates range from 0.10 to 0.25 tons of high P fertilizer per hectare of tailings pond (St. Germain, pers comm). The final nutrient concentrations should fall in the nutrient ranges of 0.002 - 0.230 mg/L phosphate, 0.004 - 0.80 mg/L nitrate, 1 - 282 mg/L sulfate and 0.2 - 33 mg/L potassium for vigorous algae growth (Nordin, 1985; Stockner, 2001).

N:P Ratio The ratio of N:P is crucial to algae diversity and density. The ideal nutrient ratio is 14N : 1P for most species.

Application Method Liquid fertilizer or dissolved granular fertilizer can be mixed into the surface water using the wake of a boat, but it is a time-consuming method. Aerial fertilizing of the shallows and/or the shoreline is fast and effective. Fertilizer can also be dissolved into flowing water, bearing in mind that cooler water with its dissolved nutrient load will find the depth in the pond with a matching density, usually near the bottom.

Initially we applied 500 kilograms of 0-45-0 granular fertilizer to the shallow areas of Trojan pond by helicopter in May 1998. Un-dissolved granules released nutrients to the sediment where they can stimulate macrophyte growth. We moved to using 3 doses of 25 gallons each of liquid ammonium polyphosphate (10-34-0) and urea ammonium nitrate (28-0-0) during the 2005 growing season. Less fertilizer was added in 2006 and 2007 and pond productivity started to slow down. The full amount of fertilizer resumed in 2008. In other tailings ponds, diversion of high nitrate blast rock seepage would be an effective treatment for the seepage and maintain nitrate concentrations in the tailings pond as well.

The maintenance fertilizer program at Trojan tailings pond supports a diverse algae population of 20-25 species and boosts algae production significantly.

2. Bacteria Introductions

One of the biggest goals of tailings pond reclamation is to establish an organic layer on the sediments to support bacteria. Over 99% of the bacteria in any pond reside in the upper two centimeters of the substrate. The types of bacteria present in this crucial habitat are controlled by redox and their activity is affected by temperature.

Once water chemistry is suitable, bacterial colonizing by photosynthetic bacteria and chemotrophs begins without assistance (Koschorreck, 2002). Initial bacterial growth can be accelerated using introductions of surface substrate removed from other ponds in burlap sacks transported in sealed pails or by introducing aquatic plants. After algae and plant organic carbon is available, bacterial flora expands rapidly to include decomposers such as methanogens and sulphate reducing bacteria (SRB). The bacterial colonization process only took 4 – 5 years in Trojan but is still expanding after 15 years.

3. Algae Introductions

The easiest algae introductions are unavoidable; if there is natural inflow, donor material will come with it. The addition of natural sediments and aquatic plants also introduced hitch-hiking algae species and accelerated reclamation. Without the introduced microflora, fertilizing tends to cause the super abundance of one or two algal species. When that bloom collapses, other microflora may or may not be able to replace it if the species pool is small.

For larger algae, deliberate introductions are often required. Stonewort algae species do not transplant successfully in weed sandwiches (Sec.4) and attempts to hand-plant *Chara* from Trojan to other HVC tailings ponds had poor success. Stoneworts are worth the effort though; in Trojan they harbor more invertebrates and accumulate more metal than any other plant. All algae introductions are enhanced by fertilizer additions.

Oscillatoria is an ecologically important blue-green alga whose filaments form dense mats that chelate metals. *Oscillatoria* is well adapted to low light conditions and grows deeper than most algae or aquatic plants. They can be introduced by collecting mats off the sediments of a donor pond, but they will usually “show up” when nutrient concentrations are sufficient. Currently, *Oscillatoria* mats cover more than 20% of Trojan’s substrate.

It is difficult to prevent introduced filamentous green algae from blowing up on shore. Enclosing the material in bird netting weighted with rocks has had some success. Most filamentous algae grow in a relatively narrow selection of conditions and pH, thus the donor site must match conditions in the recipient pond. Filamentous algae growth in a single season can be explosive if nutrients are abundant. Masses of *Mougeotia* and *Spirogyra* that could not be walked through established in the Bethlehem Main Tailings Pond in one year. The biomass produced far exceeds that of plankton algae.

All types of algae perform bioaccumulation and are the biggest transporter of molybdenum to the bottom of natural lakes (Wetzel, 1975). Trojan algae production prevented the expected increase in aqueous Mo as Trojan water concentrated by evaporation. Molybdenum bioconcentrations in algal tissues ranged from 77x to 630x the aqueous molybdenum concentrations. Copper concentrations ranged from 3,600x to 51,000x at Trojan. Filamentous algae and *Chara* bioaccumulated the most metal without direct contact with the metal-rich sediments. Filamentous algae contained more Mo than any other plant tissue (up to 460 mg/kg), but are an unfortunately minor component of the algae community at Trojan.

4. Submerged Aquatic Vegetation (SAV) Introductions

A tailings pond with vigorous bacterial and algal production is ready for aquatic macrophyte introductions. Large quantities of rooted macrophytes were introduced using “weed sandwiches.” Plant sandwiches consist of 0.5 -2 m square section of stucco wire, folded over a 2 - 4 cm layer of local, native milfoil or pondweed that had developed adventitious roots. They were tagged according to species mix. The sandwiches were kept moist and installed within 24 hours. Installing them was a matter of throwing them from a boat into 1 to 4m deep water. The sandwich method has a similar survival rate to hand planting but with far less effort.

For some plants, collecting seeds (Potamogetons) or turions (Elodea) and tossing them in over soft sediments was successful. Another effective means of introducing local aquatic macrophytes was by transferring the upper sediments from weed beds. While the plants may not survive the transfer, root fragments and the seed bank in the mud do.

Using local transplants takes advantage of ecotypically adapted varieties, but the biggest benefit is the hitchhikers. The attached microflora on the leaves and roots can be more valuable than the plant itself. Algae such as the filamentous *Mougeotia* and *Spirogyra*, nematodes, and fresh-water shrimp were introduced with the macrophytes.

At Highland Valley Copper, the best introduced aquatic plants included:

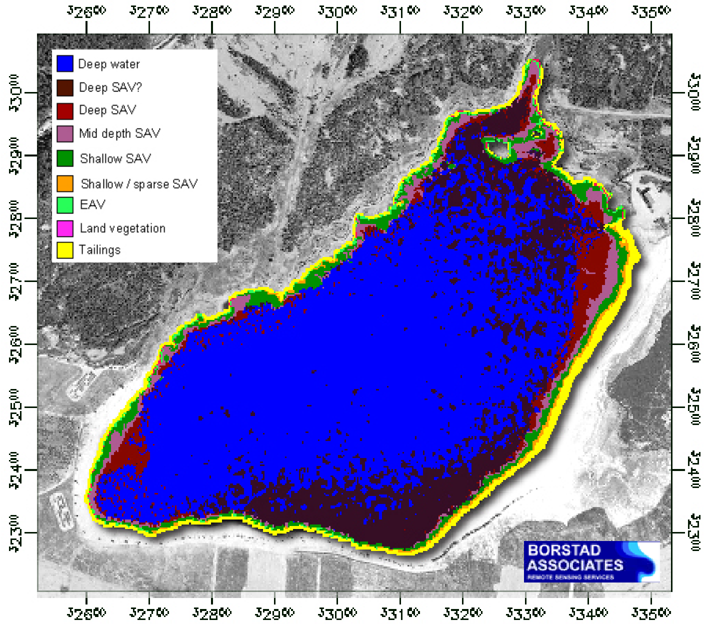
- Slender pondweed *Potomageton pectinatus* - tolerates high turbidity
- Native milfoils *Myriophyllum exalbescens* & *farwelli* - very high growth rates and form seed heads
- *Elodea canadensis* - forms carpet preferred by fish for foraging
- *P. richardsonii & P. crispus* - seed heads used by waterfowl
- Aquatic buttercup - *Ranunculus aquatilus* - survives some exposure of weed bed
- *Zannichellia palustris*- tolerates fluctuating water levels (Warrington, 1980, Wetzel, 1975)

The depth range for optimal SAV growth is 0.5 to 4 metres, although the milfoils and aquatic buttercup have persisted at 8 m in clear water. In general, planting should not exceed the Secchi depth or light will be insufficient. Transplanting results are best after growth from the root crowns is well established and adventitious roots have developed (usually in late summer).

The sandwiches were planted in a range of depths and a selection of each sandwich type was planted in the donor lake as a control. It was then possible to decide if the transplant techniques or something in the tailings pond affected success. Granular high phosphorous fertilizer was applied for two to three years prior to weed sandwich installation and the weed beds recycled nutrients after that.

Lateral expansion of two to three times the original sandwich in one season is maximal, but the main cause of plant expansion is rooted fragments. Most macrophytes lose fragments that have adventitious roots and many of those fragments will settle and root. In several small Highland Valley Copper tailings ponds, a 250 man-hour weed sandwich planting effort translated to full plant cover within 3 years. At Brenda Mines 80 ha tailings pond, macrophyte cover expanded from 0 to 60 % in three years from the initial investment of 400 man-hours. Over the years since planting, weed bed size and density increased and species composition shifted.

Figure 4: Aquatic Plant Image of Trojan Tailings Pond



NOTE: the blue area is too deep to discern plant growth accurately with remote imaging (After Borstad, 2007)

Trojan's aquatic macrophyte cover is about 9.25% for shallow, dense beds and 35.2% for deep, sparse *Chara* (Fig. 4).

Submerged macrophytes use roots primarily as anchorage and rarely pick up metals from the sediments. They simply adsorb metals in a process akin to ion exchange so that older tissues and even dead plants usually contain many times the molybdenum of live tissue. While it is affected by a variety of other factors, molybdenum concentrations have decreased in macrophyte tissue since 1994; a reflection of lower aqueous concentrations - circumstantial evidence that sediment concentrations are less involved in macrophyte metal contents than aqueous metal levels.

6. Zooplankton & Invertebrate Introductions

Zooplankton No zooplankton transplants were required at Trojan. The tailings pond consistently supports a large copepod - chladoceran zooplankton community despite the changes in algae dominance. Water temperature and the amount of food available is more important to zooplankton growth than the particular food types. In other tailings ponds, plankton hauls from local ponds can be transferred. Zooplankton and other invertebrates come in on the weed transplants or simply "show up" when conditions are suitable. At Trojan, the zooplankton population is diverse but dominated by copepods and chladocerans, a desirable situation. Invertebrate density and diversity now approximates that of a local natural lake. Amphipod and copepod numbers decreased after fish predation began. Their tissues did not accumulate molybdenum as they did copper.

Invertebrates Invertebrates were not introduced until there was algae and detritus for them to graze on. Freshwater shrimp (*Gammarus and Hyalella*) are easily netted and are essential to fishery development.

They were dumped into macrophyte transplants or filamentous algae. There are restrictions and permits required to transfer live invertebrates in many jurisdictions. We avoid these issues at HVC by transferring from established ponds on the property. Trojan Tailings Pond has consistently high benthic invertebrate densities but fewer taxa compared to natural local lakes. The benthic community consisted mainly of facultative (tolerant of moderately impacted sites) *chironomids, nematodes* and *copepods.* Benthic invertebrate samples collected since 1995 contained progressively fewer amphipods (Hatfield, 1997). Predation by fish is the probable cause of their decline, but their inability to utilize blue-green algae would also compromise their growth in the years that had blue-green algae blooms.

7. Riparian Emergent and Shrub/Tree Introductions

Progressive planting along riparian areas included transplanted clumps of cattails and sedge, cottonwood and willow stakes, willow branch wattling and hybrid aspen-cottonwood plugs.

Emergents Sedge (Carex rostrata) clumps were removed by backhoe from a nearby donor site on mine property and hand-planted at the matching depth after being chopped into 15 cm^2 sections. For cattails, (*Typha latifolia)*, hand digging and hand planting worked best. Taking a minimum of 15 cm^2 clump reduced shock as compared to bare root transplants. As an added benefit, the sediments in the transplanted clumps carried vital bacteria. Sedge and cattail clumps were transplanted to saturated sub-oxic tailings within a few hours. Where the tailings were sandy, the plants were installed closer to the shoreline where lower survival rates were expected.

Shrubs 30 percent of all the organic carbon used by natural pond ecosystem is supplied by the shoreline vegetation. Emergent and shoreline plants grow much faster than their submerged relatives. Shoreline vegetation is a key component of the aquatic system and provides habitat for wetland animals. Since some of the vegetation will be consumed, metal content is important. Transplanting when the plants are semi-dormant in early spring or mid fall worked well. At Trojan, transplanting in late September took advantage of low water levels and increasing fall precipitation. Planting should be several weeks ahead of a hard frost. High phosphorous fertilizer pellets were inserted near the roots and a small depression left around the clumps to catch rain. Planning for losses and for foliar metal monitoring is prudent.

Short-term survival of shrub stakes and plugs was generally high but survival declined over time due to drought stress, tailings salinity, foraging by deer, competition from grasses and girding by rodents. Oscillating water levels and wind erosion are also very hard on newly planted material. Well-established plants can withstand fluctuating tailings pond water levels, just as they do in natural wetlands.

The hybrid aspen/cottonwood plugs planted in 2006 grew phenomenally well with 98 - 100% survival. Even the plants installed in dry, sandy Trojan tailings beach grew an average of 20 cm and had 85% survival after 15 months.

The nutrient and metal content of spring and fall composite leaf samples indicates the health of the plants as well as their usefulness as browse. For example, in 2006 & 2007 tailings autumn leaf samples from shrubs, the following occurred:

Nutrients

- the nutrients N and P trended together
- natural plantings contained less nitrogen than the riparian tailings plants but more phosphorus.
- plantings had lower P in 2007 than in 2006. (tailings are inherently P-poor and fertilization is indicated for 2008)

Metals

- substrates with high available metal concentrations grew plants with high leaf concentrations
- shrubs grown on natural soil contained less Cu and very little Mo compared to their tailings-grown counterparts
- all tailings-grown shrubs contained elevated sodium, and depended on the sodium content of the tails
- there was less calcium in tailings-grown cottonwood leaves than in cottonwood leaves grown on natural material. Copper trends with calcium, probably through related uptake mechanisms

Ongoing leaf sampling ensures that shrubs are planted in areas where the leaves will be suitable for browse.

Although survival varies between HVC tailings ponds, the following chart summarizes our experience in HVC tailings:

Summary of Riparian Planting Techniques

STAKES – Cottonwood, willow

- Stake diameter must be > 2 cm with at least 50% of the stake in the ground
- Diagonally planted 30 cm stakes grew well
- Taller stakes (>30 cm) are only needed in inundation zones
- April planting showed extrusion of stakes by frost; best dates were in late May
- Summer stake plantings in June, July and August all grew well with most leaves stripped and placed in damp tailings
- Spring planted cottonwood achieved 60-80%, but fall plantings in dry conditions gave less than 20% survival
- Fall planted stakes need to be painted with latex to avoid desiccation (several weeks ahead of hard frost)
- Stream-side “living shade” plantings grew very well
- In general, stakes planted in the driest areas were the slowest to break dormancy and the first to show drought stress in August. Drought stress was particularly bad in saline tailings.
- Stakes planted into receding water leafed out slower than those planted on dry land although planting willow by boat at Beth Main had better survival than shore planted stakes
- Submerged and thin cottonwood stakes did not survive
- Pockets of air beside stakes killed them, better results occurred in clay tailings that melt against the stake
- Stakes planted near tailings cracks had 100% mortality
- Coarser tailings gave increased mortality of both species

WATTLING

- Small branches wattled into damp tailings in April and May grew well

RIPARIAN SEED – cattail sedge rush

- Cattail seed heads collected in late September and pushed into cracks in the tailings between the low and high water lines were successful
- The buoyancy of sedge seed makes it hard to track; seed collected after frost (October) germinated best when mixed in with cattail seed
- Bulrush seed collected in October was trialed for the first time in 2006, mixed with other riparian seed. Its effectiveness is not known; lesser rush is propagating on the tailings already

BUCKET PLUGS – sedge willow cattail

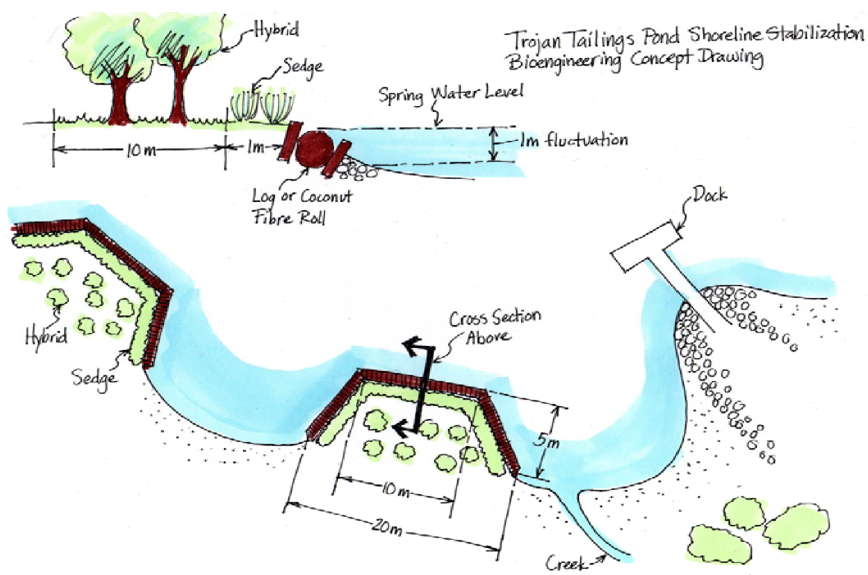
- The minimum clump size for transplanting was 10 x 10 cm planted in the fall between the high and low water lines gave the best results

PLUGS – hybrids, aspen dogwood

- Plugs can be planted in tailings that will dry to the depth of the plug provided there is adequate moisture to initiate growth
- The planting hole must be completely covered over the top of the peat
- Plugs planted in the fall or early spring were extruded by freeze/thaw cycle in the riparian tailings Late May or early June would be ideal in most years
- Using a moisture retention dip did not improve growth but did seem to increase metal adsorption
- Plugs planted near cover and in well-spaced rows seemed to encourage browsing by deer.

9. Bioengineering of Trojan Shoreline

The shoreline areas shallower than 1 m are vulnerable to sediment re-suspension and need emergent vegetation to reduce wave turbulence. Unfortunately, Trojan's dramatically fluctuating water levels of recent years make this difficult to achieve with sedge and cattail plugs or seed. Armoring of selected areas of the unstable windward shore should be attempted in 2008 as illustrated in the following concept drawing:



Illustrator: R. Massey

FISH INTRODUCTIONS AND WILDLIFE USE

In 1991, 1500 rainbow trout fry from the government hatchery at Loon Lake, each weighing about 20 grams were introduced to Trojan Pond. Additional fry were added in succeeding years (1,500 in 1992, 2000 in 1993, 2,500 in 1995 and 750 in 1996, 500 in 1999. Success was almost immediate. After one year, the 1991 fry had gained an average of 250 grams; they gained another 850grams in the second year and a further 1170 grams in year three. By 1996, some fish had grown to a length of 68cm (27 inches) and weighing 4,535 grams (10 lbs, 9 oz). Rapid growth and maturation was due to the limited number of fish relative to the abundant feed. After the installation of a spawning channel in 1996, the trout population in the lake increased dramatically. The fish remain healthy but are not reaching trophy proportions. The presence of a healthy, productive trout population is another indication that the development of the aquatic ecosystem in Trojan has been successful.

Large birds such as bald and golden eagles are frequently sighted taking advantage of the fish in the spawning channel. About 15 species of waterfowl and 30 species of shore bird currently utilize Trojan Tailings pond. Other birds are routinely sighted around the pond and make occasional use of it. Large animals such as black bear, moose, deer and coyotes also use the shoreline of this recently developed ecosystem.

WATER COVER IMPROVEMENT AFTER TROJAN TAILINGS POND ECOSYSTEM DEVELOPMENT 1990 – 2008

At Trojan, molybdenum Mo and copper Cu are the metals of concern. The major influences on Trojan water chemistry are 1) inflowing water quality and 2) recycling within the water cover. Normal Trojan Ck inflows dilute molybdenum concentrations cycling within the pond and match copper concentrations, however, metal loading in excess of the pond water occurs during high flow periods and is associated with particulate iron.

Every summer, the surface water Cu and Mo concentrations decline slowly during stratified periods via microfloral adsorption and increase following wind storms. Storm mixing suspends fines and increases the sediment-water contact for dissolution of metal ions.

When Trojan tailings pond was deep enough to stratify, the deep water accumulated nutrients and contained an average of 20 - 30% less Mo than the surface water due to negative redox and precipitation with H_2S generated by sulphate reducing bacteria. In low water years with frequent destratification, the bottom water averaged a Mo removal of only 5 %. The sediments under the anaerobic zone contain much higher molybdenum concentrations, indicating the fate of the dissolved metals.

HVC tailings pond dissolved Cu and Mo concentrations did not show significant dissolved metal release during extensive spring re-flooding of sediments exposed from June 2005 through May 2006. The increased organic content may have helped retain the sediment metals.

The annual organic carbon production generated at Trojan tailings pond after reclamation is detailed in Table 1, below.

Table 1: Trojan Tailings Pond Annual Primary Productivity

Trojan Tailings Pond Primary Productivity at 15.6 ha	standing crop (kg biomass)	cover %	annual production kg/growing season
Expected for productive pond	0.16/m^2/yr	100	2500
Trojan algae + blooms	40–50 kg/pond + 400 kg/bloomx4wk	100	1120
Trojan aquatic macrophytes	0.02–0.12 kg/m$^{2/}$yr	16	1750
Riparian vegetation	not available	0.5	100 approx
Total in Trojan Tailings Pond			**2870**

NOTE: phytoplankton 56-450 g C/m^2/yr : macrophytes 2.5 - 120 g C/m^2/yr; attached algae 62 – 70 g C/m^2/yr –Wetzel 2001

Theoretically, a further 800 kg of leaf litter could be donated by a fully vegetated riparian zone, and would enhance and stabilize Trojan Pond productivity.

Typical lake sediments from the Highland Valley region range from 3 to 12 % total organic carbon. A newly decommissioned tailings pond contains near non-detectable TOC. After reclamation, the deepest area of Trojan showed an organic content of 1.62% in recent sediments and 1.21% in sediments deeper than 50 cm. Organic accumulations are improving but are still well below the concentrations in natural sediments. At Trojan, organic, bacteria-rich sediments up to 2 cm thick have developed under weed beds versus 3 - 5 mm in non-vegetated tailings.

From limited sampling over five years, Trojan surface sediments with low organic content averaged 22 ppm Mo and 377 ppm Cu; not much different from the 17 ppm Mo and 356 ppm Cu average for uncontaminated lakes in B.C. (Reiberger, 1992). Organic, bacteria-rich sediments developed under dense weed beds accumulated 30% more molybdenum and 25% more copper. Anaerobic sediment taken from the deepest point in Trojan pond contained significantly more metal than shoreline sediments at 75 ppm Mo and 474 ppm Cu. Biochemical activity in the anaerobic zone encourages metals to precipitate to the sediments (Bryar & Maki, 1995). Determining the exact compounds that are formed can be difficult, but a predominance of metal sulphides is expected.

EXPECTED FUTURE CHANGES

As Trojan tailings pond matures, the additional organic material produced in the pond and along its shoreline will increase sediment bacteria activity and lower sediment redox. Trojan tailings pond's capacity for passive metal removal will increase with these accumulations, as will nutrient storage and recycling. Further reductions in hydraulic conductivity and oxygen penetration are expected as the organic deposits on the tailings thicken. The macrophyte populations will slowly expand from the present 60 - 80% to complete cover in the 1 - 4 meter range. Dominant macrophyte and algae species will slowly change within the context of a stable, diverse aquatic ecosystem.

SUMMARY

The establishment of an aquatic ecosystem at Trojan would have occurred naturally without intervention, but over a much longer period. Reclaimed tailings ponds perform some passive water quality improvement, preserving and slowly improving the quality of the water cover. The linkage between bioaccumulation in plant material and SRB induced metal sulphide precipitation forms a pathway for continual metal accumulation in the sediments (Hedin et.al. 1998). Aquatic vegetation also holds a pool of nutrients in organic forms and encourages recycling, helping the aquatic ecosystem to continue with minimal assistance. Molybdenum precipitation in Trojan's anaerobic zone is indicated by increased sediment and decreased aqueous concentrations in that zone. In natural passive systems, metal removal is usually slow and accounts for only part of the declining molybdenum concentrations at Trojan. Conditions in the pond will naturally shift with time, causing gradual changes in the flora and fauna. Fish will continue to thrive in Trojan Tailings Pond as long as physical and chemical conditions maintain the aquatic ecosystem.

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