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CONSTRUCTED WETLAND - BULLMOOSE MINESITE, TUMBLER RIDGE, B.C.

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ABSTRACT

Wetland development on a minesite sedimentation pond consisted of the alterations of a sedimentation pond to control water flow rates and to aid in planting cattails, rushes, sedges and other aquatic plants into the system in an attempt to reduce nutrient enrichment. It is believed that wetlands can act as a buffer between the mine working and the receiving environment.

A wetland was designed and constructed to establish both aerobic and anaerobic conditions within the rougher lagoon. The aerobic cell was planted with a diversity of marsh plant species such as sedge (Carex sp) which is more desirable for water treatment purposes.

The anaerobic cell uses an underflow method. Flows are adjusted using control gates and weirs. Both cells were filled with a substrate suitable for wetland development.

The objectives of the project are to design and monitor the water treatment results of a large scale constructed wetland. The specific objectives will be to determine design specifications for the construction of wetlands on the other minesite sedimentation ponds, determine optimum water retention time on treatment results, quantify the removal of nitrogen from the water passing through the different wetland cells during the year and to provide information on the operation and maintenance of a wetland to enhance plant survival and growth.

INTRODUCTION

The Bullmoose Operating Corporation (BOC) began coal production in October 1983 from coal licenses located 87 km south of Chetwynd, B.C. and 40 km west of Tumbler Ridge, B.C. in what is generally known as the Northeast Coal Block (see Figure #1).

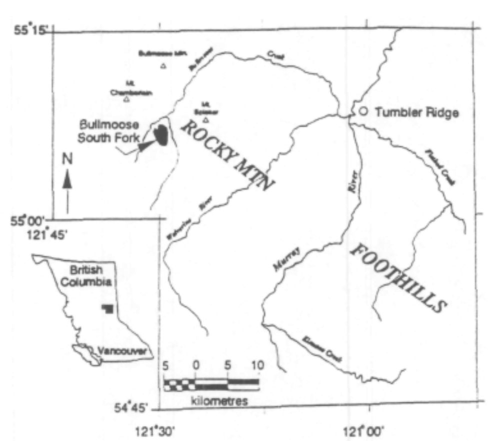

Figure 1 Location Map

The Bullmoose Mine is presently mining coal from the South Fork deposit located on the north facing slope of Mount Collier. The mine operation is situated between the 1300m and 1800m elevation which includes northern boreal forest to alpine areas. The plantsite is situated in the valley at the 1100m elevation. Pre-mining land uses include habitat for wild life, exploration for gas, oil and coal, recreation (fishing and hunting), and forestry in the valley areas.

Since 1983, research and assessment of agronomic and native species which grow successfully on the mine site has been performed annually. Small scale test trials that began in 1985 were conducted in order to determine which agronomic seed and fertilizer amounts/rates were suitable for specific conditions found on the mine site. Large scale agronomic seeding and fertilizing on the mine site was started in 1989.

In 1990, a constructed aerobic wetland project was undertaken in the valley on sedimentation pond #3 (fig.2).

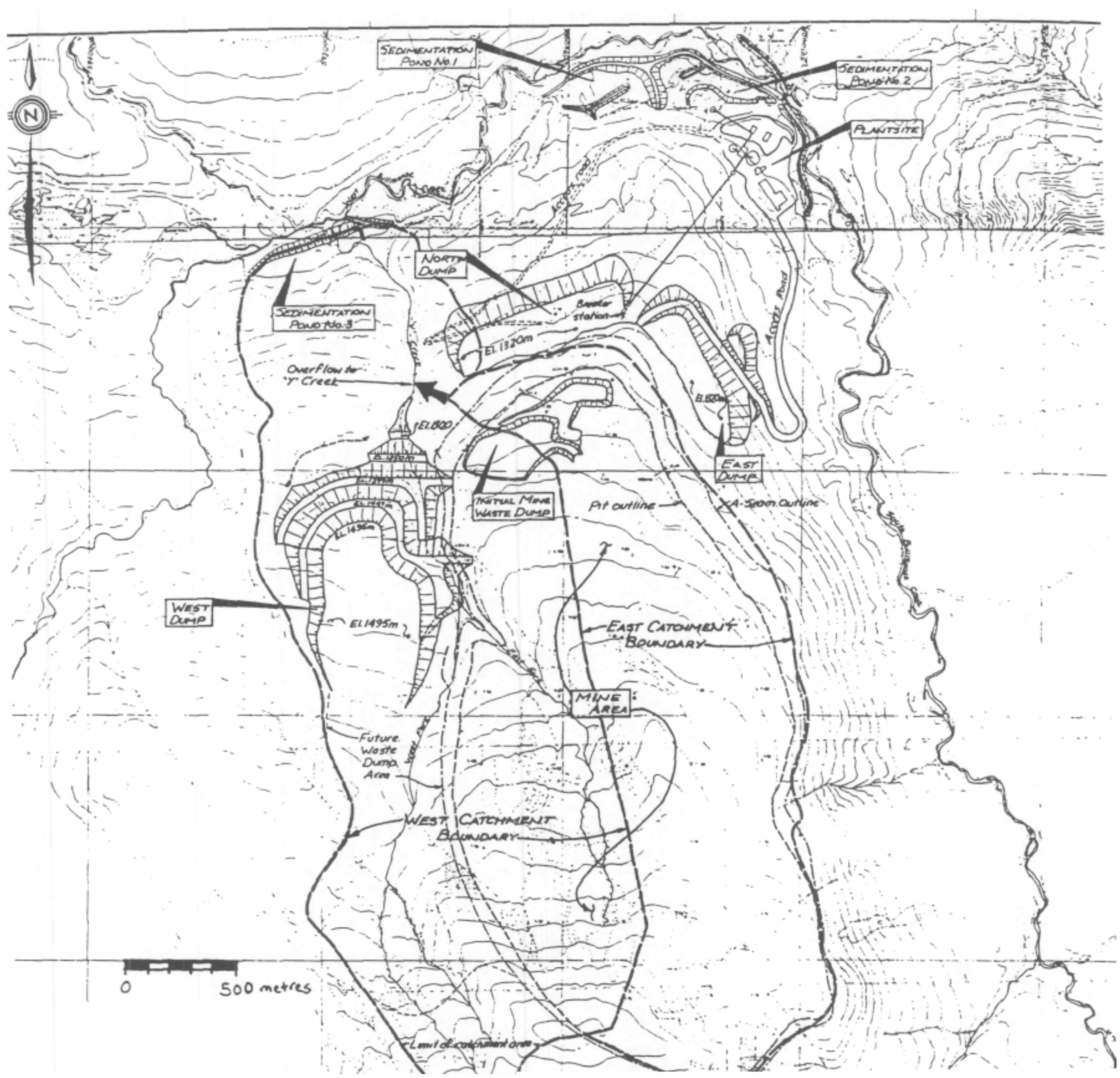

Figure 2 Bullmoose Mine Site - Location of Sedimentation pond no. 3

In 1992, an aerobic and anaerobic cell was developed on the same site. This was set up as an experiment to see if nitrate removal would be possible in either of the cells. At Bullmoose during the late 1980's , concern over the increasing amount of nitrates in the sedimentation ponds lead to investigations into likely treatment methods. The physical and chemical nature of open pit mine effluent has a potential to affect the environment of a receiving water system. A constructed wetland offered the most cost effective alternative for the treatment of nitrogen enriched effluent. However, the results from other constructed wetlands have proven to be poor to fair (Titus, 1992). Bullmoose decide to construct and maintain a small wetland and assess results on a year to year basis.

The challenge in constructing a wetland is understanding the interrelationships between its physical and chemical components. The complex nature of biochemistry within a hydrological system is not easily determined. Designing, constructing and maintaining a healthy wetland is dependent upon the level of understanding, monitoring and enhancements. The contaminant removal efficiency of the system will depend upon how well the system is managed. In addition, five to ten years will be needed of consistent management including research and enhancements before the system might be maintenance free (Kadlec, 1989).

MINING PROGRAM

South Fork Coal Deposit

The South Fork coal measures occur in the lower part of the Gates Formation in the lower Fort St. John group. They consist of 100 meters of non-marine sediments including six (6) coal seams. All of these seams will be mined in the South Fork Area, where the lower Gates strata form a platter shaped outline which dips gently to the north and is crudely concordant with the slope. Erosion has exposed the coal seams around the entire periphery of the area.

In 1983, mining began at the northern and lower end of the deposit, and has proceeded in a southerly, up-dip direction over the past eleven (11) years. In 1990, some pre-stripping shifted to the top of the deposit for a downward, bench-mining approach. In 1993, full scale mining was undertaken on top of the deposit using the same downward, bench-mining approach.

REHABILITATION OBJECTIVES

The rehabilitation and environmental control programs at the Bullmoose mine are an integral part of mine planning and the mining operation. Throughout the duration of the rehabilitation program, the focus has been on research and evaluation to develop seed mixes, native tree and shrub planting, habitat featuring, wetlands, and development of native plantations in forest and alpine areas to create wild life habitat. There are two main objectives of the rehabilitation program:

<u>Primary Objective:</u> To re-establish wild life habitats within the mine site.

<u>Secondary Objective:</u> To reduce erosion and prevent pollution, and to stabilize soil through the use of vegetation and the water management plan.

Four (4) principles have guided the development and management of the erosion and sediment containment plan:

- Pre-production pit preparation carried out when needed, with natural vegetation preserved in areas not under development.
- Soil erosion control practices carried out as part of the pit operation.
- Sediment containment practices carried out to limit the amount of turbid, sediment-laden water entering the receiving environment.
- Water control and system maintenance programs carried out during the mine operation will develop a stable water management system.

On a larger scale, the 1992 Water Management Plan has been designed to reduce erosion within the pit area. Armoured channels and overflow spillways have been designed for the purpose of minimizing erosion. Runoff is collected within the pit and in-pit mined rock piles or directed towards Wilfred (Y) Creek from the west mined rock piles and pre-production areas, eventually, all water is directed to the sedimentation pond wetlands.

DENITRIFICATION

The Nitrogen Cycle

The majority of nitrogen transformations from one form to another involves biological mediation of the nitrogen cycle (McCarty et al, 1970)(Fig. 3).

Fiqure 3 The Nitrogen Cycle (Chapelle, 1993)

Under aerobic conditions, nitrification may occur. Ammonia is oxidized to nitrite and further to nitrate. It may then be incorporated into biomass as protein in a process called assimilative nitrate reduction. If oxygen levels are low ,i.e. suboxic, many heterotrophic bacteria, known as denitrifiers, will utilize nitrate as an electron acceptor in the oxidation of organic matter to energy for metabolic life processes. Dentrification occurs in suboxic waterlogged soils and natural waters as illustrated in the Nitrogen Cycle. Each phase is mediated by microorganisms.

The redox potential of the environment into which sources of nitrogen are introduced will determine whether or not specific forms, such as nitrate, will accumulate. Under aerobic conditions, nitrification will occur but denitrification is blocked and therefore nitrate will accumulate. Under suboxic and anaerobic conditions, nitrate can be converted to gaseous nitrogen species via denitrification. Since nitrification is blocked and gaseous species will tend to escape to the atmosphere, depletion of aqueous nitrate results.

Nitrate is very soluble in water. Within a temperature climate, the soluble nature of nitrate means that, after source removal such as mined rock piles, elevated levels tend to be rapidly reduced. High nitrate mobility in the aerobic aqueous environment calls for systems designed for lowering nitrate levels to focus on biological nitrate reductions as the primary removal mechanism.

Biological nitrate reduction includes: nitrate assimilation into organic matter by both autotrophic and heterotrophic organisms and denitrification to nitrogen gas by predominantly heterotrophs under suboxic and anaerobic conditions. Under favourable conditions, denitrification will account for as much as 98% of the nitrate mass removal within a biological reactor such as a wetland.

DENITRIFICATION IN FRESHWA TER WETLANDS

The reduction of nitrate concentrations in wastewaters passing through wetland soils exploit biological denitrification. At least ten (10) factors will influence wetland treatment at the Bullmoose mine.

- Zone of denitrification
- Dissolved oxygen concentration
- Role of macrophytes
- Temperature
- pH
- Biodegradable organic carbon
- Chemical inhibition of denitrification
- Soil type
- Wetland type
- Hydrology

Zone of denitriflcation

Although the thermodynamic argument that organic matter decomposition coupled to repiration in the order $O_2 > NO_3 -> MnO_2 > FeO(OH) > SO_4 2- > CO_2$ (Thauer et al, 1977) does not fully explain the microbial activity distribution, the progression is often observed (Hesse, 1986; Manahan, 1991; Chapelle, 1993). This progression is expressed as a vertical seguence of microbial respiration with the more energetically favourable electron acceptors used first (Fig. 4).

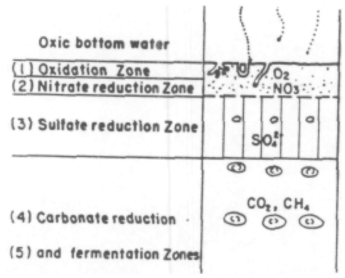

Figure 4 Organic matter oxidation in anoxic sediments (Hesse, 1987)

Nitrate reduction zone commences where the concentration of dissolved oxygen drops below about 0.5 mg/l (Devol, 1978). Denitrifying bacteria, which live at dissolved oxygen levels between 1.0 and 0.1 mg/l are charateristic of the suboxic environment which usually exists within the 10 cm of wetland soils (Faulkner and Richardson, 1989).

Dissolved Oxygen Concentrations

Although discussion over the levels of dissolved oxygen at which denitrification will start is inconclusive (Stengel and Schultz-Hock, 1989; Seitzinger, 1988). It may be explained by the presence of suboxic microsite within an overall dissolved oxygen regime of 2 to 3 mg/l which allow denitrification to occur at these theoretically inhibitory concentrations.

Role of Macrophytes

Wetland plants are capable of growing in an environment that is periodically inundated with water for more than five days during the growing season (Hammer, 1992). An inventory of natural wetlands surrounding a constructed wetland should determine suitable species but generally in northern temperate climates, the following list of rooted emergent species have the greatest potential (Norecol, 1992).

- Cattail (Typha sp.)
- Giant reed (Phragmites sp.)
- Bullrush (Scirpus sp.)
- Rush (Juncus sp.)
- Sedge (Carex sp.)

Plants have a complex effect on denitrification by allowing gaseous exchange between anaerobic wetland soils and the atmosphere (Hammer, 1992; Brix, 1993)(Fig. 5) and releasing root-exudates and carbon compounds within the root-zone which improve conditions for microorganisms (Chalamet, 1983; Geller et al, 1990).

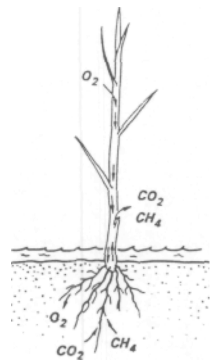

Figure 5 Transport of gases in the lacunal system of wetland plants (Brix, 1993)

Plants may also interact with microoganisms by excreting nutrients and biodegradable carbon into the soil via the root system (Fig. 6) (Stefanson, 1972; Chalamet, 1983; Geller et al, 1990).

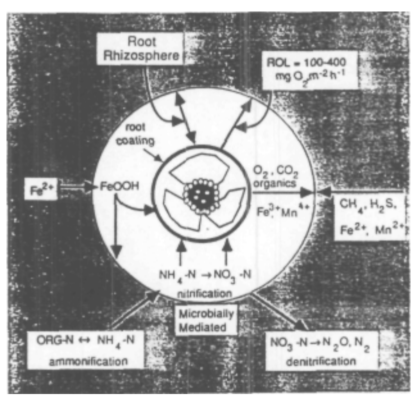

Figure 6 Dynamics of the root-sediment interface (Faulkner and Richardson, 1989).

Temperature

The influence of temperature on the efficiency of the wetland denitrification process is a direct consequence of temperature affects on microbial activity and oxygen solubility and diffusion in soils (Chalamet, 1983). In temperature ranging between 2 degrees C to 25 degrees C a continual increase in rate of denitrification is observed (Bremner and Shaw, 1958). Denitrification can be enhanced in low temperature wetland by the introduction of methanol or straw percolate (Stengel and Schulk-Hock, 1989).

pH

Denitrification rates are most rapid between pH 7 and pH 8 (Bremner and Shaw, 1958) but pH is not considered a serious limiting factor (Koskinen and Keeney, 1982). The effect of pH is on the gaseous production of denitrification. In acidic soils, the predominant gases produced by nitrate reduction would be nitric oxide (NO) and nitrous oxide ($N0_2$) since the enzymes required to reduce nitrous oxide are significantly inhibited below pH *5* (Knowles, 1982).

Biodegradable Organic Carbon

Since most denitrifying bacteria are heterotrophic, the presence of an adequate supply of biodegradable organic carbon is essential if denitrification is to occur within a wetland (Burford and Bremner, 1975). Under anaerobic conditions, organic material in the detrital pool is decomposed by microbial fermentation and methanogenesis (conversion to methane).

Inhibition of Denitrification

Few compounds inhibit denitrification in situ (Chalamet, 1983). Sulphur compounds can alter the therrnodynamic sequence of the carbon oxidation (Westermann and Ahring, 1987; Capone and Kiene, 1988). The presence of elevated levels of sulphates stimulates populations of sulphate reducing bacteria. Sulphate reducing bacteria have a higher affinity for substrate also required by microorganisms involved in fermentation and methanogenesis. In anaerobic pore waters with high sulphate concentrations, fermentation and methanogenesis are suppressed (Westermann and Ahring, 1987; Capone and Kiene, 1988). This indirectly inhibits denitrification in a carbon limited system by slowing the rate of recycle of plant biomass to organic carbon forms.

Acetylene (C2H2) inhibition of denitrification process has been well documented (Sorensen, 1978; Chan and Knowles, 1979).

Soil Type

Generally, soil type used in constructing wetlands can range from fine silty sands to gravel, so long as even water flow is maitained through the soil, the denitrification process is controlled by available organic carbon not by soil grain size (Bowman and Focht, 1974). However, a loose textured, highly organic soil in not recommended since it supplies inadequate physical support for the plants.

Wetland Type

Subsurface flows systems are efficient because they provide more attachment area for microbial communities. The design of subsurface flow constructed wetland is well documented (Titus, 1992). However, no concensus has been reached on the the most efficient model.

Hydrology

Hydrology is the most important factor controlling wetland design and construction. Three principal parameters should be considered in the designing a wetland.

1. Contaminant mass loading;

2. Hydraulic loading of the system;

3. Residence time of contaminated wastewater.

A number of equations can be used to determine as proposed by Metcalf and Eddy (1991) for hydraulic residence time, hydraulic loading rates, specific area requirements, water depth,flow velocity, basin area and geometry and loading rate. Caution is advised in using any of the equations, for designing wetland systems as they are derived from a limited number of systems.

BOC CONSTRUCTED WETLAND

Wetland development on sedimentation pond #3 has consisted of the alteration of ditching and the construction of a weir and drop culvert system to control water flow rates through the area and to aid in planting cattails, bulrushes, sedges, and other aquatic plants into the system to reduce nutrient enrichment (Fig. 7). Its believed that wetlands can act as a buffer between the mine and the receiving environment by reducing oxides of nitrogen and sediments from the mined rock piles (Norecol Environmental Consultants Ltd., 1992).

A constructed wetland will continue to be developed within and below the rougher pond above sedimentation pond 3. The wetland enclosure has been planted with a diversity of marsh plant species such as sedge and cattails, the former being more desirable for water treatment purposes.

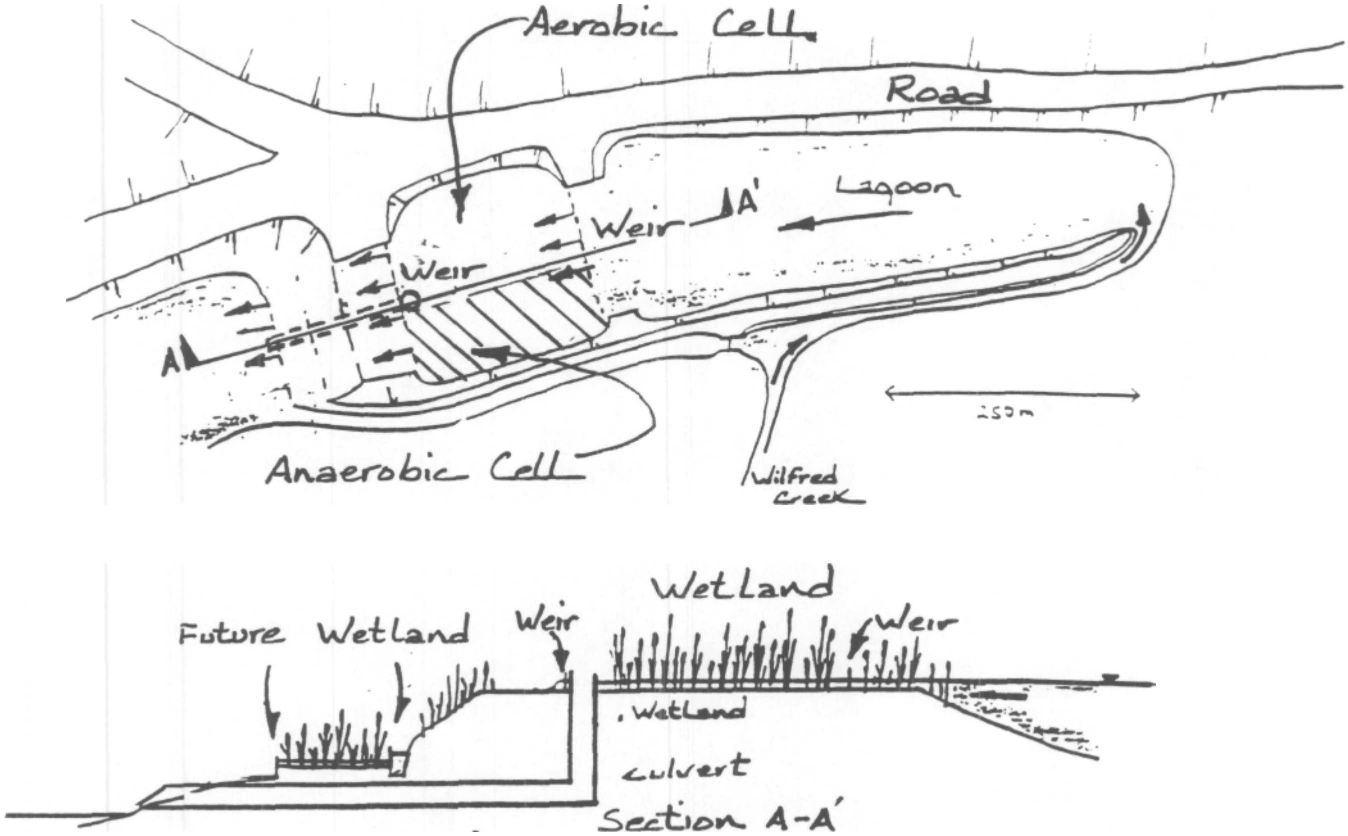

Figure 7 Constructed Wetland at Sedimentation Pond no. 3

Transplanted grasses and sedges show the most productive growth. The decision on how to create wetland environments within the additional sedimentation and tailings ponds will be based on the success of the growth of wetland vegetation in sedimentation pond #3.

Ammonium nitrate (N_2H40_3), in combination with fuel oil, is used as a blasting agent at Bullmoose mine. Apparently, the main source of nitrogen in surface water and pond effluent. It has been found that "nitrogen-based explosives commonly used at mines may leach to surface waters where they can stimulate algae growth" (Norecol Environmental Consultants Ltd., 1992, p. 1-1). How nitrogen will be removed is not totally understood and will be the subject of further research.

The objectives of the project are to design and monitor the water treatment results of a large scale constructed wetland. The specific objectives will be to determine design specifications for the construction of wetlands on the tailings pond and the other sedimentation ponds around the mine site, determine optimum water retention time, quantify the removal of nitrogen from the water passing through the different wetland cells (i.e. aerobic and anaerobic), and to provide information on the operation and maintenance of a wetland to enhance plant survival and growth. In fact, the plants and microorganisms sustained by wetlands are capable of removing pollutants and improving water quality (Hammer, 1989, p. 12).

A control structure was built to uniformly discharge water over a wide surface area, to control water depth, and to maximize contact of the water with a plantation of cattails, rushes, sedges and other aquatic plants. It has been found that these types of plants have become "adapted to fluctuating water and nutrient levels and are more tolerant to high pollutant concentrations" (Hammer, 1989, p. 13).

A wetland was constructed and designed to establish both aerobic and anaerobic conditions within the rougher lagoon located near sedimentation pond 3. Water depth in the aerobic cell averages 0.1 m (Fig. 8). Flows are adjusted by using control gates and weirs. The aerobic cell was planted with a variety of marsh plant species such as sedge *(Carex* spp.) and bullrush *(Scirpus* spp.). The former being the most desirable for water treatment purposes.

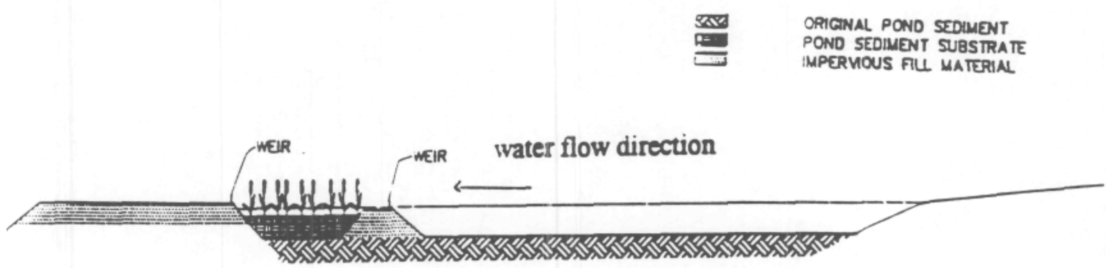

Figure 8 Constructed 'aerobic' cell

Both cells have been filled with a substrate suitable for sustaining wetland plants. The substrate in the anaerobic cell consists of local organic matter, and till. The substrate in the aerobic cell is comprised of clay-like till, sand, gravel and organic matter dredged from the sedimentation pond rougher pond adjacent to the wetland.

The anaerobic cell uses an underflow method with water flowing through the soil beneath the soil surface (Fig. 9). The BOC cell uses three perforated pipelines to drain this wetland cell. The presence of microorganisms in the wetland is important for nutrient removal from effluent, and this system allows maximum attachment surface for microorganisms (Norecol Environmental Consultants Ltd., 1992, p.2-29).

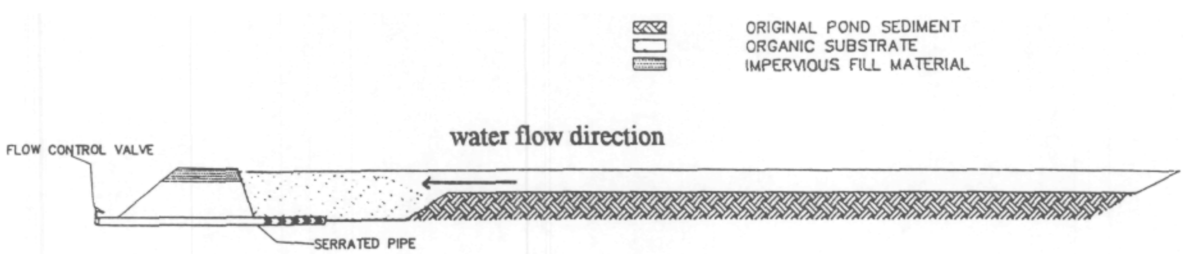

Figure 9 Constructed 'anaerobic' cell

In most cases, microorganisms in anaerobic conditions change and convert environmentally detrimental chemicals (i.e. nitrate) into less harmful chemicals. The manner in which microorganisms remove harmful chemicals from water is as follows:

> "To chemically change an organic material... micro-organisms will utilize an enzymatic or biological chemical process to 'bioconvert' a targeted substrate. This, of course, is the whole focus of a constructed wetland, namely, to optimize contact of microbial species with a substrate, with the final objective being bioconversion to carbon dioxide, biomass, and water." (Hammer, 1989, p.90)

BOC WETLAND CONSTRUCTION

1990: Wetland development commenced in sedimentation pond #3 with cattails, sedges and willows being planted in a shallow sections of the sedimentation rougher pond. Some cattails were relocated to the other sedimentation ponds from native wetlands. This introduction of wetland plants into the other sedimentation ponds was to provide future transplanting stock for the sedimentation pond #3 constructed wetland project.

1991: The program also focused on developing wetlands (i.e. cattail plantation). The success of plant growth in sedimentation pond #3 prompted the decision to continue with the constructed wetland project. In 1991, a weir and a pond level control gate was constructed in the rougher pond of sedimentation pond #3. The wetland development included improving the aerobic cell and the construction of an anaerobic cell in order to monitor the effect of both wetland systems on nitrate removal. Additional cattails, bulrushes, willows, and grasses were planted in all three ponds so that transplanting stock would increase.

1992; The 1992 rehabilitation program focused on the research, evaluation and development of seed mixes, habitat features, and wetlands. Although this was done, growth was sparse due to a drought.

The weir and control gate in the rough pond above sedimentation pond 3 was improved, and additional cattails, bulrushes, willows, and grasses were planted in sedimentation pond #3.

1993: The 1993 rehabilitation program focused on the assessment of wetlands development. Additional cattails, bulrushes, willows, and grasses were planted in sedimentation pond #3 wetland. The weir and control gates were monitored to control the flow rate of water from the rough pond to sedimentation pond 3.

1994; The rehabilitation program focus on wetland development. Wetland development continued with more cattails, sedges and wetland grasses were planted in the aerobic cell. The aerobic cell was drained for a short period of time in the spring of 1994, and seeded with grass. Draining the aerobic cell facilitated the establishment of the grass. In fact, it has been said that: "Periodic droughts may contribute to the maintenance of species diversity in natural wetlands (Norecol Environmental Consultants Ltd, 1992, p.2-13).

The cattails, sedges, and bulrushes that were planted in the aerobic cell in the summer of 1994 were collected from the sedimentation pond #2 plantation. It has been stated that "plants collected from the wild are more closely adapted to local environmental conditions than those obtainable from any other source" (i.e. nurseries) (Hammer, 1992, p.215).

Cattail plantations that have been established in sedimentation ponds 1 and 2 continue to vigorously multiply. The successful propagation of the cattails in these areas and not in the constructed wetland may likely be due to the warm temperatures of the water, and the abundance of solar radiation that these sedimentation ponds receive.

For a reason not totally understood, cattails and bulrushes are not thriving in sedimentation pond #3. An explanation maybe the temperature of sedimentation pond 3 is lower than that of sedimentation ponds 1 and 2. It has been stated that "higher temperatures promote increased production until thermal maxima are reached" (Hammer, 1992, p.40). When optimal growth temperatures are not present, the metabolic rate of wetland plants decreases, therefore, reducing biomass production. The plant is not capable of functioning normally. Further assessment is needed to understand the conditions control the growth rate and survival of the cattail and bulrush species. Sedges and grasses continue to grow well in the constructed wetland.

CONCLUSION

Some conclusions can be made on how to manage a wetlands. These include:

- Samples of the wetland plants should be taken above and below the root collar for chemical analysis. This information would determine whether or not nutrient removal is occurring within the plants.

- Statistical tests should be done to see if there is a correlation between the amount of precipitation and nutrient removal. High precipitation levels could cause flushing and dilution, and low precipitation levels could cause stagnation of nutrient removal, and possibly storage of nutrients within the plants.

- When cattails are being transplanted from a nearby site to the wetland, they should be cut to a length of 20-25cm in order to prevent windthrow while roots are trying to establish themselves in the substrate.

There are several features that are desirable in a wetland species. These are:

- Efficient at colonizing.

- Able to tolerate cold temperatures and drought.

- Able to tolerate low levels of nutrients.

- Will not compete with surrounding plants.

This work reflects Bullmoose's efforts to develop a progressive rehabilitation program.

Nitrates will be draining from the mountain for some time after closure, and it is thought that with the existence of wetlands within the sedimentation ponds, that nitrate removal will occur. This will protect the receiving environment from sudden flows of nutrients and sediment from spring runoff and "flashy" storm events.

ACKNOWLEDGMENTS

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