RESIDUALS REUSE IN AGGREGATE MINE RECLAMATION: A DECADE OF BC EXPERIENCE

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ABSTRACT

Stockpiled soils, if available for aggregate mine reclamation, are often poorly developed, lack fertility and organic matter and are biologically on life support. Residuals, in the form of municipal biosolids, pulp and paper mill sludge, lime mud, ash and animal manures can provide the physical, biological and nutrient capital to promote and sustain soil development.

For almost a decade many aggregate mines throughout BC have been active participants in the research and use of residuals in reclamation activities. Biosolids, pulp sludge and lime mud have been used extensively in reclamation, research and demonstration activities completed at Ministry of Transportation and Highways pits, municipal quarries, and large private industry mines including Lehigh Northwest Materials' (Lehigh) Sechelt mine in Sechelt, BC and Producers Pit, situated between the communities of Colwood and Metchosin, on the southern tip of Vancouver Island.

These examples illustrate successful and innovative utilization of organic residuals in small-scale to high-profile sand and gravel mine reclamation projects. Through prudent organic residuals management and transparent communication of the considerations and benefits of residuals use to the many stakeholders involved in these projects, successful reclamation of aggregate mines is achieved. These successes are cost effective, regionally supported reclamation programs that demonstrate the highest level of environmental stewardship.

INTRODUCTION

Reclamation is a required element of aggregate mining operations, be it following or concurrent with resource extraction and site development. Final land use objectives proceeding reclamation vary, and typically include the restoration of the sites to their state prior to mining to more unique uses such as the development of parkland or urban areas. Re-establishment of vegetation on aggregate mine sites is often made difficult by the condition of the existing soils. Primarily composed of overburden removed to expose sand and aggregate, then re-applied uniformly on the site, the soils are typically poorly developed, lacking nutrients, organic matter and whose physical attributes and inadequate biological characteristics are not conducive to optimal growing conditions. Nutrients are leached out of these soils by heavy rains and are also eroded by wind. Furthermore, nutrient deficient soils may facilitate the spread of some invasive weed species which are adept at colonizing in poor soil conditions.

Amendment of poor quality soils can be achieved by the addition of residuals such as municipal biosolids, pulp and paper mill sludge, lime mud, ash and animal manures. Addition of these residuals can improve the physicochemical properties of the existing soil necessary for successful vegetation establishment by serving as important sources of nutrients, organic matter and moisture. The benefits and demonstration of environmentally responsible utilization of residuals is well documented and widely accepted. With this established, the focus of residuals use in aggregate mine reclamation can concentrate on the development of sustainable, innovative and regionally supported reclamation programs.

The paper presented here provides a brief overview of the beneficial properties of several residuals pertinent to reclamation. The paper provides examples of residuals use in aggregate mine reclamation in British Columbia over the past decade, illustrating the evolution of residuals use from basic land applications to innovative and creative uses of residuals in high profile reclamation projects.

BACKGROUND

Residuals Characteristics

Residuals used in reclamation activities can be classed in two general categories: organic residuals and inorganic residuals. Organic residuals include biosolids, pulp and paper mill sludge and animal manures and are characterized by typically high organic matter content and nutrient concentrations. The addition of organic matter to underdeveloped soils may improve several soil physical properties including porosity, density and aggregation, subsequently improving the movement of air, water and nutrients throughout the soil. In contrast to chemical fertilizers, which contribute an immediate “flush” of available nutrients, which are quickly dissipated, organic residuals contain a fraction of readily available nutrients as well as a fraction of organically bound nutrients, which are stored and mineralized to useable forms through time.

Depending on treatment processes, biosolids typically range from 50-60% organic matter (e.g. Moffet et al., 2005) and contain between 2-6% nitrogen. Biosolids can be applied as dewatered solids (~ 70% total solids), liquid (~ 5% total solids) or as a dried, pelletized product. Pulp and paper mill sludges typically exist as either primary or secondary sludges. In the pulp production process, wood chips are mixed with water and chemicals, and are cleaned and ground into pulp. The resulting wastewater contains short wood fibres not amenable to paper production, and grit from the cleaning process. Primary treatment of the wastewater removes wood fibre and other solids collected during various stages of the pulping process. Secondary treatment consists of removal of dissolved solids from the wastewater through microbial digestion in lagoon or basin systems. During secondary treatment, nitrogen and phosphorus are added to the process to provide energy sources to the naturally occurring microbial population (Watson et al., 2003). The resulting primary sludge consists mainly of waste wood, and is high in organic matter but deficient in nutrient content, while the secondary sludge consists of microbial biomass and is high in organic matter and nutrients (Rechcigl, 1995). Improved treatment processes in the pulp and paper industry have resulted in a continual decrease in the concentrations of many deleterious substances in the sludges, including heavy metals and dioxins (Feldkirchner et al., 2003). In most mill processes, primary and secondary sludges are combined to produce a product similar in physical and chemical composition to municipal biosolids.

Inorganic residuals include lime mud and ash, both of which are derived from the pulp and paper industry. Lime mud is primarily composed of calcium carbonate and is a by-product of the initial extraction of wood fibre in pulp production. Ash is recovered from the burning of hog fuel used to generate power for the pulp and paper process. These materials are typically valued as liming materials and contain beneficial concentrations of base cations such as sodium, calcium and potassium (Mahmoudkhani et al., 2004). Additionally, ash can improve soil water holding capacity, and has cementitious properties that may improve soil aggregation when applied at moderate rates (Matsi and Keramidas, 1999).

Residuals Use in Aggregate Mine Reclamation outside British Columbia

Residuals use in aggregate mine reclamation has not been widely documented in other parts of North America. A recent quarry reclamation project in eastern Canada utilized only the existing overburden in their reclamation activities (Deschesnes and Fontaine, 2004). In Prince George's County, Maryland, poplar plantations have been established on gravel mine spoils and fertilized using a deep-row biosolids application (Kays et al.). This method involves digging 1 meter deep rows and filling them with 0.5 – 0.6 meters of dewatered biosolids, filling the remainder of the row with overburden and leveling and disking the area prior to planting. The poplars were planted as stem cuttings above the trenches, and as they developed a root network, could obtain essential nutrients from the biosolids. In 1992, Pierce County, Washington purchased the 700 acre Steilacoom Pit located near its Chambers Creek Regional Wastewater Treatment Plant. Pierce County began the reclamation of the mine site in 1994 with the installation of demonstration plots. Biosolids use at the mine site has reduced the county's biosolids transportation costs, as the county has reduced their dependency on agricultural applications, typically 50-90 miles away (Pierce County, 2004).

RESIDUALS USE IN AGGREGATE MINE RECLAMATION IN BC

SYLVIS has participated in successful aggregate mine reclamation projects for almost a decade. Using each project as an opportunity to gain experience and knowledge regarding the use of residuals in reclamation, the scope, scale and complexity of the programs have evolved over time. Each project is unique, and presents their own site-specific challenges including regional topography and climate, mine location, economic and environmental sensitivities, public/stakeholder perception, land use objectives and availability of residuals. Seven individual reclamation projects, including ongoing operational programs are reviewed below. Each of these projects highlights a characteristic unique to the use of residuals in aggregate mine reclamation.

Ministry of Transportation and Highways – Pennask Lake Gravel Mine

In 1998, the Pennask Lake Gravel Pit owned and operated by the BC Ministry of Transportation and Highways was reclaimed. Biosolids from the Greater Vancouver Regional District were applied at an agronomic application rate to 10.5 hectares of the 65 hectare site located near Kelowna, BC. The biosolids provided nutrients and organic matter to the otherwise unproductive soil. The site was seeded with grasses, and within a year developed a densely vegetated cover used for cattle grazing.

Resort Municipality of Whistler – Emerald Forest

In 2001, the Resort Municipality of Whistler (RMOW) identified two significant reclamation and restoration projects. One of the projects the RMOW identified was the reclamation of one of two orphaned gravel pits. This location was recognized as priority reclamation areas within the designated RMOW conservation lands, as its revegetation would contribute towards the completion of an important wildlife corridor in the Whistler valley bottom. The disturbed areas of the gravel pit were composed of nutrient deficient, coarse textured sand and gravel, highly compacted in areas subjected to repeated vehicle traffic and lacking in organic matter and water holding capacity. Anthropogenic use of the gravel pit perpetuated the disturbance, preventing the establishment of pioneer colonizers in all but the fringe of the disturbed area.

Class A biosolids produced by the RMOW were identified as a suitable organic residual to amend the underdeveloped soils for establishment of vegetation. The biosolids supplied a source of slow release plant essential nutrients and organic matter which increased water holding capacity, increased soil aggregation and generally improved conditions for the establishment and growth of native vegetation. Prior to application, the gravel pit was contoured to reduce existing slopes from angle of repose to stability. While the site was very permeable, a berm was created around the perimeter of the gravel pit where required to prevent any overland flow from leaving the application area that could possibly occur during incorporation and vegetation establishment.

The biosolids were mixed with yard waste at the Municipality's landfill prior to application. In October 2001, 109 dry tonnes of biosolids and 497 dry tonnes of yard waste were mixed together, transported to the gravel pit and evenly applied to a depth of 15 cm using an excavator spreader. Following application, volunteers from the community assisted with the planting and seeding of native trees, shrubs, grasses and wildflowers.

"Pit to Park" – Aldergrove Lake Regional Park Gravel Pit Reclamation

In 1969, the GVRD purchased a portion of land for inclusion in the Aldergrove Lake Regional Park bordering Aldergrove and Abbotsford. Despite owning the land, the GVRD did not possess mineral/resource extraction rights to the site, and these were subsequently purchased by Valley Gravel Sales. Prior to excavation of their property, the GVRD developed a partnership with Valley Gravel Sales to ensure that site development would proceed in a manner that would not compromise the long-term objectives of the land (i.e. establishment of park land). This partnership also required that Valley Gravel Services restore the site to a desired grade and place native topsoil on the site following completion of its extraction operations. The GVRD was responsible for park planning and supplying biosolids. SYLVIS was retained to obtain required biosolids application authorization, establish an environmental monitoring program and provide project management. Photograph 1 shows the gravel extraction operation prior to reclamation activities.

Photograph 1: Final excavation and pre site contouring.

Consultation activities regarding the use of biosolids were immediately undertaken to address stakeholder concerns. To investigate the effects of biosolids applications on the already environmentally sensitive Abbotsford – Sumas Aquifer, on which the park was to be developed, a lysimeter study was conducted to investigate the potential of trace element and nutrient leaching. Six treatments were established in the study:

1. Biosolids;
2. Biosolids compost;
3. Nutrifor NT, a product composed of waste paper fibre and biosolids;
4. Biosolids with biosolids compost;
5. Inorganic chemical fertilizer; and a
6. Control (no treatment)

Three replicates of each treatment were randomly applied to monolith lysimeters constructed and installed at the gravel pit. The treatments were seeded, to concurrently evaluate the vegetative growth response to the 6 treatments. The trial was established in August 1997, with water samples collected from the lysimeters from September 14, 1997 through April 26, 1998. During the sampling period, water samples were collected every two weeks for nitrogen, phosphorus and carbon analysis, and every four weeks for trace element analysis. Visual assessments of the vegetation were made at each sampling event; at the end of the trial, the vegetation was removed, dried, weighed and analyzed for plant nutrients.

Analysis of water collected from the lysimeters revealed no negative effects on groundwater quality resulting from the application of organic amendments. Nutrient and trace element analysis did not reveal any negative impacts on groundwater quality. The vegetation assessment compared biomass production and foliar nutrient content between treatments. The biosolids and biosolids compost treatments produced the most above ground vegetation, approximately 13 times more than the control treatment.

Operational reclamation of the gravel pit was initiated in 1999. Shortly before application, 930 wet tonnes of GVRD biosolids and 3,918 bulk tonnes of compost were delivered to the site, and mixed with native soil at a volume ratio of 1:1:4 compost:biosolids:native soil. This mixture was applied to 11 hectares of the mine site, incorporated to a depth of 15-30 cm and seeded with a sports turf seed mixture. Photograph 2 illustrates the dramatic transformation the property underwent in its metamorphosis from a gravel mine to parkland.

Photograph 2: Canoeing lake and established vegetation two months following amendment application.

In response to stakeholder requests, and to ensure that the biosolids and compost were used in an environmentally protective manner, an environmental monitoring program was established. The program monitored ground water monitoring wells, surface water monitoring of the lake established in the park as well as five domestic drinking water wells. Analysis from the environmental monitoring program did not provide any evidence of negative impacts on soil or water quality resulting from residuals applications. Reclamation was completed in fall 2000.

AGGREGATE MINE RECLAMATION: THE LEHIGH EXPERIENCE

Heidelberg Cement and Lehigh Northwest Materials own several sand and gravel quarries throughout BC. A subsidiary company, Construction Aggregates Limited (CAL), have been proactive participants in research and reclamation projects involving residuals for almost a decade, all of which SYLVIS has been involved in. The experience and knowledge gained through past projects using residuals in aggregate mine reclamation has resulted in the development of many successful programs with ever-expanding scope, innovation and complexity.

Monteith Bay Quarry Mine Reclamation and Water Quality Improvement

The Monteith Bay silica mine is located in a remote inlet on the northwest corner of Vancouver Island. Rock found in association with the silica can be acid generating. The frequent and intense rainfall events that occur on the west coast, in contact with the exposed rock result in acidic surface water runoff. This run-off can be highly acidic, can have elevated concentrations of trace elements, and can adversely impact adjacent water bodies. To minimize acid generation the waste rock is temporarily covered with tarps, and lime is used in buffering the pH of water collected on site. The long-term objective in reducing the acid generation is to minimize the exposure of the rock to air. In the absence of oxygen, acid generation is minimized. Increasing the pH of water that reacts with the exposed rock faces will assist in neutralizing run-off.

Interim reclamation has focused on establishing a mantle of fabricated soil with an elevated pH. As the mine operates only several months a year, and access is limited to boat or barge, a biosolids soil product was manufactured in Southwestern BC and transported by barge to the mine site. Approximately 3,000 m^3 of soil was fabricated from biosolids, sawdust, compost, lime paste and overburden. The lime paste was added to increase the pH of the soil, and sustain an elevated pH for the next three to five years. The soil was fabricated with a low porosity, using overburden that had a high concentration of silt and clay. The soil met the requirements of the Organic Matter Recycling Regulation (OMRR), but did not resemble a typical potting soil. This massive, and somewhat “pasty” soil was fabricated in the spring of 2003 and transported to the mine by barge. At the mine site it was unloaded and applied to previously disturbed areas and the face of steep waste rock piles. The soil was applied to slopes using an excavator, and the soil seeded and covered with an erosion blanket. Photograph 3 shows the soil and erosion blanket placement on a waste rock dump.

Photograph 3: The application of a high pH biosolids fabricated soil to a waste rock pile.

The significant rainfall (over 2 m annually with a 50% chance of precipitation every day) results in a saturated soil profile at depth. This saturation minimizes the potential for acid generation. The elevated pH of the soil water assists in neutralizing any acid generation that may occur. The pH and quality of the surface water on the mine site has improved following the application of the biosolids fabricated soil products. The fabricated soils are sustaining vegetation with minimal erosion, despite steep slopes and intense rainfall events.

Watts Point Shoreline Restoration and Wildlife Corridor Enhancement

Watts Point quarry is located approximately 6 km south of Squamish, BC. ConAgg Quarries, who owns and operates the Watts Point operation, leases a portion of a lower access road which is used by multiple users to access adjacent properties. Over fifty years ago a forestry access road was built at, and in the intertidal zone. Located directly adjacent to the ocean, and at 1 to 6 m in elevation, the road was progressively eroding into the sound and adversely affecting the aquatic environment.

With Fisheries and Oceans Canada approval, road repair work was initiated in February 2003. The majority of the work involved the removal of eroding material, and the placement of armour and filter rock. Between the shoreline and the roadway, a continuous riparian corridor was constructed. Varying in width and extending the length of the road improvement, the planting corridor was designed to facilitate detention and treatment of roadway runoff, establish a biodiverse plant and animal corridor, and to improve aquatic habitat. Approximately 1,800 m^3 of fabricated soil was delivered and applied in May 2003. The fabricated soil was composed of 20% biosolids, 20% compost, 20% sawdust and 40% sand.

Over six hundred native trees and shrubs were planted in the rehabilitated riparian corridor along the multi-user access road in May 2003. Signs were posted on site to describe the work that had been completed to date and to attempt to educate users of the road as to the sensitivity of this roadside habitat. The rehabilitated riparian corridor is positively impacting both terrestrial and foreshore habitat. Surface water no longer directly enters the ocean. The roadside berm, soil, ground cover and planting stock slows and treats the road runoff. The corridor has also stabilized the reconstructed roadway and will prevent mass erosion.

Producers Pit – Biosolids Soil Fabrication

Producers Pit is a 200 hectare sand and gravel mine located approximately 20 km southwest of Victoria, sandwiched between the District of Metchosin and City of Colwood. As the mine nears its scheduled closure date at the end of 2006, there exists a need to develop and implement a dynamic and aggressive reclamation program that is in theme with the unique final land use objectives. Rather than typical reclamations objectives of returning the land to how it existed previously, the mine will be developed into a subdivision known as Royal Bay. This comprehensive development includes residential properties, greenways, two schools, ten parks and waterfront village center, and will be home to up to 10,000 people.

Reclamation objectives are two-fold – to establish permanent vegetation on portions of the mine site in transition to parks, greenways and playgrounds, and to establish temporary vegetative cover to minimize erosion and improve visual quality prior to subsequent development. A three phased approach was developed to address the reclamation goals at Producers Pit. Each phase concentrated on reclamation activities and stakeholder consultation. Phase 1 introduced the use of biosolids as an option for reclamation to stakeholders through the installation of demonstration plots. Following this initial phase, it was concluded that the application of biosolids alone would not be a feasible reclamation strategy. There was insufficient overburden available on the mine site to reclaim the mine site using a straight biosolids application technique, and without immediate incorporation, there would be potential for odour concerns due to the proximity of the mine site to residential areas.

In response to these concerns, the development of fabricated soil using biosolids was proposed. Incorporating biosolids as part of a fabricated soil prior to land application would reduce odour concerns for nearby residents, and would allow the uniform distribution of a fertile, aesthetically appealing soil throughout reclaimed areas of the mine site.

At Producers Pit, wood waste from land clearing, wood shaving and sawdust were used as carbon sources; biosolids from the Greater Vancouver Regional District and the Capital Regional District were used as a nutrient source; and sand and sedimentation pond fines from Producers Pit were used as a structural material. The objective of soil development was to fabricate soils using high quality feedstocks to produce growing media that comply with biosolids growing medium standards. Compliance with the standards allows for the distribution and application of the fabricated growing media products without permit or approval or volume restrictions.

An ALLU bucket was used to mix growing media in Phase 1 for use in the demonstration plots. The ALLU mixer was used to fabricate a series of preliminary mixtures and to mix wood waste, sand and peat for reclamation activities elsewhere on the mine site. The ALLU bucket produced acceptable growing media, but for larger scale mixing, would be too small. During the summer of 2004, Phase 2 utilized a 4 m^3 horizontal soil mixer at an area on the mine site dedicated solely to growing media mixing. The growing media was discharged from the mixer into a conveyor to an adjacent stockpile area.

An iterative approach was utilized in the testing and refinement of biosolids growing media. In total approximately 40 fabricated soils were blended in Phase 2. Preliminary analytical results from several fabricated mixtures were evaluated to determine which growing media optimized agronomic, economic and aesthetic utility. From these evaluations, growing media were refined and their qualities were confirmed by additional analysis. Of the soils developed, three were selected for operational production. Approximately 3,000 m^3 of these operational soils were fabricated in 2004 and applied to 1 hectare of land using mine haul trucks and excavators. These areas were seeded with grasses and wildflowers.

Phase 3 of the reclamation program has seen the installation of a soil mixing facility on the mine site, including a temporary covered building for storage of biosolids and a front-end loader and ALLU mixing bucket dedicated solely to soil fabrication. Over the next 4 years, a minimum of 50,000 m^3 of soil will be fabricated at the facility for use in reclamation at the mine.

Sechelt Mine – Multiple Residuals in a Regional Reclamation Program

Located on BC's Sunshine Coast, Lehigh's Sechelt mine is the largest sand and gravel mine in Canada, occupying in excess of 250 hectares and producing over 5 million tonnes of product per year. After identifying reclamation as a significant challenge and important component of their operation, the Sechelt mine explored the opportunity to use residuals in their reclamation activities. Following an extensive period of public consultation and research, a reclamation plan was developed that uses several residuals produced in the region, including biosolids from nearby municipalities, and pulp mill sludge and lime mud from a local paper mill.

The initial research and demonstration project involved the use of biosolids from the Town of Gibsons and pulp sludge from Howe Sound Pulp and Paper Limited. These residuals were applied to retaining berms visible from the town of Sechelt and seeded with grasses. The results of this demonstration project were two fold. The project displayed the benefits of organic residuals in improving physical and chemical properties of soil and subsequent vegetation establishment, and increased stakeholder support of the use of residuals through visual evidence, education and awareness.

Biosolids from the municipalities of Sechelt, Gibsons, and Powell River and Greater Vancouver Regional District, and pulp mill sludge and lime mud from Howe Sound Pulp and Paper Limited are used over the mine. Dewatered biosolids and pulp mill sludge are used in the fabrication of reclamation mixes. Liquid biosolids are used to both fertilize and irrigate. The partners in this regional recycling program work with SYLVIS, who coordinates and oversees the program. Biosolids mixing, application, vegetation establishment and regulatory compliance are all completed by this consultant/contractor to the mine.

Over the past year, two innovative projects utilizing biosolids have been implemented at the Sechelt mine. Over the spring of 2004, a wetland was established using biosolids fabricated soils, and in spring of 2004 and 2005 two poplar plantations were established using liquid and dewatered biosolids to fertilize and irrigate.

Due to the large volume of impermeable clay that settles out of the process wash water, a decommissioned sedimentation pond can form an artificial water table and depressions in the surface can fill with water. During the spring of 2004, an initiative was undertaken to transform one such water-filled depression into a wetland habitat. The formation of the wetland was initiated by contouring the slopes leading into the depression. Undulations and slope discontinuities were established using mine site overburden. This overburden serves to elevate the surrounding riparian zone from the water table. An island was created by excavating a deep trench around a shallow edge of the basin. To address the fertility deficiencies evident in the applied overburden, and to improve the establishment of a functional wetland, a biosolids amendment was fabricated for use around the wetland. This fabricated soil was placed around the pond. Large stumps and rocks were placed throughout the planting zone to improve slope stability and create micro-habitats for both flora and fauna. The area was planted with a variety of native trees, shrubs and herbaceous plants and seeded to grass and wildflowers. Aquatic vegetation was established through transplants, willow cuttings and cultured native plants.

The pond retains water during the dry summer months and has a fixed overflow to maintain a constant water level during the winter rains. Surface water drainage from adjacent roadways is directed into the wetland. The wetland serves to moderate surface run-off, and effectively filter the surface run-off. Water quality monitoring after biosolids product placement and planting identified minor increases in total organic carbon and electrical conductivity. There was no mineral nitrogen detectable in the water and phosphorus concentrations were low. Photograph 4 shows the wetland in the first year following establishment. This area will form part of a wildlife corridor created across the mine site.

Photograph 4: Wetland following reclamation (August 2004).

Elsewhere on the mine site plantations of fast-growing hybrid poplar have been established. These poplar plantations provide education and employment opportunities for the Sechelt Indian Band (SIB) and other community members. The plantations are irrigated and fertilized with liquid and dewatered biosolids, and will provide an economic return upon harvesting in 12-15 years. To date, approximately 10,000 poplar trees have been planted in two plantations over 23 hectares of the mine site. The poplar plantations achieve reclamation objectives, will generate an economic return and provide education and employment opportunities.

The Sechelt mine has been at the forefront of residuals use in aggregate mine reclamation for several years and is a recognized leader in reclamation throughout the country. The mine was honoured to receive the prestigious BC Minister's Environment Award (1998), the Al Watt Environmental Award for excellence (1999), and a citation from the BC Technical and Research Committee on Reclamation (2000). In 2005, the Sechelt mine received the Dr. Edward M. Watkin Award from the Canadian Land Reclamation Association in recognition of their proactive research and extensive community involvement and training in their residuals recycling-based reclamation program.

SUMMARY

Residuals use in aggregate mine reclamation has developed substantially over the past decade. The evolution of residuals utilization presented here is the result of building upon education and experiences, both good and bad, and the development of projects made possible though prudent residuals management, diligent environmental stewardship and ongoing education and consultation with stakeholders. The aggregate mine reclamation projects at the Lehigh sites currently represent the leading edge of regionally supported, cost effective and innovative use of residuals in aggregate mine reclamation and research.

REFERENCES

British Columbia Ministry of Water, Land and Air Protection. 2002. Organic matter recycling regulation (OMRR) [Online]. BC Ministry of Water, Land and Air Protection. Available at http://www.qp.gov.bc.ca/statreg/reg/W/WasteMgmt/18_2002.htm (Verified 21 June 2005) BC MWLAP, Victoria, BC.

Deschesnes, M. and M. Fontaine. 2004. Quarry rehabilitation in an urban fringe context: Lafarge St-Constant case study. 16th International Conference, Society for Ecological Restoration, August 24-26, Victoria, Canada.

Feldkirchner, D.C., C. Wang, S.T. Gower, E.L. Kruger and J. Ferris. 2003. Effects of nutrient and paper mill biosolids amendments on the growth and nutrient status of hardwood forests. Forest Ecol. Manag. 177:95-116

Kays, J.S., G. Felton, E. Flamino and P.D. Flamino. Use of deep-row biosolids application to grow forest trees: A case study.

Mahmoudkhani, M., T. Richards, and H. Theliander. 2004. Recycling of solid residues to the forest: Experimental and theoretical study of the release of sodium from lime mud and green liquor dregs aggregates. Process Saf. Environ. Prot. 82:230-237.

Matsi, T. and V.Z. Kerimidas. 1999. Fly ash application on two acid soils and its effect on soil salinity, pH, B, P and on ryegrass growth and composition. Environ. Pollut. 104:107-112.

Moffet, C.A., R.E. Zartman, D.B. Webster, and R.E. Sosebee. 2005. Surface biosolids application: Effects on infiltration, erosion and soil organic carbon in Chihuahuan Desert grasslands and shrublands. J. Environ. Qual. 34:299-311.

Pierce County Public Works and Utilities. 2004. The biosolids program at the Chambers Creek wastewater treatment plant [Online]. Pierce County Public Works and Utilities. Available at http://www.co.pierce.wa.us/pc/abtus/ourorg/pwu/envsvcs/sewer/biosolid.htm. (Verified 22 June 2005) Pierce County, Washington.

Rechcigl, J.E. 1995. Soil amendments: Impacts on biotic systems. Lewis Publ., Boca Raton, FL.

Watson, S.B., J. Ridal, B. Zaitlin and A. Lo. 2003. Odours from pulp mill effluent treatment ponds: The origin of significant levels of geosmin and 2-methylisoborneol (MIB). Chemosphere. 51:765-773.