Examination of Revegetation Methodologies for Dry Stack Tailings in Northern Environments

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1.0 INTRODUCTION

Considerable research has been carried out into the reclamation and revegetation of disturbed lands in the Yukon, including operating and abandoned mines, and mineral exploration sites in the Yukon. Reclamation efforts on tailings have focused on methods to establish an initial vegetative cover on disturbed areas. Guidelines have been established by Kennedy (1993) and Hill *et al*. (1996) for the optimum mixtures of fertilizer and seeds (both agronomic and native varieties).

Some studies have also been conducted in the Yukon, into ways to encourage later succession stages of vegetative growth. The natural revegetation of a few selected abandoned trenches and drill pads was observed by Mougeot (1996) and some experimental revegetation of abandoned mineral exploration sites was carried out by Craig *et al.* (1998) and Withers (2002). Another similar study has been initiated by Teck Cominco Ltd. at the Sä Dena Hes Mine as part of an ongoing revegetation test program to meet the goals of their decommissioning and reclamation plan. Access Consulting Group (in association with Stu Withers Consulting) have developed and carried out trial revegetation test plots for the tailings facility at the mine site.

Reclamation of the tailings facilities at decommissioned mines can be challenging. Traditional tailings disposal has been to deposit a slurry (saturated tailings) into a tailings impoundment. One of the major concerns with these facilities is the long-term geotechnical stability of the water retaining structures (tailings dams). Often these tailings retain high levels of metals or other compounds and are generally devoid of the organic constituents that are required for vegetative colonization. To remedy this, a capping material is usually proposed to seal the tailings and to provide a suitable organic medium to facilitate vegetative growth.

A relatively new and unique method of tailings processing and disposal that is being used at a few mines around the world is called dry stacking. This method of tailings disposal has the potential to provide many benefits to mining companies and affords numerous environment advantages that slurry deposits do not.

There are currently no proposed or operating mines that use dry stack tailings technology in the Yukon. In 2001, AMT Canada Inc., a potential buyer of the Elsa Mine, had proposed to deposit reprocessed tailings in a single location on the property using the tailings management technology known as dry stacking. To our understanding, no other Yukon based project has employed this tailings disposal methodology, although the Minto Project has proposed the deposition of thickened tailings. The technology offers significant advances for environmental protection and tailings management when compared to the wet tailings deposition method previously mentioned. There are, however, several challenges for reclamation.

The purpose of this proposed project was to research current practices in other jurisdictions and to examine the best approaches for encouraging vegetative establishment on dry stack tailings in northern environments, particularly for potential mine sites in the Yukon.

It was felt that an evaluation of the performance of revegetation methods at sites using the dewatered tailings technology would allow for a more accurate assessment of the likelihood that any future Yukon-based operations proposing reclamation methods for similar projects will meet desired performance goals.

2.0 OBJECTIVES OF THE STUDY

The specific objectives of this project included the following:

- Conducting an examination current literature and operational practices regarding the reclamation/revegetation of Dry Stack Tailings Facilities (DTFs);
- Develop one or more promising revegetation protocols for application on DTFs in the Yukon;

3.0 METHODOLOGY

Work on this project was comprised primarily of a literature review. Journal articles, magazine articles, conference proceedings, and workshop presentations were examined both in hard copy and in electronic formats, via the Internet. Information regarding the revegetation of dry stack tailings specifically was the first level of review with subsequent research activities directed toward dry stack tailings technology, revegetation of tailings, general dewatered tailings technology, tailings management and stewardship. Promising and project specific leads, beyond the theoretical, were followed up with emails and by telephone correspondence.

The literature review was compiled into an annotated bibliography, which is included in Appendix A of this report. The bibliography contains a document reference and a brief description or précis of each work. It is expected that this Appendix will serve as a resource for directing further research and study by interested individuals, agencies, and/or project proponents. The bibliography may also serve to facilitate connections between those interested in the technology and experts in the field.

Management of such facilities were also reviewed and evaluated for applicability to the north. Overarching considerations during the review of design and management strategies was the applicability of the technology and its potential effectiveness for Yukon.

Little of the literature reviewed in this project contained specific information about revegetation of DTFs. Much of the information regarding current practices and research is focused on engineering and operational aspects of the milling processes or the construction, operation, and cover design for such tailings facilities. The knowledge and experience of scientists and engineers at AMEC Earth and Environmental Ltd., Steffen, Robertson, and Kirsten, and Klohn-Crippen form, in large part, the body of information available respecting dry stack tailings. Environmental impact statements, detailed project descriptions, and regulatory reviews are the sources of much of the information presented here.

This report is not so much an analysis of the technology as it is an introduction to and an anthology of current research and practice in the field. This document will likely serve most appropriately as a source of reference material for potential project proponents in Yukon and as an information source for regulators and the public respecting general concepts of the technology and reclamation efforts for closure planning.

4.0 DRY STACK TAILINGS TECHNOLOGY

4.1 WHAT IS DRY STACK TAILINGS TECHNOLOGY?

Dry stack tailings can be described in the simplest terms as finely ground, dewatered, and processed mine ore, which due to its unsaturated nature can be stacked in stable layers up to heights not achievable using conventional tailings dams. The processed ore material is dewatered by large capacity vacuum and pressure filter technology. The tailings material are referred to a filtered cake. The process allows the opportunity to store tailings in a dewatered or 'dry' state as opposed to conventional slurry tailings, which may contain as much water as 60% to 70%. With this technology, tailings can be dewatered to a point where its water content is typically below 20% moisture.

With this water content, the tailings can no longer be pumped as opposed to slurry. Martin et. al. (2002) explains that with this moisture content, the material can be transported by conveyor or truck, and placed, spread and compacted to form an unsaturated, dense and stable tailings stack, which requires no dam for retention. Conventional earthmoving equipment can be used to manage dry tailings. One option has been forwarded by Martin et. al . suggesting that the tailings could be transported with foam via a pipe to the tailings facility whereupon an antifoaming agent or rolling could be applied to remove the foam prior to dry stacking. The savings from the reduced cost of transporting the tailings could be beneficial in making the technology more attractive and affordable for proponents if it is proven a viable solution.

Ruse and Boger (2002) explain that a dry stack facility typically involves building up impoundment walls gradually using coarse tailings fractions, depositing thin layers of thickened tailings solids and allowing drainage underneath the layer and evaporation from the surface before the next layer is added.

The combination of dry stacking tailings and paste backfill can also be used to dispose of tailings. For example, this is the method being proposed by Teck Resources for the Pogo Gold Project in Alaska. The Pogo Environmental Baseline Document (Teck, 2001) describes the tailings production and handling in the following manner:

> *The milling of Pogo Ore will create two types of tailings: flotation tailings, and sulfide bearing tailings from the CIP (carbon-in-pulp) process. Flotation tailings represent 2,250 tpd, or 90% of tailings production, and CIP tailings 250 tpd (10%). Half of the flotation tailings will be filtered to reduce moisture to 15% or less, and then placed as a fine sand material in a dry stack structure within the upper Liese Creek Basin…. These tailings will be compacted, seismically stable, non-acid generating, and virtually impermeable due to their fine-grained nature, degree of compactness and the unsaturated nature of the tailings. This approach of dry-stack tailings storage will provide a stable and impermeable method of disposal. In addition, it will allow for closure and reclamation to a high standard. The remaining flotation tailings will be placed in mined-out areas as cemented paste backfill to support the mine workings.*

In this project, the relatively small volume of sulphide bearing tailings will be returned underground where the potential for acid rock drainage is reduced. The dry stacking method affords a more environmentally friendly and reclaimable tailings deposit.

4.2 ADVANTAGES OF THE TECHNOLOGY

The economic and environmental advantages of the technology certainly make dry stack technology worth examining for many different projects. Martin et. al. (2002) and Davies and Rice (2002) both explain that while the technology is currently, and often considerably, more expensive per tonne of tailings stored than conventional slurry systems, it has unique advantages.

1. In arid regions where water conservation is important:
   - Water management is optimized when the supply is scarce and/or expensive by reclaiming much of the process water via the filtration processes at or near the main mill site.

2. In situations where economic recovery of metals from solution is enhanced by tailings filtration;
   - Mines dealing with precious metals, in particular, are well served by maximizing the recycling of metal laden process water;
   - The recycling and recapture of processing chemicals is also a cost saving achieved by recycling process water.

3. Where very high seismicity presents a high risk for conventional tailings impoundments;
   - Filtered tailings placed in dry stacks are "essentially immune" to catastrophic failure and can be readily designed to withstand static and seismic forces;
   - The unsaturated nature of the tailings is extremely resistant to saturation;
   - A wider variety of foundation conditions is also available to this sort of tailings deposition because the tailings within the dry stack, which become more solid because of pressure, are not as susceptible to static liquefaction or catastrophic breaching.
   - There is a corresponding reduction in seismic design costs.

4. Cold regions, where water handling is very difficult in winter;
   - Recycling and retention of process waters via the filtration process are again important here.

5. Relatively low-tonnage operations including coal, for example, where tailings can be co-disposed in waste rock dumps.

6. Dry stack tailings are attractive from a regulatory and environmental standpoint because the disposal area requires a smaller footprint for tailings storage, tailings are easier to reclaim, and have much lower long-term liability in terms of structural integrity and potential environmental impact.

7. There is extremely limited leachate development due to the relatively low seepage rates. Moisture penetration of dry stack tailings is limited by the dense, compacted, unsaturated, and hydrophobic nature of the high matric suction tailings surface (Pers Comm., Davies, 2002).

8. With respect to site decommissioning and closure, another advantage of this tailings disposal method is that the tailings area can be reclaimed on a continuous basis with progressive covering and reclamation. All dry stack tailings facilities require a cover to minimize erosion from runoff, fugitive dust releases, and to provide the medium for vegetative recolonization of the site.

   The cover system has two objectives:
   - Provide a water-infiltration barrier over the underlying unsaturated tailings and waste rock using a low permeability layer and/or a moisture storage and release layer.
   - Provide a medium for establishing a sustainable vegetation cover that is consistent with the surrounding environment.

While this technology is relatively new and no closed dry stack tailings facilities were identified during the research, closure plans do exist and include considerations of reclamation. It is recommended by Martin et. al. that adequate engineering studies be completed to demonstrate the feasibility of using the technology before basing mining operations on the technology.

4.3 WHERE IS THE TECHNOLOGY BEING USED?

Currently there are several operating mines using the technology and others that are proposing to use dry stack tailings. Examples of operating mines include the Raglan Mine in Northern Quebec and the La Coipa Mine in Chile. These operations are located in the alpine, in the case of the Raglan operation, and in a very arid region of Chile, as in the case of the La Coipa Mine. Neither of these sites would include significant revegetation as part of closure activities due to the relative paucity of vegetation existing in the habitats surrounding the facilities. They, therefore, have little to offer with respect to revegetation information.

The Kennecott Greens Creek Mining Company operation in Southeast Alaska has detailed a comprehensive management and has prepared reclamation plan for the tailings at the gold property (2001). The General Plan of Operations for the mine considers several factors respecting the operation of the tailings facility, including:

- Permitting Issues and Reporting Schedules;
- Emergency Action Plan;
- Loading and Hauling of tails;
- Placement and Compaction of Tailings;
- Water Management;
- Concurrent Reclamation;
- Final Reclamation;
- Tails Pile Inspections;
- Facility Maintenance;
- Facility Monitoring, including:
  - Geochemistry of tailings;
  - Pore water chemistry;
  - Water flux and cover performance;
  - Water balance and mass loading model development;

Other proposed mines are planning to use the dry stack tailings technology including Mineral Hill in Montana where revegetation will include the planting of grass and legume species and coniferous tree species on an engineered cover (Pers. Comm., M. P. Davies).

The Las Cruces mine in Spain is planning the construction of a dry stack tailings facility which will be built from the outside inwards to allow for easier covering and revegetation, and to minimize aesthetic (or visual) effects on the landscape during and after mining. The plate, below, depicts the proposed Las Cruces dry stack tailings development.

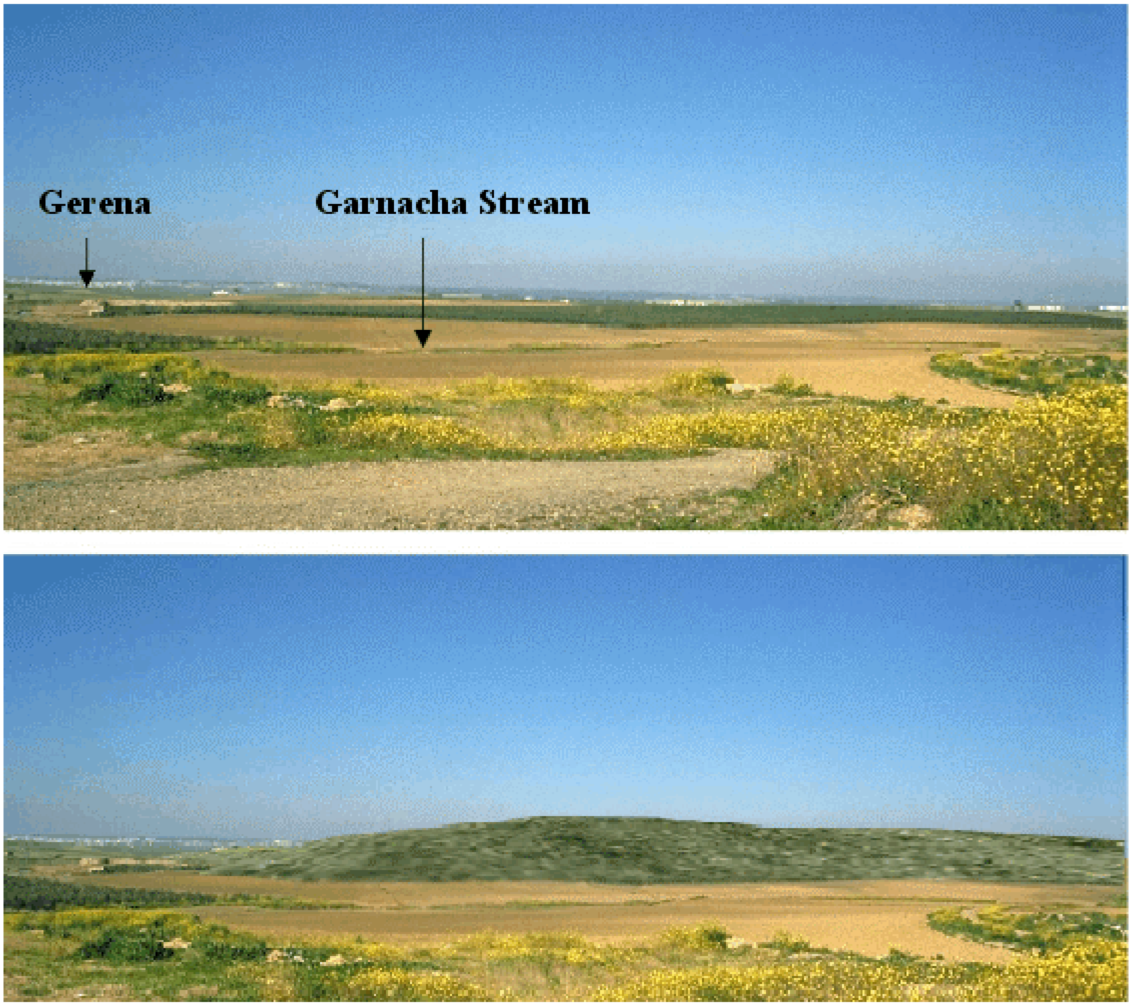

Plate 1 Before and After Images of Proposed Dry Stack Tailings Development Las Cruces Mine, Spain.

As mentioned previously, Teck Resources Inc. proposed Pogo Gold Mine in Alaska is also planning to employ filtering and dry stack tailings technology.

Schoenbrunn and Laros (1997) posit that the use of dry stacking as a disposal technique is expected to increase as more mines find it to be a practical alternative to tailings ponds and dam construction and a means of reducing environmental impact, simplifying mine closures, and increasing water and chemical recovery.

4.4 REGULATORY CONSIDERATIONS

While relatively new, dry stack tailings technology and the construction of tailings facilities are generally no different to permit than other methods of tailings disposal. The engineering and environmental assessments of such facilities are just as rigorous and comprehensive as with other systems. Dry stack tailings disposal typically represents a smaller footprint and less environmental liability than the more typical slurry tailings disposal, which involves the use of tailings dams and significant water management infrastructure. It is in this regard that dry stack tailings may be more appealing from a regulatory standpoint, and in the long-term represent less environmental liability for proponents.

Davies and Rice describe the use of dry stack tailings disposal as “regulatory-friendly” and go on to state that the primary challenge for dry stack tailings management systems is to become cost-effective for more operations that would benefit from its consideration.

Permits for such facilities may include terms and conditions for quality control/assurance for construction, operation, and closure and may include monitoring for years after a facility has seen its useful life and has be decommissioned.

In Alaska dry stack tailings facilities are permitted through the Solid Waste Regulations (18 AAC 60). Several mines in the state that are permitted or are in the process of permitting proposed dry stack tailings disposal (also called “monofill” in Alaska). In addition to the typical construction and operation controls, terms and conditions of these permits sometimes include a significant long-term monitoring component. In recent years, ADEC has issued solid waste disposal permits for mine tailings impoundment facilities at the Fort Knox and Illinois Creek mines with requirements for 30-year post-closure monitoring and a financial warranty to cover the cost of post-closure monitoring.

5.0 DRY STACK TAILINGS MANAGEMENT AND REVEGETATION

5.1 GENERAL MANAGEMENT CONSIDERATIONS

Davies and Rice state that tailings management is one of the most important components with respect to the viability of a filtered tailings operation. The relatively higher costs of transporting, placing, compacting, covering and reclaiming dry tailings must be examined when designing an operation. Water management is an obvious concern that can be addressed in the following manner:

a) Non-contact surface water should be routed around or underneath the structure with design considerations for the particular hydrology of the site catchment.
b) Contact water (water within the dry stack area) should be routed through armoured channels to a management area within the facility for treatment, disposal or reapplication to the revegetation areas of the facility.

Long-term management of water is also a consideration of the design of such facilities. Wetlands treatment, underground biotreatment, and other passive, yet effective, treatment methods have been contemplated for long-term use.

If effective water interception strategies are employed and seepage into the dry stack is mitigated by a suitable cover, the potential for acid rock drainage can be significantly minimized. Merely revegetating the surface of the tailings pile that has a suitable growth medium can provide even greater moisture penetration reduction acting as a storage and release mechanism during and after precipitation events.

5.2 REVEGETATION METHODS

5.2.1 GENERAL SELECTION CRITERIA

As discussed previously, very little information could be found regarding revegetation of dry stack tailings facilities, specifically. Despite the paucity of information in this regard, since most, if not all, DTFs require a suitable cover, it has been assumed that the revegetation of such sites would follow plans similar to that of other land disturbance reclamation plans. Many of the MERG projects conducted to date have addressed the issue of approaches to revegetation of disturbed areas and a significant body of knowledge is available to assist in reclamation efforts.

With respect to the development of reclamation plans for a DTF, the selection of a suitable cover is very important. The structural integrity of a DTF depends largely on control of its saturation, post deposition. Saturation is controlled by a suitable cap and adequate drainage, if it is necessary. The limiting factor of the saturation control can often be the effectiveness of the pile cap. A common covering strategy is to place a capillary break on the dry stack followed by a filter compatible base and moisture retention layer and then the growth media layer (Pers.

Comm., Davies, 2002). Depending on the site conditions, locating and providing a suitable capping material for a DTF then becomes a significant challenge and other methods of establishing successful native/local vegetative colonies on the dry stack tailings piles may have to be explored.

Site stripping and segregation of organics and overburden materials would be one way of supplying a suitable cover for the tailings piles. In the North, special considerations would have to be made for sites that would expose permafrost. In the case of many development sites in Yukon, it is generally considered imprudent to remove the overburden layer where the permafrost layer may be exposed to melting conditions. At an operating mine, progressive stripping could accommodate a growing tailings pile while at the same time not allowing too much uncovered permafrost to be exposed prior to being recovered by tailings. The stripped overburden could then be stockpiled for later use. If this is found to be an unacceptable methodology of procuring a suitable cover material then other sources may have to be found.

Once a suitable cover is designed, plant species that are most adaptable to the substrate and local environment could be selected for trials. Revegetation protocols could be designed from existing information available on the subject, including several volumes produced here in the Yukon, both through MERG and through other reporting channels.

5.2.2 Options for the North

Experimentation and test trials were identified in much of the literature as important to determining whether the use of the technology would be successful. Experimentation with alternative tailings cover designs could be attempted at operating and decommissioned or abandoned properties to evaluate their relative effectiveness and applicability to the use of dry stack tailings facilities. Test programs could be undertaken to design cover alternatives and monitor field tests over a multi-year period. Variables to be assessed during the field tests could include combinations of cover material, topsoil, vegetation types, soil amendments and surface topography. In the interest of acquiring some preliminary information on successful methods for revegetating DTF facilities, cooperation between groups interested in developing and evaluating engineered cover designs, and those interested in long-term stability issues and revegetation of DTFs would be a beneficial starting point.

6.0 CONCLUSIONS

Dry stacking of dewatered or unsaturated tailings is a useful technology that is appealing from an operational point of view but also from a regulatory point of view. Dry stack tailings are less susceptible to catastrophic failure than typical slurry tailings impoundments and their unsaturated nature reduces concerns regarding leachate. DTFs can be revegetated on an ongoing and progressive basis limiting short and long-term environmental impacts. Finding methods of making the technology more widely applicable to differing mining projects and making it cost effective at the same time is viewed as a key challenge.

With respect to reclamation and revegetation in particular, dry stack tailings are not considered more challenging than other tailings revegetation projects. Engineering suitable and stable covers for the facilities is a challenge and the success of revegetation on those covers has not yet been characterized due to the limited number of operations using the technology and the paucity of information in that regard.

Dry stack tailings offer a couple of general advantages for reclamation, including:

- Opportunities to initiate reclamation early in the project lifecycle;
- Opportunity to conduct reclamation activities on an ongoing and progressive basis; and,
- Reduced environmental liability for operation and upon closure.

The reviewed literature indicates that reclamation and closure costs for DTFs are significantly reduced when compared with conventional tailings. Davies and Rice indicate that when viewed in the context of long-term corporate risk and liability, dry stack tailings offer a much more attractive price tag.

The following excerpt from Davies and Rice provides a succinct assessment of the technology.

> “Filtered tailings, a form of dewatered tailings, are not a panacea for the mining industry for its management of tailings materials. Purely operating economic considerations rarely indicate a preference for dry stack tailings facilities over conventional slurry impoundments. However, under a growing number of site and regulatory conditions, filtered tailings offer a real alternative for tailings management that is consistent with the expectations of the mining industry, it regulators and the increasingly industry-aware public.”

Site specific reclamation and revegetation studies, including test plot trials for individual dry stack tailings reclamation areas should be developed to ensure successful long-term dry stack tailings closure.

7.0 ACKNOWLEDGEMENTS

This project was completed with assistance of Theresa Mundell, an Environmental Science student whose research talents were made available to Access Consulting Group by Sam Wallingham of the Nacho Nyak Dun Development Corporation.

Technical resources were provided by Dr. Michael Davies of AMEC Earth & Environmental Ltd. (Burnaby, BC), who has authored several papers of the subject of dry stack tailings and has had design, construction, and operational experience with several mining projects utilizing dry stack technology.

Mr. Chris Carr, a geotechnical engineer with the Government of British Columbia Department of Energy and Mines provided direction for research on dewatered tailings.

The authors would also like to thank the Mining Environmental Research Group for their direction and funding for this research and review project, with particular thanks to Karen Pelletier and Lori Walton.

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for Dry Stack Tailings in Northern Environments

Appendix A

Annotated Bibliography

Dry Stack Tailings

Anand, R., Biles, G., Major, K., and Teh, H. "The Economics of Exploration". Larox Solutions. Adapted from a paper presented to the Canadian Mineral Processors 1998 annual conference.

The authors are marketing the Larox Pressure Filter as a means to dewater Eskay Creek's tailings. The plan demonstrates a Larox PF 60-144 filtering the tailings before they are discharged into a storage area. The tailings at Eskay Creek are dewatered to allow them to be deposited in the same sub-aqueous manner as the waste rock.

Bentel, D. and Luppnow, D. "Benefits of Dry Tailings Disposal". SRK's International Newsletter No.29: p. 3. 4 July 2002. <http://www.na.srk.com/newsletters/SRKnews29-Tailings.pdf>

Much of the information contained in this small article is quoted from Adriaan Meintjes, a director at SRK who has published a paper regarding mining waste management as it pertains to South Africa. The use of dry tailings instead of the traditional forms of tailings disposal is stated as especially advantageous for water conservation and the reduction of groundwater pollution. Through surface management the amount of liquid infiltrating the tailings impoundment can be reduced, thereby reducing the amount of water available in the dry stacks that can potentially contribute to seepage and groundwater pollution.

Davies, M.P. and Rice, S. "Dry stack filtered tailings". Mining Environmental Management. January (2002): 10-13.

This article includes information and advantages of dry stacking tailings. Tailings are first filtered through a vacuum or pressure filter and dewatered beyond being pumpable which is particularly advantageous in cold climates where handling water is difficult in the winter. Other advantages of dry stacks are their small footprint in comparison with traditional methods of tailings disposal and the ease with which they can be reclaimed, thereby lowering long-term liability. Lowering development, reclamation, and closure costs counteract the higher DTF operating costs. The substance being mined (i.e. Silver) as well as the process chemicals can be recovered from the water used in filtration. Tailings can be more densely packed and stored in areas previously unusable for tailings disposal such as valley slopes. Progressive reclamation of dry stacks is essential to combat dust generation and also eases reclamation and closure. Non-contact water should be diverted away from the dry stack and contact water should be collected.

Currently dry stack operations are limited to those under 20,000 t/d.

Figure 1 – Tailings Continuum lists the alternative types of tailings and elaborates on the properties of both "Dry Cake" and "Tailings Slurry" for comparison purposes.

Kennecott Minerals. "Kennecott Greens Creek Mining Company, General Plan of Operations". Appendix 3, Tailings Impoundment. August 31, 2000.

This appendix explains the details of the tailings impoundment at the Greens Creek Mine.

Section 2.1.4 on Tailings Pile Operations and Maintenance details the procedures of tailings monitoring, placement, compaction, and drainage. Section 2.1.5 on Concurrent Reclamation claims concurrent reclamation is limited to the side slopes that have reached the limit of the permit and where access is no longer required. Section 2.1.6 on Final Reclamation projects into the future when mine waste rock will cap the tailings followed by an engineered cover with the ability to support vegetation. The slopes of the dry stack will be 3:1 on all sides except the north where, under their circumstances, 2:1 slopes are allowable.

<u>Kensington Mine Project</u>. City and Borough of Juneau, Community Development Department. 4 July 2002 <http://www.juneau.lib.ak.us/cdd/Kensington/index.htm>.

This extensive review of the Kensington Mine Project describes their proposed operations. Related to dry stack tailings, thickened tailings will be transported by pipeline to a filter plant near the deposition location where they will be filtered and trucked to the dry tailings facility. The construction of the dry tailings facility will commence with site preparation (dewatering, stripping and stockpiling topsoil, and laying 2 ft of development / waste rock), preceding the tailings placement by three months. The tailings will be placed in 28 ft high lifts that will be covered immediately upon completion with, first, an infiltration barrier, then geotextile wrapped drainpipes and a layer of development rock. Concurrent reclamation is expected to include covering areas no longer in use with topsoil and grass seed. A final cover of low permeability fine till followed by coarse till and topsoil will be added. Because the Kensington Mine is located outside Juneau, AK, much the tailings sections of the review focus on monitoring the tailings and their ability to withstand the earthquakes common to the area.

Martin, T.E., Davies, M.P., Rice, S., Higgs, T., and Lighthall, P.C. "Stewardship of tailings facilities". Mining, Minerals and Sustainable Development Project. International Institute for Environment and Development, 2002.

Section 6.1.3 on Dewatering Technologies describes dry filtered tailings as those filtered using either pressure or vacuum force for disposal in a dewatered state. The paper goes on to briefly detail comparisons of the two filtration methods and their properties. It states that this technology is particularly advantageous under cold climatic conditions where water handling is difficult during the winter. Falconbridge's Raglan operation in northern Quebec and a new gold project located in central Alaska (Pogo) are cited as examples.

Dry stacks propose reduced environmental footprints, easier reclamation and closure, and lowered long-term liabilities.

Figure 9 – Classification of tailings by degree of dewatering

Figure 10 – Examples of a filter plant

Figure 11 – Example Dry-Stack Tailings Facility

<u>Raglan – An Arctic Achievement</u>. The Mining Journal. 2000. 4 July 2002 <http://www.mining-journal.com/miindex.htm>.

This article describes Raglan's Nickel Mine located in a remote area Northern Quebec. The mine's tailings are dewatered using a Svedala filter press to produce filter cake tailings with a 12-15% moisture content. They are then trucked to the tailings impoundment where they are progressively reclaimed with a cover composed of compacted sand and rock, allowing the permafrost to penetrate and freeze the tailings. Any runoff from the dry stacks is directed by surrounding ditches to a 100,000m^3 pond and recycled. The Raglan mine has been designed to minimize liquid waste, and provide a basis for progressive tailings reclamation.

Ruse, B. C. and Boger, D. V. Department of Chemical Engineering, Melbourne, Australia. "Alternatives for tailings and accounting for sustainability". Proceedings of The Global Mining Initiative Conference, Toronto, 2002.

In a small excerpt from this paper, dry stack tailings are described. The method of dry stacking tailings is stated as particularly suited to areas where limited space is available. Thin layers of thickened tailings solids are allowed to drain and sufficient evaporation is permitted prior to the addition of subsequent layers. Because of the dry nature of the tailings, it is suggested that they can be stacked to heights unachievable with other forms of tailings disposal.

Schoenbrunn, F. and Laros, T.J. "Dry tailings disposal using Hi-Density thickening". Proceedings of Tailings and Mine Waste '97, Balkema, Rotterdam. 1997. pp. 357-363.

This paper states that dry tailings disposal is becoming increasingly common. Currently dry stacking operations use material that is high slump and low viscosity in order to deposit tailings in relatively thin layers (6") over wide areas. The layers are allowed to dry and usually crack so subsequent layers fill the cracks. The authors' think dry stacking will be used in dry climates where water conservation is important and evaporation is a more effective means of tailings volume reduction. Although most of the paper promotes the use of Hi-Density thickeners, it also concludes that dry stack disposal will likely increase as a viable alternative when considering reducing the impact on the environment, easing mine closure, and recovering water and processing chemicals.

Teck Resources Inc. "1.2 Project Overview". Pogo Environmental Baseline Document. Fairbanks, AK. March 31, 2000.

This document claims the tailings site at Liese Creek will be capable of handling tailings for 3-4 times the mine's projected life. 50% of these tailings will be in surface dry stacks in the upper Liese Creek basin. They will be filtered to less than 15% moisture producing a compacted, stable and non-acid generating tailings dry stack. The tailing pile's impermeability is aided by the compact, unsaturated nature of the dry stack tailings.

U.S. Department of Agriculture, Forest Service (USFS). "Kensington Gold Project Final Supplemental Environmental Impact Statement". Vol. I-II. August 1997. Ch2

The proposal indicates that a conveyor would move the tailings to a covered storage area prior to being trucked to the DTF while reclaimed water would be piped back to the mill. The drainage system below the DTF would consist of drains spaced in 100 ft intervals and filled with gravel that has been wrapped in geotextile materials to preserve its integrity. This would be followed by at least 2 ft of waste rock before the tailings are added. The DTF would be constructed out of cells with each cell containing 5-7 28 ft lifts of non-compacted tailings. As sections of the lifts are completed they will be covered immediately with till and waste rock in order to minimize infiltration to the dry stacks. The final cover will consist of 6-8 ft of fine and coarse till and a layer of topsoil to support vegetation. The alternatives of either compacting the dry stack tailings or adding 3 percent cement were eliminated because they are more costly without providing increased structural stability.

Figure 2-9: Typical Section and Cover Details of Dry Tailings Facility

Revegetation of Tailings

Equity Silver Mine – Case Study. Aziz, M.L. and Feruson, K.D. Placer Dome North America Ltd. 4 July 2002 <http://mend2000.nrcan.gc.ca/cases/equity/equity.htm>.

The article focuses on acid rock drainage (ARD) and the cover composition that limits water and oxygen infiltration to the waste rock. Initially 1.0m of non-compacted till covering the waste rock allowed approximately 40% infiltration, while tests showed a compacted clay cover allowed only approximately 5% infiltration. The compacted clay was added to 20^{o} slopes at a thickness of 0.5m. A 0.3m layer of loose, non-compacted till was added to help limit erosion and provide a medium for vegetative growth. This second layer allowed the first to retain moisture, reducing the oxygen infiltration.

Felleson, D. "Iron Ore and Taconite Mine Reclamation and Revegetation Practices on the Mesabi Range in Northeastern Minnesota". <u>Restoration and Reclamation Review.</u> 5 (1999): Reclamation of Contaminated Land and Water. <www.hort.agri.umn.edu/h5015/rrr.htm>.

This article presents ways to restore growth potential to mine tailings piles. It suggests that organic matter be used in addition to fertilizer. The organic matter has water retention properties while the fertilizer provides essential nutrients needed to revegetate the nutrient-poor soil of the mine tailings. The increased cost incurred by the addition of organic matter is countered by the reduction in costs when subsequent applications of seed and fertilizer aren't required.

Kennecott Minerals. "Kennecott Greens Creek Mining Company, General Plan of Operations". Appendix 14 Attachment A, Detailed Reclamation Plan Cost Estimates. November 15, 2001.

As in the December 1998 reference to the Greens Creek Mine, the tailings cover will consist of first an 8-12" capillary break, followed by a 24" compacted barrier layer, an upper 8-12" capillary break, and a minimum 24" growth layer. This will be constructed with 3:1 slopes to minimize the grading requirement upon closure. Concurrent reclamation of the south and west slopes is already underway and includes, erosion control, hydroseeding, water drainage, and the addition of topsoil. The concurrent reclamation of the north and east slopes will commence in 2-5 years. To prevent erosion and minimize air and water infiltration the tailings are compacted, the surfaces are sloped, and the water is diverted.

Table A.1 – Engineered Cover Design Summary for Reclamation use

Figure 2 – Existing Tailings Area - General

Figure 2A – Tailings – Utilities Detail

Figure 2B – Tailings – Final Contours Concept

<u>Kensington Mine Project</u>. City and Borough of Juneau, Community Development Department. 4 July 2002 <http://www.juneau.lib.ak.us/cdd/Kensington/index.htm>.

This is a comprehensive review of the entire intended operations at the Kensington Gold Mine. The permanent cap for the dry stack tailings would consist, according to the applicant, of first, 2 ft of low permeability till, followed by 5 ft of coarse till and 6" of topsoil. The fine till will function to inhibit water infiltration to the dry stack tailings, the coarse till will protect against frost as well as provide sufficient depth preventing roots from penetrating the barrier layer. The topsoil is added as a medium to support vegetative growth. The revegetation is proposed to proceed as the dry stack cells are completed, with grass being seeded to stabilize the soil. Forest succession is expected to occur naturally.

Maxim Technologies, Inc. "Final Long-Term Revegetation Monitoring Plan, New World Mining District Response and Restoration Plan". USDA Forest Service, Northern Region. Missoula, Montana, 1999.

This document focuses mainly on the purpose of revegetation and includes an extensive procedure for revegetation monitoring. It describes many sampling methods in detail for the purpose of measuring such community characteristics as species density and species diversity.

Myers, K.L. and Crews, A.E.W. "Cover design considerations for tailings and other waste". Mining Environmental Review. January (2002): 14-15.

This article outlines the importance of covers for tailings impoundments. A cover can provide a medium for vegetative growth, protect from erosion and frost, act as an infiltration and bio-intrusion barrier, and contribute to surface and subsurface drainage. The article continues by detailing these cover functions with particular emphasis on stability and drainage. It states "cover deployment on dry stacked waste is a simple grading operation".

Nevada Division of Environmental Protection. "Nevada Guidelines for Successful Revegetation for the Nevada Division of Environmental Protection, the Bureau of Land Management and the U.S.D.A. Forest Service". September 3, 1998.

This document provides guidelines for establishing vegetation on disturbed mine sites. Reclaimed Desired Plant Communities, consisting of diverse groups of perennial, native species, are of primary importance. It states that evaluation of vegetation success should be evaluated no sooner than three growing seasons after planting.

Norman, D.K. and Raforth, R.L. "Innovations and Trends in Reclamation of Metal-Mine Tailings in Washington". Washington Geology. vol.26 no.2/3. 1998.

This publication provides information on most types of tailings and their reclamation. In cover designs gravel layers have been used for drainage. Some covers incorporate a biointrusion layer preventing root penetration and animal activity from harming the drainage layer; these layers are also designed to inhibit burrowing animals from surfacing contamination from the tailings. The effectiveness of these layers has been deemed questionable following root penetration studies.

A capillary barrier is composed of a layer of fine soil over coarse soil and acts as a barrier towards the influx of oxygen and water, until it can be utilized by vegetation through evapotranspiration. The effectiveness of a capillary layer decreases as it becomes saturated.

Revegetation can be aided by the availability of topsoil and additions of compost, biosolids, hay, and paper residue. Re-establishing native plant species is important because they are adapted to the specific climatic conditions and are of more use to wildlife. If soil recently stripped from a nearby area is used as a cover it will likely contain native seeds needed to aid rapid revegetation. Woody debris scattered over the area being reclaimed aids revegetation and the placement of lichen-covered rocks increases lichen colonization.

Reclamation and Long-Term Care Requirements for Mine Sites in Wisconsin. Wisconsin Department of Natural Resources. 11 July 2002 <http://www.dnr.state.wi.us/org/es/science/mining/infosheets/rec-ltc/rec-ltc.htm#top>.

This website presents guidelines for mine reclamation, giving minimum standards and goals for environmental protection. Also included is a reclamation plan that briefly runs through everything from the pre-mining phase to the final phase of mine reclamation, providing some suggestions for monitoring and evaluating the plan.

Ripley, E.A., Redmann, R.E. and Crowder, A.A. Environmental Effects of Mining. Delray Beach, Florida: St. Lucie Press, 1996. pp.121-130.

This publication contained information regarding all forms of mining and some specific environmental concerns and remediation suggestions. It states that transpiration by plants limits the amount of water available to infiltrate the waste rock. Fine soils contribute to water and nutrient retention and are best for cereals and forages. Coarse soils will grow most trees, shrubs, native grasses, and forbs, and they are less susceptible to erosion than fine soils. Mulch can be used as a surface stabilizer. Soil temperature is affected by the colour of the substrate and the flux of radiation, which is highest on south and west facing slopes.

Teck-Pogo Inc. Pogo Project. "Project Description, Section 5.0-6.2". 2000.

This is a section of the Liese Creek Mine project description focusing on the proposed reclamation of the dry stack tailings facility. The dry stack tailings will be contoured to control runoff, and subsequently covered with a soil layer specified to inhibit water infiltration, and a soil layer specified to promote vegetative growth. A three-year test program will be conducted to compare and contrast the effectiveness of different combinations of cover, topsoil, vegetation, and topography.

Unsaturated Soils Engineering Ltd. "Final Report, Waste Rock Cover Design". Kennecott Greens Creek Mining Company, 1998.

Unsaturated Soils Engineering Ltd. conducted a series of cover test experiments and found the best results with Profile 4. Profile 4 consisted of, first, an 8' capillary break above the waste rock, followed by 24" of compact 23A-8 soil, another 8' capillary break, and finally a minimum of 24" of loose 23A-8 soil. This combination resulted in a net infiltration of 48mm/yr and a minimum barrier saturation of 95% - the highest of the 4 profiles.

Profile 1 also produced acceptable results with a net infiltration of just 28mm/yr and a minimum barrier saturation of 85% (the lower limit). It was composed of 12" of compact 23A-7 soil above the waste rock, followed by 12" of compact 23A-8 soil, and a minimum of 24" of loose 23A-8 soil. Profile 1 is not recommended in the case of an extreme storm event – a detail important to the Greens Creek Mining area in southern Alaska.
23A-8 is coarser till and 23A-7 is finer till.

Yukon & North – Specific Revegetation

Bidwell, J. "Reclamation of the Usibelli Coal Mine near Fairbanks, Alaska". <u>Restoration and Reclamation Review.</u> 1 (1996): Restoration Case Studies. <www.hort.agri.umn.edu/h5015/rrr.htm>.

This article describes the reclamation process at the Usibelli Coal Mine in Alaska. It overviews the selected types of seedlings planted as well as methods of seed dispersal, giving recommendations.

Craig, D.B., Craig, J.E., Pelletier, K., Emond, D., and Copland, H., 1998. Reclamation practices and research on mineral exploration properties in the Yukon Territory. Mineral Resources Directorate, Yukon Region, Indian and Northern Affairs Canada, 36 p.

The bulk of this publication discusses reclamation of post-mine trenches and pre-regulatory reclamation in the Yukon; however, there is some useful information pertaining to revegetation methods and practices. At one site in particular, the grasses that were planted appeared to out-compete native species, but it was determined that these grasses might subsequently form a compost layer with the potential of nursing colonization of native species. Graminoids, such as redgrass, bluegrass, and fescues, are recommended for seeding on erosion prone slopes because they promote rapid revegetation. Five different seeding test scenarios were carried out in each case and the results are provided. It is recommended that no topsoil be imported as it is of little benefit and may include undesirable plant species. Only a single application of fertilizer is recommended.

Department of Indian Affairs and Northern Development, Mining Land Use Division. <u>Handbook to Reclamation Techniques in the Yukon, Yukon Placer Mining Land Use Regulations</u>. Department of Indian Affairs and Northern Development, Mining Land Use Division, 1999.

This handbook provides suggestions for erosion control and revegetation on a variety of surfaces. There is also information pertaining to the reclamation of tailings piles such as sloping, contouring and providing an appropriate cover.

EBA Engineering Consultants Ltd. "Research of Low Permeability Cover Performance at the Arctic Gold and Silver Mine Site, Carcross, Yukon". Mining Environmental Research Group, 2001.

This document summarizes reports on the Faro tailings and acid rock drainage. This information is used to test the cover at Arctic Gold and Silver as a means to prevent acid rock drainage. It concludes that the low conductivity, clay/silt cover is acting as an effective barrier towards moisture and oxygen.

Helm, D.J. "Seed and "Topsoil": To Use or Not To Use". Proceedings of the Northern Latitudes Mining Reclamation Workshop, Whitehorse, Yukon, Canada. pp. 11-20. 2001.

The author concludes that seeding and using other plant material typically reduces erosion and, although seeding may appear to inhibit natural colonization, it has been the experience of the author that natural colonization usually proceeds onto seeded areas.

Indian and Northern Affairs Canada. "Reclamation Guidelines for Northern Canada". Calgary: Hardy BBT Limited, 1987.

Chapter 5 – Revegetation
Surface preparation ensures a higher seed catch. Surfaces should be level and slope edges rounded. Smooth surfaces should be roughened to create furrows for seeds to establish in; whereas, they might blow away if surfaces are left smooth. Moisture will also collect better in furrows. Seeding and fertilizing are best done in the spring, immediately after snowmelt and runoff, but can also be accomplished in the fall and winter. Any cuttings should be planted following a grid pattern.

Chapter 6 – Seed Mixture and Fertilizer Recommendations
If the region of reclamation and the soil moisture content are known, a seed-specifications chart is provided. Fertilizer requirements can be found experimentally but there are recommendations that have proven adequate in many northern situations.

Kennedy, C.E., ed. "Guidelines for Reclamation / Revegetation in the Yukon". Yukon Renewable Resources, Habitat Management Section, Fish and Wildlife Branch, 1993.

The primary objectives of revegetation are stated to be both establishing self-supporting vegetation and controlling erosion. The secondary objectives are maintaining a thermal regime, enhancing aesthetics, providing forage, and reducing maintenance costs.
Northern soils are most often nitrogen and phosphorous deficient with the cold climate limiting the microbial metabolism and immobilizing nutrients below the active layer. Because of the wide range of environmental conditions present in the north, native seeds are thought to fare better than south-developed agronomic seeds, which might have a harder time adapting. Mulches are favoured in areas of low moisture retention, of low precipitation during the growing season, with steep/unstable slopes, and in alpine and subalpine areas. Slopes > 2:1 (27^o) should be mulched and south-facing slopes > 3:1 (18^o) should be mulched for water retention purposes. Hydroseeding should be used on slopes to minimize traffic and the possible destabilizing of the slope.

Table 67: Seed mixture and fertilizer specifications for subalpine environments
Table 71: Seed mixture and fertilizer specifications for sand and gravel cut slopes
Table 72: Seed mixture and fertilizer specifications for silty-clay cut slopes

Macyk, T.M. "Three Decades of Reclamation Research in the Alpine and Subalpine Regions of Alberta". Proceedings of the Northern Latitudes Mining Reclamation Workshop, Whitehorse, Yukon, Canada. 2001. pp. 21-38.

According to Macyk (2001) obtaining an adequate native seed supply is a limitation of seeding with solely native species as it was found that the seed of some native subalpine species of grasses and legumes had low germination rates when compared with agronomic seeds. The grasses and legumes planted in the study responded markedly to fertilizers but it was determined that long term fertilization was not required; all plots needed fertilization the year of seeding and the following year, while those containing only grasses needed to be fertilized a third time in their 5th year before fertilizer use was discontinued.

McBride, B. "Caribou Reclamation Project and Sediment Control During the Construction Phase of a Major Mine". Proceedings of the Northern Latitudes Mining Reclamation Workshop, Whitehorse, Yukon, Canada. 2001. pp. 101-114

In this paper, revegetation is considered the most effective means to prevent surface erosion. The method of hydroseeding is described as an expensive application that distributes a mixture of seed and fiber mulch. It is most effective when seed needs to cover a large area or be applied quickly. The fiber mulch acts as a short-term protective soil cover. Strawmatting can also be used as a protective cover while the least expensive alternative is mulching with loose straw to a depth of approximately 20cm.

Mougeot, C. and Withers, S. "Assessment of Long Term Vegetation and Site Conditions at Reclaimed Yukon Mineral Exploration Sites". Proceedings of the Northern Latitudes Mining Reclamation Workshop, Whitehorse, Yukon, Canada. 2001. pp. 39-53.

In the summary of this paper, it is suggested that importing topsoil is not practical as a reclamation measure because of the cost involved and the possibility of introducing undesirable plant species. Mulch can aide in effective erosion control. Organic-rich material was the only stated means of aiding revegetation and re-establishing native colonization.

Mougeot, C. Mougeot GeoAnalysis. "Natural Land Reclamation for Mineral Exploration Properties and Placer Mines in Yukon". Exploration and Geological

Services Division, Mineral Resources Directorate, Indian and Northern Affairs Canada, Yukon Region, 1996.

This report summarizes disturbed mine site reclamation in the Yukon. Some findings include: slopes 45° or lower appear stable but gullying and runoff are still active until revegetation occurs; 15-20% of the surface 20cm should be composed of a fine matrix although steeper slopes may require a thicker surface material less likely to be washed down with runoff; compacted surfaces allow for faster runoff and should be loosened; and organic material should be stockpiled and replaced upon reclamation.

Mougeot GeoAnalysis and S.P. Withers Consulting Services. "Assessment of Long Term-Vegetation and Site Conditions at Reclaimed Yukon Mineral Exploration Sites". Mining Environmental Research Group, 2000.

This publication predominantly refers to the trench reclamation projects at Red Ridge, Nucleus Property, Hawk Property, Division Mountain Coal Exploration Property, and Jason Knoll Mineral Exploration Property. It concludes that rough, loose surfaces appear to revegetate well, original soil contributes significantly to revegetation, the replacement of tree debris improves habitat for small mammals, and mulch aids in erosion control.

Northern Water Resource Studies. "Mine Reclamation in Northwest Territories and Yukon". Northern Affairs Program. Steffen, Robertson and Kirsten (BC) Inc., 1992.

This paper on mine reclamation states that revegetation controls erosion, re-establishes habitat and site productivity, and improves aesthetics.

Withers, S.P. and Laberge Environmental Services. "Native Vegetation Succession at Yukon Mine and Mineral Exploration Sites". Mining Environmental Research Group, 1999.

This document provides suggestions for both initial reclamation and revegetation, and the encouragement of native species succession. It is recommended that revegetation of disturbed sites proceeds with, first, site selection, followed by data collection, species selection, seeding, and monitoring.

Appendix B

List of Individuals/Agencies Contacted

Personal Communication, December 2002. *Ed Emswiler*. State of Alaska, Department of Environmental Conservation – Environmental Health Solid Waste Program, Juneau, Alaska.

Personal Communication July 2002 and March 2003. *Dr. Michael Davies*. AMEC Earth and Environmental Ltd., Burnaby, British Columbia.

Personal Communication March 2003. *Peter Lighthall*. AMEC Earth and Environmental Ltd., Burnaby, British Columbia.

Personal Communication March 2003. *Chris Carr*. Government of BC Department of Energy and Mines, Victoria, British Columbia.