A REVIEW OF
TAILINGS RELOCATION PROJECTS AND METHODOLOGY

Prepared for:

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Type II Mines
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TAILINGS RELOCATION PROJECTS
RESULTS OF LITERATURE SEARCH

1. INTRODUCTION

1.1. BACKGROUND

Tailings deposits at Faro Mine and Mt. Nansen mines in Yukon currently pose an environmental hazard due to the physical and chemical instability of the materials. Physical concerns include long-term performance of the containment dams and water diversion works. Chemical stability issues include arsenic leaching at Mt. Nansen and acid rock drainage (ARD) at Faro Mine.

Reclamation options for these tailings can be grouped into: in-situ solutions where the stability issues are addressed with the material remaining in place, or ex-situ solutions where the material is relocated to a new containment facility. The focus of the work described in this report is on ex-situ or relocation options.

Tailings removal could be conducted in one of two primary methods. Mechanized excavation involving excavator and truck or scrapers is the most common method. In this case, selection of the equipment and excavation method would depend upon a number of factors including; quantity to be removed, existing and final location for the material, slope stability and trafficability of the excavated surface.

An alternative to mechanized removal would involve hydraulic mining. In this method, the tailings are liberated from the deposit by a high pressure water jet and the resulting slurry is pumped away. Success with this method will require careful consideration of the slurry pumps and associated piping and power requirements. Mines have been moving tailings in slurry form for decades. It is clear that if you can get the tailings into the pump then they can be relocated hydraulically. The outstanding questions relate to how to efficiently get the tailings into the pump on a continuous basis.

1.2. OBJECTIVES

The objective of this project is to look at industry experience with tailings relocation, with the aim to understanding:

1. methodologies which have been used,
2. tailings properties (physical and chemical) which will influence selection of removal methodology and potential efficiency, and,
3. site conditions which should be considered in the project design.

1.3. APPROACH

Section 2 describes aspects of tailings properties and deposition which should be considered in the design phase of a relocation project.

The results of a literature search are summarized in Section 3. The original plan was to obtain relevant information from libraries, industry publications and associations, conference proceedings, government sources and an internet search. Preliminary attempts found that suitable references where scarce and that obtaining copies of the material would be difficult. Consequently, it was decided to use the services of a professional research firm. InfoAction of the Vancouver Public Library was used. Two separate searches were conducted. The relevant references are included in Appendix A.

Due to the relatively small number of references which were found to be directly applicable to the potential relocation of northern tailings deposits, other sources were consulted. These included a review with the Toyo Pump Company and examination of the available project files from 1989/90 tailings relocation which was conducted at the Giant Mine.

2. TAILINGS DEPOSITION

This section provides a brief description of tailings deposition as it pertains to potential relocation projects. The methodologies which may be considered for tailings relocation will depend upon a number of factors including: the tailings properties, pore water quality, original deposition, climatic factors and the volume of tailings to be managed. Each of these factors is discussed as follow.

2.1. TAILINGS PROPERTIES

Tailings properties which must be considered in the design phase of a potential relocation project can be considered in two categories, physical and chemical. The physical properties of interest are particle grain size distribution and settled density. The specific gravity of the particles may also be important if hydraulic mining is being considered. Tailings may develop cohesion due to the fines content and consolidation.

Despite the apparent uniform nature of mine tailings, it is incorrect to assume that a tailings deposit is a homogenous mass. Many factors will cause heterogeneity in a tailings deposit. These include: variations in the mineralogy of the ore, hydraulic sorting during beach deposition, distance from the discharge point, and consolidation above and below the water table. Heterogeneity should be expected both horizontally and vertically in a deposit. There are numerous good references on tailings deposition (such as Vick, S. 1990, Planning, Design, and Analysis of Tailings Dams) which provide additional information regarding the in-situ properties of a tailings deposit. Ultimately, these variables would have to be determined on a site specific basis.

Historically, tailings deposits were used as waste repositories for material other than tailings. In addition to randomly located bits of wood, there may be localized deposits of tires and general refuse.

In addition to the physical properties, chemical effects such as precipitates from the metallurgical reagents or oxidation of any reactive minerals may create an additional binding effect in the tailings. Any binding of the tailings particles due to chemical effects is likely to increase the energy required to remove the material.

2.2. PORE WATER QUALITY

The in-situ pore water quality may consist of metallurgical reagents or products of oxidation and/or metal leaching from the tailings minerals. It should be expected that the pore water quality will have an effect on the design of the water management and treatment system associated with any tailings relocation project, particularly if hydraulic mining is being considered.

2.3. ORIGINAL DEPOSITION

Aspects of the original deposition which are important will include the site setting as it influences surface runoff and groundwater flow in and around the tailings deposit, and the potential for debris in the tailings.

The situation of the tailings deposit, including both deposition area and meteorological factors, must be considered in evaluating how the tailings are to be excavated. Very wet tailings due to high precipitation and excessive runoff from the surrounding area, or a high groundwater table will exhibit low trafficability and thus not be amenable to removal using conventional earth moving equipment.

Historic tailings which were discharged to low areas such as creeks and dry gulches may be difficult to remove due to the topographic constraints and the relatively thin deposits which result from discharge into an unconfined area.

Many older tailings impoundments were filled without removal of the original vegetation. The presence of trees and shrubs will impede the removal of the lower layers of tailings, in the case of both hydraulic and mechanized excavation. Trash processing will be required. This may consist of either removal prior to hydraulic transport or shredding and transport of the trash with the tailings. Other debris which could affect tailings removal would be buried pipelines, trestles, and rock causeways.

2.4. CLIMATIC FACTORS

Climatic factors, primarily the influence of cold weather, may require flexibility in operating procedures. Winter deposited tailings may have ice lenses. It may be necessary to provide additional excavation energy to remove these layers or shift to mining an unfrozen area while the frozen area thaws.

Tailings dust could be a problem at arid sites or during the dry season. Dust control measures such as irrigation or use of a soil adhesive, such as Soil Sement may be required.

2.5. VOLUME OF TAILINGS

Aside from the obvious design parameter of having an appropriately sized repository for the tailings, equipment mobilization and commissioning are the main factors which will be influenced by the volume of tailings. Truck and shovel operations will probably have a lower initial cost and higher operating costs than a hydraulic operation, which is likely to have a higher set-up cost but off-setting lower operating costs. It is likely that small projects will favor truck and shovel operations, while both methods will be worth considering for larger projects.

If the tailings are being processed for additional mineral recovery, then the metallurgical process rate will probably govern the mining rate. However, when the tailings are to be relocated for environmental reasons it will generally be preferable to complete the work in a reasonable period of time. Process rates which are 5 to 10 times greater than were used during the original mining may be appropriate, especially if a shut-down during winter is expected. Therefore, it should be expected that even if some of the original mine equipment (trucks, pumps, pipelines, water treatment plant) still remain on site, that they will likely be severely undersized for the task at hand.

3. LITERATURE RESEARCH

3.1. GENERAL

The literature search conducted by InfoAction looked for reference material containing the key words:

- tailings remove/removal,
- tailings relocate/relocation, and,
- tailings excavate/excavation.

This search included a variety of sources including:

- Periodical indexes: Applied Science & Technology Index/ EVSO (Academic Business & Master Files); OCLC Databases; Dow Jones; CBCA (Canadian Business & current Affairs); Elibrary Canada; etc.

- Government Publications: US Environmental Protection Agency, Natural Resources Canada, Federal and Provincial Agencies; etc.
- Industry Associations,
- Reference books within the Vancouver Public Library, and
- Internet Search.

The initial result of the work was:

- A total of 51 references were found.
- There are few references which deal specifically with the subject matter.
- Many of the references found dealt with either projects where tailings relocation was being considered as an option, was proposed but not yet initiated or was the option requested by some stakeholders.

Copies of the relevant reference material are included in Appendix A.

As a result of the limited research findings, a second search was conducted. This second phase included a number of key words in combination with "tailings" such as:

- Hydraulic mining or re-mining,
- Slurry,
- Permafrost, arctic, cold climate.

The result of the second phase work was:

- A total of 27 references were found.
- There are few references which deal specifically with the subject matter.
- Many of the references which were found dealt with projects where tailings disposal in a cold climate was being planned or conducted. These did not involve re-mining of tailings.

Copies of the relevant reference material are included in Appendix A.

3.2. PHASE 1 SEARCH – RELEVANT INFORMATION

This section presents a brief description of the useful findings of the first phase of the literature search.

1. US EPA Re-mining of Pinto Valley tailings. This project involved hydraulic recovery of tailings for vat leaching and copper recovery. Approximately 38 million tons of tailings are to be ultimately processed. “the hydraulic mining operation uses up to four 4-inch hydraulic mining jet monitors, feeding two separate educator pump sets capable of pumping 523 gpm of water at 28 bars of pressure. The hydraulic monitors are automatically controlled. The hydraulic mining peptizes the tailings into a 32.4 percent solids slurry.” The remainder of this reference describes metallurgical factors.

2. Indian and Northern Affairs Canada, Open File 1993-9(T), Faro Down Valley Tailings Research Program Report: Tailings Reprocessing. Written by G. McDonald of Curragh Resources Limited. This report should be in the current government files for the Faro project. Most of the effort is focused on the lead and zinc recovery from the tailings.

3. The Aznalcollar tailings dam failure in 1998 in Spain resulted in the release of 1.3 to 1.9 million tons of tailings. The resulting clean-up, which included removal of some native soil, was conducted using truck and shovel operation.
4. Table 1 summarizes mechanized tailings removal projects. It is worth noting that most of these projects involved semi-arid sites. Many of the smaller projects dealt with historic tailings disposal into rivers and creeks. Although most of these projects consisted of conventional shovel and truck operations, a few of the larger projects utilized rail cars for transport of the material.

Table 1
Summary of Tailings Removal Projects by Mechanized Excavation
(In no particular order)

Location	Site Name	Volume Removed
Montana	Curlew	89,250 yd^3
Montana	Maxville	16,000 yd^3
Montana	Douglas Creek	Very small
Montana	Comet	200,000 yd^3
Utah	Monticello	2.3×10^6 yd^3
Idaho	Bunker Hill	$1.16 \times 10^6 yd^3$
Colorado	Eagle	> 150,000yd^3
Colorado	Bonanza	116,000 yd^3
Colorado	Lackawanna	< 100,000 yd^3
Missouri	Newton	<50,000 ? yd^3
Washington	Ruby Gulch	40,000 yd^3
California	Eureka	6000 yd^3
Montana	High Ore Creek	31,000 yd^3
Utah	Moab	$11.9 \times 10^6 yd^3$
Idaho	Taache	16,000 yd^3
Washington	Kaaba-Texas	? yd^3
New Mexico	Cleveland	165,000 yd^3
Idaho	Silver Crescent	100,000 yd^3
Colorado	Atlas	12×10^6 yd^3
Idaho	Talache	1.9×10^6 yd^3

3.3. PHASE 2 SEARCH – RELEVANT INFORMATION

This second phase of searching provided few relevant documents. Most of the references found involved subaqueous tailings disposal or stabilization by permafrost, either directly or with a cover. A few useful documents were found and are discussed as follow.

1. Reclamation of massive sulphide tailings at the Caribou mine in New Brunswick was proposed by Breakwater Resources. The tailings were to be removed by excavator and then slurried. After treatment the product will be pumped to a new disposal pond.

2. In a 1985 paper, the president of the Toyo pump company (now called “Toyo Pumps North America Corp. of Burnaby, B.C.) describes some case histories involving hydraulic removal of tailings. The tailings removed included zinc/silver, potash, arsenic trioxide, placer gold, overburden, tar-sand, and coal tailings. It is recognized that pumping of granular material in a slurry can be conducted (as has been done for many years in tailings disposal). Reference is made to agitator pumps and units with cutters, which may compliment a pump-

based approach. The author suggests that hydraulic based mining for unconsolidated material may be less than half the cost of mechanized mining. Pump based methods, using either submersible pumps or in a dredging arrangement may be an effective method for re-mining tailings.

3. A PhD thesis titled "Hydraulic Mining in Cold Regions" was submitted to the University of London in 1996 by Sadek E. El-Alfy. He was the lead engineer on the two relocation projects noted below. His thesis describes permafrost and cold regions effects as they pertain to tailings and describes three case histories. His summary of major tailings retreatment operations from around the world is reproduced here as Table 2. The case histories are:
    a. Tailings reclaim project at Giant Yellowknife Mines (named the "TRP" for Tailings Retreatment Plant),
    b. ERG Timmins Gold recovery project,
    c. Proposal for hydraulic mining of the arsenic trioxide dust in the underground chambers at the Giant Mine.

    The author describes the tailings relocation projects and suggests that the results of those projects are a good basis for future tailings recovery projects. Although neither of these project were highly successful, both the Giant Mine and the ERG Timmins projects demonstrated that hydraulic reprocessing of tailings can be undertaken. Both projects were terminated prematurely. It is not clear if this was due to technical or economic factors, although both factors may have contributed to the decisions. The arsenic trioxide project was not initiated.

    Some details from the two projects are discussed in the following sections.

Table 2
Major World Tailings Retreatment Operations
(Reproduced from S. El-Alfy, 1996)

Company	Location	Commissioned Date	Through-put (ton/month)*
Freegold JMS	O.F.S, South Africa	1976	1.6 million
East Rand Gold & Uranium (ERGO)	Transval, S. Africa	1978	1.8 million
Chemwes	Transval, S. Africa	1979	290,000
Simmergo	Transval, S. Africa	1982	180,000
Mt. Morgan Gold Mines	Australia	1982	250,000
Rand Mines & Milling Co. Ltd.	Transval, S. Africa	1982	370,000
ERGO CIL Plant	Transval, S. Africa	1985	2.0 million
ERGO Daggafontein	Transval, S. Africa	1987	1.0 million
Eastmaque Gold Mines	Kirkland Lake Ontario	1987	80,000
Giant Yellowknife	Yellowknife, N.W.T.	1988	230,000
ERG Res. Timmins Gold Tailings Project	Timmins, Ontario	1990?	1.0 million

* The author has not indicated if the through-put rates are design or actual achieved.

GIANT MINE

Mine records are not precise, however, it is estimated that 2.3 million tonnes of tailings were removed and processed at the Giant mine over two summer seasons. The monthly process rate was in the order of 200,000 tonnes.

Pilot work was conducted prior to full scale mining. Photographs 1, 2 and 3, courtesy of Toyo Pump Company, show the liberation of tailings using a high pressure water monitor and removal with a submersible pump. Note that the water monitor is remotely operated by hydraulic controls. A pad of mine rock was placed to support the water monitor and the excavator which supported the submersible pump.

Tailings recovery seems to have started at the western edge of the North Pond and progressed eastward. A working surface of waste rock was advanced over the original ground surface as the tailings were removed, as shown in Figure 4 (courtesy of Toyo Pump Company). This allowed movement of the sump pumps and hydraulic monitors by a crane. The tailings face was in the order of 20 m high.

It appears that basic operation involved cutting the tailings with the high pressure monitors and washing the material to a sump. A high lift dredge pump operated in the sump to remove the material and send it to the processing plant, which was located several hundred meters away and about 30 m higher in elevation.

It is understood that the hydraulic monitors were supplied by the English Clays Lovering Poching & Co. Ltd. of England. A dated product brochure obtained from the Giant Mine files is included in Appendix B. Remotely-operated monitors allow the nozzle to be as close as practical to the operating face while maintaining the operator at a safe distance. In this way, slumping or a wash-out of tailings stops moving before reaching the operator.

The author has suggested that the frozen tailings at Giant were being thawed by the water. Company records indicate that hydraulic mining was not practical without the use of dozers to loosen the tailings. Mining of this material left near vertical faces up to 5 m high in the tailings. These faces have not slumped or collapsed in the 10 years since the mining was conducted, as can be seen in Photo 5 (Brodie Consulting Ltd). It is suggested here that the tailings have a cohesion which is in addition to any ice effects and that this may have influenced the mining of this material. This uncertainty in the tailings properties may have affected the performance of the tailings removal process.

A section of the thesis discusses the merits of vertical versus horizontal mining of the tailings. It is suggested that horizontal mining, similar to laterally advancing benches in open pit mining, is more effective because it keeps equipment well away from the working area and allows gravity to aid in the loosening of the material. This appears to be practical advice.

Based upon review of the project files, located at the Giant Mine, the following supplemental information and discussion is presented.

- Three hydraulic monitors, with two dozers for assistance, were unable to produce the target of 10,000 tons per day.

- Problems were experienced with the submersible Toyo pumps. These included performance of the seals and motor overheating. An employee of the Toyo Pump Company was aware of these problems and reports that TRP staff would not replace the seals as recommended and insisted on operating the pumps without the cooling jacket.
- The approximate operating costs at the Giant Mine were $1.03/tonne in 1987 dollars. This consisted of $0.39/tonne for power (37%), $.055/tonne for labour (53%), and $0.09/tonne for maintenance supplies (10%). No estimate of the amortizing capital cost was found.
- In a brief discussion with a former Giant Mine employee (Malcolm Robb, Robbm@inac.gc.ca), the following key points were identified as factors which contributed to the termination of the TRP project:
    1. The difficulty of mining the frozen tailings was under-estimated.
    2. The volume of wood debris, primarily mine junk – not trees, was under-estimated. This mostly affected the TRP plant and not the mining of the tailings.
    3. There was not enough drilling to characterize the variability in the tailings deposit. There were no maps of the spigot points used in filling the tailings pond.
    4. There was no thickener in the first year of operation, resulting in a low slurry density to the plant.

ERG PROJECT

The thesis by El-Alfy includes an operations manual for the ERG Tailings project. This material could be useful in the design of hydraulic mining plan. Much of this manual is directed at the day-to-day operations for the conditions and equipment as existed at the ERG project. It may be of use in planning future operations.

It should be noted that at the ERG operation, tailings recovery from the working sump to the processing plant was conducted with a high lift dredge pump. Some aspects of pumping and pipe arrangement are discussed further in the following section on Toyo Pumps.

The author has included a number of drawings and description of the method and sequence for removal of tailings using hydraulic monitors. In general, it is suggested that the monitors provide peak performance if the upper portion of a face is cut away first, followed by washing of the slumped material and then cutting of the lower portion of the face.

3.4. PHASE 3 – TOYO PUMPS

A key issue in the design of the tailings removal method is the selection of the pumps for transporting the material away. An investigation into pump technology was conducted with the Toyo Pump company. They suggest that two basic options exist: high-lift end-suction pumps and submersible agitator pumps.

High-lift end-suction pumps are the type commonly used in dredge applications. These use a conventional horizontal-mounted motor and pump assembly which is operated on a platform just above the water level. An intake pipe extends from the pump down to the surface of the material to be removed. Movement of the water over the material lifts it in much the same way as a domestic vacuum cleaner works. Cutters may be added to the intake end of the pipe to aid in loosening the material. The advantage of this method is that very large motors can be used as they do not have to be operated underwater. Disadvantages include typically low slurry density and inability to process high density slurry.

The Toyo Pump company is a recognized world leader in pumps. They manufacture a range of pumps from 3 to 1200 hp units. The largest standard submersible pumps are 150 hp. A brochure is attached as Appendix B.

In the context of the potentially large tailings relocation project at Faro, the review with Toyo Pump staff focused on their largest submersible pumps. The DP 150B pump is reported to achieve a peak performance of about 1000 cubic yards per hour at 70 – 80 % solids. This rate would depend upon particle density and elevation that the material is lifted. The manufacturer suggests that pre-feasibility production be based upon not more than 300 – 350 yd^3/hr for mining of slightly cohesive fine grained sand.

The key feature of the Toyo submersible pump is the shaft mounted agitator. It breaks up the tailings material and mixes it with water to produce a high-density slurry at the pump intake. The agitator also breaks up any debris such as wood which may otherwise clog the intake.

A submersible pump could be used in one of two methods. The shaft mounted agitator allows the pump to be used as the "mining machine". Suspended by a crane it could be lowered into the tailings and it would excavate its own hole, assuming that there was sufficient water available. Although this may not be the normal operation, it could be used to dig a new sump each time it becomes necessary to relocate the sump closer to the working face.

In the more likely scenario, the pump would remain stationary in a sump, suspended about a foot off the bottom of the sump. Material washed from the working face would be flushed into the sump and removed by the pump. A limiting factor in an operation of this type would be the slurry density of the flow into the sump. The slope and length of the ditches which drain to the sump would have to be carefully regulated in order to achieve optimal efficiency.

3.5. DISCUSSION

GENERAL

Re-mining of tailings could be conducted by a truck and shovel method or hydraulically. Hydraulic re-mining of tailings can be undertaken by one of two basic approaches; dredging (sub-aqueous) or cutting and slurrying (sub-aerial). Each of these are discussed in the following sections.

TRUCK & SHOVEL

Re-mining of tailings using truck and shovel methods has been conducted at many sites. This approach is likely to be problematic at sites such as Faro and Mt. Nansen where there is a high water table in the tailings. The presence of excess water in the tailings will make it very difficult to effectively excavate and load the material into trucks. Extensive use of geotextile and a constructed road way on the tailings could alleviate this problem. Slopping of the material out of the truck boxes during transport would also be a problem. Operation during winter conditions could help to off-set these concerns, although additional energy from either dozers or blasting would be required to excavate the material.

Although a truck and shovel approach may be effective for some parts of the Yukon projects, such as perimeter areas or final clean up of the original ground surface, this approach is unlikely to be the primary method used. Consequently, emphasis is placed on hydraulic methods in this report.

DREDGING

Dredging is a well established technology for removal of sediment from the base of water bodies. It is practiced around the world in harbors, lakes and rivers. No references were found where it is used for tailings. However, it is understood that this approach is used for recovery of alluvial diamonds in Africa.

It is important to note that a dredge must operate in a body of water. As more solids are removed, the body of water will grow. Careful attention to the mining sequence and water management would be required to avoid a very large pond. The dams associated with the Yukon projects may not have an acceptable factor of safety against failure (seepage and piping) if the tailings are removed from the upstream face. A practical solution could involve a dredge operating in a small stationary pond which is continuously fed with slurry from sub-aerial hydraulic mining, as described in the following section.

Dredging operations typically move a low density slurry, less than 20% solids. In conventional applications this is probably not much an issue because the product is not lifted very high or far. In the case of the Yukon projects the tailings must be moved a significant distance both horizontally and vertically. Consequently, it would be appropriate to carefully consider the power implications associated with moving water in this approach.

CUTTING & SLURRY METHOD

Sub-aerial hydraulic re-mining using cutting and slurrying appears to be a viable approach. Curiously, documented case histories of successful operations are difficult to locate. There are several outstanding issues which must be addressed in the detailed design phase of a project. Based on the review completed to date, the most efficient method of hydraulic mining would involve cutting and washing the material with monitors and removing and transporting the material using submersible pumps. Major components, general operating procedure and outstanding design and operation issues are discussed as follow.

MAJOR COMPONENTS

The major components of a hydraulic re-mining operation would be:

- Remote high-pressure water monitors and associated high pressure pumps,
- A supply of clean water for the high pressure monitors (either off-site water or on-site water which has been clarified by settling/filtering and/or flocculation),
- Submersible agitator pumps, each with a dedicated crane,
- Excavator, dump truck and dozer to construct gravel working pad for the cranes, (depending on the substrate, geotextile may also be required), this equipment may also be required to remove any internal dams, buried causeways, and trestles,
- Pipe lines and booster pumps, as necessary, to transport the material to the discharge location,
- Water treatment system for circulating process water and/or tailings treatment before final disposal,
- Power supply and distribution system,

MINING

The most practical mining method appears to involve excavation of horizontal slices, rather like open pit mining. A full height face of 10 m or more could be opened up in front of a series of sumps for removal of the tailings. The number of sumps would depend upon the desired overall process rate and the pump capacity. Ditches would be excavated from the face to the sumps using the hydraulic monitors. These ditches could be either narrow channels to maintain high velocity or steep cone-shaped funnels to direct the water and tailings into the sumps. In the latter case, the slope of the cone leading to the sump would have to be steeper than the beaches on which the tailings originally deposited. The sumps must be moved periodically. Otherwise, the slope of the ditch will gradually decrease as it becomes longer, resulting in settling of the tailings particles.

Performance of the system will depend, in part, upon the ability of the monitors to liberate the tailings. This will be influenced by the selection and operation of the monitors. A paper which may aid in optimization of monitors may be found at www.wjta.org/Book%201/3_4a_Davies_and_Jackson.pdf .

If practical and safe, mining of the full depth of tailings down to the original ground surface should be conducted. This avoids having to maintain trafficable surfaces on the tailings and minimizes the requirement to move pipelines. It does require maintaining sumps below the original ground surface which could be a problem if bedrock is encountered. There is a safety issue associated with slope failure of the working face, which increases as the face gets higher.

In the case of both the Mt. Nansen and Faro sites, the length of pipe from the tailings pond to the pit will be significant; two or more kilometers. It should be recognized that it will be virtually impossible to operate the entire tailings relocation project without an upset condition resulting in lack of solids and or water flowing to the collection sump. When an upset condition arises movement of tailings in the line will slow or stop. If the tailings settle in the line it may be very difficult to resume operations. A solution to this problem would be to have a surge tank of water, possibly with a dedicated pump to flush the line. The surge tank should have a volume which is equal to the volume of the pipe.

At the Giant Mine, the replacement of submersible pumps with cantilever pumps partially solved the problems with performance. Cantilever pumps will operate with lower maintenance requirements than submersible pumps. However, this is provided at a loss of operational flexibility because they require a rigid platform and some sort of "pump box" in which to operate. This pump box must be placed in an excavated sump. It cannot "dig" its own sump.

Several options could be considered for routing the discharge from the sumps to the final disposal site. A single pipeline leading from each pump, with booster pumps as necessary could be installed. This approach would allow each pump to operate at or near to its peak efficiency. However, there may be a significant cost in pipes, especially if insulated pipes are required. The alternative would involve a single pipeline leading from a central point at which all of the sumps discharge.

A single pipeline leading from a pump box, as is commonly used in many mills could be used. This is a relatively low cost approach. However, the pump discharging from the pump box would often operate a low efficiency due to surges arising from the sumps in the mining area. In cases such as Faro Mine where the tailings must be pumped up several hundred metres in elevation, pump efficiency will have an effect on energy requirements. If the pump box were large enough to provide surge capacity, then the tailings would settle. The solution to this problem would be the installation of a thickener to keep the tailings in suspension. Although a thickener may be costly to install, it may be justified by the saving in pipelines, and improved pump efficiency. Furthermore, excess water could be decanted, thus avoiding the need to pump it up hill.

A single pipeline with a manifold to receive the discharge from multiple sumps is not recommended because of the inefficiency due to back pressure from one pump on another. This condition would be expected to arise regularly because of variations in slurry density being discharged from each sump.

Mining of the tailings in the perimeter area of the impoundment, and any other areas where the deposit is relatively thin, may require a modified approach. In these areas, buried trees, vegetation and local topography may prevent efficient removal with the monitors. Removal may be conducted using dozers to push the tailings into mounds. These may be reduced in volume by washing some of the tailings away. The balance may have to be removed using conventional truck and shovel methods. It may be difficult for the dozer operator to identify the bottom of the tailings deposit, particularly where the vegetation is sparse. Estimates of the volume of tailings to be removed should include an allowance for a layer of the subgrade material.

4. CONCLUSIONS

The following conclusions are presented:

1. The lack of references to tailings removal in any manner suggests that this is not a common practice in North America (or else rarely documented), even including cases where there is residual mineral value in the tailings.

2. Based upon the number of references found, mechanized mining of tailings is far more common than hydraulic mining. Even some larger relocation projects involving more than a million cubic yards of material were done with truck and shovel.

3. Hydraulic re-mining of tailings is technically viable. It is probably less costly than mechanized mining, if the operational problems can be resolved. Careful characterization of the tailings deposit is essential for success. A pilot operation may also be helpful in resolving some problems before full-scale mining is initiated. It appears that the very early stages of a hydraulic mining operation can be made to work. Success of the overall operation will depend upon how the method is adapted to move across the tailings deposit.

4. Two tailings relocation projects involving hydraulic mining were conducted in Canada. Although these were not entirely successful, some knowledge can be gained by reviewing the discussion on these projects. It appears that a viable methodology has evolved from the lessons of those projects. Virtually no useful information on the cost of hydraulic mining of tailings was found in the literature.

Please contact the undersigned if you have any questions concerning this report.

Brodie Consulting Ltd.

M. John Brodie, P. Eng.

APPENDIX A

RELEVANT REFERENCES

APPENDIX B

PHOTOGRAPHS

TOYO PUMP COMPANY
SPECIFICATION SHEET FOR
SUBMERSIBLE AGITATOR PUMPS

ECLP – HYDRAULIC MONITOR DATA

Photographs provided by Toyo Pump Company

Photo 1 Close up of hydraulic mining trail showing remotely operated monitor and submersible pump suspended from excavator

Photo 2 and 3 Same as photo 1 from different view points

Photo 4 View of North Pond at Giant Mine, looking north from TRP plant

Photo 5 – Giant Mine Central Pond – Note escarpment left by tailings removal. (Brodie Consulting Ltd. 1999)