

Paste – The Future of Tailings Disposal?

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Abstract

In the last decade paste technology has progressed from a research based backfill idea to a widely accepted, cost effective backfill method with the potential to radically change the way tailings are disposed of on surface. Paste is simply dewatered tailings with little or no water bleed that are non-segregating in nature. It can be ‘stacked’ on surface and the risks associated with dam failure significantly reduces since there is no liquid containment and therefore no mechanism for the tailings to travel for tens of kilometres downstream in the event of a containment failure. The operating costs for the preparation and transportation of paste may be higher but life-of-mine cost analysis shows comparable costs to conventional disposal with significant environmental benefits. In addition, the eco-political impact of non water-retaining tailings dams could reduce permitting time considerably.

Introduction

The acceptance of paste backfill plants, especially in bulk mining, has been extensive in the seven years since the first modern plants were constructed in Canada. Extensive research work by INCO in the early 1990s resulted in advances in the preparation and transportation of paste. Since that time, over 30 plants have been built or are under construction. The advantages of paste backfill over hydraulic fill include reduced binder consumption, slimes handling, stope preparation and surface disposal together with productivity improvements associated with an increased mining cycle.

The increased utilisation of paste technology has improved the reliability and reduced the cost of preparation and transportation systems. This has led to the possibility of using paste for surface disposal. The final prize of such an endeavour is the introduction of virtually water-free surface tailings storage. This can eliminate the need for large water-retaining dams and remove the associated liability such structures pose to the environment. Such a step appears logical, as regulatory pressures become more demanding in Europe after recent high profile dam failures, increasing the permitting requirements for conventional tailings disposal.

The Bulyanhulu Mine in Tanzania, successfully commissioned in March 2001, is the first mine in the world to adopt a total paste solution for all its tailings. A portion will be used underground as backfill and the remainder will be ‘stacked’ on surface as paste. The advantages cited by Barrick Gold in their decision to develop the system include:

- Reduced capital cost (no large starter dam required)
- Water conservation (traditional disposal may have led to water scarcity and the need for a dedicated water pipeline from Lake Victoria, ~100 km)
- Decreased footprint of tailings disposal site

This paper discusses the future of paste technology as a surface disposal method and presents a case study for a fictitious mine producing non-acid generating tailings. Conventional slurry disposal is compared with paste and an NPC (Net Present Cost) analysis is completed.

In addition this paper will present a definition of paste and discuss the current areas of research into paste for surface disposal including tailings dewatering and transportation, current and future regulatory constraints on tailings disposal and the likelihood of successfully applying the technology to acid generating tailings.

Paste Definition

The definition of paste can become a very scientific and, sometimes, emotive, issue. Golder Associates, who have been working with paste technology since its infancy, has adopted a more empirical definition based on our experience in backfill and, more recently, surface disposal.

A paste can simply be defined as a mixture of solids and water that has little or no bleed water when idle. It must also, however, possess some yield stress such that when tested using a conventional concrete testing slump cone, it does exhibit slump. Figure 1 shows two slump tests, one measuring 175 mm of slump and a second, measuring 250 mm of slump, (note: the slump is measured from the top of the cone).



Figure 1 – Paste Slump – 175 mm (left) and 250 mm (right)

Paste *backfill* is always placed cemented and the optimum slump that minimises transportation pressure losses and maximises strength gain is often found between 150 and 200 mm. Pumping of paste for backfill is rare but for surface disposal, where cement is not routinely added, pumping makes up a very important part of the paste system. As a result, the optimum slump is higher, between 200 and 275 mm of slump. This reduces the friction losses and allows the paste to be transported 2 to 3 km with one large pump.

The difference between ‘backfill’ paste and ‘surface disposal’ paste is subtle but impacts significantly on the preparation method and hence the cost of plant construction. At present, it is not possible to consistently manufacture a ‘backfill’ paste (i.e. a slump of <200 mm) without the use of mechanical dewatering (filtration). Improvements in dewatering technology have enabled the production of higher slump pastes to become possible for some tailings and this has opened up the possibility of low cost paste production, thus bringing environmentally beneficial paste disposal one step closer.

Paste Advantages

The environmental benefits associated with paste surface disposal can be divided into two main categories - the physical characteristics of the paste itself and the operational advantages associated with its placement.

The primary advantage is that there is very little free water available to generate leachate. In addition, the relatively low permeability of the poorly sorted full plant tailings limits infiltration, resulting in reduced seepage volume present in the

deposited paste. Hydraulic conductivity values are not easy to determine for an uncemented paste but values have been determined for weakly cemented samples. These range between 10^{-7} and 10^{-8} m/s.

The preparation of paste can allow for the material to be 'engineered' with the use of additives that can enhance the beneficial properties of the paste. Although not widely used at present, probably due to cost fears, additives hold significant potential for further improving the behaviour of disposed tailings.

The most commonly used additive for paste backfill is a pozzolanic binder such as cement, slag, flyash etc. These provide significant strength underground at addition levels of 3 – 6% by weight. For surface disposal, the cost makes them unattractive although tests have shown that 1 wt% cement addition can increase the neutralizing potential by an order of magnitude. It also raises the pH, which can lead to immobilisation of some metals through mineral precipitation.

Other additives that require investigation include speciality chemicals, resins and surfactants that could enhance the adsorption of metals; organic carbon and bacteria to aid biofixation and the addition of organic material (topsoil, seed and fertiliser) to assist rehabilitation work.

The solids concentration (by mass) at which tailings exhibit paste properties can vary significantly and are a property of the fines content and the colloidal chemistry associated with such fines. For example, high clay content tailings such as aluminium tailings (red mud) can exhibit paste properties at ~45 wt% solids, (wt. Solids / (wt. Solids + wt. Water)). Base metal tailings, especially when combined with sand or waste rock can develop solids contents as high as 85 wt% solids and still be easily transported as a paste. Chemically altered tailings, e.g. from Uranium and Soda Ash processing, are pastes at very low solids content, 20-40 wt% solids.

Co-Disposal

One of the most exciting opportunities for paste disposal is the wide range of co-disposal options that are available. The primary example is that of acid generating waste rock (a common occurrence for many mines) being sent to the same waste facility to be 'encapsulated' in tailings paste. This significantly reduces the oxidation risk and reduces the number of waste facilities requiring closure.

With the possibility of engineering the paste to become an effective encapsulating material, other wastes can be effectively sealed into the paste, subject to local and European regulatory approval.

For some mines, such a concept could be logically extended to include non-mining hazardous waste from other industries. This would also generate revenue streams for the mine. Such a concept would truly result in the mine becoming a waste management company. There are significant permitting and regulatory impacts of such a concept. However, the recent publicity regarding the possible use of a closed open pit in Northern Ontario to take domestic waste from Toronto highlights the possible synergy between mine waste handling and general waste management. In addition, at the time of writing this paper, a company in England is considering re-opening the South Crofty Mine (tin) in Cornwall with additional revenue streams from the storage of incinerator ash underground when mixed with tailings for backfill. The concept should certainly be discussed more openly.

Paste Preparation – Tailings Dewatering

The dewatering method for paste backfill made from run of mine tailings is normally a two-stage process. The tailings are conventionally thickened and then filtered to

form a wet cake. This material is then re-pulped under closely controlled conditions to accurately prepare the correct consistency paste.

Recent equipment development has allowed paste to be prepared in a one-stage process. These systems are called 'deep tank dewatering systems' and there are manufacturers that have succeeded in constructing such units. Essentially, the thickeners retain the tailings for longer and are higher, which allows for the added dewatering associated with compression of the tailings. The consistent preparation of paste from such equipment is tailings dependent and testing is required.

When Alcan developed a thickening technology for their red mud stacking disposal system, they wanted to prepare stable slurry that could be placed sub-aerially from a central stacking unit to form a shallow cone, reducing the water management at their tailings facility, Figure 2. The method has proved successful and is in use around the world. Indeed the perforated pipe disposal method for stacking has been adopted at Bulyanhulu for their paste disposal.

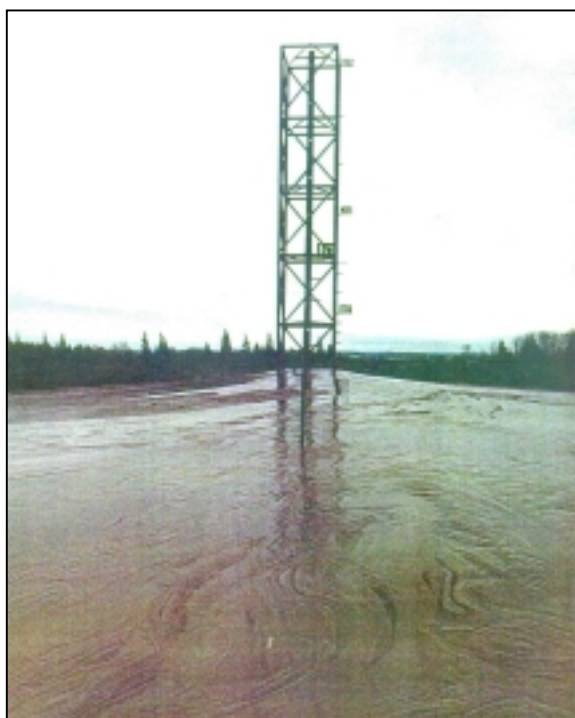


Figure 2 – Stacking of Red Mud Aluminium Tailings

Paste Preparation – Tailings Transportation

For paste backfill careful transportation design is required to ensure a full line which reduces hammer and wear, in turn reducing the risk of plugging the line. For surface disposal the transportation issues are more straightforward, normally related to finding a pump that can provide the necessary driving force with the required availability to operate 24 hours a day. Positive displacement pumps can provide the necessary pressure and capacity.

As discussed above, additives have the potential to reduce friction losses. Experience gained to date has been inconclusive but this may be because commercially available plasticisers were developed for concrete pumping and act on the cement fines. For paste backfill, cement content is minimal and for the surface disposal of paste, there is unlikely to be any cement.

Acid Generating Tailings

Reactive tailings need to be protected from oxidation and this is normally achieved through sub-aqueous disposal that inhibits oxygen contact with the tailings. Conventional sub-aerial disposal of reactive tailings as slurry results in segregation of the tailings that can result in accelerated oxidation leading to acid generation. Paste is homogenous and has a low permeability such that only a thin exposed layer can oxidise.

Hence, a possible paste solution is to ensure that each layer of tailings is subsequently covered with fresh tailings before oxidation takes hold, effectively ensuring acid generation does not gain impetus. The practicalities of such a method have not been fully investigated and there are a number of questions that remain to be answered. However, the Kidd Creek Mine in Timmins, Ontario (Canada) stacks thickened tailings (very little segregation) and has found that as long as tailings are covered with a fresh layer within 12-18 months then acid generation does not become a problem. However, many tailings are much more reactive and covering of old tailings may have to be far more frequent and the issue of total coverage can become problematic.

Research into opportunities with paste and reactive tailings is to start in Europe during 2001 and will involve colloidal chemistry and careful site design and management in order to be successful. Pre-treatment of reactive tailings or the concept of a rolling continuous cover, akin to a domestic landfill site, may sound far-fetched and excessively expensive but recent tailings failures in Europe are increasing the requirements for more control at tailings disposal areas.

Regulatory Concerns regarding Tailings Disposal

Within the European Community there are a number of Directives, Decisions and Regulations governing the management of waste. The Integrated Pollution Prevention Control (IPPC) Directive (96/61/EC) is a wide-ranging edict that stipulates the use of best practice in a range of industrial installations including waste management sites. It should have been brought into force in the Member State in October 1999 and all new installations falling within its remit should be permitted under its aegis. Existing waste sites have until 2007 to comply with its requirements. The IPPC Directive expands on the more general Waste Framework Directive (from 1975, amended 1991) that introduced the requirement to permit facilities with the stated objective of ensuring “waste must be recovered or disposed of without endangering health and without using processes or methods that could harm the environment”

More recently the Landfill Directive (1999/31/EC) was enacted in July 1999 with Member States required to bring it into force by July 2001. The definition of a landfill site is very wide ranging and includes both surface and underground disposal of all types of waste (as defined in the Waste Framework Directive including tailings) that can be considered permanent. The Directive defines permanent as more than three years. All liquid waste is banned from landfill disposal and this may impact severely on current mine waste practices. Excluded from the Directive is “..unpolluted soil or non-hazardous inert waste resulting from...” mineral activities. In addition to this exception, member states can choose to further exempt “..the deposit of non-hazardous waste, to be defined by a committee established under Article 17 of this Directive...” (Technical Adaptation Committee or TAC) from the provisions of the Directive.

Hence, it will be the definition of “non-hazardous waste” that will define whether mine tailings are exempt from the Landfill Directive.

It is unlikely that sulphide tailings will be classified as non-hazardous and although historically, such directives have been resisted by interested member states, legal challenges will force the issue in the next few years. As a result of such a challenge the mining industry may find itself tied to the same waste management practices currently employed at mainstream landfill sites.

Do the regulations really apply to mining? In the past year, there have been at least two separate communications from the EC (COM(2000) 265 and 664) that have explicitly stated the desire for mine tailings to come under the legislative umbrella of the Landfill Directive.

In addition the recently published Baie Marie Task Force report (set up after the cyanide spill in Romania) recommends that the storage of tailings slurry containing cyanide in surface impoundments should cease forthwith. The larger impact of the report may be felt in a general increase in resistance to all type of wet surface storage systems. They can be no mistaking the powerful lobby within the European Union that wants to see significant changes in the way mine waste is currently regulated.

If a tailings pond is classified as a landfill site then paste can offer a semi-dry alternative to full filtration that may prove acceptable to the authorities. In addition, the co-disposal possibilities discussed generally above could provide alternative revenue streams for the mine that could offset the paste preparation and landfill management costs.

It is interesting to note that companies that began their lives as mineral extraction (quarry) companies are active in the mainstream landfill industry in the UK. The future of the mining industry in Europe may see mining companies becoming more and more like waste management companies and the advantages of having a large permitted waste disposal site with an effective encapsulation process (paste) could, with time, generate more income for some mines than actual metal extraction.

Case Study

In the case study prepared we have invented a fictitious (new) mine located in Europe that will produce 1,000,000 tonnes of tailings per year for 10 years. The tailings are non-acid generating but do contain heavy metals and stringent leachate production controls have been imposed on the mine.

Assumptions

Particle (tailings) density	= 2.9 tonnes/cubic metre
Total tailings to be disposed	= 10 million tonnes
Dry density of placed tailings	= 1.43 (placed as slurry), vol. req. 7 million m ³
	= 1.8 (placed as paste), vol. req. 5.6 million m ³

Site Description

The mine is located at the head of a gently sloping v-shaped valley with a distance of ~ 1 km between the mill and the TMA.

Conventional Disposal

The tailings will be thickened from flotation to about 55 wt% solids and then pumped to the TMA. Water reclaim will be done using a floating barge that will return the water to the mill for re-cycling. At year 4, the dam will be raised to the final profile (Figure 3) and it is assumed that mine closure will take place in year 11 and will involve the draining of the facility and placement of a permanent soil cap.

Paste Disposal

Tailings will be dewatered to a paste consistency using a tank dewatering system. Positive displacement pumps will transfer the tailings to the TMA. There will be no water reclaim arrangements from the TMA. Precipitation run-off and limited water bleed from the paste will be collected in the water retaining dam and this will be treated locally prior to discharge at acceptable quality levels. Run-off from the valley is diverted around the TMA. As above the construction will be phased with completion during year 4 and closure assumed in year 11, although some rehabilitation will likely start in year 6 (Figure 4).

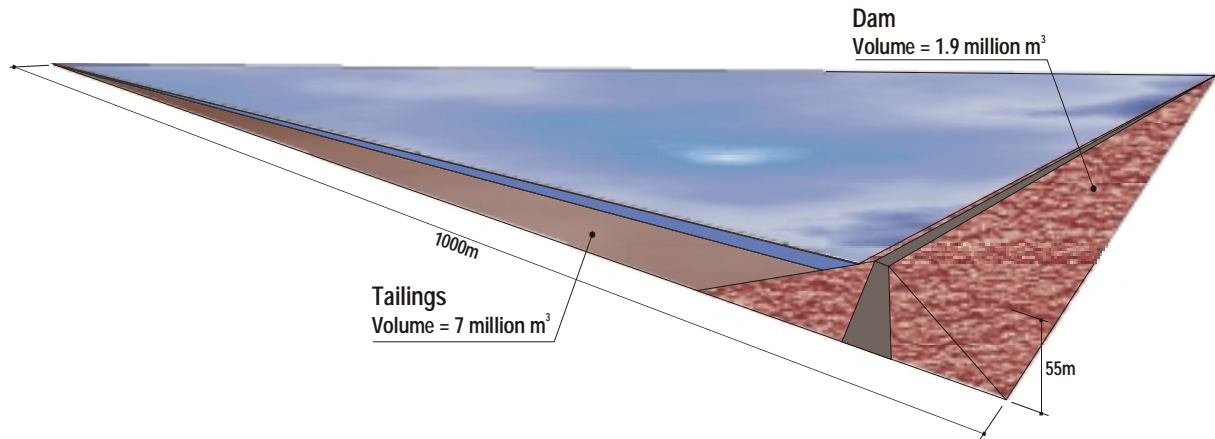


Figure 3

Schematic Cross-Section - Conventional Slurry Tailings Dam

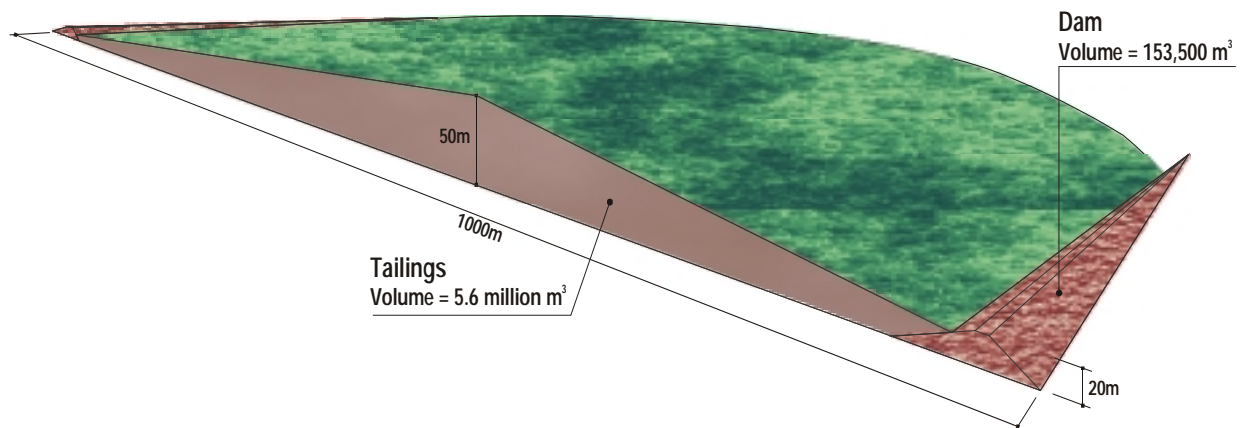


Figure 3

Schematic Cross-Section - Surface Paste Disposal Dam

Capital Costs

The capital costs have been estimated based on recent European tailings management projects and assume that the area is cleared of moderate woodland and prepared for a full lining system as currently required under IPPC regulations. Such facilities have been constructed recently in Ireland (Galmoy and Lisheen Mines) and are currently being designed in Greece.

The capital cost of the TMA includes clearance, foundation preparation, liner (500mm of clay plus 2mm geomembrane), diversion ditches and general dam fill. The smaller dams (or berms) required for the paste solution reduces the capital cost although the saving is offset by the paste plant capital cost (~\$3.15 million).

The delayed capital cost (yr 4) is also higher for conventional slurry and the closure costs are significantly higher given the drainage and stabilisation work required before rehabilitation can begin.

Operating Costs

The operating costs are not dissimilar for the two options since some thickening is assumed in both cases and flocculent consumption will be the same. The tank dewatering system for paste production achieves higher solids content through compression thickening and more precise automation and process control.

Labour costs will be slightly higher for the paste operation, as would power consumption and maintenance costs, mainly associated with the operation of the positive displacement pumps.

NPC Analysis

The NPC (Net Present Cost) analysis (Table 1) assumes a discounted cash flow (10%) over the mine life. The results show that the adoption of a paste solution, although requiring a slightly higher initial capital expenditure, \$10.3 million vs. \$9.8 million, the final NPC values are essentially the same, \$15.3 million vs. \$16.1 million.

The following additional advantages are not included in the cost analysis but are considered to be of significant value to the project:

- elimination of a tailings 'dam' and the associated negative public perception of the dam
- reduction in environmental disruption afforded through increased management of the facility and the use of concurrent rehabilitation of the site
- significantly reduced liability for the mine with respect to any TMA failure that may occur, this may impact on bond payments or insurance premiums
- possible co-disposal of other mine waste (notably acid generating waste rock) that reduces the number of waste areas requiring closure and monitoring
- possible additional revenue streams through the expansion of the paste facility to take other waste streams
- possible time saving from reduction in permitting constraints by the company adopting a more pro-active, waste management orientated approach to its regulatory interaction

Discussion and Summary

Approximately 10 years ago the use of paste technology for backfill was considered by many as an unrealistic goal. Paste backfill was considered a high risk / high cost option. It was the commitment of a few mines and individuals that proved the

technology as a viable backfill method and thousands of tons of paste are poured each day without problems.

It appears that history may repeat itself with paste for surface disposal. It is accepted that the operating costs are higher but regulatory pressure to eliminate the liability of tailings dams are the driving force with some cost savings being realised through reduced capital expenditure and faster permitting. The savings associated with water conservation is driving the technology in more arid countries (Southern Africa) and their experiences will further reduce the costs. Indeed, it may be the success of Barrick Gold (Bulyanhulu) and DeBeers (2 projects expected in 2001 in South Africa) that will drive the authorities to identify paste as a low risk “best practice” for surface disposal.

Major mining companies such as Rio Tinto, Anglo and Billiton are committed to ever increasing environmental standards, pushing the bar higher in terms of compliance. It may appear that paste tailings disposal is the natural progression for this race for the moral high ground in an environmental sense. In Europe, regulatory pressure has increased significantly in recent years and many companies will have to adopt significantly more controlled waste management practices.

If a mine that could take 7 – 10 years from discovery to production can be in positive cash flow in 5 years with no tailings dam to consider, what financial impact will that have on a major mining company?

Mining activities in Europe have reduced significantly over the years and the challenge for paste technology is to offer a new alternative to existing waste management problems. The application of paste is more likely for an existing mine applying for a tailings dam extension and such a move may prolong the life of the few remaining mines in Europe.

Technology continues to drive down the cost of mining production and paste, although it may increase day to day operating expenses it will save significant amounts of money over the life of the mine and, subsequently, add value to the mining company operating the facility.

References

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Verburg, R.B.M., 1997. Environmental Benefits Associated with the Use of Paste for Surface Disposal of Tailings. Proceedings of the 50th Canadian Geotechnical Conference of the Canadian Geotechnical Society. 20-22 October 1997, Ottawa, Canada. pp. 484-491.

Table 1 - Net Present Cost Analysis of Base Case versus Paste Disposal

Assumptions

	Yr	0	1	2	3	4	5	6	7	8	9	10	11
Paste Disposal													
Capex - Paste Plant		3,153,300											
TMA Capex, Yr 0		7,177,885											
TMA Capex, Yr 4		4,213,275											
Reclaim Cost, Yr 6-11		800,000											
Operating Cost		290,668											
	Investment Required												
	Paste Plant	3,153,300											
	Surface Installation	7,177,885				4,213,275							
	Total Capex	10,331,185				4,213,275							
	Operating Costs												
	Operating Costs		290,668	290,668	290,668	290,668	290,668	290,668	290,668	290,668	290,668	290,668	
	Rehabilitation Costs							50,000	75,000	100,000	100,000	100,000	375,000
	Total Opex		290,668	290,668	290,668	290,668	290,668	290,668	290,668	290,668	290,668	290,668	
	Total Cash Flow	10,331,185	290,668	290,668	290,668	4,503,943	290,668	340,668	365,668	390,668	390,668	390,668	375,000
	Net Present Cost	\$ 15,320,699											
Base Case													
Capex - Thickener		400,000											
TMA Capex, Yr 0		9,405,356											
TMA Capex, Yr 4		6,406,297											
Reclaim Cost, Yr 10-11		3,600,000											
Operating Cost		112,500											
	Investment Required												
	Plant (thickener)	400,000											
	Surface Installation	9,405,356				6,406,297							
	Total Capex	9,805,356				6,406,297							
	Operating Costs												
	Operating Costs		112,500	112,500	112,500	112,500	112,500	112,500	112,500	112,500	112,500	112,500	
	Rehabilitation Costs											500,000	3,100,000
	Total Opex		112,500	112,500	112,500	112,500	112,500	112,500	112,500	112,500	112,500	612,500	3,100,000
Discount rate	10%												
	Total Cash Flow	9,805,356	112,500	112,500	112,500	6,518,797	112,500	112,500	112,500	112,500	112,500	612,500	3,100,000
	Net Present Cost	\$ 16,151,509											