

Literature Review of Studies Completed on using Paper Pulp Sludge as a Hydraulic Barrier Layer in Landfills



Completed for the Cinder Lake Landfill, Flagstaff, Arizona

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ABSTRACT

The Cinder Lake Landfill is the only local municipal landfill serving the City of Flagstaff, Arizona. The landfill is nearing capacity and will have to expand to remain in operation. As a cost and landfill space saving initiative the City is investigating the possibility of using waste paper pulp sludge as the hydraulic barrier layer in the liner system of the expansion area. This paper is the result of a literature review of the extensive research has been conducted on using paper pulp sludge as a hydraulic barrier layer in landfill applications. This research indicates that a hydraulic barrier layer constructed of paper pulp sludge will have a hydraulic conductivity very close to the regulatory requirements of a maximum hydraulic conductivity of $1 \times 10^{-7} \frac{cm}{sec}$ at the time of construction and that once consolidation has progressed for two years the hydraulic conductivity will be in the range of $1 \times 10^{-8} \frac{cm}{sec}$, far below the maximum allowable limit. Additionally the test show that paper pulp sludge is actually a more effective hydraulic barrier than the normally prescribed clay soil barrier. Lastly, while paper pulp sludge does experience decomposition of some of its organic material, test indicate that this decomposition further reduces the material's hydraulic conductivity resulting in a more effective hydraulic barrier.

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INTRODUCTION

This report provides the results of a literature review on the feasibility of designing a landfill liner system for a municipal landfill using paper pulp sludge as the hydraulic barrier layer of that liner system. The Cinder Lake Landfill is currently the only local landfill serving the City of Flagstaff and will need to expand within the next ten years in order to continue operations. Since 1997 the Cinder Lake Landfill has used waste paper pulp sludge from the SCA Tissue plant in Flagstaff as alternate daily cover (ADC) on the landfill working face. (Grosvenor 1998, p-1) The use of this material as ADC has proven successful in maintaining Arizona Department of Environmental Quality (ADEQ) standards for landfill daily cover as well as diverting material destined for burial in the landfill to use as part of the landfill system.

Research has been conducted on putting pulp sludge to many uses like; part of fire resistant barrier layers, soil coverings, fuel for heat generation, soil conditioning, additives to concrete, and composting. However, results indicate that the most promising application of pulp sludge is in the construction of hydraulic barriers in landfill applications since its geotechnical properties like shear angle, cohesion, unit weight, permeability, and modulus of elasticity resemble those of clay soil usually used for hydraulic barrier construction. (Zule 2007, p-539) An initial internet search returned over 400,000 sites dealing with paper pulp sludge use in landfills. Further filtering of this list returned just over a thousand sites with research, documents, or regulations unique to employing pulp sludge as a hydraulic barrier in landfills. The fifteen documents referenced here represent the papers most often cited in other works and regulations or which have research unique to the long list of documents. This list is not exhaustive. There are many other documents that apply to using pulp sludge as a hydraulic barrier and new research and application reports are being generated.

Paper pulp sludge has successfully been used as a hydraulic barrier layer in landfills since 1975. (Moo-Young 1997, p-593) The National Council for Air and Stream Improvement (NCASI) reports that between 1990 and May 2003 more than twenty nine landfills were closed using paper pulp sludge as the hydraulic barrier layer. (Maltby 2005, p-1) These landfills ranged in size and composition from a 1.6 acre municipal landfill to a 30 acre industrial landfill. The NCASI report goes on to give a synopsis of the case histories of five of these landfills. (Maltby 2005, p-34) The use of paper pulp sludge as part of the liner in the landfill expansion will reduce the need to truck in clay from a location offsite. In light of rising transportation cost this could prove to be a substantial monetary savings. The use of this pulp sludge will also continue to divert material destined to be placed in the landfill to part of the landfill structure.

This feasibility study is separated into two phases. Phase I consists of a literature review to glean information from studies previously completed on using paper pulp sludge as a hydraulic barrier layer in landfill applications. Phase II will consist of laboratory testing of material samples from SCA Tissue to ensure it continues to meet the physical properties needed for use as part of the landfill liner system. If appropriate, this second phase may continue on into addressing any needed modifications to the liner system previously approved by the Arizona Department of Environmental Quality (ADEQ). This will enable the entire proposal to be presented to ADEQ for their consideration and approval.

BACKGROUND

The Cinder Lake Landfill is currently planning for the development of an expansion area to increase the overall life of the landfill. The expansion area is to act in accordance with the Resource Conservation Recovery Act (RCRA) Subtitle D minimum requirements for landfill liner and cap. In 1997 the City of Flagstaff received approval for the expansion with proposed liners and caps from The Arizona Department of Environmental Quality (ADEQ). The approved liners include the prescriptive and proposed liners with the following characteristics:

Prescriptive Liner (Subtitle D)

- Sand drainage layer (minimum 1 foot thickness)
- Geotextile filter fabric and 60 mil HDPE Geomembrane Liner
- Clay layer with the minimum characteristics
 - minimum 2 foot thickness
 - maximum wilting point of 0.367 (cm³ of water per cm³ of soil)
 - minimum field capacity of 0.418 (cm³ of water per cm³ of soil)
 - maximum saturated hydraulic conductivity of 1.0 X10⁻⁷cm/s
 - maximum porosity of 0.427 (cm³ voids/cm³ soil)
- Foundation layer (minimum 6" thickness)

Proposed Liner (Proposed)

- Sand drainage layer (minimum 1 foot)
- Geotextile filter fabric
- 60 mil HDPE Geomembrane liner
- 0.33 inch Geocomposite liner with the following characteristics
 - minimum 0.33 inch thickness
 - maximum wilting point 0.400 (cm³ of water per cm³ of soil)
 - minimum field capacity 0.747 (cm³ of water per cm³ of soil)
 - maximum saturated hydraulic conductivity of 3.0X10⁻⁹cm/s
 - maximum porosity 0.750 (cm³ voids/cm³ soil)

- Foundation Layer (minimum 6 inches)

The approved caps include the existing disposal area and the future expansion area:

Existing disposal area

The final cover configuration for the existing landfill footprint will have a permeability of no greater than $1 \times 10^{-5} \frac{cm}{sec}$ and will consist of:

- Erosion layer consisting of 6 inches of topsoil (or cinders)
- 12 inches of random fill (or cinders)
- 6 inch sand drain (or cinders), draining to a stormwater collection system
- A 60-mil HDPE or other appropriate flexible membrane liner
- A minimum of an 18 inch foundation layer (intermediate cover)

The Expansion Area will have:

- Erosion layer consisting of 6 inches of topsoil or cinders
- 12 inches of random fill (or cinders)
- 6 inch sand drain layer (or cinders)
- 60 mil HDPE or other appropriate flexible membrane liner (FML)
- Geocomposite clay liner
- Minimum 18 inch intermediate foundation layer (intermediate cover)

There is a limited amount of clay available onsite to use to construct the clay layer. The on site clay is deposited in lenses within the volcanic cinders in the proposed expansion site. These lenses vary in size and quality making extraction time consuming and thus more costly. This lack of a sufficient quantity of clay in an easily accessible on site source creates the need to develop an alternative to a purely clay layer in the liner system.

In 1997 ADEQ granted the City of Flagstaff permission to conduct a pilot project in the expansion area that would last three years. The pilot project would consist of using a 3.5-foot thick monolithic cap consisting of compacted local soils for expansion area A. The cap was to have the following properties:

- maximum wilting point of 0.453
- minimum field capacity of 0.190
- maximum porosity of 0.085
- maximum hydraulic conductivity of $7.2 \times 10^{-47} \frac{cm}{sec}$

The Hydrogeologic Evaluation Landfill Performance (HELP) computer model (version 3.05) was used to estimate maximum leachate production for the expansion area. The HELP model estimates that the given expansion area will produce 2.4 inches (per square foot area) of leachate via the Leachate Collection and Removal System (LCRS), however the HELP model over-estimates quantities of leachate generated by waste cells, particularly in climates with low annual precipitation rates. The Facility Plan also states that “If no leachate is collected by the LCRS system for a period of at least three years (including at least one year with precipitation rates higher than normal), the City of Flagstaff will request that ADEQ approve the monolithic cover as an alternative final cover system for Areas D and E. If leachate continues to be generated in Area D after the trial period for the monolithic cap, the City will replace the cap on Area D with the final cover specified above and pursue this final cover for Area E. (Matt Morales, personal communication, August 2008)

CAP VS. LINER

Most of the published studies on this subject address using paper-pulp sludge as part of a landfill cap system. A few of the studies address using the material as a landfill hydraulic barrier without specifying where in the landfill it would be used. The only study found that specifically addresses using pulp sludge as a landfill liner material is a 1987 paper by Dorairaja Rajhu. That paper concludes that the paper pulp sludge meets the New Jersey Department of Environmental Protection criteria for use as a sanitary landfill liner and that it is feasible to design a liner using this material. (Raghu 1987, p-755) Almost all of the studies were conducted in the Midwestern and Eastern states where there is much more precipitation and the water table is closer to the surface than in Flagstaff. Though the studies do not specifically address using pulp sludge as part of the liner system the material properties are the same as those needed for the liner hydraulic barrier. The environment underneath the landfill would likely provide better conditions for maintaining the integrity of the sludge barrier than those on top where the cap barrier would be. As a liner under the landfill the sludge barrier layer would be protected from freeze-thaw cycles. Additionally the pressure on the sludge layer from the landfill above would enable a higher degree of consolidation which would reduce the hydraulic conductivity.

PAPER PULP SLUDGE DESCRIPTION

The landfill currently receives a daily average of seven truckloads (semi & end dump) of waste-paper-pulp-sludge daily from the SCA Tissue plant in Flagstaff. This material is a waste product from the process of recycling various paper products and appears as a grayish material with the consistency of a fibrous organic clay. At present the pulp sludge is

combined with a mixture of wood chips and crushed glass at the landfill. This mixture is then spread and compacted as an alternate daily cover on each designated daily cell of garbage on the landfill working face. In this application the pulp sludge replaces clay as the hydraulic barrier layer material. If the pulp-sludge could be used as part of the liner for the future expansion area, the landfill could save monetary resources by not having to import clay from a location offsite.

Paper Pulp Sludge can be referred to using several different terms. Some of these terms are general and interchangeable while others refer to slightly differing materials. Terms like those below refer to the general material remaining after paper making and paper recycling water is put through a series of water treatment steps.

- paper pulp sludge
- waste paper pulp sludge
- paper sludge
- paper clay
- paper process residuals
- paper water treatment residuals
- paper residuals

The paper making, recycling, and de-inking process involves breaking down the raw material into a slurry of fibers and other materials. The useful fibers are separated from the slurry and taken to make paper products. The remaining slurry is treated to separate as much of the solids from the water as practical. This treatment includes primary and secondary treatment.

Primary sludge is recovered from the first, or primary, stage of wastewater treatment. This is usually accomplished using sedimentation or dissolved air flotation techniques. (Scott 1995, p-270)

Secondary sludge is recovered from the biological treatment of the effluent remaining after primary treatment. (Scott 1995, p-270) Secondary sludge has a much lower fiber content than primary sludge and a higher percentage of organic material.

Blended or combined sludge is a mixture of primary and secondary sludge. Test indicates that blended sludge has the best characteristics for use as a hydraulic barrier.

Pulp sludge has been widely studied for its use as a hydraulic barrier in landfill caps. In these studies the material characteristics such as hydraulic conductivity, shear strength,

consolidation, changes over extended periods of time, moisture content, and the effects of environmental conditions, were studied as well as equipment and methods that worked for handling and applying the material. Generally waste paper pulp sludge is similar to highly organic clay in many respects. The critical difference is in the fiber content of the two materials. The high fiber content of the paper pulp sludge necessitates changing some test procedures to accommodate them and obtain meaningful data from test. (Maltby 2005, p-9)

NCASI technical bulletin 848 "Laboratory Hydraulic Conductivity Testing Protocols for Paper Industry Residuals Used for Hydraulic Barrier Layers" provided details of testing methods that should be used when studying paper pulp sludge. Pulp sludge is similar to organic clay, however the fibrous nature of the sludge necessitates some changes in test methods. Examples of these challenges include:

1) Biological activity within the pulp-sludge can generate gas that affects hydraulic conductivity testing.

2) The compressible nature of pulp sludge necessitates using a very low hydraulic gradient when testing.

3) It is very difficult to measure the Attenburg limits of pulp sludge because of the fibrous nature of the material. (Maltby 1997, p 13-15)

HYDRAULIC CONDUCTIVITY

Paper pulp sludge must be at a high water content to be workable. The exact water content needed for each sludge to be workable varies with the exact properties of the sludge. Overall each of the sludges studied needed to have a moisture content between 50 and 100 percent wet of the optimum moisture content to obtain minimum hydraulic conductivity. (Maltby 2005, p-17) The hydraulic conductivity varied from a high of $1 \times 10^{-4} \frac{cm}{sec}$ to a low of $1 \times 10^{-7} \frac{cm}{sec}$ for several types of paper pulp sludges tested in a laboratory. (Moo-Young 1996, p-770) In May 1997 pulp sludge from the SCA Tissue plant was tested to determine its material properties prior to application to ADEQ for its use as an alternate daily cover. These test indicated that the material had a hydraulic conductivity of $1.2 \text{ to } 2.6 \times 10^{-7} \frac{cm}{sec}$. (Woodward-Clyde 1997, p-3-2)

It was also noted by several investigators that as the various sludges consolidated and the organic material in them decomposed the hydraulic conductivity decreased. After an eight year test period hydraulic conductivity for a combined sludge was measured at $4 \times 10^{-8} \frac{cm}{sec}$. (Moo-Young 1996, p-772) As noted by young and Zule this decomposition of organic

matter reduces the sludge's hydraulic conductivity making it a more effective hydraulic barrier.

SHEAR STRENGTH

The sludges displayed adequate shear strength to withstand slopes as great as 1:4. The sludge was most prone to failure shortly after placement and prior to significant consolidation. Slumping also occurred if the sludge was too wet when placed or if the sludge was exposed to heavy rain prior to being compacted with a smooth roller. Sludge that was compacted to a smooth surface but still exposed to the rain did not suffer slumping. Maltby noted that these failures occurred within the sludge layer and not at its interface with other layers of the cap system. The low unit weight of the sludge and the lack of confining pressure are the primary factors leading to these failures. (Maltby 2005, p-20)

In an extended field study sponsored by NCASI four separate hydraulic barrier layers were tested. Two of the layers were constructed of a low plasticity clay from a pit that had previously supplied clay landfill barrier layers. One of the other layers was constructed of a primary pulp sludge and the other of a combined pulp sludge. (Maltby 1997, p-2) Figure 1 shows the hydraulic conductivity of each of the test layers over a five year period.

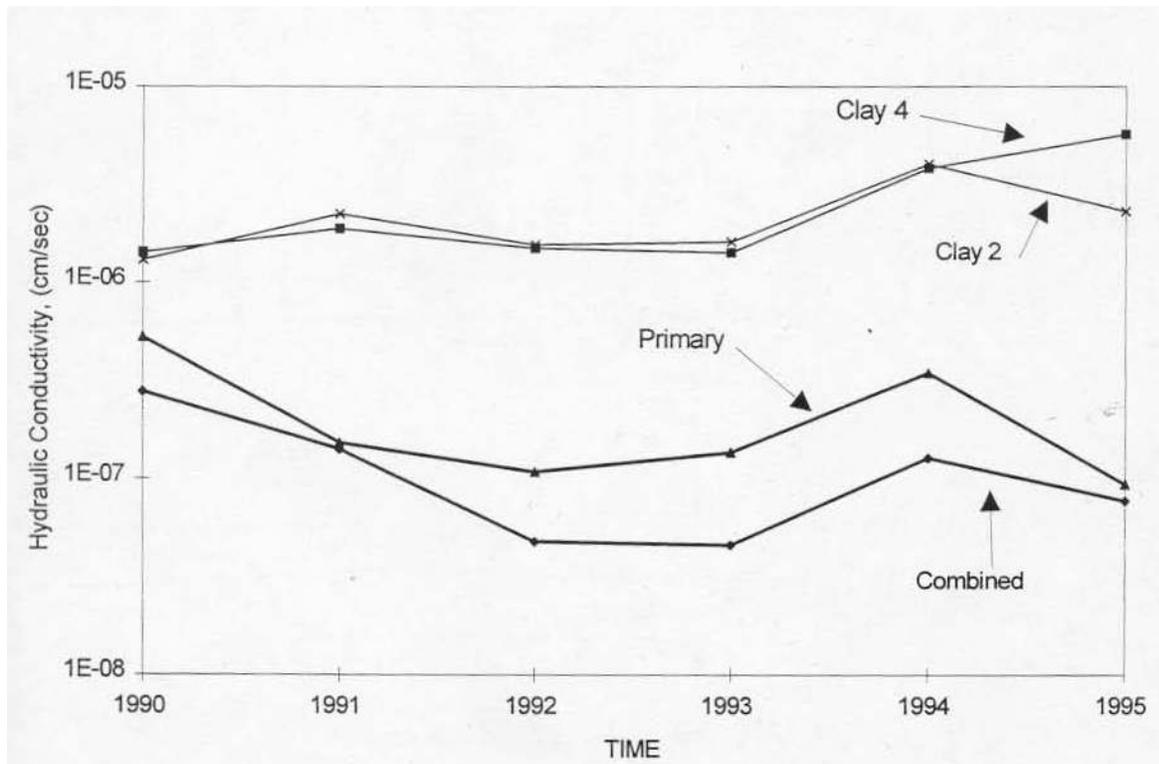


Figure 1: Average Annual Hydraulic Conductivity from Water Balance Data. From (Maltby 1997, p-9)

The addition of dye to the water used to determine the hydraulic conductivity and subsequent dissection of each test layer revealed clues to explain the differences in layer performance. Both of the clay layers displayed preferential flow paths including flow along the boundary between clay lifts. The pulp sludge layers only displayed one preferential flow path. This path appeared to have formed at the end of the test when the sealed double ring infiltrometer (SDRI) was installed to measure hydraulic conductivity. Close study revealed that “nearly all of the flow in the clay barrier layers occurred in preferential flow paths, whereas nearly all flow in the sludge barrier appeared to occur in micropores.” (Maltby 1997, p-26)

Maltby concludes that pulp sludge barrier layers are less prone to construction defects caused by compaction deficiencies than clay layers. He goes on to state that “as with clay layers, care must be exercised during construction to ensure that sludge is free of deleterious materials.” (Maltby 1997, p-26) In the case of the SCA Tissue pulp sludge this material is in the form of finely shredded plastics.

FIELD CAPACITY

Field Capacity was not addressed in the reports reviewed.

ENVIRONMENTAL EXPOSURE

From 1987 to 1995 NCASI conducted an 8 year field pilot study to evaluate the long-term performance of paper pulp sludge used as a landfill hydraulic barrier. This study had two main objectives. First, under field conditions, to compare the performance of pulp sludge layers with typical compacted clay soil layers as a landfill hydraulic barrier. The second objective was to diagnostically evaluate the reasons for differences in performance of the clay and pulp sludge barriers. (Maltby 2005, p-2)

At the end of the eight year study the combined sludge had a hydraulic conductivity of $4 \times 10^{-8} \frac{cm}{sec}$ while the primary sludge showed a hydraulic conductivity of $1 \times 10^{-7} \frac{cm}{sec}$ and the compacted clay soil layer showed $1 \times 10^{-6} \frac{cm}{sec}$. Throughout the test the sludge barrier consistently produced more runoff and allowed less leachate generation than the clay soil layer. (Maltby 2005, p-3) In another study Dr. Moo-Young observed that, in samples taken from sludge barrier layers that had been in place for two years, the sludge material was more cohesive and clay like in texture than when initially placed. (Moo-Young 1996, p-770) This appears to show some decay of organic matter in the pulp sludge layer. However, test conducted by Janja Aule and Marko Likon concluded that sludges subjected to landfill

conditions in most cases do not undergo any significant chemical or biochemical changes. (Zule 2007, p-545)

When exposed to the environment pulp sludge is affected by freeze-thaw cycles. These cycles adversely affect the hydraulic conductivity of pulp-sludge barrier layers as they do compacted clay layers. In “Geotechnical Properties of Paper Mill Sludges for Use in Landfill Covers” Dr. Moo-Young explains the complex relationship between the type of paper sludge, its water content when applied, pressure from overburden, and the number of freeze-thaw cycles exposed to and the hydraulic conductivity of the sludge barrier layer. During those test permeability ranged from a low of $1 \times 10^{-8} \frac{cm}{sec}$ to a high of $1 \times 10^{-5} \frac{cm}{sec}$. (Moo-Young 1996, p-773) The insulating effect of the landfill above the barrier layer and its overburden pressure should eliminate the effects of freeze-thaw cycles on the pulp sludge when used as part of the landfill-liner.

CONSOLIDATION

A major difference between pulp sludge and clay soil barrier layers is the amount of consolidation they experience. In all the studies reviewed that addressed this issue, paper pulp sludge displayed a maximum consolidation of 35% of the original layer thickness after two years. Clay soil barrier layers displayed a maximum of 3% consolidation under the same overburden pressure and in the same two year period. (Maltby 2005, p-5)(Quiroz 2001, p-40) This amount of consolidation brings up two concerns. The first is how much the SCA Tissue pulp-sludge will consolidate under the pressures expected at the bottom of the landfill. This is necessary to calculate how thick the layer must be when constructed so that it meets regulatory requirements after consolidation. The second concern involves how consistently the material will consolidate over the area of the landfill and as the pressure decreases along the sloped edges of the landfill basin. If the sludge layer experiences large differentials in consolidation rate or amount over a short distance stress could be transferred to the HDPE liner damaging it and compromising the overall integrity of the liner system.

Figure 2 depicts consolidation in the clay and pulp sludge barrier layers during the NCASI sponsored eight year field test.

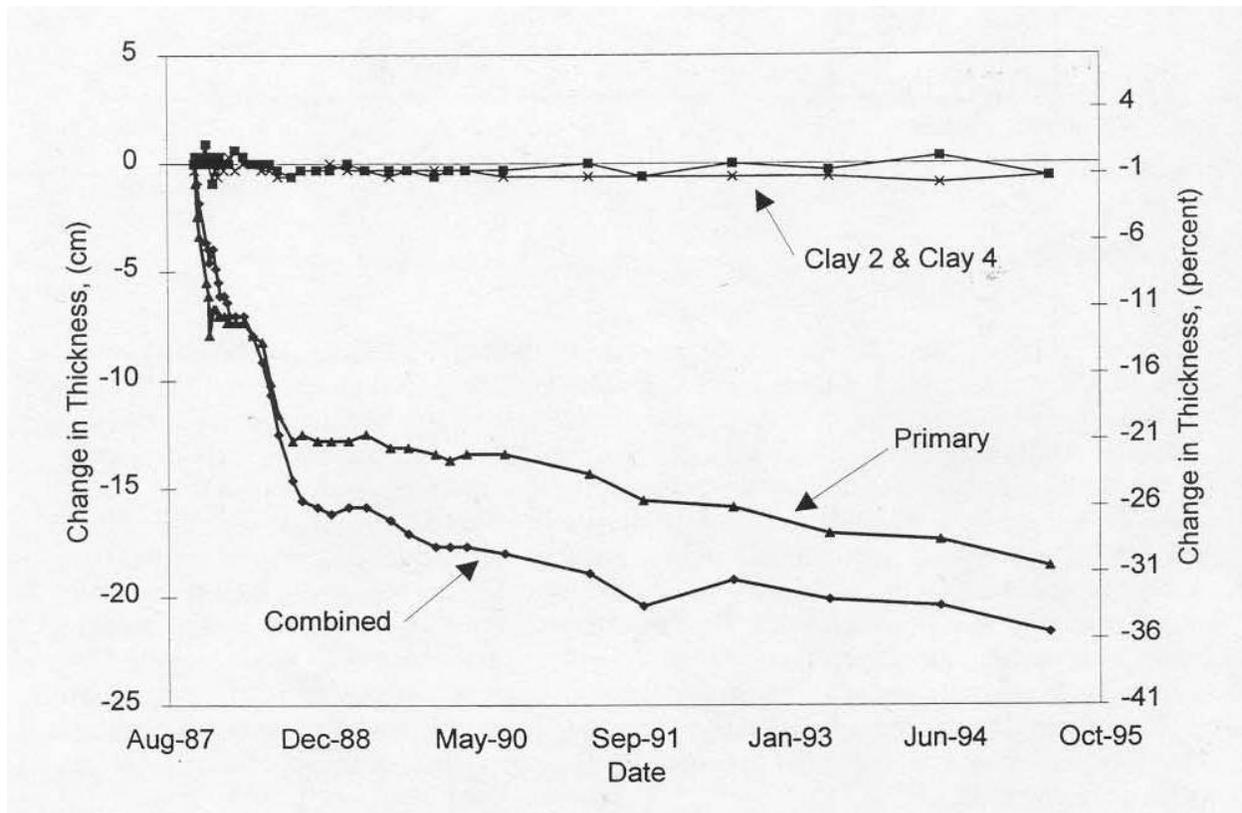


Figure 2: Barrier Layer Consolidation, from (Maltby 1997, p-8)

STOCKPILING

Testing conducted by Dr. Moo-Young indicates that stockpiling the material for several years prior to constructing the hydraulic barrier does not adversely affect the finally constructed barrier. (Moo-Young 1997, p-594) This would enable pulp sludge to be stockpiled at the Cinder Lake Landfill in a separate cell for later recovery and use in constructing the landfill liner.

MATERIAL HANDLING EQUIPMENT

Several types of equipment have been used to construct barrier layers with pulp-sludge. Normally Sheepsfoot rollers are used to compact clay. However, when used on pulp sludge layers these immediately clogged due to the cohesive nature of the sludge and its high water content. Additionally vibratory methods, including a vibrating plate compactor and a small ground pressure vibratory drum roller, did not provide homogeneous mixing and did not compact the sludge effectively. (Moo-Young 1997, p-595) The most effective equipment for placing and compacting the sludge layer was a low ground pressure tracked dozer towing a smooth roller. (Maltby 2005, p-30) An example of which is displayed in

figure 3. This equipment was successful in removing virtually all voids from the sludge layer. (Maltby 2005, p-31)



Figure 3: Low Track Pressure Dozer with Smooth Roller. (From Maltby 2005, p-30)

MATERIAL CONSISTENCY

The SCA Tissue plant receives waste paper from multiple sources from several States. Even with this wide variety of suppliers the raw material is fairly consistent in quality. Most of it is office type paper or other mass printings or trimmings from paper product manufactures (such as envelope makers). There is some variability in the raw material on an annual cycle. Most of this occurs during the Christmas season when the percentage of colorful display and wrapping paper in the raw material increases. The colors in the paper causes SCA some hardship in dealing with the color, however it does not appear to affect the physical properties of the pulp sludge. While some variation in the paper-pulp-sludge coming from the SCA Tissue plant is inevitable the magnitude of it should not adversely affect the performance of the constructed barrier.

Several researchers commented on variations in the appearance of pulp sludge as it was delivered to the landfill. Most often these variations indicated changes in the water content which operators quickly learned to detect. Thus material that was not at the correct working water content could be set aside for other uses such as part of the ADC. (Maltby 2005, p-31)

SCA TISSUE PULP SLUDGE

The chemical and physical properties of the pulp sludge from the Flagstaff plant were initially tested in 1997 by Test America Laboratory and Woodward-Clyde Consulting. (Woodward-Clyde 1997), (Test America 2008) A project report was completed in December 1998 by Harley Grosvenor, P.E. (Grosvenor 1998) At that time the plant was owned by Wisconsin Tissue. The plant has since been acquired by SCA Tissue, however operations at the plant remain essentially the same. There have been some improvements in the process enabling SCA to reclaim a larger percentage of the fibers from the paper they recycle. This has the effect of increasing the percentage of clay in the waste paper pulp sludge. Currently SCA estimates the clay content of the sludge at approximately 60%. Increased sludge values may decrease the hydraulic conductivity of the sludge while used as a barrier layer.

The sludge currently shipped to the Cinder Lake Landfill contains fairly large amounts of shredded plastic. This material comes in with the raw paper to be recycled. Much of the paper is clippings and rejects from an windowed envelope making operation. During recycling the plastic is separated from the pulped paper and stockpiled. The plastic is then mixed with the pulp sludge to facilitate its transportation to the landfill. The plastic's shredded condition and light weight make it challenging to keep in the truck when transporting. Mixing it with the sludge makes it much easier to transport.

As the sludge comes out of the processing plant it does contain a small amount of plastic that was not separated in earlier stages of processing. This amount of plastic was probably present in the samples tested in 1997 and did not adversely affect the samples hydraulic conductivity. However, new test should be conducted and specific attention paid to evaluating the effect these plastic fragments have on the pulp sludge's properties.

SUMMARY OF SPECIFIC RECOMMENDATIONS

- 1) Prior to testing paper pulp sludge anyone involved in the testing should become familiar with NCASI Technical Bulletin 848. This will save time and frustration when learning how to deal with the peculiarities of paper pulp sludge.
- 2) Conduct laboratory test on the pulp sludge from SCA to:
 - a) Verify that the material properties are essentially the same as the 1997 test indicate.
 - b) Verify that the plastics present in the pulp sludge do not adversely affect its hydraulic conductivity.
 - c) Determine the field capacity of the pulp sludge.
- 3) Conduct field test to determine the amount, rate, and variability of consolidation the sludge is likely to experience as part of the landfill liner.

CONCLUSION

Many landfills have been closed using paper pulp sludge as part of the landfill cap. Many more use paper pulp sludge as an alternate daily cover. Extensive research has been conducted on using paper pulp sludge as a landfill hydraulic liner. Most of this research has focused on using the pulp sludge as part of a landfill cap. The physical properties needed for the hydraulic barrier of a landfill liner are nearly the same as for the cap. Paper pulp sludge will probably prove a more effective hydraulic barrier when used as part of the liner than when used in the cap. As a liner material the pulp sludge will not be exposed to freeze-thaw cycles and will be subjected to increased pressure from the weight of the landfill above. This increased pressure will cause more efficient consolidation of the pulp sludge layer improving its hydraulic conductivity.

The pulp sludge from the SCA Tissue plant was thoroughly tested in 1997 in application for use as an alternate daily cover. Testing should be done to ensure the current material has the same physical properties. Additionally, test should be conducted to determine how much consolidation can be expected as well as how evenly the pulp sludge layer will consolidate. This is especially important along the sloping edges of the landfill where the material will not be subjected to the same weight of overburden at all points. Differential consolidation could put excessive stress on the HDPE liner damaging it. Testing must also verify that the small amount of plastic in the sludge does not adversely affect its physical properties like hydraulic conductivity. With that accomplished it is likely that an effective hydraulic barrier layer can be designed and constructed using waste paper pulp sludge.

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