RECLAMATION OF WASTE ROCK STOCKPILES UTILIZING PAPER MILL RESIDUALS AT CLIFFS MICHIGAN MINING COMPANY[1]

Allan E. Koski[2]

Abstract: Two of the largest industries in northern Michigan, pulp and paper manufacturing and iron mining, formed a mutually beneficial partnership and collaborative research program to utilize paper mill residuals for waste rock stockpile reclamation. Historically, the majority of the paper industry's residuals have been disposed of in landfills. The beneficial use of paper mill residuals for mine reclamation provides an environmentally sound recycling solution for the solids generated at northern Michigan paper mills and eliminates the need to strip additional overburden (glacial till) for final mine reclamation. Residuals offer a cost-effective source of organics and nutrients necessary for successful reclamation and waste rock stockpiles offer an economical and environmentally sound solution for disposal of residuals. The goal is to successfully pioneer technical development of paper mill residuals to accomplish vegetation of steep waste rock stockpile slopes and benches to establish a self-sustaining plant community that meets final reclamation requirements. Of the various types of iron mining wastes, rock stockpiles pose the greatest reclamation challenge. Success depends on incorporating sufficient organic matter into the rock stockpiles to produce a growth medium that can sustain vegetation without the need of overburden. This is an ongoing research program that is evolutionary in nature with numerous field trials, greenhouse studies, data collection and monitoring over multiple growing seasons. The program is a combination of innovative ideas and accepted reclamation practices that is proving to be a beneficial and economic approach to paper mill residual management and mine reclamation that will eventually lead from research to standardized reclamation procedures. The observations in this paper are from the first field season.

Additional Key Words: land application, beneficial use, mill residuals, WTP residuals, solid waste management, paper sludge, land spreading

---

[1] Paper was presented at the 2005 National Meeting of the American Society of Mining and Reclamation, June 19-23, 2005. Published by ASMR, 3134 Montavesta Rd., Lexington, KY 40502.

[2] Allan E. Koski is Senior Engineer, Cliffs Michigan Mining Company, Ishpeming, MI 49849
Proceedings America Society of Mining and Reclamation, 2005 pp 627-644
DOI: 10.21000/JASMR05010627
https://doi.org/10.21000/JASMR05010627

Introduction

The early 1950's saw technological advances that allowed the open pit mining and processing of low-grade iron ore in northern Michigan. The ore is a hard, banded, sedimentary rock containing fine particles of iron that require complex and expensive processing to transform it into marble-sized iron ore pellets for consumption in the blast furnaces of both domestic and foreign integrated steel producers. Cliffs Michigan Mining Company (CMMC) traces its origins to the early 1960's with construction of the initial plant and production of the first pellets in late 1963. Today CMMC produces 13.0 million long tons of high quality iron ore pellets annually making it the leading mineral producer in Michigan. Through 2004 total pellet production has exceeded 300 million long tons. Mining activity is projected well into the 21st century.

The primary landforms currently reclaimed by CMMC are waste rock stockpiles. All material movement in 2005 is approximately 80 million long tons, of which approximately half is waste. Since inception of mining in 1962, over 1.2 billion long tons of waste rock have been placed in stockpiles. Stockpiles are sited adjacent to mining areas minimizing haulage distances while not encumbering future pit design changes that result from new economics. Recently, in-pit stockpiling has become a cost-effective reclamation alternative as older mining areas become exhausted.

The goal of CMMC's reclamation program is to establish self-sustaining communities of grasses, legumes, shrubs and trees that effectively control erosion, improve aesthetic quality and give the land future utility for wildlife and other activities. Cliffs Michigan Mining Company is committed to leadership in the mining industry, including excellence in reclamation:

- By managing and developing reclamation activities that protects local economies, CMMC's economic future, and preserving and protecting natural resources and ecosystems.
- By a commitment to open communications with members of the communities in which we operate.
- By making efforts to be aware of, and to comply with all relevant environmental regulations.
- By implementing innovative, sound reclamation practices with cost-effective and measurable results.

Reclamation Vision

To successfully pioneer technical development of paper mill residuals to accomplish vegetation of waste rock stockpile benches and slopes meeting final reclamation requirements without soil cover or other amendments under Part 631, Reclamation of Mining Lands, of the Michigan Natural Resources & Environmental Protection Act 1994 PA 451.

Mining and Paper Mill Partnership

With rising landfill costs, increased regulations and greater expenses associated with permitting new landfills, northern Michigan's two largest pulp and paper mills began a concerted effort to find beneficial alternatives for disposal of paper mill residuals. In addition to landfilling, one mill investigated silviculture applications and the other established a Farm Management Plan for agricultural application of residuals. Climatic conditions, soil types and a short growing season in northern Michigan are not conducive to farming, resulting in limitations to large-scale agricultural land application programs. A typical agricultural land application program consisted of 50 farms of 20 acres each during a short growing season. For the remainder of the year residuals had to be disposed of by landfilling or incineration. For these reasons and others, landfilling, agricultural and silvicultural applications were not entirely satisfactory and the pulp and paper mills continued to investigate other alternatives.

Faced with a limited supply of overburden and increased regulatory requirements CMMC began to investigate reclamation alternatives. Developing adequate quantities of overburden to sheath stockpiles would unnecessarily disturb additional lands, which was not an ecologically sound approach and was not permitted by the Michigan Department of Environmental Quality (MDEQ). Additionally, glacial till has low fertility for plant growth. For these reasons, CMMC initiated investigations into innovative ways to establish vegetation on rock stockpiles to meet final reclamation requirements. Water quality monitoring demonstrated that rock stockpiles contained nothing toxic to plant growth and that water quality was not degraded when stormwater percolated through the stockpiles and discharged into nearby surface waters. The use paper mills residuals on CMMC tailings basins indicated that if enough organic matter were incorporated into the rock stockpile surfaces, vegetation could become successfully established without the need for overburden. In effect, an artificial growth medium capable of sustaining plant growth could be created. The question was how to develop methods to incorporate enough organic matter into the barren rock stockpiles so that self-sustaining vegetation could be established. It also became evident with this approach that substantial quantities of organic matter would be required for successful long-term plant growth. Economic availability of large quantities of peat moss, composts and farm manures were not available or necessarily desirable. After considerable investigation, paper mill residuals became the most likely candidate for creation of such a growth medium.

Recognizing that paper mill residuals are economic quality by-products for mine reclamation that provide large quantities of nutrients and organic matter, CMMC and northern Michigan's two largest pulp and paper mills, initiated discussions with the MDEQ. Each generator submitted documentation to MDEQ to obtain a site-specific inertness designation for long-term application of residuals to rock stockpiles. After extensive discussions and a review of each mill's analytical data the MDEQ granted both paper mill's residuals an "inertness designation for rock stockpiles" and accepted a CMMC plan to use the residuals to develop a process to vegetate barren rock stockpile benches and slopes meeting final reclamation requirements. Additional agreements with the paper mills completed the framework for this multi-year research program that began in 2003. The mutually beneficial relationship between the mine and the paper mills provides an environmentally sound recycling solution for the solids generated at the paper mills.

Residuals Benefits

Paper mill residuals have long been utilized as a beneficial amendment for mine land reclamation and have successfully vegetated thousands of acres of disturbed lands across North America. Residuals provide slow-release fertilizing action that is often superior to chemical fertilizers over time. Land applied residuals enhance soil productivity and ultimately biomass production (Wolterson, 2004). Research by the National Council for Air and Stream Improvement has shown that paper mill residuals have low concentrations of heavy metals, no problematic organic compounds, no human pathogens, or other constituents of concern. There is no evidence of nitrate leaching because of their slow release or any threats to grazing animals or wildlife. Residuals have proven to be environmentally compatible when used with good management practices. Well-managed land application programs have proven to be an environmentally beneficial and economic approach to residual management (Vance, 2000). The major benefits of using residuals for rock stockpile reclamation include:

- Establishment and support of a diverse microbial community
- Increased supply of nutrients, with some in slow release, organic form
- Increased organic matter and recycling
- Increased nutrient storage capacity
- Increased water infiltration and retention capacity
- Deeper root penetration and improved air supply to roots
- Increased cation exchange capacity (CEC)
- Increased vegetation survival and growth
- Improved surface temperatures resulting from lighter color
- Higher species and structural diversity with darker healthier foliage
- Less costly, economic nutrient source
- Reduced reliance on commercial fertilizers for reclamation
- A stable, healthy and dynamic ecosystem will develop
- Aesthetically, the stockpiles look better
- Improved erosion control, once vegetation is established
- Improved structure of growth medium
- Compliance with MDEQ Metallic Mining Permits issued to CMMC

Additionally:

- Nearby property values appreciate.
- Economic benefits are derived with additional job opportunities handling residuals.

Paper mill residuals are an effective and economical source of nutrient-rich organic matter for reclamation of rock stockpiles. The program's goal is to use residuals for rock stockpile reclamation incorporating enough organic matter into the barren rock to produce a growth medium that can sustain plant growth without the need of soil. This requires substantial economic quantities of nutrients and organic matter such as that found in the paper mill residuals.

Creating a growth medium with large quantities of organic matter on the stockpile's slopes and surfaces may actually be more environmentally responsible than sheathing them with rocky, low fertility glacial till. With limited availability of overburden, mining additional amounts would require increased ecological damage as additional land is disturbed.

Climatic and Geographic Setting

Cliffs Michigan Mining Company is located in Michigan's Upper Peninsula. Geographically the surrounding area is rolling to rugged topography. Mining is located in highland areas, which are old mountain remnants. Elevations range from 1,300 to 1,900 feet in elevation, whereas most surface land in Michigan lies between 600 and 1,000 feet with Lake Superior having a mean elevation of 602 feet.

Climatologically the area is classified as cool to temperate with an average annual temperature of 40 F degrees, a high relative humidity, and a low percentage of possible sunshine. July average temperature is 65 F degrees. The close proximity of Lake Superior, 10-15 miles, makes the climate highly variable with rapid swings in temperature and precipitation. Annual precipitation is 35 inches of water equivalent of which 50-60% is in the form of snow. The area generally experiences a surplus of water regime. There are 110 to 130 frost-free days, although patchy frost is possible throughout the summer. Winters can be severe with heavy snowfall and the summers hot with unpredictable droughty periods (NWS, 2005).

Vegetation assemblages are primarily climax hardwood and conifer stands composed of sugar maple (Acer saccharum); hemlock (Tsuga Canadensis); red maple (Acer rubra); basswood (Tilia americana); red oak (Quercus rubra); yellow and white birch (Betula species); trembling aspen (Populus tremuloides), big tooth aspen (Populus grandidentata), and balm of gilead (Populus species); red pine (Pinus resinosa), jack pine (Pinus banksiana), and white pine (Pinus strobus) and balsam fir (Abies balsamea) on well drained upland soils. Poorly drained lowland soils generally support northern white cedar (Thuja occidentalis); spruce (Picea species) and ash (Fraxinus species) (Summers, 1978).

Soils in the region are the result of continental glaciation with the final retreat occurring 9,500 years ago. Since the retreat a variety of soils have developed and at the soil order level they range from Inceptisols, Entisols, Spodosols, Alfisols, and Histosols. The northern latitude and the cooling effects of Lake Superior result in a mean annual soil temperature of less than 36 degrees Fahrenheit. The mean evapotranspiration rate is approximately 19 inches (Shetron and Ovanic, 1995). Overall, climatic conditions are conducive to vegetation with timing of planting for seed germination critical. Most planting is done between May 15th and June 15th to take advantage of good spring moisture conditions.

Waste Rock Stockpile Characteristics

Geomorphically the rock stockpiles resemble mesas with rocky slopes that have been exposed to the local climate for only a few years. The stockpiles are essentially time zero in age and evidence of soil formation is nonexistent. Analyses of the general physical and chemical properties of the waste iron formation stockpiles have revealed that the rocks contain nothing toxic to plant growth and pH adjustment is not necessary.

The natural dark color of the stockpiles creates extreme surface temperatures during the growing season. The stockpiles with their dark colors are heat sinks in the same manner that asphalt parking lots are in urban environments. Surface temperature differences of 60-70 F degrees have been observed between day and night on waste iron formation (Shetron, 1982). Various temperature profiles exist on the stockpiles with barren rocks having the highest temperatures and successfully vegetated areas having the lowest temperatures. Field observations have shown that a mulch or residual-like cover reduces surface temperatures about 20 F degrees during the growing season. By early fall, surface temperatures moderate and remain close to ambient temperatures (Ovanic, 1996).

With a 50 percent post blasting swell factor and a 36-degree angle of repose the stockpiles are loosely consolidated with poor moisture retention (Bohnet, 1990). They are devoid of organic carbon and lack plant essential nutrients. This results in severe droughty conditions during periods of low precipitation. The few poorly naturally vegetated areas are characterized by low species and low structural diversity. Sparse pioneer aspens are the predominant vegetation. Their limited growth and pale chlorotic color demonstrate a severe nutrient deficiency. In essence, the rock stockpiles are well-drained and nutrient poor. They are not naturally functioning systems and they are not in equilibrium with the surrounding environment. With low water retention capabilities, adverse surface temperatures, a lack of organic material, microbial populations and soil nutrients the stockpiles do not provide a medium that supports and sustains vegetation (Table 1).

Over forty years of mining activity have resulted in rock stockpile site conditions that vary widely in characteristics. Site-specific application plans must be developed for each stockpile. Early stockpiles dating to the 1960's had minimal terraces with few restrictions on lift heights. Michigan reclamation law now mandates stockpile lifts no higher than 50 feet with 50 feet wide terraces. Additionally, all stockpiles slope inward toward the interior of the stockpile to control run-off.

Residual application sites are differentiated and categorized using three criteria; slope design, slope material and visibility to the public. Slope design is either terraced or non-terraced. Slope material is either (FR) for fragmental rocks greater than 6 inches or (SA-FR) for sandy, shaley, rocks up to 6 inches. Slopes are classified by visibility or non-visibility from public highways and residential areas.

<u>Paper Mill Residual Characteristics</u>

The two largest pulp and paper mills in northern Michigan utilize the Kraft process that produces nearly 80% of the chemical pulp produced in the United States. The residuals are generated from elemental chlorine-free bleach pulp mills utilizing a variety of trees. The physical and chemical properties of the residuals from each mill are different and unique to that generator and vary depending on the products manufactured and species of trees used. For this reason it is best to determine application rates based on the chemical composition of the residual as well as the vegetation needs (Brady, 1990). Analyses of the paper mill residuals general characteristics are shown in Table 2.

Table 1 General Properties of Waste Rock and Paper Sludge

General Physical & Chemical Properties	Waste Rock	Paper Sludge
Texture	Highly Fragmented	Smooth
Compaction	33% Voids	Well Compacted
Drainage	Well Drained	High Water Retention
Organic Matter	None	50 % Organics
Soil Content	None	50 % Clay & Calcium
PH	7.5-8.5	7.5
Nitrogen	None	1.50 %
Phosphorus	None	0.75 %
Potassium	None	0.10 %
Toxicity to Vegetation	None	None
Color	Dark Gray, Black	Light Gray, White
Reflectivity	Low	High

Table 2 Chemical Characteristics of Two Paper Mill Residues

Paper Mill	Percent Ash	Percent Nitrogen	Carbon/Nitrogen	pH
MeadWestvaco	54 %	1.5 %	14:1	7.5
International Paper	50 %	1.2 %	24:1	7.5

Ash represents the mineral or non-organic fraction of the sludge and includes clays and calcium. The ratio of organic carbon to total nitrogen (C/N) provides an indication of the potential of the residuals to decompose and provide plant available nitrogen. At a C/N of less than 20:1, the residuals generally decompose readily; although some nitrogen addition is required for immediate plant growth at a C/N greater than 12:1. At a C/N of 20:1 to 30:1, the residuals require a nitrogen addition for decomposition and support of vegetation during the first growing season of application (Shimek, 1988). Because of their slower decomposition higher C/N residuals allow for higher application rates without creating nitrate-leaching concerns. When residuals with a C/N greater than 30:1 break down, the microorganisms completely rob the nitrogen during the early stages of decomposition depleting supplies needed for plant growth. All residuals have the potential to go anaerobic and produce odors if applied thickly or stockpiled.

The residuals are rich in organic matter and nitrogen, have a near neutral pH, contain plant-available nutrients and microbial biomass generated during the treatment of process water. Approximately 50 percent of the sludge is organic matter and the remaining 50 percent consists of lost fillers and coating (primarily kaolin and fine-grained calcium carbonate). The total nitrogen content includes both organic and inorganic forms of nitrogen and is controlled by the secondary solids content. The secondary solids result from secondary wastewater treatment, where nitrogen is added to the wastewater to promote biodegradation. The inorganic form of nitrogen is immediately available to plants. As organic nitrogen is converted to mineral forms, it also becomes available to plants (Shimek, 1999). Representative analyses of the residuals organic matter and nutrients are shown in Table 3.

Table 3. REPRESENTATIVE RESIDUALS ORGANIC MATTER AND NUTRIENT ANALYSIS

PARAMETER	DRY BASIS	
	Amount	**Units**
Organic Matter	1,000	Lbs/Ton
Primary Nutrients		
Total Nitrogen (N)	25 – 30.0	Lbs/Ton
Available Nitrogen		
1. Ammonium Nitrogen (NH_4-N)	0.30	Lbs/Ton
2. Nitrate Nitrogen (NO_3-N)	0.02	Lbs/Ton
Phosphorus (P)	10 – 15.00	Lbs/Ton
Potassium (K)	1 – 2.00	Lbs/Ton
Secondary Nutrients		
Calcium (Ca)	150 - 200	Lbs/Ton
Magnesium (Mg)	1 - 5	Lbs/Ton
Sodium	2.0	Lbs/Ton

The residuals from both mills require a nitrogen supplement at planting to reduce the time for decomposition. The residuals lack appreciable quantities of potassium, plant available phosphorus and micronutrients. Phosphorus in the sludge is largely bound by fine mineral and organic particles (Shimek, 1999). Mineralogical testing of rock stockpiles indicates that most micronutrients are present and will be available with geochemical weathering of the waste rock long term. The residuals have an appreciable amount of calcium and generally adequate amounts of magnesium and sulfur to support vegetative cover (Shimek, 2004). With nutrient poor waste rock, a plant available potassium and phosphorus supplement is required. A micronutrient supplement will be considered based on annual plant tissue tests.

Application of Residuals And Seedbed Preparation

Residuals are applied to both stockpile surfaces and slopes. To achieve successful reclamation of rock stockpiles large amounts of organic matter must be incorporated into the rocky surfaces to change both the physical texture and structure of the surfaces. Establishing a self-sustaining growth medium also requires relatively large quantities of nitrogen over time.

The rock stockpiles are steeply sloping and blanketed with a rough uneven surface of unconsolidated material. Preparation of a friable seedbed for the germination, establishment and growth of plants on the steeply dipping slopes presents a challenge. Due to the steep, 36-degree angle of repose, conventional seedbed preparation cannot be utilized. Application on continuous slopes that on some sites rise vertically for hundreds of feet is difficult.

Initial residual application rates for stockpile surfaces are generally 12” in depth or approximately 200 dry tons per acre. On stockpile slopes the rate of application varies from 100 to 400 dry tons, where the physical size of the slope material dictates the application rate. Residual applications on level stockpile surfaces have been made with a small bulldozer. Residuals crust over when spread requiring mechanical tillage or scarification to break up the crusted surface prior to planting (Fig.1). The use of dozers, spreaders, and a long stick backhoe has not proven to be entirely satisfactory for applications on the slopes of older, higher stockpiles. Spreading sludge on slopes with uniformity of thickness has been a concern. In 2004 a large manure type spreader with a low trajectory was used with mixed results. Future research efforts involve utilizing pumping technology to repulp the residuals and spray them on stockpile slopes resulting in deeper penetration of the rock surface, providing for deeper root penetration while creating a wicking effect for capillarity to bring moisture to the slope surface. A local well drilling firm is constructing a pilot plant. Seeds will be added to the final sprayed layer incorporating them into the residuals. Residual applications are only made on areas that current plans indicate will not be re-disturbed over the course of the mine life.

Site Management

A minor amount of anaerobic degradation causing odors is generated when residual piles are disturbed during spreading operations. Most of the residual spreading occurs within a few months of delivery. Spreading takes place year around minimizing odors. Residuals from each paper mill are segregated when stockpiled and spread to comply with MDEQ regulations. The storage, use, handling, and applications comply with all applicable federal and state laws. Additionally, individual paper mill Environmental, Health and Safety Policies regarding the beneficial use of residuals waste materials are observed. Paper mill residuals are not applied to reclamation sites that have received other industrial or municipal wastes. The MDEQ receives an annual monitoring report, makes field inspections and receives project updates and water quality monitoring reports. An environmental professional closely manages the field activity, contractor communications, residuals placement, vegetative reclamation, water quality sampling, reclamation monitoring and record keeping.

Vegetation Establishment, Success and Observations

The rock stockpiles represent new vegetation surfaces that have not been subjected to the same environmental and geologic time period as native in-place soils. The initial challenge is to determine what types of plant species are suitable for a growth medium comprised of residuals and rocks. The most successful vegetation strategies use the initial phase of vegetation to prepare the ground for the next and allow for the migration of native species from surrounding undisturbed lands. This successional approach is an integral part of CMMC paper sludge reclamation project design. The goal is to first establish a grass community to be followed by shrubs and small trees with limited root volumes to create wildlife habitat. This approach lays the groundwork for ultimate succession of a climax community while still providing stormwater and erosion control, wildlife habitat, reduction of visual impact, and restoration of the land.

In 2004 hydroseeding was the preferred method of application on both slopes and level surfaces. With the extreme heights of the stockpiles, wind direction must be carefully monitored because it creates significant problems during residual application, seeding and mulching operations especially on stockpile slopes. Seed and fertilizer are applied together. Plans in 2005 on flat surfaces include the use of a 12-foot wide tractor pulled Brillion agricultural grass seeder, covering seeds with ½” of residuals, resulting in reduced seed requirements, improved seed/ground contact and elimination of mulch and tacking agents. Maintenance of seeded sites is done as required until the site stabilizes and the vegetative community becomes self-sustaining.

With the exception of geese and sand hill cranes there have been no significant seed losses due to bird or animal scavenging because the barren stockpiles are essentially devoid of wildlife prior to seeding. Experience has taught that multiple bird species immediately move into residual reclaimed sites with the seeding and growth of grasses. In 2005 bird surveys will be conducted during the spring and fall migrations.

Because of their high water content (67%) when delivered, frozen residuals applied during the winter need until late April or early May to thaw. Generally, most planting is done between May 15th and June 15th to take advantage of good spring moisture conditions in our temperate, cool/humid climate zone. Seeding in July and August is often too hot and dry. September seeding is not conducted because of the risk of winterkill in northern Michigan. Each residual reclamation site has a different exposure to the sun. No area is seeded until the surface soil temperature reaches 50 degrees Fahrenheit. All reclamation on the stockpiles is done by contract to CMMC specifications, with the successful bidder providing all equipment, seed, fertilizer and mulch necessary to complete the job. Mulching rates have been three tons of hay per acre. Analyses of first year reclaimed sites during the 2004 field season are shown in Tables 4 and 5.

Table 4. Effect of Paper Residues on Plant Characteristics.

Stockpile Surfaces	Paper Company	Average Grass Height	Maximum Grass Height	Percent Cover	Average Root Depth
Fox Valley	Int’l Paper	21”	30”	100 %	6”
Fox Valley	MeadWestvaco	20”	30”	100 %	6 “

Table 5 Effect of Paper Residues and Aspect on Plant Characteristics.

Stockpile Slopes	Paper Company	Site Aspect	Average Grass Height	Maximum Grass Height	Percent Cover	Ave. Root Depth
Fox Valley	Int'l Paper	South	20"	30"	40 %	6"
Fox Valley	MeadWestvaco	South	20"	30"	40 %	6 "
Fox Valley	MeadWestvaco	East	20"	30"	75 %	6"
Fox Valley	MeadWestvaco	North	20"	30"	75 %	6"

Rock stockpile vegetative results demonstrate slightly greater density and height of grasses with lower C/N residuals and slightly decreased vegetative growth with higher C/N ratio residuals. However, vegetation growing on higher C/N ratio residuals was the only ones that recovered when a drought was simulated in a greenhouse study at Michigan Technological University. On flat surfaces percent cover was less than 100 percent only in small areas where geese ate new shoots as fast as they sprouted. As would be expected, the slopes with north and east aspects fared better than slopes with a southern exposure. Root depth indicates that at this stage of development the grasses are deriving all their nutrient supply from the residuals and supplemental fertilizer. The results in both density and height of the vegetation have been impressive (Fig. 2). This is especially so, since no irrigation was supplied to the planted areas. Second year maintenance will consist primarily of hand broadcasting small areas damaged by geese.

Seed Selection

A self-sustaining community of perennial grasses and legumes is the primary project goal. Seed selection has been based on seed cost, germination rates, species adaptability to site conditions and previous reclamation experience. Experience has shown that grasses grow better on residuals with low C/N ratios and legumes do better on residuals with a high C/N ratio (Shimek, 2004). A short germination time is critical for seeds resting on steep slopes exposed to scavengers, wind, rain, and the sun. The more rapidly grasses become established, the greater the chance of success. Seeds selected in 2004 generally have germination times from 7 to 14 days.

Prior to the 2004 growing season CMMC contracted with a Michigan Technological University graduate student to conduct a greenhouse study to determine seed selection and fertilization requirements. Twenty seed types were planted in 160 containers over an eight-week trial period. Each of the seeds was planted in four growing mediums, fresh paper sludge, fresh paper sludge amended with 19-19-19 fertilizer, six-month old paper sludge and paper sludge amended with twenty percent wood ash from the paper mills. Final seed selection for the 2004 growing season that resulted after reviewing vegetative success included red clover, (Trifolium pratense); timothy, (Phleum pratense); tall fescue, (Festuca arundinacea); perennial rye, (Lolium perenne); orchard grass, (Dactylis glomerata); creeping red fescue, (Festuca rubra); birdsfoot trefoil (Lotus corniculatus), Canada wild rye (Elymus canadensis) and barley, (Hordeum sp.), as a nurse crop. All these species have proven effective in reclamation sites across northern Michigan and northern Wisconsin. Creeping red fescue and tall fescue are clump or bunch type grasses, which were selected because of their low nutrient demand and their ability to grow in the small niches and voids found among rocks on the stockpiles. General application rates are detailed in Table 6.

Table 6. Application Rates Used at Three Reclamation Sites

MeadWestvaco Mix		#'s per Acre	
Barley (Nurse Crop)	(Hordeum)	100 # per Acre	
Red Clover	(Trifolium pratense)	15 #	9.1 %
Timothy	(Phleum pratense)	25 #	15.2 %
Tall Fescue	(Festuca arundinacea)	25 #	15.2 %
Perennial Rye	(Lolium perenne)	25 #	15.2 %
Orchard Grass	(Dactylis glomerata)	25 #	15.2 %
Creeping Red Fescue	(Festuca rubra)	25 #	15.2 %
Canada Wild Rye	(Elymus canadensis)	25 #	15.2 %
		165 # per Acre	
MWV Fertilizer (one application)	19-19-19 300# per Acre		
International Paper Mix		#'s per Acre	
Barley (Nurse Crop)	(Hordeum)	100 # per Acre	
Red Clover	(Trifolium pratense)	15 #	9.1 %
Timothy	(Phleum pratense)	25 #	15.2 %
Tall Fescue	(Festuca arundinacea)	30 #	18.2 %
Perennial Rye	(Lolium perenne)	10 #	6.1 %
Orchard Grass	(Dactylis glomerata)	30 #	18.2 %
Creeping Red Fescue	(Festuca rubra)	25 #	15.2 %
Birdsfoot Trefoil	(Lotus corniculatus)	30 #	18.2 %
		165 # per Acre	
IP Fertilizer (one application)	20-30-10 600# per Acre		
MDOT Roadside Mix		#'s per Acre	
Barley (Nurse crop)	(Hordeum)	100 # per Acre	
Kentucky Bluegrass	(Poa pratensis)	25 #	15.0 %
Perennial Rye	(Lolium perenne)	83 #	50.0 %
Creeping Red Fescue	(Festuca rubra)	57 #	35.0 %
		165 # per Acre	
Fertilizer same as indicated depending on whether site is MWV or IP.			

Approximately 25 species of weeds naturally established themselves on the paper sludge stockpiles prior to any reclamation activity. Their success was noted and a list of these species compiled. If these do not appear on any state or federal noxious or invasive weed lists, consideration will be given to planting seeds from some of these in the future.

Wildlife Species

Deeper soils are needed for the establishment of climax forest trees. Generally, soil depth for timber production is two feet over broken rock. In the early successional stages of residual applications on rock stockpiles, such depths will not be achieved and there will not be adequate root volume for climax trees such as white pines (Pinus strobus) and northern red oak (Quercus rubra). In 2005, test plots of wildlife species shrubs and small trees requiring lesser soil depths will be established on residual reclamation sites. These were selected because of their wildlife value, adaptability to clay type soils which are similar to residuals, and their adaptability to the local climate.

Plantings in test plots will include Chokecherry, (Prunus virginiana); Black Chokecherry, (Aronia melanocarpa); Roselow Crabapple, (Malus sargenti); Highbush Cranberry, (Viburnum trilobum); Wild Black Currant, (Ribes americanum); Red Osier Dogwood, (Cornus stolonifera); American Elderberry, (Sambucus canadensis); Red Berried Elderberry, (Sambucus pubens); Common Hackberry, (Celtis occidentalis); American Hazelnut, (Corylus americana); Washington Hawthorne, (Crataegus sp.); American Mountain Ash, (Sorbus americana); Nannyberry, (Viburnum lentago); Ninebark, (Physocarpus opulifolius); Sand Cherry, Serviceberry, (Amelanchier arborea); Snowberry, (Gaultheria hispidula); Speckled Alder, (Alnus rugosa); Staghorn Sumac, (Rhus typhina); American Wild Plum, (Prunus); and Witch Hazel, (Hamanelis virginiana).

A primary goal of this reclamation project is to establish wildlife habitat as part of the natural succession to a climax forest. Habitat that supports wildlife requires several essential components – food, cover, water and space. Each is addressed with this reclamation project.

- The availability of staple foods is critical to support a wildlife population. This goal is met in three ways; planting of annual grains such as barley and oats; plantings of perennial grasses and legumes such as clovers and fescues and ryegrass and plantings of wild herbaceous plants and possibly weeds.
- In addition to food, the plantings provide breeding, nesting, escape cover, as well as shelter and thermal cover for wildlife species. The next stage of CMMC's program is to determine which wildlife habitat shrubs and trees are best adapted to residuals keeping in mind that diversity is the basic principle for developing wildlife habitat.
- Water requirements are met in several ways. Generally the area has a surplus water regime. The high clay content of the residuals results in a high water content and even puddles rainfall.
- The vast aerial extent of the stockpiles, which cover thousands of acres, provide space for wildlife. Older stockpiles are relatively isolated and free of human disturbances.

Initial experience with paper mill residuals indicates that two alternatives for wildlife habitat can be initially created on residual reclaimed stockpile sites – grasslands and brushlands. Grasslands could be solely developed and maintained and are relatively rare in northern Michigan providing habitat for birds, rabbits, skunks and the like. The second alternative, a more traditional approach, is establishment of brushlands, which is often the transition of between grassland and forest. At this point in time, brushlands will likely be the preferred direction because of reclamation permit requirements to re-forest stockpile terraces.

In 2004 small experimental plots of red pine, (Pinus resinosa); larch, (Larix laricinia); blue spruce (Picea parryana); white spruce (Picea glauca); white pine (Pinus strobus); paper birch, (Betula papyifera); silver birch (Betula sp.) and willows (Salix sp.) were planted in residuals.

Fertilization

Paper mill residuals function initially as a nitrogen sink during the early stages of organic matter decomposition, due to the high C/N ratio, which results in nitrogen immobilization. When this occurs the nitrogen concentration of the residuals is insufficient to meet the demands of the soil microbial community and results in reduced growth from the nitrogen deficiencies (Shimek 2004). The immobilization period can vary and be unpredictable. CMMC practices three strategies to overcome nitrogen immobilization.

- Applying and spreading residuals 6-12 months in advance of planting activity reducing the C/N ratio to the point that immobilization is significantly reduced.
- Using a nitrogen supplement at planting to satisfy microbial demand for nitrogen to decompose the sludge.
- Planting grass mixes with legumes so that residual nitrogen demand is reduced.

Spreading the residuals 6-12 months in advance of planting not only reduces the C/N ratio, but also reduces odors created by anaerobic degradation when stockpiled residuals are allowed sit for lengthy periods of time. With a short growing season, site amelioration includes the supplemental application of NPK fertilizers during hydro seeding. The fertilizer provides an initial boost of nitrogen to offset early nitrogen immobilization in the residuals and provides needed phosphorus and potassium. For the first field season one application of 57 lbs. of N per acre was used on MeadWestvaco residuals. International Paper residuals with a higher C/N ratio received 120 lbs. of N per acre. Due to the short growing season successive or staged applications were not considered in 2004.

A well-planned fertilization program is essential for successful vegetation. Refertilization to supplement the initial base application will be done as needed to improve vigor and density. After 3-5 years it is anticipated that plantings on residuals will reduce their reliance on commercial fertilizers. Fertilization recommendations are determined by plant tissue and residual fertility analyses performed by the AgSource Soil and Forage Laboratory in Bonduel, Wisconsin.

The nutritive regime of applied residuals gradually becomes depleted. The organic nitrogen and carbon decrease with mineralization of the cellulose-rich organic matter. Approximately 25 percent of the total nitrogen content of the residuals becomes available over the growing season. Generally, within three years the nutrients in the paper sludge are consumed. At that time it is anticipated that the vegetation will become self-sustaining, but may show signs of stress and be more vulnerable in drought conditions. For these reasons, additional residual applications by top-dressing are planned every third or fourth year to increase biomass and add nutrients.

Plant Tissue Analysis

Plant tissue and soil analyses have evolved as a diagnostic tool to determine the lack or excess of plant nutrients that may impact the plants establishment and productivity. By coupling paper mill residuals analytical data with plant tissue analyses a nutritional profile of the residual-plant system is developed that can be studied to monitor performance of nutrient cycling. Plants mine the residuals for nutrients and when the nutrients are depleted or unavailable growth may become restricted. One of the management objectives of this reclamation program is to develop an input/output balance resulting in a residual-plant nutrient equilibrium that sustains vegetation. Agronomic literature deals with natural soil agronomic plant systems. Performance of similar plants using residuals as a growth medium on rock stockpiles is unknown. A primary objective of data collection for this reclamation project is to develop recommendations to manage and establish vegetation on rock stockpiles and to establish a nutrient balance for selected grass and legume mixes.

Symptoms of nutrient deficiency are closely monitored during regular field evaluations, particularly during periods of insufficient rainfall and high temperatures. Annual monitoring of each residual reclamation site is conducted to verify the agronomic aspects of the residuals management program. The monitoring and sampling program confirms fertilizer requirements and adjusts the timing of applications, if necessary. The monitoring program includes annual in-season agronomic assessments of plant nutrients by plant tissue analyses. Both the Sufficiency Range System and the DRIS Index (Diagnosis Recommendation Integrated System) are used because each has their strengths and weaknesses (Agvise 2004). Used together they provide a more complete picture. Final vegetation plans are modified over several growing seasons based on these observations. Primary macronutrients monitored include nitrogen, phosphorus, potassium, calcium, magnesium and sulfur. Micronutrients monitored include manganese, iron, zinc, aluminum, copper, sodium and boron. Vegetation on each site is sampled for each of the first three years. First year results show adequate nitrogen and slight deficiencies in potassium and phosphorus.

The residuals have a CEC several times that of the local sandy glacial till indicating a greater ability to provide nutrients for plant use (Table 6).

Table 6 Cation Exchange Capacity of Glacial Till and Paper Residues

CEC – Cation Exchange Capacity			
	Glacial Till	MeadWestvaco	Int’l Paper
Organics	7	28	34

Quality Assurance Monitoring

CMMC conducts annual quality assurance monitoring of the residuals from each mill for the MDEQ. Grab samples are taken regularly from delivered loads of residuals and stored in a cool refrigerator at a temperature of 4 degrees C. From these an annual composite sample is tested for the Michigan Ten Metals monitoring for toxicants, solids and nutrients. The paper mills also collect residual samples for analyses and submission to MDEQ. Items tested for include arsenic, aluminum, barium, boron, cadmium, chromium, copper, lead, mercury, molybdenum, selenium, silver, zinc, nickel, dry solids (%), total Kjeldahl nitrogen as N (%), total phosphorus as P (%), total potassium as K (%), ammonia nitrogen as N (%), nitrate nitrogen as N (%) and TOC.

Water Quality Monitoring

Monthly surface water quality monitoring is conducted at all locations where runoff and or infiltration from stockpiles with residual applications occur and made available to MDEQ. Baseline data is collected for 8-12 months before residual applications. Each sample is tested for the twenty-two parameters: PH, temperature, dissolved oxygen, conductivity, hardness, nitrate, total Kjeldahl nitrogen, phosphorus, ammonia, arsenic, barium, cadmium, chromium, copper, lead, mercury, selenium, silver, zinc, sulfate, total manganese and total iron.

Summary

Cliffs Michigan Mining Company's waste rock stockpile residual reclamation program is evolutionary in nature with numerous field trials, studies, data collection and monitoring over numerous seasons. Interpretation of data collected over time will guide decisions with respect to residual application rates, reclamation plant species selection, planting patterns, usage of fertilizers, and other reclamation aspects. Individual residual and plant species characteristics, seasonal variability, insects and disease and variability of the rock stockpile surfaces can make it difficult for absolute interpretations. Valuable data is being collected with respect to how vegetation is responding to this newly created "growth medium" and this will eventually lead from research to standardized reclamation procedures.

Some areas to be investigated in 2005 include:

- Work with a well drilling company to develop a pilot plant utilizing pumping technology to repulp the residuals and spray them on steep stockpile slopes resulting in more complete coverage and deeper penetration of the rock surface, providing for deeper root penetration while creating a wicking effect for capillarity to bring moisture to the slope surface.
- Work with a contractor using a Brillion 12-foot wide tractor pulled agricultural grass seeder and packer, covering seeds with ½" of residuals, resulting in reduced seed requirements, improved seed/ground contact and elimination of mulch and tacking agents.
- Work with International Paper's Environmental Department and the MDEQ to determine the practicality of using paper mill wood ash, another paper mill waste, as an amendment to the residuals on reclamation sites.

For over forty years Cliffs Michigan Mining Company has produced high quality iron ore pellets that have become fine steel products for families, businesses, agriculture, transportation and national defense. Cliffs Michigan Mining Company has a proven commitment of maintaining the high quality of northern Michigan's environment.

Fig. 1 Spread and Disked Residuals on Top Surface, June 2004

Fig. 2 Vegetative Success, September 2004

Literature Cited

Agvise Laboratories. 2004. p. 2 Interpreting Plant Tissue Analysis Reports.

Barnes, B.V. and W.H. Wagner. 2004. Michigan Trees. University of Michigan Press.

Bohnet. E.L. and L. Kunze. 1990. p. 485-494. Waste disposal – planning and environmental protection aspects. Surface Mining. Society for Mining, Metallurgy, and Exploration, Inc.

National Weather Service. Marquette, Michigan Office. 2005.

Ovanic, C. E. 1996. p. 12-41 Summary of 25 years of reclamation research on Cleveland Cliffs mine wastes. Michigan Technological University Forestry Department.

Shetron, S.G. and C.E. Ovanic. 1995. Succession of plant communities on reclaimed iron tailings in northern Michigan. Proceedings 1995 American Society for Surface Mining and Reclamation Conference. https://doi.org/10.21000/JASMR95010708

Shetron, S.G. 1982. Cleveland-Cliffs mine waste reclamation guide, Marquette Iron Range properties.

Shimek, S. et al. 1988. p. 1-7 Paper sludge land application studies for three Wisconsin mills. The Technical Association of the Pulp and Paper Industry. V71 pp.101-107.

Shimek, S. J. 1999. Land Application of Sludge Field Plot Study, p. 1 MeadWestvaco Corporation, Mead Publishing Division.

Shimek, S.J. 2004. p. 1-4. Evaluation of paper mill residuals for supportive cover on mine waste rock stockpiles.

Sommers, L.M. 1978. Atlas of Michigan. p. 14-39. Department of Geography, Michigan State University Press.

Vance, E. 2000. Utilizing paper mill by-products as forest soil amendments: forest responses, recommendations, and industry case studies. p. 1-16. NCASI Technical Bulletin No. 798

Wolterson, E. 2004. Pulp mill residuals as soil amendments: the effects on soils. p. 16-17. *In:* British Columbia Reclamation.