RECLAMATION OF KYANITE MINE TAILINGS WITH SURFACE RECONFIGURATION[1]

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Abstract: As part of the processing of kyanite from a pyritiferrous quartzite-kyanite ore body in Georgia, several tailings ponds were created; the largest of which was 77 acres. The acidic tailings interstitial water (pH < 2.7), coupled with the acid producing nature of the tailings, hampered reclamation efforts. A technique which has been recently developed, deals with the configuration of the surface of the tailings ponds into a series of ridges and furrows which creates a surface that provides for the successful establishment of vegetation. The first year of a test plot study, consisting of six plots 50' X 100' each, with various ridge orientations, soil amendments and treatments, demonstrated that using a plow to generate a surface ridge and furrow topography served to divert surface runoff into vertical infiltration. Initially, six inches of straw was incorporated into the top one foot of tailings and lime was applied at rates of 40 to 60 tons/acre. Ridges, approximately 1.5 ft. high and 2.5 ft. in diameter with corresponding sized furrows, were installed by lightweight farm equipment. The function of the reconfiguration was to allow for ponding of rain water within the furrow and the leaching of acidity from the ridges. The ridges and furrows were further amended by 600 #/acre of 10-10-10 fertilizer and seeded with an eleven seed mix. Lime and fertilizer have been reapplied during the last two seasons and vegetation has been successfully (>90%) established for three years. The study showed that the surface reconfiguration technique can be used to reclaim an acid producing tailings pond as indicated by: 1) the growth of the planted species, 2) the intrusion of volunteer species, 3) an increase in the pH of the runoff water (pH 5.5-7.5) and 4) a decrease in the surface water discharge due to increased evapotranspiration. These factors are integrated into an extended study.

Additional Key Word: Acid mine drainage, Acid rock drainage

Introduction

A pyritiferrous quartzite-kyanite ore body at the Graves Mountain site in Lincoln County, Georgia, was mined from the early 1960's through the mid-1980's for kyanite and, at times, pyrite (Cook, 1985; Hartley, 1976). The processing entailed blasting, crushing and further wet-crushing the ore to a minus 28 mesh size. The minerals were separated from the slurry by flotation and the waste minerals, including quartz, micas, pyrophyllite, lazulite, rutile, ilmenite, geothite, hematite and often pyrite, were pumped to several tailings ponds. The largest and most recent tailings pond is approximately 77 acres and referred to as the East Tailings Pond (ETP). The acidic interstitial water, coupled with the acid producing nature of the tailings hampered previous reclamation attempts of the tailings ponds. Other researchers evaluating tailings pond reclamation have suggested the use of a cap or cover material (Peters, 1989) or pre-treatment of the tailings for several years (Nawrot,et al, 1997). This paper demonstrates the effectiveness of a new technique used to reclaim the surface of a tailings pond without the addition of a cap material and during which seeding is accomplished in the first year.

The tailings pond (ETP) has a sandy loam texture of quartz, silt, clay and

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approximately 2% pyrite. The operation ceased mining in the mid 1980's and the tailing pond had not been successfully reclaimed. Attempts had been made to vegetate two smaller and upper ponds; one of which, even with a cap of native soil, did not have plant survival into the second year of growth. The other, which had a higher percentage of sand size particles (approximately 90% sand) had sparse weeping lovegrass (Eragrostis curvula) clusters.

Methodology: Trial and Test Plots

Studies at the ETP site were begun in the spring of 1994. Tailings samples were collected for analysis of pH, specific conductance, acidity and water content. The tailings had a paste pH which varied from 2.75 to 3.2 and had a high specific conductance (ranging from 1500 to 3000 µS). Kinetic leaching studies (Bradham and Caruccio, 1995) of collected samples indicated that most of the acidity was contained in the interstitial water and that the tailings produced only minor amounts of acidity (on the order of less than 0.15 mg/g tailings/wk after 80 days). The sandy loam texture (75-80% fine to very fine sand, 8-13% silt and 10% clay) and the slurry pipe distribution of tailings during the ore processing, provided for variations in the moisture/water content of the tailings. The driest and most coarse material was in the northern portion of the pond while the most moist and often thixotropic conditions, coupled with a higher percentage of silt and clay sized particles, occurred in the southern portion of the pond. The average water content from three locations with samples collected at one foot intervals to a depth of five feet varied from 29.3% (Ww/Ws) from the 2-3' depth to 39.9% from the 4-5' increment. Overall, the average water content was 34.5% with a range of variation from 9.0% to 42.3%.

The infiltration rate of the ETP surface material was also evaluated by installing five cased holes on the surface of the pond, saturating the material and measuring the rate of water drawdown in the holes. Infiltration rates varied from 1" to 2"/hr (2.5-5 cm/hr) at the surface. The tailings are thixotropic, especially in the southern and western portions of the ETP, and do not freely drain. Water table elevation data was variable, but varied from several feet in the northern end to zero (water at the surface) at the southern dam. At least half of the pond had a water table within 6-8 " of the surface.

Therefore, to provide a surface environment conducive to reclamation, it was necessary to 1) decrease the acid level of the near surface material, 2) allow for greater infiltration rates to flush out the acidity and 3) enhance surface water run off quality during periods of rainfall. The technique, which was proposed for this reclamation effort, was a Ridge and Furrow configuration of the surface .

Field trials in the 1970's by Charles Riley , Ohio (1979) suggested that abandoned surface coal mines with ridges of acidic spoil from dragline operations, could be successfully reclaimed as a result of the preferential leaching on the ridge slopes. Expanding upon this concept and incorporating other principals, the ridge and furrow configuration was applied at the ETP site. Ridges approximately 30" (75 cm) wide and 18" (45 cm) tall with corresponding sized furrows or troughs were constructed and would provide the following benefits. First, the ridges would allow for the enhanced leaching of acid material to provide a medium with a lower acid load. Second, the freshwater rainfall with a low conductivity (approximately 10-20 uS) was less dense than the acid water and, according to the Guyben-Herzberg principle, the rain would float on the much higher density acid waters in the troughs. The rain water provided an environment that would eventually displace the acidic water and create a freshwater source in the furrows.

Another consideration in the construction of the ridges was to minimize the wicking effect, caused by capillary action of acidic interstitial water during the drier times of the year being drawn closer to the surface. The surface configuration in conjunction with a thick (6") mulch layer incorporated into the tailing surface, would impede the capillary connection and decrease the potential for wicking.

To field test the efficacy of the ridge and furrow method as a means of enhancing the tailings ponds surfaces for plant growth, four trial plot areas were delineated. The trial plots were 50 feet long separated by 15 feet of undisturbed material and about 6 furrows wide. The crests of the furrows were about 30 inches (76 cm) apart and 12 to 18 inches (30-45 cm) deep, the details of which are presented in Figure 1. Two plots were installed on the ETP, and one in each of the two West Tailings Ponds (WTP-1, WTP-2). The ridge and furrow configuration improves the pond surfaces by two mechanisms. First, the rain water, being less than the density of the acidic interstitial waters of the tailings ponds, collects in the furrow and floats, thereby generating pockets of fresh water within the furrows to sustain plant growth. Secondly, the flushing of the ridges by rainfall, tends to flush the residual acidity from pore spaces within the ridges and provide a substrate which is less acidic and which, when combined with a comprehensive reclamation plan, provides for improved plant growth.

The trial plots were constructed in late September, 1994. Samples of the surface material from each of the trial plots was collected and analyzed for paste pH. The paste pH values from the samples collected from the West Tailings Pond #1 (WTP-1) varied from 5.65 to 6.75 and the specific conductance values were low (less than 100 uS). Samples collected from the remaining three trial plots were more acidic. The paste pH of samples from West Tailings Pond #2 (WTP-2) varied from 3.2 to 4.9, while those collected from the East Tailings Pond (ETP) had paste pH values which varied from 2.75 to 3.10 with much higher specific conductivity (on the order of 1500 to 3000 uS).

The trial plots were allowed to weather during several rainfall events and samples were collected in late December 1994. The results of these tests indicated that the ridges were being leached of their residual acidity as shown by higher pH values and lower specific conductance values from the samples collected from the ridges than from the furrows. Additional samples were collected from the trial sites and analyzed for their soil properties. These tests showed very low average base saturation (4%), low average cation exchange capacity (8%), and low average selected minerals (P=5, K=5, Ca=75, and Mg=16 lbs/ac).

The preferential leaching of acidic material from the ridges was visually apparent in the spring of 1995. Volunteer vegetation began growing along the ridges of the trial plots in both the WTP-1 and WTP-2. In the ETP, no volunteer growth occurred; most likely due to the lack of a seed source, nutrients and the still low pH values. However, the improvement in the tailing surface material in the ridges, as shown by both the increase in pH and volunteer vegetation in WTP-1 and WTP-2, strongly suggested that the ridge and furrow methodology would be beneficial to the reclamation plan.

Based on the success of the trial plots, a reclamation plan for vegetation test plots was developed and the test plots were constructed in the spring of 1995. The reclamation plan included the use of the ridge and furrow technique in conjunction with a method including: lime and fertilizer application; the incorporation of mulch to provide an organic substrate and to help reduce the wicking effect; a mix of seeds suited for the soils and climate; and a surface cover with a straw and tackifier to improve moisture retention, shade for the seeds, and reduce wind erosion.

Six test plots were surveyed in the ETP and numbered consecutively beginning with #1 nearest the dam and moving in a north/north easterly direction and are shown in Figure 2. Each test plot was 50 feet (15.2 m) wide by 100 feet (30 m) long and separated by 10 feet (3 m) of control. Variables were randomly assigned to each plot as noted in Table 1.

Table 1. East Tailings Pond Test Plot Variables

Test Plot #	Lime Rate	Ridge Direction	Incorporated Mulch
1	20 t/ac	parallel	none
2	20 t/ac + quicklime @ 0.5 t/ac	parallel	straw
3	20 t/ac	perpendicular	PFP
4	40 t/ac	perpendicular	straw
5	40 t/ac	parallel	none
6	40 t/ac	perpendicular	PFP

"Ridge direction" refers to the orientation of the ridge and furrows with the reference direction as the southern portion of the tailings pond dam (i.e., parallel or perpendicular to the dam in the vicinity of Plot #1). Winds blowing across the open and unreclaimed 77-acre pond often carried significant amounts of tailings material. To determine whether the wind-borne tailings would have an impact on seed retention and therefore, reclamation success, the ridge directions were varied as parallel or perpendicular to the normal wind direction (generally northwest to southeast) which equates to generally perpendicular with the dam. Agricultural lime was spread at the specified rate and disked into the top 8-12." The lime not only affords neutralization of the acidity, but also assists in detoxifying the metals, especially copper (McHale and Winterhalder, 1996). Quicklime was added to Plot 2 at 0.5 tons/acre in addition to the agricultural lime and disked into the tailings. Previous studies (Rich and Hutchinson, 1994) suggested that the quicklime may increase the stability of the tailings pond. A 10-10-10 fertilizer was then applied to all the plots at a rate of 600#/acre and incorporated into the tailings. "Incorporated mulch" refers to the mulch material subsequently cut and plowed (12-15" deep) into the tailings pond surface. A 6" (15cm) layer of wheat straw was cut and harrowed into plots #2 and #5 and a 6" (or 120 tons/acre) layer of PFP (a recylced paper fiber product available from HWV, Inc., Appling, GA) was disked into plots #3 and #6. All six plots had a final surface treatment including: seed mix (Table 2); covering seed with slight soil cover by dragging the surface with a chain; and applying a final surface treatment of straw (100 bales/acre) and asphalt tackifier to minimize soil moisture loss and wind erosion effects.

Table 2. Plant Species and Seeding Rates

Plant Species	Seeding Rate pounds/acre
Common Bermudagrass (Cynodon dactylon)	20
Carpet grass (Axonopus compressus)	15
Clovers (Trifolium spp.)	10
Deertongue (Panicum clandestinum)	15
Sericea lespedeza (Lespedeza cuneata)	15
Weeping lovegrass (Eragrostos curvula)	5
Foxtail Millett (Setaria italica)	30
Japanese Millet (Echinochloa crusgalli)	30
Pearl Millet (Pennisetum glaucum)	25
Rescuegrass (Bromus catharticus)	25
Sorghum (Sorghum bicolor)	20

The results of the test plots can be seen in Figure 3. Good growth occurred in Plots #1, 2, 4, and 5, although some areas of each plot had more profuse vegetation. Soil samples were collected from the plots in July 1995 and analyzed for pH and other selected chemical properties to determine the reason for better growth in some areas. The results are provided in Table 3, but generally indicate an improvement in all soil characteristics. The highest nutrient content and average soil paste pH of the plots with vegetation occurred in Plot 4 which had 6 inches of straw incorporated into the tailings with 40 t/ac of lime applied. Although the visible growth in Plots 4 and 5 was not significantly different during Year 1, based on the analyses, it was determined that the incorporation of straw into the tailings to a depth of 6-12 inches was beneficial to sustained growth.

The results also show that the samples collected from the ridges generally have a higher pH than from the furrows. The results, however, provide no indication for the lack of growth in plots #3 and #6. However, observation of the soil moisture content suggests that the PFP product dried very quickly leaving little soil moisture for the plants. PFP used on other sites had shown good growth, but it was usually mixed with sewage sludge. Also noteworthy is that even though samples were collected from areas with either profuse (>90%) vegetation or sparse (<25%) vegetation, there were few chemical differences and in the second growing season, Plots #1, 2, 4, and 5 exhibited similar growth of >90% cover. Figure 4.

Site Reclamation

During the Spring of 1996, the remaining 76 acres of the ETP was reclaimed using the treatments similar to test plot #4. Using small farm equipment (due to the thixotropic nature of the tailings), straw was spread at a rate of 400 bales per

Table 3. Selected Chemical Properties from Vegetation Test Plots

Sample[1]	pH	Phosphorus	Potassium	Calcium	Magnesium	Cation Exchange Capacity	Base Saturation
		------lbs/ac*------				cmol (+)/kg	%
1-P-T	5.0	26	24	1410	880	11	65
1-P-R	6.6	28	31	1390	1069	8	100
1-S-T	5.1	22	35	510	265	6	39
1-S-R	6.5	19	34	1230	620	7	88
2-P-T	6.8	57	56	2080	1132	10	100
2-P-R	7.2	35	85	2350	884	10	100
2-S-T	7.4	27	134	2030	835	9	100
2-S-R	7.5	29	122	2540	943	10	100
3-T	7.8	35	126	4350	519	13	99
3-R	7.9	31	82	13650	226	35	100
4-P-T	7.6	40	22	4720	1644	19	100
4-P-R	7.8	25	101	3940	1568	17	100
4-S-T	7.9	18	92	3390	1409	14	100
4-S-R	7.8	19	76	4780	1628	19	100
5-P-T	7.5	27	37	3230	1345	14	100
5-P-R	7.6	24	43	3150	1403	14	99
5-S-T	7.5	27	71	2330	1130	11	100
5-S-R	7.6	27	74	3180	1323	14	100
6-T	8.0	46	141	9470	1003	28	100
6-T1	7.9	55	137	8210	991	25	100
6-R	8.0	32	64	11620	1049	34	100

[1]Number refers to vegetation plot number.
P or S means profuse or sparse vegetation.
R or T means ridge or trough sampling location.
6-T1 was trough, towards #5.

acres (6 inches thick) and lime was spread at a rate of 40 tons/acre. This mixture was disked into the top 12 inches (30cm) of tailings. Nineteen samples were collected and tested for paste pH, conductivity and net acidity. These indicated that in certain areas, 40 tons per acre was not sufficient to raise the pH above 4 and therefore, 20 additional tons/acre of lime were added to that portion of the ETP and disked into the tailings.

Subsequently, the ridge and furrows were constructed by plowing the ETP with a small tractor with a modified plow implement which constructed the ridges and furrows of appropriate size. Due to the nature of the tailings, the tractor on occasion had to be removed from the tailings with a series of winches and vehicles. Once the surface topography had been modified with the ridges and furrows, the construction effort would have been destroyed if the seed and fertilizer were applied by ground vehicles. Therefore, the seed and fertilizer were applied by a modified crop dusting airplane. The straw and tackifier, which could be spread from a distance from the vehicle, was applied by surface application. The Year 1 reclamation effort of the ETP was completed by June, 1996, and within several weeks, vegetation was established. Figure 5. Additionally, the pH of the runoff water from the site improved from pH 2.7 near the south dam prior to reclamation to pH 6.7 within 9 months after completion of the reclamation.

Meanwhile, the test plots continued to be monitored and during 1996 (Year 2 of the test plots), an additional 10 tons/acre of lime was added and the vegetation thrived especially in plots #4 and 5, but dense vegetation also grew in plots #1 and 2.

The reclamation plan for the entire ETP provided for the addition of lime and fertilizer for at least three years. During the winter/spring of 1997 (the end of Year 1) vegetation in a crescent shaped area in the center of the tailings pond experienced stressed and loss of vegetation. Analysis of the water quality in the troughs and paste pH's of soil in the ridges, indicated low pH values and high acidity and specific conductance in this area. Significantly, even though the pH was too low to sustain vegetation, the pH from samples taken from the top of the ridges was higher than the pH in the furrow. Table 4. Therefore, in the Spring of 1997, the entire ETP was scheduled for an additional 10 tons/acre of lime and 400 #/acre of 10-10-10 fertilizer, but the crescent shaped area was to receive an additional 30 tons/acre lime (40 tons/ac. total) and additional seed.

Table 4. pH and Specific Conductance (SC) data from the Crescent Area of the ETP, 4 February 1997.

Sample	pH	SC (uS)	Vegetation**
1-R*	6.20	768	G
2-T*	2.95	4750	P/G
3-R	5.95	825	P/G
4-T	2.65	4600	P
5-R	6.00	2400	P
6-T	2.70	4230	N
7-R	5.20	2650	N
8-T	2.75	4520	N
9-R	5.10	3250	N
10-T	3.20	3570	N
11-T	2.20	5200	N
12-R	2.40	4030	N
13-T	2.25	4610	N
14 to 19:	2.0-2.45	~4800	N

*R=Ridge, T=Trough
** G= Good vegetation, P=Poor, N=No vegetation

To accomplish the liming, required a new methodology. Surface spreading would destroy the ridge and furrows and application of a lime slurry would also require disturbance of the ridges. Therefore, the limestone was applied by airplane. An airstrip was constructed less than three miles from the site so that the numerous trips could be accomplished in a reasonable time frame. During the summer of 1997, greater than 50% of the site had 100% vegetative cover, 30% had approximately 75% cover and the crescent area (with <10% cover) decreased in areal extent from 30 to 20% for the ETP. Additional lime and fertilizer applications during 1998, improved the overall growth rate and the crescent continued to decrease.

In addition to the vegetative cover which was established and which also has a strong growth for 1999, other positive aspects of the reclamation include a decrease in the channelization of stormwater runoff, and an increase in the surface water run off pH. Prior to reclamation, the stormwater would create channels and erode the surface, exposing additional tailings. In addition, during rainfall events, the near surface water table would rise and acidic ground water seeps would emanate from the tailings, the location of which corresponded with the crescent shaped area in the center of the pond. As a result of the surface reconfiguration, the flow is no longer channelized and eroding the surface, rather most of the rainfall is contained in the troughs and is converted to infiltration for plant uptake. The water quality in the troughs continues to improve and where the runoff does accumulate in the southwestern area of the ETP, the surface water pH is consistently between pH 6 and 8. It is further suggested, based on the decreased flow from the ETP to the treatment pond, that the overall water table of the ETP has been lowered due to the increased evapotranspiration.

Conclusions

The reconfiguration of the surface of the tailings ponds by the newly developed ridge and furrow technique provided an environment which provided for the leaching of acidity from the ridges to enhance growth, allowed increased infiltration of rainwater into the troughs and, when integrated with an overall reclamation plan of soil amendments, seeding and mulching, successfully reclaimed the site.

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References

Bradham, W. and F.T. Caruccio, 1995. Sensitivity Analysis of Laboratory Based Mine Overburden Analytical Techniques for the Prediction of Acidic Mine Drainage. Pittsburgh, PA: DOI/Office of Surface Mining, GR 196451. p.258.

Cook, R. B., Jr., 1985. The Mineralogy of Graves Mountain, Lincoln County, GA. The Mineralogical Record, Vol.16, no.6, pp. 443-458.

Hartley, M.E.,III, 1976. Graves Mountain. Georgia Geological Society, Field Trip Guidebook, Vol 16, Pp. 42-52.

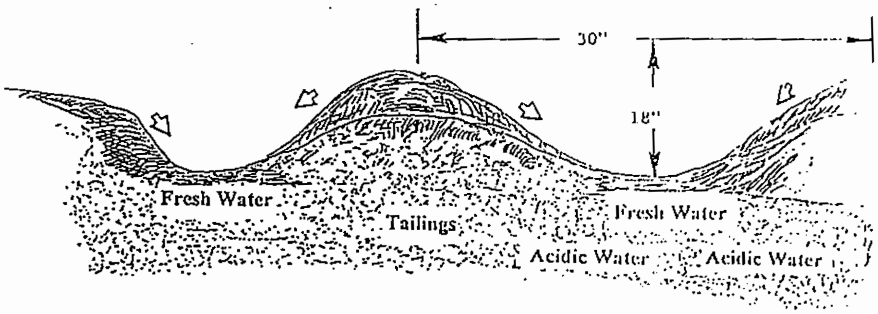
McHale, D and K. Winterhalder, 1996. The Relative Merits of Dolomitic and Calcitic Limestone in Detoxifying and Revegetating Acidic, Nickel- and Copper-Contaminated Soils in the Sudbury Mining and Smelting Region of Canada. In Daniels, Burger and Zipper (eds), 1996 Nat. Meeting of the Am. Soc. for Surface Mining and Reclamation, Knoxville, TN, May 18-23, 1996. Virginia Tech Reserch Division, Powell River Project, Blacksburg, VA, USA. Pp. 504-515.
https://doi.org/10.21000/JASMR96010504

Nawrot, J.R., V.A. Skeel, B. Gray and R. Newton. 1997. Warm Season Grass Establishment on Limestone-Amended Coal Slurry. In Brant, Jon E. (ed), 1997 Nat. Meeting of the Am. Soc. for Surface Mining and Reclamation, Austin, TX, May 10-15, 1997. Pp. 82-89.
https://doi.org/10.21000/JASMR97010082

Peters, T.H., 1989. Overview of Tailings Reclamation in Eastern Canada. Proceedings of the conference "Reclamation, A Global Perspective," Calgary, Alberta, Aug. 27-31, 1989. Ed. Walker, Powter, and Pole. Alberta Land conservation and Reclamation council Report #RRTAC 89-2. 2 Vols. Pp. 695-706.
https://doi.org/10.21000/JASMR89020695

Rich, D. H. and K.R. Hutchinson, 1994. Coal Refuse disposal using Engineering Design and Lime Chemistry. In proceedings of International Land Recl. and Mine Drainage Conf. and 3rd Int'l Conf. On the Abatement of Acid Drainage. Pittsburgh, PA, April 24-29, 1994. Pp. 392-399.
https://doi.org/10.21000/JASMR94010392

Riley, Charles, 1979. Personal communication.



The surface configuration of a scarified pond surface will encourage rainfall to accumulate in the furrows. The less dense rain water should establish pockets of fresh water that float within the acidic matrix. Through time the ridges become purged of acidity and fresh water zones become established.

Figure 1. Details of Ridge and Furrow Technique

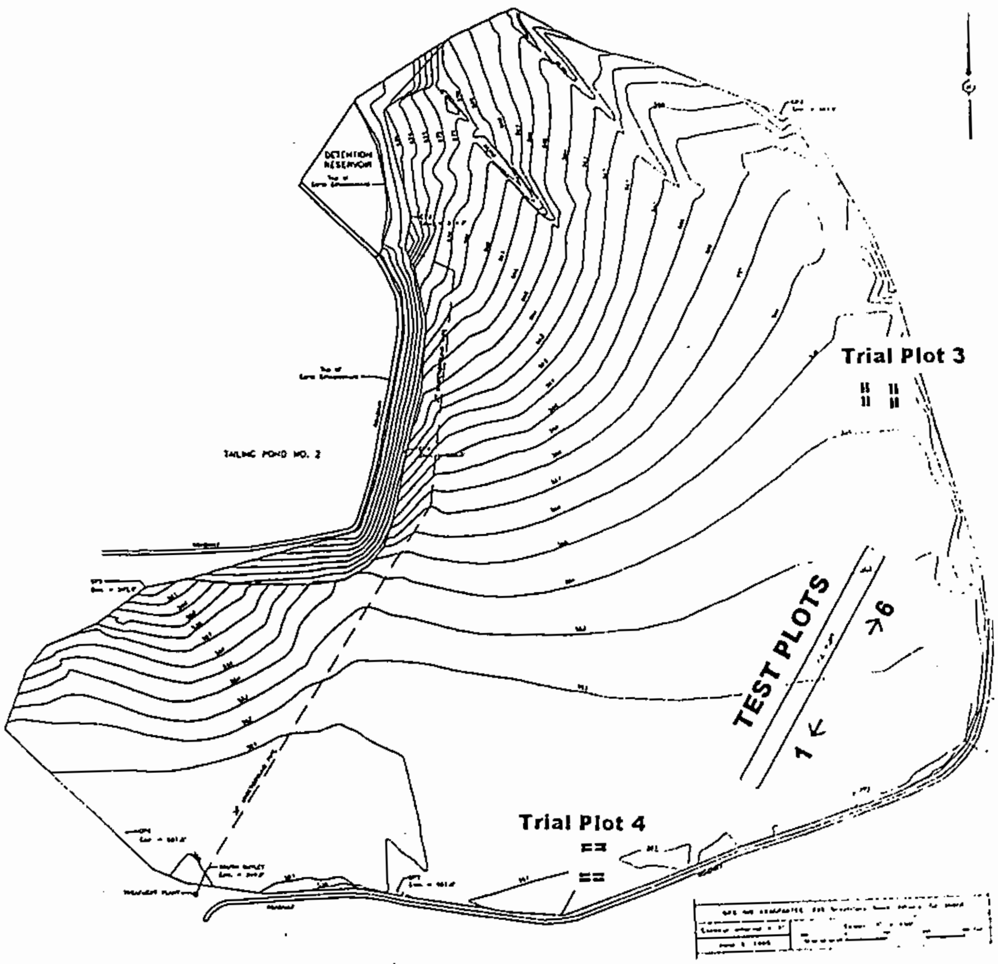


Figure 2.
Topographic Map of the East Tailings Pond
Graves Mountain, GA

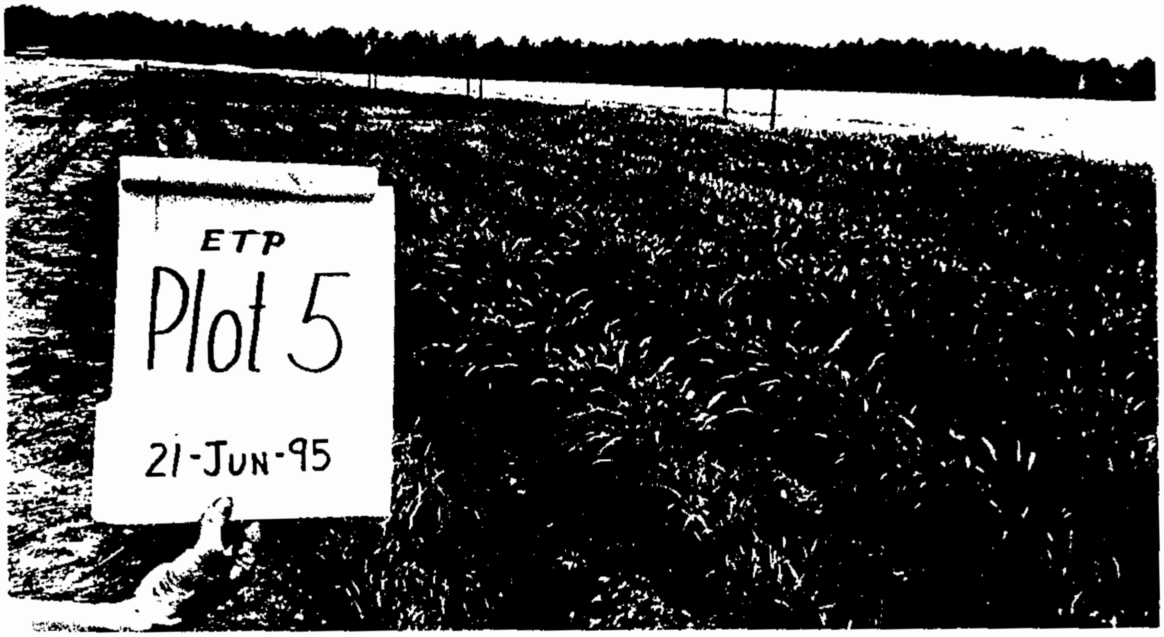


Figure 3. Test Plot #5, looking south to Plots #4 to 1, June 1995.

Figure 4. East Tailings Pond reclamation, looking north from plots August, 1996

Close up of second year growth of
ETP test plots - 8/24/96

Figure 5. Test Plot #4 reclamation, Year 2. East Tailing Pond reclamation Year 1, August 1996.