Phosphate Mine Reclamation in Tennessee

E. J. Griffith and H. N. Lyles[1]

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Abstract-Throughout the life of the Columbia Tennessee Elemental Phosphorus Plant, it was necessary to beneficiate our phosphate ore by washing illite clay from the ore. The clay was delivered as a 4% slurry to large tailings ponds where the solids were settled and de-watered. The largest tailings pond (number 15) was almost 200 feet deep in settled clay and over 400 acres at the surface. When settled and drained, the clay in the ponds have a consistency similar to mayonnaise, but dry to a solid cracked crust on the surface, causing them to appear deceitfully safe. This is particularly true after scrub vegetation covered the surface of an abandoned mud flat. After a few years, men can usually be supported by the dried crust of an abandoned tailings pond, but machinery can break through the crust and sink into the soggy slimes below.

Settled waterlogged clays are thixotropic and can easily be liquefied when suddenly stressed. In the event of a dam failure, this could result in a dangerous undesirable event. To render our effete tailings pond system safe and environmentally pleasing, an asset to the state of Tennessee, the decision was made to plant the pond surfaces with 3,500,000 cypress trees. This report is a history of the planting, care for, and maturing of Monsanto's Columbia Tennessee Cypress Garden. Some of our cypress trees are more than 55 feet tall in less than twenty years. A 1,350 year old Tennessee cypress tree grew to the amazing height of 175 feet, and is reported to be the largest tree east of the Mississippi River. Our best growth has been 2.75 feet per year. If the growth continued at this rate, the trees will be 175 tall in only 65 years.

INTRODUCTION

An article by George T. Wilson (1995) appeared in the July 1995 issue of The Tennessee Conservationist. It illustrates why we chose to plant 3,500,000 cypress trees to stabilize clays left in tailings ponds of the Columbia, Tennessee phosphorus plant, when the plant was decommissioned. The long term prospects of this project are exciting because the ponds have proved to be an ideal environment for the growth of huge cypress trees. The trees are already attracting considerable interest because our trees, supplied by the Tennessee Division Of Forestry, have performed magnificently.

Phosphate ore in Tennessee contains Illite clay. As much as 50% of the weight of the ore can be clay. The clay is encapsulated in very small sheaths of ferric hydroxide. Because the ferric hydroxide is undesirable in furnace operations the clay fraction was removed with either hydro separators or clones. In either case the clay was suspended as a 4% slurry while the phosphate ore was concentrated, processed, and fed to electric furnaces to manufacture elemental phosphorus, an important item of commerce.

Twenty years ago Columbia, Tennessee was the elemental phosphorus capitol of the world. As a result of environmental concerns no phosphorus has been produced in Tennessee since 1989 costing the state much revenue and hundreds of jobs.

The clay slurry in Tennessee ore had no known uses and created a huge disposal problem. The primary considerations in disposing of 20,000 gal/min. of a creamed coffee colored liquid was economics and safety. During peak productions periods as much as 90,000 dry net tons of tailings solids were processed each month. Without question, the most economical and safe solution to the problem was to pump the slurries into especially designed lakes called ponds. Lakes were formed by building earthen dams across mouths of valleys. As long as the ponds were small and relatively shallow it took little imagination to deactivate a tailings pond in a safe way. Trees and grass grow on the surface of shallow ponds and the vegetation stabilized soil. This is not the case when the lakes are large (400 acres) and very deep (200 feet).

The ore deposits formed along the shoreline of inland seas about two to three hundred million years ago. Much of the phosphate was contained in very small bones of creatures living and dying along the shores of the sea. Millions of these bones are found in the tailings solids, being too small to be captured during the separation of phosphate ore and clay. Illite clay mixed in these ore deposits by glacier action during the last ice age. The clay is believed to have come from Illinois from which it derived its name. It is an extremely fine colloidal clay and settles slowly to about twenty percent solids before it begins compression settling that can take many years to reach fifty percent solids.

Illite clay contains much potassium that is readily available for plant life by ion exchange. Trees planted in the clays have a large supply of phosphate from the very fine particles of bones found in the tailings. There is also a plentiful supply of water all year long. With these advantages there is every reason to believe that these trees will become outstanding examples of what can be done with otherwise unproductive land.

It is easily understood how a deep pond might require less initial investment than a large shallow pond. This is particularly true if the shallow pond is built on expensive farming land while the deep pond is built on a rocky hillside. The initial investments are less on the rocky hillside despite the fact that a larger dam is required to retain the settled solids. Too little thought was given to the ultimate reclamation of the pond sites when they were built. Before environmental concerns prohibitively increased the price of electricity and phosphate detergents were banned there was no reason to believe that the Tennessee phosphorus industry would not thrive throughout perpetuity. Conversely, much thought and effort was expended to be certain that the dams and ponds were safe and attractive (Griffith et al. 1992).

Very pure water is returned to the river from which it was taken, but deep ponds built on hillsides present two unique problems. Firstly, water must migrate through many feet of clay before it can be decanted to the river. Migration is a slow diffusional process. The denser settled clays become the slower the escape of water. A second problem is large ponds built on hillsides store enormous potential energy. These issues must be properly prosecuted when filled ponds are to be responsibly abandoned.

The natural process to stabilizes swamps is tree growth when the water becomes shallow enough to support rooted vegetation. All lakes begin to die from the moment of creation, with or without human intervention. They receive runoff silts from surrounding land to become a swamps and ultimately dry land. Deep rooted trees function to de-water deep soil while respirating deep water to the atmosphere. The root structure binds soil to the substrata below it. Cypress trees can drop deep tap roots and they thrive on marshy terrain. It was for this reason cypress was the tree of choice after experiments with pine, oak and other trees.

It was not known for certain that cypress would grow well in Tennessee tailings ponds. Many questions required answers:

How does one plant millions of trees on clay slimes that are too fluid to walk on?

What will be the survival rate of young trees in wet clay?

What will be the primary attacks on young trees?

How rapidly will cypress trees grow on a tailings pond when it is surface is dried and cracked?

On what centers should cypress trees be planted to assure a coverage sufficiently great to stability of a tailings swamp when the trees reach maturity?

How close to a dam can cypress trees be planted?

What will be the contour of a pond surface when it is drained as completely as it can be drained without allowing the drainage to become muddy as it returns to the river?

How much drainage is required?

How deep must a spillways be constructed to allow optimum drainage and safety?

How quickly will runoff silts fill low spots left in a planted pond?

Can cypress compete with vegetation such as grasses and willows?

What can be done to give the cypress trees an advantage?

EXPERIMENTAL

The cypress tree program at Columbia, Tennessee has been active for more than twenty years. The program can be divided into three parts. Firstly, determine what kind of trees should be chosen. Secondly, experiment with smaller ponds to determine if cypress is a good choice. Thirdly, initiate planting of 3,500,000 cypress trees on the drained ponds while correcting for any misconceptions arising from the earlier experiments.

It was not known which animal or diseases might attack the trees. One problem was soon noted. Grasses, weeds and willows grow more rapidly than cypress seedlings. But, cypress seedlings are capable of living under water for periods longer than grasses. To give cypress an advantage ponds were intentionally flooded and re-drain as necessary. This killed weeds and grasses, but not cypress seedlings unless they are submerged too long.

Most of the animals that were expected to attack the trees did not materialize. The only life form found to destroy the young seedlings are birds called coots (*Fulica Americana*). These birds pull the young trees from the soft clay and eat the tubers on their roots. This problem was solved with the help of the United States Department of Agriculture-Animal Damage Control Division. They arranged that guns be fired with blanks to frighten the birds away while the trees were small enough to be easily pulled from the soft clay. The Tennessee Division Of Forestry has also been very helpful with the cypress project and did much to make the project a success. We are indeed appreciative of their assistance.

A problem that was most feared during the early stages of the planting was that the grasses might become ignited in some way, either by lightning or by some careless person. It is doubtful that young trees can withstand a prairie fire and several years plantings can be lost. Flooding ponds did much to alleviate this danger.

If a relatively small shallow pond is drained the surface of the water logged mud will be more or less flat and the surface of the mud will slope downward toward the dam which is usually the deepest point in the pond. If most of the water can be drained the surface of the clay will slowly dry and shrink. This will cause the surface to become badly cracked and these cracks may extend several feet into the clay.

In time weathering and runoff debris will fill the cracks and the surface will become smooth and fast growing trees and grasses will cover the surface. While this is happening it would appear on casual observation that no additional changes are taking place in the pond. This is not the case. Muds in the lower regions of the pond continue to settle for many years. Water that was trapped in the mud migrates toward the surface while clay continues to contract and settle in the lower pond. The result is a sandwich ten or more feet thick, of very fluid tailings slurry, trapped between the upper crust and the lower condensed muds. This represents a dangerous condition in deep ponds. See Figure 1.

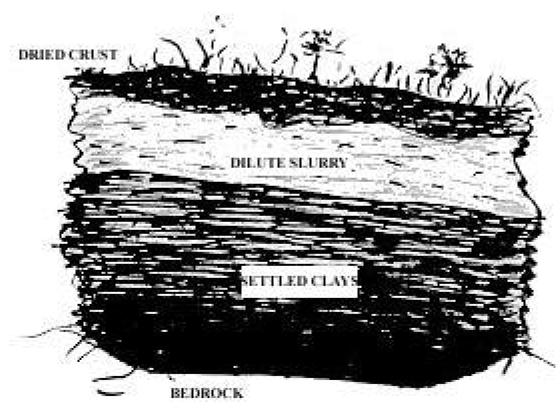

FIGURE 1.

It is possible for both men a equipment to fall though the dried crust of a pond and sink into the slimes below the surface. At Columbia Plant two separate events occurred to confirm this conclusion. In one case an operator drove a bulldozer on to an abandoned tailings pond that had been out of service for many years. The surface of the dried clays were not strong enough to support the weight of the heavy equipment. The bulldozer broke through the crust and was lost in the muds below. Fortunately no one was injured.

A worker collected a sample of the slurry where the bulldozer fell through the surface crust. It was discovered that the slurry contained only about 12% solids. A misunderstanding of the behavior of the system led to the belief that Illite tailings would not settle to more than 12% solids irrespective of the time given for them to settle and consolidate. This was later shown not to be the case. Many years may be required if the water must leave the clay by diffusing through many feet of clay, but there is no barrier to settling.

It can be seen in Figure 2. how the tap roots of large cypress trees can not only stabilize the pond solids but also eliminate the sandwiching behavior of the settling clays. This occurs because the trees remove water by respirating it from the dilute slurry between the crust and the settled clays as it attempts to form. In the case of No. 15 Pond the planting of the trees began before the crust ever had a chance to dry to any depth. The trees should prevent the dilute slurry from ever forming in the pond while the trees can drop a tap root quickly through the soft uniform clays below.

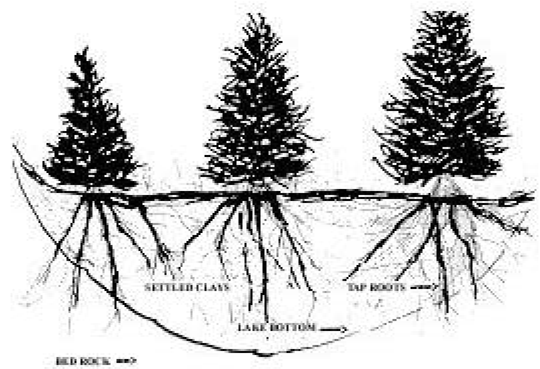

FIGURE 2.

DRAINING TAILINGS PONDS

The surface of a large drained tailings pond is not level and flat. Even when the clays were covered with water the mud surface varied many feet in elevation from one place in a pond to another. The high point in a pond is usually near the entry point where the tailings enter the pond depositing the courser fractions of solids, while the lowest point is usually at the farthest edges of the pond. Moreover when water is drained from a pond the muds in the pond have a tendency to slide toward the deepest part of the pond and will more or less follow the contour of the original bottom. The deepest point in the pond when the pond is constructed will also be the lowest elevation of the mud surface when the pond is drained, if the mud slides can occur. In very large ponds the distant shores may be far removed from the deepest point and distant mud shores may remain some deeper than the mud surface at the deepest original bottom of the pond.

PREPARING NO. 15 POND FOR PLANTING

Work with smaller ponds had shown that sliding could be significant in larger ponds and it was possible to destroy any young trees that had been planted before a slide took place. This behavior was also a problem in No.15 Pond during the years electroendosmosis was used to density the settled tailings. The three most important ponds in this work were No.7, No. 12, and No. 15 with Nos.12 and 15 requiring the most attention because of their dams and their elevation above the Duck River. No.9 Pond was included in the tree planting experiment to learn more about the behavior of trees in shallow ponds. Trees were not planted extensively in No. 11 Pond, but some were planted around the pond to give an idea of the rate of growth of trees that were not growing In tailings per se.

Mud slides in No.12 Pond had been intentionally caused during electroendosmosis testing and some slides were intentionally induces in No.15 pond when the pond was probed to release trapped water. Because of the size of No.15 it was allowed to lay idle for several years while the electroendosmosis unit continued to compact the bottom of the pond bring the denser muds closer and closer to the surface. When the electroendosmosis unit was decommissioned the dense bottom of the pond was determined to be no more than 90 feet from the surface at the deepest points. The depth was determined with the use of the pond probe to which was attached a mud thief. This depth and concentration is satisfactory for tree planting and roots should easily reach the dense compacted clays.

The first preparation for planting No.15 Pond was to dredge the pond to remove obvious high spots while filling low spots with the dredgings. The high areas were certain to give troubles when the ponds were drained. The second preparation was to drain the pond as completely as possible. Draining allowed slides to take place and gave an opportunity to observed trouble spots likely to be encountered during planting.

HISTORY

No. 15 Pond was first drained in 1989. Other ponds had been drained much earlier. Figures 3 shows the results of draining No. 15 Pond. It is also worth noting the nature of the clay as is freezes and thaws and dries. Judging from past experience, the concentration of the top lumps are about 30% solids or less. This is another example of the contraction of the clay as water is removed. It points up how much of the volume of an abandoned pond is occupied by water. Figures 4 and 5 show Ponds 15 and 12 before they were drained.

Figure 3. The behavior of drying clays in No. 15 Pond to prepare it for planting.

Figure 4. No. 15 Pond as an active mountain lake.

Figure 5. No 12 Pond as an active pond.

Figure 6 shows No.7 Pond after it was drained to plant trees in the lower end of the pond. Unfortunately the drain pipe for this pond collapsed when the pond was first filled and the drain was grouted closed with concrete. The original drain pipe can be seen as a light colored spot at the end of a short road on the far right side of the picture. This is a road leads from the road on top of the dam. The collapse of the drainage pipe required the construction of a deep drainage ditch to rid the pond of most of its water. This ditch can be seen as a straight line leading from the water's edge to near the top of the picture forming a "V" with the light colored road on top of the dam.

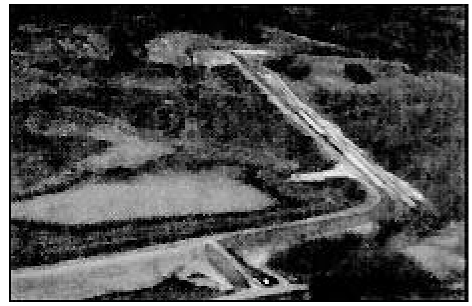

Figure 6. No. 7 Pond when it was drained for tree planting experiments. (Note: The large trees to be discussed later were planted on the drained part of No. 7 Pond far to the left of the picture.

Once a pond had been drained it was allowed to lie dormant for several months as water was collected on the surface as a result of the muds settling and squeezing water from below. Only runoff water could be used to refill a pond because the pumps which had been used to pump water to the ponds had been decommissioned.

Several attempts were made to find ways to plant trees on the sloppy quagmire. A hover craft-air suspension all terrain vehicle- was attempted, but it proved to be too unstable. It was finally decided that the only way that would be reasonable was to flood the pond and plant the trees from a boat. The level of water would be lowered to expose a few feet of clay surface around the edges of the pond during each years's planting. This caused the first trees to be planted where the sub-soil was close to the surface and the new trees should soon be tacking the clays to the bedrock below.

Planting generally started in winter after the pond level had risen far enough to allow planting to begin and the trees had become dormant. The first plantings from the boat was long and very slow. Later, two experienced workers on a fourteen foot Jon boat could plant about 3,000 seedlings per day. After the high survival rate had been established spacing was increased to four feet. The length of the shore line was several miles and trees were planted on one foot centers. This proved to be too close but there was no good way to determine how many trees would survive. It was much more economical to over plant that it would be to replant.

Each year as the previous year's plants became established planting moved toward the center of the pond. The first planting of No. 15 Pond began in the fall of 1989. As can be seen from the photographs most of the surface of No. 15 Pond has been covered by the summer of 1995. It was practice to keep the surface covered with as much water as possible. This was done to control weeds and grass. The fresh surface of the ponds were ideal seeding sites for all manner of trashy undergrowth. Willow trees being one of the more prolific spreaders. The Willow is a short lived, shallow rooted tree and is not desirable on deep muds where respiration from great depths is desired. For this reason it has been necessary to thin the

Willows from time to time to assist the cypress.

It should be noted from the photographs trees were intentionally **NOT** planted near dams. This would violate the Safe Dams Act. It is well known that tree roots are not desirable in dam structures. In the case of No. 15 Pond the trees were kept at least fifty feet from the shoreline of the dam. Not only does this protect the dams from invasion by tree roots it places the trees at the very deepest points along the pond side of the dam. The berm that is left at the foot of the dam functions as platform for work and observations of the conditions of the dam. Unfortunately, dams require constant attention and are very costly to maintain. This is a major reason all lakes were not left for recreational use. Those that were considered to be perpetually safe and visible from public roads were left for recreational areas, part of the Monsanto Ponds Wildlife Observation Area.

The ponds were beautiful fishing and boating lakes even when they were in full operation killing forever the myth that these tailings killed fish or destroyed their breeding sites.

Although it is a mute question, because the industry is gone forever, it is doubtful that Tennessee tailings ever did any harm to the river in any way. The river contains very large quantities of Illite clay as land runoff every time the river floods, which it does very often. Nevertheless, during the last thirty-five years not one case of river pollution attributable to our pond system was ever recorded. It is an excellent example of remedial responsibility and is a record Monsanto employees are justifiably proud!

Most of the photographs were taken of Nos. 15, 12, and 7. No.7 Pond was a large surfaced relatively shallow impoundment with a very steep dam. It is important because it was the first pond to receive experimental trees about 1975. It supports trees of all ages. No. 12 is important because it was a relatively small pond on a steep ridge. It was subject to mild sliding of the muds when drained and had some of the problems anticipated with No. 15 Pond. No. 12 Pond had also been the experimental pond for the demonstration of electroendosmosis which was to be used in No. 15 Pond (Griffith 1978). No. 15 Pond is important because it is the largest of all of the ponds and is also on a hillside. No. 15 Pond contains practically all of the plant's production from 1967 until the plant closed. Small quantities of tailings were pumped to the remainder of the system during the start up of No. 15 Pond. Nos. 12 and 15 were the ponds of greatest concern and were the primary reason the planting was undertaken.

Figure 7 shows trees planted in No.9 Pond. No.9 Pond is very small and shallow. Trees have grown well in this pond even though many were planted in water and remained in water. The progress of the growth can easily be seen in Figure 8 which is three years growth of the trees from Figure 7. Note the hill in the background for reference.

Figure 7. No. 9 Pond in the early days of planting in May 1992.

Figure 8 is almost the same picture of No.9 Pond as was Figure 7. Figure 8 vividly demonstrates what only three years growth can bring to the cypress tree sizes. The trees are perfo rming splendidly. It is expected that the shallow water in No.9 Pond will eventually be replaced with silt and that the cypress trees will seed new growth themselves. At this time there seems to be no need to either plant more trees or to thin those that are currently growing. The process should take cared of itself leaving a grove of cypress trees with perhaps a small stream through it for a few years. All water to this pond is run off from the surrounding land.

Figure 8. No. 9 Pond in May of 1995 three years after the picture shown in Figure 7.

Figures 9 and 10 compare the growth of trees on No. 12 Pond during the period from May, 1992 through May, 1995. Aga in the growth has been spectacular. No. 12 Pond also faced a drainage problem. In this case the top water flume could not easily be lowered. A new drainage system was cut through the stones to the left of this picture. The hydrolytic loading of the dam sho uld be diminishing as the trees grow larger and stabilize and dehydrate the waterlogged soils below.

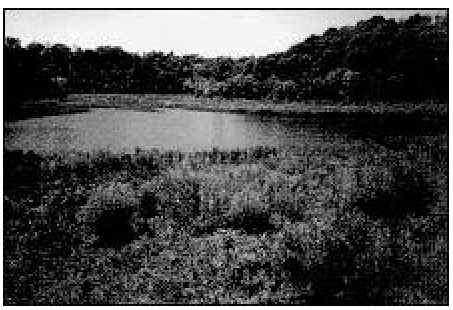

Figure 9. No. 12 Pond in early 1992. Note the small trees at the water's edge and use the hills for reference in the next picture.

Figure 10. No. 12 Pond in May 1995 showing three years of growth from Figure 9.

Figures 11 and 12 show the growth of trees on the wet end of No.7 Pond. Tree growth on this pond has far exceeded expectations and is a picture perfect example of what was desired. There was never great concern for stabilizing the soil in this pond for dam protection. There was the concern to dry up the waterlogged slimes in the depths of the pond to prevent the danger of breaking through the dried crust of the pond. As mentioned earlier there was a drainage problem with No.7 Pond also, but it is believed that this problem has been satisfactorily solved. Additional planting as the system dries could be of benefit, but the trees should seed the new growth and silting in should be rapid in this location.

Figure 11. No. 7 Pond in 1992 showing the planting at the water's edge.

Figure 12. No. 7 Pond three years after figure 11. June 1995.

Figures 13 and 14 demonstrate the progress achieved with No. 15 Pond. The pond is much too large to give more than a very selected view. The size of the pond has shrunk dramatically since 1992 until 1995. Note the planting lines as the following years grow is smaller than the year before. The spacing is almost perfect. The water level on this pond has been controlled to keep down grasses that will choke light from young trees.

Figure 13. The view of No. 15 Pond in May, 1993. The photograph was made from the tower seen in Figure 15.

Figure 14. The view of No. 15 Pond in May, 1995. Note that all water in this part of the pond has been drained.

Planting of No. 15 Pond is almost complete although planting is planned for the winter of 1997. Any areas where there have been tree losses will be planted and a new spillway is being installed to lower the water level of the pond and control what is left in the pond. As the trees age in this pond there should be only a small stream across the top of the pond. There are know to be subterranean springs buried in the muds of No. 15 Pond. It is difficult to predict which flow path these springs will eventually take. Since the springs are located in the wall of the pond it is likely that they will eventually surface near the old shore line of the pond. It is very unlikely that they should cause any problems once the tap roots of the cypress trees become established and should be helpful to water the large trees.

Figures 15 and 16 tell the story of Monsanto's Cypress Garden as well as any pictures can tell the story. Figure 15 is one of the test trees planted in a row across the back shallow side of No.7 Pond. To plant these trees the personnel doing the planting lay on big sheets of plywood and were pulled across the wet clay. By the time the picture was made of the tree in Figure 15 one could walk safely across the dried clay.

Figure 16 shows the line of trees planted in 1974 after they have grown for twenty years. Very few if any of the trees were lost.

They are growing rapidly as examples of what can be expected from the 3,500,000 trees planted on our tailings ponds. In the years to come the Cypress Garden will surely become a show place.

Figure 15. One of the test trees planted on No. 7 Pond in 1974. This is one of the same trees shown in Figure 16 twenty years later. (The late Joseph Green did much to support the early work with trees.)

Figure 16.

CONCLUSIONS

The tree planting program has been an unqualified success and there is no doubt that the cypress garden will become a show place of much value in the years to come. The garden will be unique and the threat of a dam failure will soon be of no concern. Although it is unlikely that anyone will choose to do so, the dams can probably be removed entirely within a few years with no ill effects. Any hazard initially associated with dams and ponds is diminishing daily.

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[1]*Monsanto Company, 800 N. Lindbergh Boulevard, St. Louis, MO 63167; Tel: 314/694-1000.*

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