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RAPID CLAY DEWATERING
PHASE II: FIELD-SCALE TESTS

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RAPID CLAY DEWATERING
PHASE II: FIELD-SCALE TESTS

FINAL REPORT

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PERSPECTIVE

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Phosphate mining and beneficiation produce a huge amount of phosphatic clay slurry. Approximately one ton of clay is generated for each ton of phosphate rock product. Nearly 100,000 tons/day of waste clay are generated by the active phosphate mines in Florida. The waste clay creates one of the most difficult disposal problems in the mining industry.

Although many new disposal/reclamation approaches for the phosphatic clays have been proposed and investigated, the conventional method still dominates. In this method, twenty to sixty-foot high dikes are constructed around areas 300 to 800 acres in extent. The clay slurry (3-5% solids) is pumped into the impoundment at a rate of 20,000 to 80,000 gallon per minute.

The initial dewatering of a clay pond currently is accomplished by excavating a “rim ditch” with a small dragline or backhoe along a portion of the perimeter of the dike, in order to drain surface water to the decant towers. The decant towers are part of the original pond construction and are used to recover clarified water from the pond to return to the beneficiation plant. This same water recirculation system is then used to drain the ponds after clay deposition has ceased. As the water level drops, the strength of the clay increases and the rim ditches are gradually deepened. This dewatering methodology has two major disadvantages: 1) deepening of the ditches requires judgment and experience. If the process is hurried too much, the soft clay will slump into the ditch and block the drainage; and 2) in some cases benches must be cut in the earth embankment to create a work platform, which is costly and time consuming.

At their October 1996 meeting, the FIPR Board approved funding for small scale testing of a rapid dewatering technique, in which plastic filters are installed in phosphatic clay containers to enhance evaporation and crack formation. Twenty test bins were constructed and filled with phosphatic clay at a solids content of about 15%. Each bin is approximately 16 inches by 16 inches in plan view and 4 feet tall. One side of the bin is plexiglass; the other three sides are wood lined with plastic sheet to prevent seepage. The effects of following parameters were investigated: plastic filter on crack formation, rainfall, moisture, and drain plastic. Dewatering of the clay occurred more rapidly than expected: 50% of the volume change occurred in two to three days and 90% in 15 to 30 days. The program demonstrated that the filter drain material could be used to speed up and simplify the drainage and reclamation of a phosphatic clay pond.

Perhaps the most significant findings from Phase I are: a) the filter drain material did not clog, and b) it may not be necessary to drive out the moisture from the filter using mechanical means. Encouraged by the results from Phase I, the FIPR Board of Directors approved funding for the current field-testing project.

ABSTRACT

Two geodrain test sections were installed in a phosphatic clay disposal/reclamation area. The prefabricated geodrain is commercially available and consists of a continuous sheet of dimpled plastic that is covered with a nonwoven polypropylene geofabric. Water seeps through the geofabric into the plenum between the dimples and then flows to a sump. Each test section was 150 feet long by 20 feet wide, nailed to the upstream slope of the embankment near a spillway.

The geodrains were only partially successful in enhancing peripheral drainage of the clay, owing to pipeline failures. Nonetheless, sufficient improvement in the clay shear strength was measured to recommend that another geodrain test section be installed in a new clay area, prior to filling.

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TABLE OF CONTENTS

LIST OF FIGURES

Figure **Page**

LIST OF FIGURES (CONT.)

Figure **Page**

EXECUTIVE SUMMARY

The first stage of reclaiming a phosphatic clay pond consists of draining off the supernatant water through spillways that are part of the water recirculation system. A rim ditch is then excavated in the clay in order to enhance drainage to the spillways. Initially, this ditch can only be a few inches deep because the clay is so soft and weak that it slumps into the ditch if it is over-excavated. Gradually, the clay dewaters and strengthens and the ditch can be periodically deepened. This is a slow, operator-dependent process.

The purpose of this project was to test a concept for an "instant rim ditch", which would consist of a commercially available plastic geodrain system installed on the upstream slope of a clay pond embankment near the spillways. When the pond is filled with clay, the geodrain would be used to dewater the peripheral clay and speed up and simplify the reclamation process.

The geodrain material consists of a continuous sheet of dimpled plastic that is covered with a nonwoven geofabric. This material is commonly used to drain water from soil: Water seeps through the geofabric into the plenum between the dimples and then flows to a sump. However, this geodrain has never been used to dewater a slurry of phosphatic clay, and there were two concerns: (1) The fine clay particles in the slurry might clog and "blind" the geofabric; or (2) The clay particles might pass through the geofabric and accumulate in the plenum. If either phenomenon occurred, the geodrain would cease to function and the instant rim ditch would be a failure.

In order to make a preliminary evaluation of the practicality of an instant rim ditch, a small-scale, Phase I project was sponsored by FIPR, begun in December 1996 and completed within one year. Twenty plywood test bins were filled with a phosphatic clay slurry and the drainage capability of the geodrain was observed and measured. Each test bin was approximately 16 inches × 16 inches in plan view and 4 feet tall. One side of each bin was clear acrylic plastic. Dewatering of the clay occurred much more rapidly than expected: 50% of the volume change occurred in 2 to 3 days and 90% in 15 to 30 days.

As a result of the success of the small-scale tests, FIPR subsequently sponsored the Phase II, field-scale test program that is the subject of this report. Two geodrain test sections, each 150 feet × 20 feet, were installed in an actual clay disposal/reclamation area in April 1999. These test sections were monitored until July 2001. During this period, the pond level rose and covered the geodrain. The pond is presently filled and is "resting" until reclamation begins.

The test program was only a partial success:

(1) One of the test sections, the southern geodrain, failed almost immediately when the anchors holding a conveyance pipeline to the embankment were

insufficient to resist buoyant uplift. That is, the pipeline floated as the pond level rose and apparently broke apart, thereby preventing the geodrain test section from functioning.

(2) The effectiveness of the other test section, the northern geodrain, was greatly reduced as a result of repairs to a lateral pipeline from the embankment to the spillway, caused by shifting of the clay. Ultimately, the shifting clay caused this lateral pipeline to break also. This is believed to have occurred sometime between October 2000 and February 2001. Consequently, dewatering occurred only over a period of about six months. The test program was terminated earlier than planned when it was clear no additional drainage was going to occur.

Nonetheless, the shear strength of the clay in front of the northern geodrain was 30% greater than in front of undrained areas. Although this increase in strength is not of practical significance, it does suggest that a properly installed geodrain could function much better and therefore be beneficial to the reclamation process.

Important lessons were learned and recommendations for future installations are included in this report.

It is recommended that another geodrain test section be installed in a new clay disposal/reclamation area, prior to filling.

INTRODUCTION

BACKGROUND

The Florida phosphate industry constructs approximately 4000 acres of above-ground clay disposal/reclamation ponds each year. Mandatory reclamation of new ponds was initiated in 1975. Since then, the State has required the industry to reclaim on a one-for-one basis. As a result, the time required to reclaim an area, after mining is completed, has decreased to about seven years. Most observers agree that there has been a substantial improvement compared to a few decades ago when the ponds were left to reclaim themselves, usually requiring 20 to 30 years just to drain naturally, and then with less-than-desirable vegetative cover.

The initial dewatering of a clay pond currently is accomplished by excavating a “rim ditch” with a small dragline or backhoe along a portion of the perimeter of the dam, in order to drain surface water to the spillways. The spillways towers are part of the original pond construction and are used to recover clarified water from the clay, plus rainfall, for return to the beneficiation plant. This same water recirculation system is then used to drain the ponds after clay deposition has ceased. As the water level drops, the strength of the clay increases and the rim ditches are gradually deepened. In some cases, lateral ditches into the interior of the pond are also excavated, using special low-ground pressure equipment.

The current dewatering methodology has been developed by a trial-and-error process over a number of years (Ericson and others 1984). And although satisfactory, there is still room for improvement:

(1) Deepening of the rim ditches requires judgment and experience. If the process is hurried too much, the soft clay will slump into the ditch and block the drainage to the decant towers.

(2) In some cases, the clay surface drops 15 feet or more from its maximum level as it dewaters. In order for the construction equipment to be able to reach the clay to deepen the rim ditches, “benches” must be cut in the earthen embankment to create a work platform. This is a wasteful and time-consuming process.

(3) Waiting for the clay to drain and strengthen is frustratingly slow. Several years of episodic activity are required. It is inefficient to repeatedly move equipment onto and off the site.

The purpose of this project is to evaluate a proposed method of constructing an “instant rim ditch.” The basic concept is that a plastic, prefabricated geodrain system would be installed on a portion of the upstream face of the dam, during initial construction. During filling of the pond, the geodrain would be used to remove surface water and, most important, to accelerate the formation of desiccation cracks in the clay, which in turn accelerate the dewatering process. The goal is to simplify the dewatering process and to reduce the over-all reclamation period by one to two years.

HISTORICAL PERSPECTIVE

The Florida Phosphatic Clays Research Project (FPCRP) was initiated in the early 1970s and was active for approximately five years. This project was funded by the industry through the Florida Phosphate Council. The FPCRP was terminated when the State of Florida established FIPR.

The FPCRP was created in response to a series of dam breaks and its mission was to dewater the clay more rapidly and, if possible, to eliminate the above-ground dams altogether. Dozens of dewatering techniques were evaluated at that time, two of which were later adopted by some members of the industry: flocculation and sand-clay mix. In addition, the FPCRP arrived at two very important conclusions:

(1) It is not practical to eliminate the dams, because the ponds serve a dual role: clay deposition and water storage. Even if the clay could be rapidly dewatered, it is still desirable to retain the expelled water for recycle to the beneficiation plant, rather than to simply discharge it.

(2) The dewatering mechanism was found to be a physical process that could be mathematically modeled by large strain, non-linear consolidation theory. Until the FPCRP, many people believed that dewatering of phosphatic clay was controlled by mysterious chemical processes. "Consolidation" was not part of the industry vocabulary at that time. The FPCRP put dewatering of phosphatic clay on a sound scientific basis (Somogyi 1979; Somogyi 1980; Carrier and others 1983).

More or less in parallel with the FPCRP, the US Army Corps of Engineers was conducting the Dredged Material Research Program (DMRP). New regulations had forced the reduction of ocean dumping of dredged material and required upland disposal. The Corps of Engineers was confronted with many of the same issues as the phosphate industry: above-ground dams, dewatering, and reclamation. There was considerable technology exchange between the DMRP and the FPCRP.

When FIPR was created in the late 1970s, rapid dewatering of clay remained a high priority and research has continued. A major industry-university effort was funded by FIPR in the early 1980s to determine if "surcharge" materials (sand or sand-clay mix) could be pumped onto the surface of the soft clay in order to squeeze water out of the clay faster (Townsend and others 1986; Selfridge and others 1986; Weaver and others 1986;

McVay and others 1986; Beriswill and others 1987; Townsend and others 1987). This surcharge method was found to be impractical for at least two reasons:

(1) The denser surcharge materials tended to locally over-stress the clay and "plunge" into the deeper clay. Consequently, much of the surcharge effect was lost.

(2) When the surcharge materials could be maintained on the surface, the extra stress tended to densify the upper few feet of clay, with a consequent reduction of its permeability, which then retarded the flow of water from deeper in the deposit. Thus, after an initial improvement, the overall behavior was *worse* than if no surcharge had been applied.

The mathematical model predicted and confirmed this latter behavior. It also showed the futility of constructing drains on the bottom or sides of a pond: A "cake" of low-permeability clay would form on the seepage surface and effectively block further drainage. A pond was seen to be like a sealed bathtub, only capable of draining or evaporating at the top surface.

At the same time these research efforts were underway, the first reclamation of a clay pond was begun by the industry. A rim ditch, as described above, was excavated in order to enhance the drainage of the surface water that was being held in an old pond. It had been calculated that such a ditch would have negligible effect on draining the interstitial (pore) water from the clay in the interior of the pond because of the low permeability of the clay and the high rainfall. However, the mathematics did not take into account desiccation cracking of the clay. On this first reclamation project, it was observed, totally unexpectedly, that myriads of cracks formed from the face of the ditch into the interior of the pond and that even distant surface water would drain through the cracks into the rim ditch. The "secret" of clay pond reclamation is the formation of the cracks.

Since those early days, FIPR and the phosphate industry have continued to search for methods to dewater the clay more rapidly. Some of the techniques that have been studied include: freeze-thaw; electro-osmosis; and the FIPR-DIPR process (El-Shall 1995). So far, none has been found to be economically practical (although the FIPR-DIPR process apparently has applications in other industries).

Furthermore, none of the research has been directed at accelerating the formation of the desiccation cracks in the clay. This much is known:

(1) The clay cakes and self-seals at any seepage boundary, and will not crack in a submerged condition.
(2) The clay will crack when exposed to air.
(3) Hence, what is needed is a seepage boundary that not only drains the water but also exposes the clay to the air.

INSTANT RIM DITCH

Starting in the mid-1970s, the geotextile industry has developed a number of products for surface and sub-surface drainage. Huge quantities of plastic geotextiles now substitute for natural soil and rock in the construction of highways, embankments, dams, retaining walls, etc. An example of a prefabricated plastic geodrain material is shown in Figure 1. Normally, this material would be installed between a retaining wall and the soil backfill, in order to drain water from the soil and reduce the pressure on the wall. It consists of a continuous sheet of dimpled plastic that is covered with a nonwoven polypropylene geofabric. The dimpled plastic sheet is placed against the retaining wall and the geofabric faces the soil. Water seeps through the geofabric into the plenum between the dimples and flows to a sump. The nonwoven geofabric prevents soil particles from migrating into the drain. The entire sandwich structure is less than one-half inch thick.

Until the late 1980s, the nonwoven geofabric was white and had no ultraviolet resistance: If exposed to sunlight, it would literally rot within six months to a year. Consequently, these drainage materials were only suitable for sub-surface applications. In recent years, first a gray geofabric, and then a black geofabric has been developed; the latter can now be exposed to sunlight for long periods. The geofabric is available in several grades, or thicknesses.

Thus, commercial products are available that could be used to construct an instant rim ditch, albeit, in a different application from what the geotextile industry originally intended. Conceptually, the plenum serves as the ditch while the geofabric is thin enough to expose the clay to evaporation. The geodrain would be installed on the upstream slope of a clay pond embankment near a spillway. When the pond is filled with clay, the filter drain would be used to dewater the peripheral clay and accelerate and simplify the reclamation process.

However, this geodrain has never been used to dewater a slurry of phosphatic clay, and there were two concerns: (1) The fine clay particles in the slurry might clog and "blind" the geofabric; or (2) the Clay particles might pass through the geofabric and accumulate in the plenum. If either phenomenon occurred, the geodrain would cease to function and the instant rim ditch would be a failure.

In order to make a preliminary evaluation of the practicality of an instant rim ditch, a Phase I project was initiated, sponsored by FIPR (Project Number 96-02-118). The project was begun on December 1, 1996 and completed within one year (Carrier 1997).

In the Phase I project, twenty small-scale test bins were filled with a phosphatic clay slurry and the drainage capability of the geodrain was observed and measured. Each test bin was approximately 16 inches × 16 inches in plan view and 4 feet tall. One side of each bin was clear acrylic plastic.

Dewatering of the clay occurred much more rapidly than expected: 50% of the volume change occurred in 2 to 3 days and 90% in 15 to 30 days. The geodrain had two positive effects: (1) The settling of the clay surface creates a "ditch" parallel to the geodrain, which would accelerate the drainage and dewatering of the interior of a clay pond; and (2) The dewatering of the clay in the immediate vicinity of the geodrain increases the strength of that clay so that it can be excavated to a greater depth and further accelerate the dewatering and reclamation.

Because of the rapidity of the gravity-induced consolidation, other factors such as geodrain orientation, air circulation in the plenum, relative humidity, wind, etc., were negligible, at least at the scale of the test bins.

As a result of the success of the Phase I, small-scale tests, FIPR subsequently sponsored the Phase II, field-scale test program that is the subject of this report. Two geodrain test sections were installed in an actual clay disposal/reclamation area, with the following goals:

(1) Evaluate the long-term behavior of the geodrain material under natural, variable water flow rates.

(2) Evaluate the effect of the geofabric grade.

(3) Evaluate the effect of the embankment slope.

(4) Measure the width of the dewatering zone caused by the geodrain.

(5) Evaluate the effect and efficiency of deep dewatering.

(6) Develop design and operational guidelines.

The Phase II project was initiated in July 1998 and ran for three years.

METHODOLOGY

INSTALLATION OF GEODRAIN SYSTEM

When the project began in July 1998, it was anticipated that the geodrain test sections would be installed on the north embankment of the W-1/Phase I Sand-Clay Mix Area at the CF Industries, Inc., Hardee Phosphate Complex-South Pasture Mine. This disposal/reclamation area is located immediately west of CF's Initial Settling Area (ISA). Dilute phosphatic clay from the beneficiation plant is deposited in the ISA and is allowed to settle and consolidate to a solids content of about 15%. The thickened clay is then dredged and pumped to a mix station where tailings sand (also from the beneficiation plant) is added at a ratio of approximately 2 parts sand to 1 part clay by dry weight (sand-clay ratio = SCR = 2). The mixture is then pumped to a final disposal/reclamation area, such as W-1/Phase I. This area had already been filled once and was "resting". It was planned to install the geodrain test sections when the clay surface had dropped as much as possible, just before re-filling began again.

Between July 1998 and February 1999, area W-1/Phase I was monitored and photographically documented: see Table 1. During this period, CF completed construction of an adjacent disposal area, known as W-1/Phase II. In February 1999, CF intended to fill this second area by September 1999. Thus, it was decided in February to move the installation to the west embankment of W-1/Phase II.

Installation of the geodrains began on April 5, 1999. Two test sections were assembled on either side of the east-west catwalk connecting to the spillway in W-1/Phase II. The northern test section begins approximately 10 feet north of the catwalk and extends 150 feet farther to the north. The southern test section begins approximately 140 feet south of the catwalk and extends 150 feet to the south.

The prefabricated, plastic geodrain material comes in 4-foot wide rolls, 50 feet long. Installation consists of simply nailing the strips of geodrain to the upstream embankment, like giant shingles: see Figure 2. The nails are 18 inches long, with 1-inch washer-heads (i.e., pivoting): see Figures 3 and 4. The geodrain strips are overlapped a few inches, such that, like shingles, an upper strip overlies a lower strip: see Figure 5. The nails are driven on centers of 3 to 4 feet. With a little practice and common sense, it is a simple matter to unroll the strips one at a time and work downslope.

For this experimental installation, it was decided to place the upper edge of the geodrain at Elevation 140 feet msl (mean sea level), or 5 feet below the crest elevation. Five strips were installed, extending approximately 20 feet downslope (or to approximately Elevation 132 feet msl on the nominal slope of 2.5 horizontal to 1 vertical). Altogether, each test section consisted of $3 \times 5 = 15$ rolls of geodrain. The combined area of the two test sections was 6,000 square feet.

Each test section was further subdivided as follows: Two extra layers of geofabric were added to one 50-foot portion; one extra layer on another 50-foot portion; and no extra layer on another 50-foot portion: see Figure 6. The purpose of varying the thickness of geofabric was to determine if there were an effect on the clay dewatering capability and efficiency of the geodrain. In addition, geofabric was extended above the top edge of the geodrain to the crest of the embankment to help reduce erosion of the slope onto the geodrain.

This portion of the installation went very quickly and was completed within three days, on April 8.

Over the next few months, it was learned that this installation technique was quite wind-resistant. However, unexpectedly, the extra layers of geofabric degraded in the strong Florida sunshine, although the geofabric that is part of the geodrain remained intact. The geofabrics are supposedly identical and, in particular, ultraviolet resistant. Inquiries were made to the manufacturer's Tampa representative, but no satisfactory explanation was forthcoming. It remains a mystery. For future installations, it is recommended that the extra layers of geofabric be deleted. This will save some time and nails.

On the other hand, erosion from the exposed soil above the geodrain was a minor problem. This erosion had been anticipated, but, as noted, the extra geofabric did not solve this problem. Thus, for future installations, it is recommended that the geodrain be extended to the crest of the embankment.

Next, a toe drain was installed along the bottom edge of each of the geodrain test sections. Each toe drain consisted of a 6-inch diameter, perforated PVC pipeline, placed in a shallow, shaped trench, wrapped with geofabric and covered with tailings sand: see Figures 7(a) to 7(e). The pipe comes in 20-foot sections, which were "glued" together with PVC solvent as assembly progressed. Specially welded anchors prepared by CF personnel were used to hold the toe drain in place: see Figure 8.

The geotextile industry has not developed a standardized connection between the geodrain and the toe drain, and, thus, some improvisation was required. Within a few months of installation, it was found that rainfall hitting the geodrain was flowing downhill, naturally, and eroding the tailings sand away from the toe drain. Just prior to the installation of the geodrain, the level of the pond in area W-1/Phase II was rising at a rate of nearly 4 feet per month (see Figure 28, discussed in more detail later). Had this rate been maintained, the toe drain would have soon been submerged and erosion of the tailings sand would not have been a problem. However, immediately after installation of the geodrain, CF modified its filling schedule and the fill rate dropped to about 1 foot per month. (Consequently, the completion of the initial filling was delayed from September 1999 to May 2000.)

CF personnel placed additional tailings sand on the toe drain, and sheets of impervious polyethylene plastic were nailed over the geodrain and toe drain to protect the installation from runoff: see Figure 9. The plastic sheeting was intended as a temporary measure until the water level rose in the pond and covered the toe drain. At which point, the remaining plastic sheeting was going to be cut away and discarded, thereby re-exposing the geodrain.

The plastic sheeting-and-nail combination was found to be not well-resistant to wind, as the sheet tended to tear at the nails. (Plastic sheeting is commonly used to protect excavation slopes on construction sites, but the sheet is held down with sandbags.) Heroic efforts were made to hold the plastic sheeting together with duct tape. However, ultraviolet degradation occurred very rapidly and the sheeting virtually disappeared. Consequently, CF personnel placed additional tailings sand on the toe drain a second time, just before it was submerged by the rising pond water, and that sufficed: see Figure 10.

All of these problems were due to the constraint of installing the toe drain on the slope of the embankment. For future installations, it is recommended that the toe drain either be installed on a bench on the embankment, or at the toe of the slope. This will greatly simplify placing tailings sand with heavy equipment, and, thus, a sufficient volume can be placed which will resist rainfall erosion.

In order to monitor the water level within the toe drain, 4-inch diameter PVC riser pipes were installed at either end of each test section: see Figures 11(a) and 11(b). These pipes were simply glued to the toe drain pipe with a “T” section and laid up the embankment slope. A removable, press-fit cap was placed over the top end to facilitate access. The standpipes were numbered from the north end of the northern test section to the south end of the southern test section: N-1, N-2, S-1, and S-2, respectively. Once the toe drain was covered by the pond water, CF personnel recorded the water level in each standpipe on a weekly basis.

In order to convey the water from the toe drain in the southern geodrain test section to the spillway, it was necessary to assemble a 6-inch diameter PVC (non-perforated) pipe running north, longitudinally along the embankment, and under the catwalk: see Figure 12. This pipeline was held to the embankment with the same anchors that were used with the toe drains. Unfortunately, when the pond water rose, these anchors were found to be insufficient to resist the buoyancy of the pipeline and it floated: see Figure 13. It is believed that this pipeline failed, as water was never observed to flow from the southern test section into the spillway.

Consequently, for future installations, it is recommended that longitudinal conveyance pipelines be buried a sufficient depth to resist buoyant uplift. As with the toe drain, this is most conveniently done either on a bench, or at the toe of the embankment slope.

From the face of the embankment to the spillway, it was originally intended to convey the drain water in two lateral PVC pipes attached to the catwalk, one from each of the geodrain test sections. However, the catwalk in W-1/Phase II is the floating variety and attaching pipes to it was not possible. Instead, it was necessary to construct a "pipe rack" supported on 1-1/2-inch steel pipe piles driven into the bottom of the pond with sledge hammers: see Figures 14(a) to 14(c). This pipe rack was constructed parallel to the north side of the catwalk. Near the spillway, each 6-inch diameter pipe was reduced to 3-inch diameter and a 90º elbow was installed. Two high pressure flexible hoses were connected and routed under the catwalk in order to reach the spillway boards: see Figures 15(a) and 15(b). Two PVC pipe-brass valve assemblies were used to penetrate the spillway boards: see Figure 16. Each flexible hose was then connected to one of the assemblies. CF personnel caulked the annulus between the PVC pipe and the wooden spillway boards. They also welded an extension T-handle to the top of each valve. A 4 - inch diameter PVC riser was placed around the T-handle and glued to the top of the valve assembly: see Figures 17(a) to 17(c). Thus, it was possible to open or close each valve from the top of the spillway without being affected by the rising water and clay in the pond.

The valve assembly worked well. However, the pipe rack did not. In November 1999, the clay in the vicinity of the spillway shifted and broke the pipes apart at a glued joint: see Figure 18. Water was poured into the open pipes to confirm connectivity into the spillway. The pipes were then re-joined with a series of elbows: see Figure 19. The water level in the pond was at approximately Elevation 132 feet msl at this time; that is, close to the bottom of the geodrains. The pipeline repairs, of necessity, raised the elevation at which water could flow from the geodrains, thereby reducing their effectiveness. Worse yet, the clay continued to shift, and in the process, to raise the elevation of the repaired elbows. As a result, the elbow on the northern test section was not submerged until the pond level reached approximately 138 feet msl, which occurred on May 3, 2000. The maximum pond level that CF allowed was 138.6 feet msl, which was reached on May 14, 2000 (and, as noted above, the top of the geodrain was 140 feet msl); thus, the effectiveness of the northern geodrain test section was greatly reduced.

Fortunately, as the pond level slowly declined, the lateral pipeline was "caught" by the catwalk and the repaired elbow was dragged downward, thereby allowing the northern geodrain to continue to flow.

Worst of all, though, on July 19, 2000, a leak was observed in the lateral pipeline, somewhere between the repaired elbow and the spillway. It is believed that the northern geodrain was still functioning at that time, but additional water from the pond was entering the lateral pipeline and exiting into the spillway. On October 30, 2000, the pond level had dropped to 135.4 feet msl and the repaired elbow was observed to have re-emerged and flow into the spillway had ceased. Later, CF re-filled the pond and the repaired elbow was submerged again in February 2001, when the pond level was 136.9 feet msl, but no flow occurred into the spillway. Presumably, sometime between October 2000 and February 2001, clay flowed into the lateral pipeline and clogged it, thereby preventing the northern geodrain from functioning. The maximum pond level that CF allowed during this re-filling period was 137.6 feet msl, which was reached on March 31, 2001. Thereafter, CF stopped filling the pond and the level has gradually reduced. On May 29, 2001, when the pond level was 135.9 feet msl, the repaired elbow was observed *below* the catwalk, partially submerged: see Figure 20. That is, the lateral pipeline had moved approximately 6 feet to the south due to the shifting of the clay.

Thus, the northern geodrain functioned from early May to late October 2000, somewhat less than six months.

Consequently, for future installations, it is recommended that the lateral pipelines from the embankment to the spillway be buried in the bottom of the pond and attached to the spillway in order to resist "scour" by the shifting clay. Obviously, this should be done when construction of the spillway and embankment is completed, but before filling of the pond has begun.

As noted above, installation of the geodrain system began on April 5, 1999. Construction of the toe drain, longitudinal pipeline, and lateral pipelines was not a continuous process, owing to personnel scheduling. As a result, the installation was not completed until April 26, 1999: see Figures 21(a) and 21(b). This latter date is referred to as "t = 0": Photographs taken before April 26, 1999 are "minus" and after are "plus."

PHOTOGRAPHIC DOCUMENTATION

A total of 847 photographs were taken between July 9, 1998 and July 3, 2001; see Table 1. Of these, 134 were of area W-1/Phase I (none of which are reproduced herein); and 713 were of area W-1/Phase II. Thus, W-1/Phase II may be the most intensively photographed clay disposal/reclamation area in the phosphate industry. Many of these photographs were taken from selected vantage points on each visit to the site. Figures 22 to 26 present the photographs from five of these vantage points in chronological order:

(1) Northern test section, from the embankment crest at the catwalk facing north;
(2) Northern test section, from the toe drain at the catwalk facing north;
(3) Spillway, from the catwalk facing east;
(4) Northern test section, from the spillway facing west; and
(5) Southern test section, from the longitudinal conveyance pipeline at the catwalk facing south.

IN SITU VANE SHEAR TESTS AND PISTON TUBE SAMPLING

On June 6-7, 2001, vane shear tests were run in the clay at selected depths and locations in area W-1/Phase II; and corresponding piston tube samples were obtained for laboratory determination of the Atterberg limits, sand-clay ratios, and clay solids contents.

Six sections were selected in the vicinity of the spillway, proceeding from north to south:

- Section 1 was located approximately 216 feet north of the catwalk, or about 56 feet north of the north end of the northern geodrain (i.e., in front of normal, "un-drained" embankment).

- Section 2 was located approximately 135 feet north of the catwalk, or about 25 feet south of the north end of the northern geodrain (i.e., in the middle of a 50-foot sub-section).

- Section 3 was located approximately 85 feet north of the catwalk, or about 75 feet south of the north end of the northern geodrain (i.e., in the middle of the next 50-foot sub-section and in the middle of the entire geodrain).

- Section 4 was located approximately 35 feet north of the catwalk, or about 25 feet north of the south end of the northern geodrain (i.e., in the middle of the last 50-foot sub-section).

- Section 5 was located approximately 85 feet south of the catwalk, or about 56 feet north of the north end of the southern geodrain. Section 5 is on normal, un-drained embankment and is symmetrically located with respect to Section 3, which is in the middle of the northern geodrain.

- Section 6 was located approximately 216 feet south of the catwalk, in the middle of the southern geodrain. It is symmetrically located with respect to Section 1, which is on normal, un-drained embankment.

Two pieces of plywood board, 2 feet × 8 feet, were laid end-to-end to gain access to the clay surface from the edge of the pond. Testing and sampling was done at stations located approximately 8, 12, and 16 feet from the edge of the pond: see Figures 23(ll) and 27. Vane shear tests and piston tube samples were performed at the clay surface and at depth intervals of approximately 2 feet, with the maximum depth controlled by the underlying embankment slope. Obviously, more tests and samples were obtained at station 16 feet than at station 8 feet. A total of approximately 50 vane shear tests were run, and a similar number of samples were recovered.

RESULTS

POND LEVEL AND STANDPIPES

The daily pond level elevation of the W-1/Phase II disposal/reclamation area is shown in Figure 28, covering the period January 1, 1999 to June 30, 2001, or two-and-a-half years. This data was obtained from CF records and two or three datapoints appear to be erroneous. For example, on March 24, 2000, the level was recorded as 133.7 feet msl; whereas, the day before it was 136.7 feet msl, and the day after it was 136.8 feet msl. Thus, it is likely a transcription error was made and 133.7 should actually be 136.7. However, no attempt has been made to correct the data.

It can be seen that the pond level rose rapidly from January to April 1999, and then slowed considerably, reaching a maximum in May 2000. CF “rested” the area until December 2000 and then re-filled until the end of March 2001.

In February 2000, the pond level rose above the toe drain in the geodrain test sections and CF personnel began measuring the length to water in each of the two standpipes located on either end of both geodrains. This continued on a weekly basis until the end of June 2001. The data for the N-1 standpipe, located at the north end of the northern geodrain, is shown in Figure 29. The early part of the record reflects the rising pond level (decreasing length to water) and can be used to establish a linear correlation between length to water in the standpipe vs. elevation of water in the standpipe. This has been done and the length data has been converted to elevation data. Then the elevation of the water in the standpipe can be compared with pond level elevation. This is shown in Figure 30, where the difference in elevation is plotted for the period May to October 2000, during which the northern geodrain was functioning. For much of this period, the pond level was higher than the standpipe, indicating a hydraulic flow from the clay to the geodrain and thence to the spillway. The maximum measured difference was approximately 0.7 feet. Toward the end of October 2000, the pond level was approximately 0.7 feet *below* the standpipe. It is believed that this occurred when the repaired elbow re-emerged above the clay surface (described previously), and water was actually trapped in the geodrain behind the layer of clay that had been deposited on it. Of course, water from the geodrain ceased flowing into the spillway at that time.

VANE SHEAR TESTS

The vane shear test is a simple, rapid method of measuring the undrained strength of clays in situ. A vane (which looks like a “+” sign in cross section) is connected to the end of a rod and pushed into the clay to a selected depth. Then it is rotated and the required torque is measured.. For these tests, a vane was used with a height of 6-3/16 inches and a circumscribing diameter of 3-3/16 inches. The torque measurements were converted to undrained shear strength by means of a standard formula.

The shear strength results are shown in Figure 31, where two different symbols have been used to distinguish between the drained sections (2, 3, and 4: in front of the northern geodrain) and the undrained sections (1, 5, and 6).

In general, the drained sections show a higher shear strength than the undrained sections, especially at shallow depths, indicating the beneficial effect of the geodrain. Note that one of the tests on an undrained section was much higher than any other of the measurements. At the time this test was done in the field, the vane was “felt” to be scraping on a hard, sandy bottom. If the deepest tests at each station are neglected, the average shear strength of the clay in front of the drained sections is calculated to be 31 pounds per square foot; whereas, the undrained sections average 24 pounds per square foot. Thus, even though the effectiveness of the geodrain was greatly reduced, as previously discussed, nonetheless, there appears to have been a 30% increase in the shear strength. That means an initial rim ditch could be excavated 30% deeper in the drained clay. For these particular results, that only means 1.6 feet deep vs. 1.2 feet, not of practical significance. Yet, still suggesting that the geodrain, if properly installed, could be beneficial to the reclamation process.

ATTERBERG LIMITS

The Atterberg limits are simple laboratory index tests that reflect the clay mineralogy and pore fluid chemistry. These limits were measured on three composite samples:

Composite 1: A portion of all the samples from the drained sections (2, 3, and 4)

Composite 2: A portion of all the samples from section 1 (undrained, north of the northern geodrain)

Composite 3: A portion of all the samples from sections 5 and 6 (undrained, south of the catwalk)

Prior to testing the material coarser than a No. 200 sieve (i.e., the sand fraction) was removed. The results are summarized in Table 2. Each of the parameters fall in a very narrow range; for example, the plasticity index varies from 152% to 157%. This variation is negligible and indicates that the clay mineralogy is essentially homogeneous in the vicinity of the geodrain test sections. Thus, differences in the vane shear strength are not due to changes in the clay mineralogy.

SAND-CLAY RATIO AND CLAY SOLIDS CONTENTS

The sand-clay ratio is defined as the dry weight of sand, W_S, divided by the dry weight of clay, W_C: $SCR = W_S/W_C$. As previously described, CF makes a mix of sand

and clay at an SCR of approximately 2 prior to deposition in area W-1/Phase II. However, by the time the mix reaches the spillway in the vicinity of the geodrain test sections, the majority of the sand fraction has sedimented to the bottom of the pond and the SCR has dropped to an average value of about 0.03; that is, about 3% sand. This is negligible, and for all intents and purposes, the sand-clay mix at the spillway is just clay.

Thus, differences in the vane shear strength are not due to changes in the SCR (nor the clay mineralogy) and can only be attributed to the effect of the geodrain.

The clay solids content is defined as the dry weight of clay divided by the sum of the weight of water, W_W, and the dry weight of clay: $S_C = W_C/(W_W + W_C)$. This is not the same as the total solids content, which includes the dry weight of sand: $S_T = (W_C + W_S)/(W_W + W_C + W_S)$. The clay solids content, total solids content, and sand-clay ratio are related as follows: $S_C = 1/\{[(1 + SCR)/S_T] - SCR\}$. When the SCR is very small, as in this case, $S_C \approx S_T$.

For each of the piston tube samples that were recovered from area W-1/Phase II, the total solids content and the sand-clay ratio was measured in the laboratory. The clay solids content was then calculated with the preceding formula. The results are presented in Figure 32, where two different symbols have been used to distinguish between the drained sections and the undrained sections. In general, there was very little difference in the clay solids contents, both drained and undrained averaging about 28%.

VEGETATION

As noted previously, the northern geodrain functioned from early May to late October 2000. In mid-July 2000, a "bulge" appeared in the natural pond drainage in front of the northern geodrain: see Figures 23(bb) and 23(cc). This phenomenon was (and is) attributed to a strengthening of the clay as a result of the geodrain. This bulging did not occur anywhere else in the vicinity of the spillway.

At that time, the clay was bare. As the clay became vegetated, it was noticed that the vegetation in front of the northern geodrain looked "different"; compare Figures 23(ii) and 26(u), both taken on March 23, 2001. At the last site visit on July 3, 2001, it was observed that the vegetation in front of the northern geodrain consisted of: A strip of low grass next to the geodrain, about 5 feet wide; a strip of medium height herbaceous species, about 5 feet wide; and tall cattails beyond. The herbaceous strip did not occur south of the catwalk, nor north of the northern geodrain test section: compare Figures 23(mm) and 26(x).

Thus, even though a change in solids content has not been measured, the vane shear tests and the vegetation pattern indicates the geodrain has caused a beneficial change in the clay consistency.

CONCLUSIONS AND RECOMMENDATIONS

The southern geodrain test section did not function because the anchors securing the longitudinal conveyance pipeline to the embankment were not adequate to resist buoyant uplift.

Furthermore, the effectiveness of the northern geodrain test section was greatly reduced as a result of repairs to the lateral pipeline, caused by shifting of the clay in the vicinity of the spillway. As a result, the northern geodrain only functioned for about six months, and then only at a water level differential of less than 0.7 feet.

Nonetheless, the shear strength of the clay in front of the northern geodrain was 30% greater than in front of the undrained sections. In addition, the natural pond drainage was seen to bulge in front of the northern geodrain, and the vegetation pattern was clearly different. Both of these observations indicate an improvement in the clay consistency due to enhanced drainage.

While the 30% increase in shear strength of the clay was not of practical significance (owing to the reduced effectiveness of the northern geodrain), it does suggest that a properly installed geodrain could function much better and therefore be beneficial to the reclamation process.

Thus, it is recommended that another geodrain test section be installed in a new clay disposal/reclamation area, prior to filling. Specific recommendations for a future installation include:

(1) Do not add extra layers of geofabric.

(2) Extend the geodrain to the crest of the embankment.

(3) Place the toe drain either on a bench on the upstream slope of the embankment, or at the toe of the slope.

(4) Place a large volume of tailings sand on the toe drain, using mechanized equipment.

(5) Bury longitudinal conveyance pipelines, along the embankment, at a sufficient depth to resist buoyant uplift. As with the toe drain, this is most conveniently done either on a bench, or at the toe of the embankment slope.

(6) Bury lateral conveyance pipelines in the bottom of the pond and attach them to the spillway in order to resist scour by the shifting clay.

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Note abbreviations used above:

ASCE	:	American Society of Civil Engineers
FIPR	:	Florida Institute of Phosphate Research

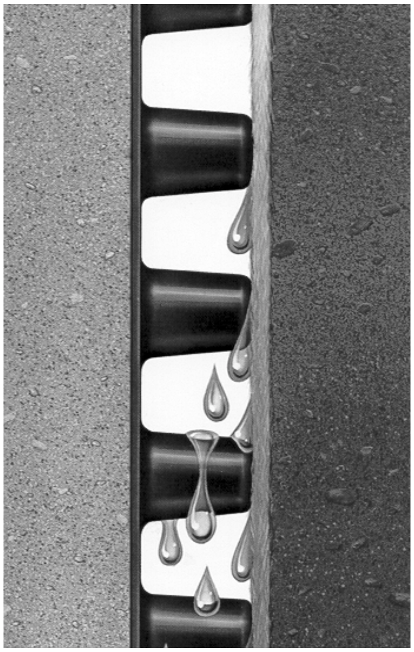

Figure 1. Cutaway View of a Typical Prefabricated Plastic Geodrain Material. (© Mirafi, Inc.)

Figure 2. Installation of Northern Geodrain Test Section.
Apr 05, 1999; t = –21 days; Pond Level = 124.1 ft msl
[04/12/99: 34]

Figure 3. Nailing Geodrain to Embankment.
Apr 05, 1999; t = –21 days; Pond Level = 124.1 ft msl
[04/12/99: 35]

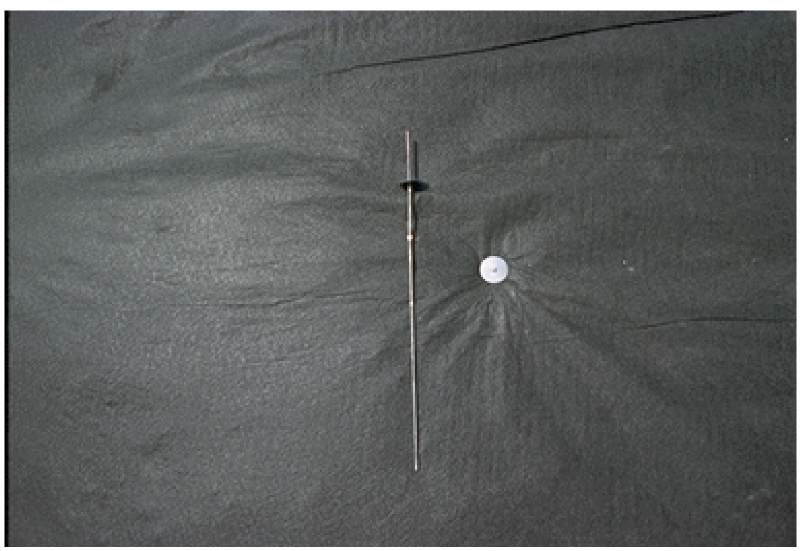

Figure 4. Closeup of 18-inch Nail.
Apr 08, 1999; t = –18 days; Pond Level = 124.5 ft msl
[04/28/99: 2]

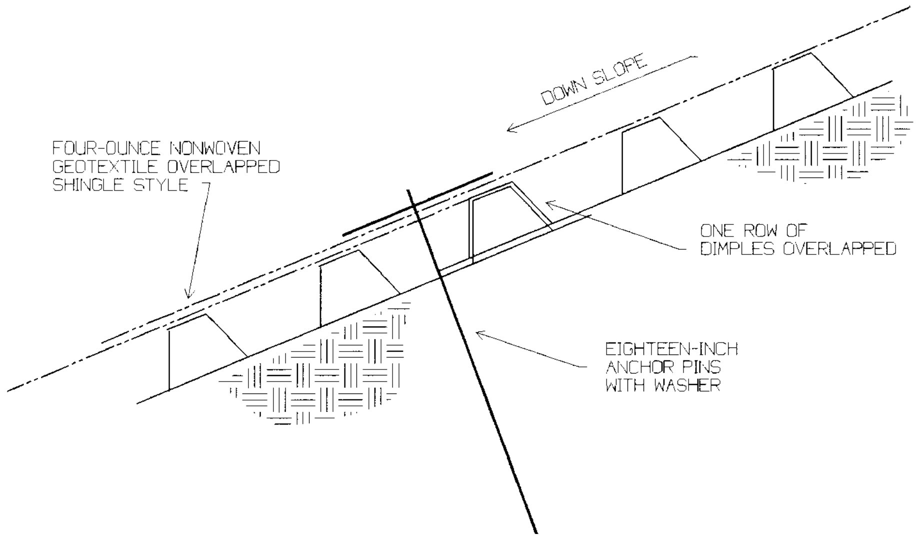

Figure 5. Typical Nail Installation.

Figure 6. Installation of Additional Geofabric on Northern Geodrain Test Section.
Apr 06, 1999; t = –20 days; Pond Level = 124.4 ft msl
[04/14/99: 3]

Figure 7(a). Installation of Toe Drain for Northern Geodrain Test Section.
Apr 07, 1999; t = –19 days; Pond Level = 124.4 ft msl
[04/14/99: 15]

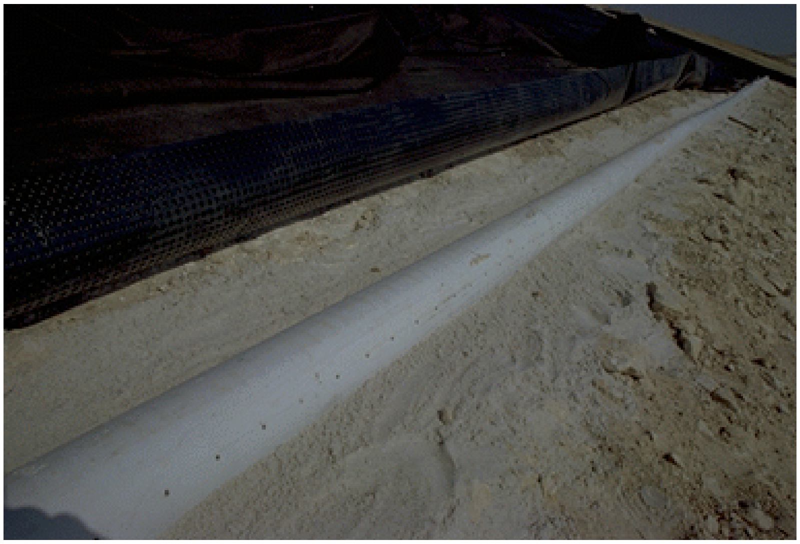

Figure 7(b). Installation of Toe Drain for Northern Geodrain Test Section.
[04/14/99: 16]

Figure 7(c). Installation of Toe Drain for Northern Geodrain Test Section. [04/14/99: 20]

Figure 7(d). Installation of Toe Drain for Northern Geodrain Test Section. [04/14/99: 23]

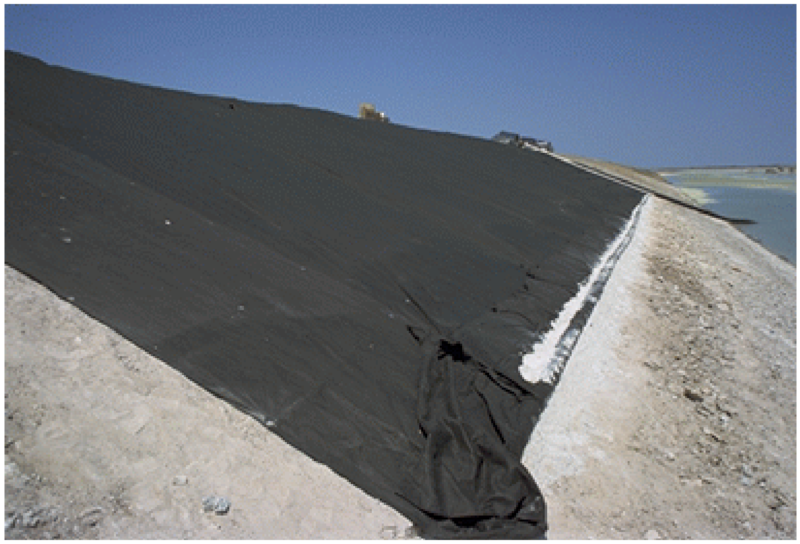

Figure 7(e). Installation of Toe Drain for Northern Geodrain Test Section.
[04/14/99: 25]

Figure 8. Closeup of Welded Anchor Used to Hold Toe Drains and Conveyance Pipeline from Southern Geodrain Test Section.
Apr 18, 1999; t = -8 days; Pond Level = 125.4 ft msl
[04/28/99: 25]

Figure 9. Northern Geodrain Test Section: Additional Tailings Sand Placed on Toe Drain and Entire System Covered with Polyethylene Plastic Sheet.
May 28, 1999; t = +32 days; Pond Level = 127.7 ft msl
[06/21/99: 11]

Figure 10. Southern Geodrain Test Section: Additional Tailings Sand Placed on Toe Drain (Second Time).
Nov 19, 1999; t = +207 days; Pond Level = 132.5 ft msl
[12/16/99: 23]

Figure 11(a). Standpipe N-1 at North End of Northern Geodrain Test Section.
Apr 07, 1999; t = –19 days; Pond Level = 124.4 ft msl
[04/14/99: 27]

Figure 11(b). Standpipe N-1 at North End of Northern Geodrain Test Section.
[04/14/99: 28]

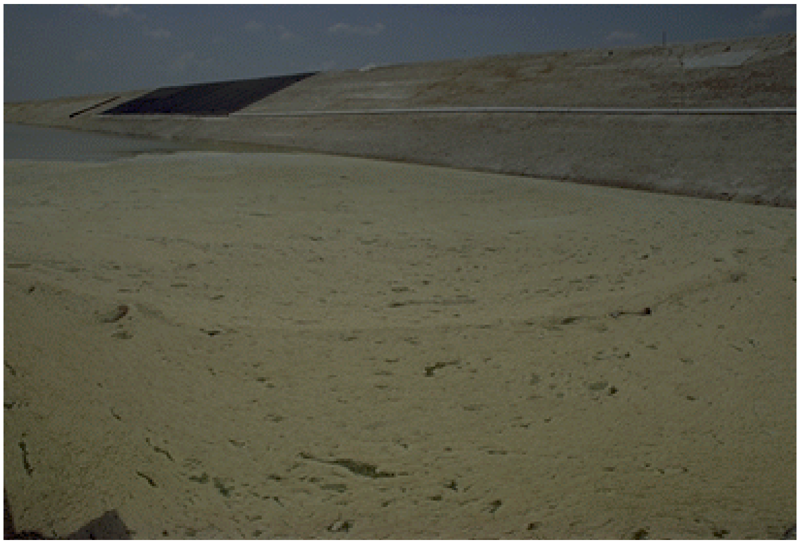

Figure 12. Longitudinal Conveyance Pipeline from Southern Geodrain Test Section.
Apr 26, 1999; t = 0 days; Pond Level = 125.8 ft msl
[06/08/99: 15]

Figure 13. Longitudinal Conveyance Pipeline Floating Free from Anchors.
Feb 16, 2000; t = +296 days; Pond Level = 134.5 ft msl
[03/15/00: 15]

Figure 14(a). Installation of Steel Pipe Piles for Support of Lateral Pipelines.
Apr 20, 1999; t = –6 days; Pond Level = 125.6
[04/28/99: 31]

Figure 14(b). Installation of Steel Pipe Piles for Support of Lateral Pipelines.
Apr 26, 1999; t = 0 days; Pond Level = 125.8 ft msl
[06/08/99: 9]

Figure 14(c). Installation of Steel Pipe Piles for Support of Lateral Pipelines.
Apr 26, 1999; t = 0 days; Pond Level = 125.8 ft msl
[06/08/99: 10]

Figure 15(a). Installation of Flexible Hoses Connecting
Lateral Pipelines to Spillway.
Apr 20, 1999; t = –6 days; Pond Level = 125.6 ft msl
[04/28/99: 34 (enlargement)]

Figure 15(b). Installation of Flexible Hoses Connecting Lateral Pipelines to Spillway.
Apr 26, 1999; t = 0 days; Pond Level = 125.8 ft msl
[06/08/99: 11]

Figure 16. PVC-Brass Valve Assembly for Penetrating Spillway Boards.
[04/12/99: 29]

Figure 17(a). PVC-Brass Valve Assembly for Southern Geodrain Test Section Mounted on Spillway.
Apr 14, 1999; t = –12 days; Pond Level = 124.9 ft msl
[04/28/99: 20]

Figure 17(b). PVC-Brass Valve Assembly for Southern Geodrain Test Section Mounted on Spillway.
Apr 14, 1999; t = –12 days; Pond Level = 124.9 ft msl
[04/28/99: 21]

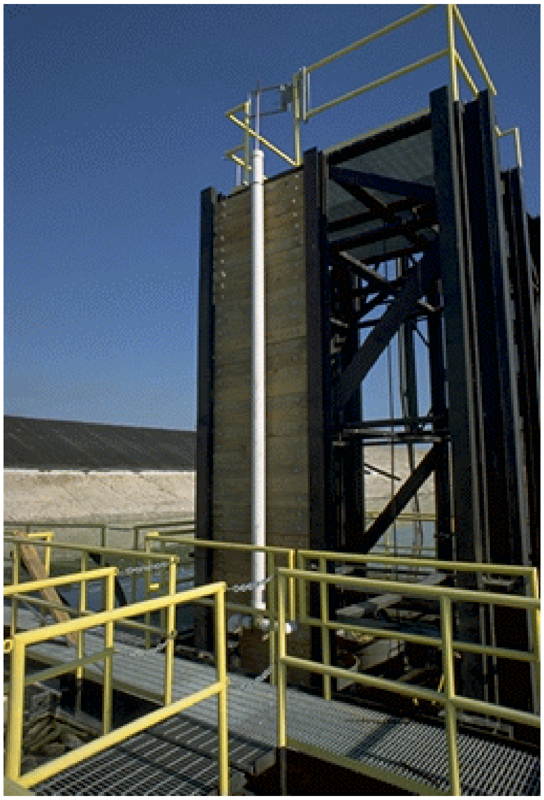

Figure 17(c). PVC-Brass Valve Assembly for Southern Geodrain Test Section Mounted on Spillway.
Apr 20, 1999; t = –6 days; Pond Level = 125.6 ft msl
[04/28/99: 29]

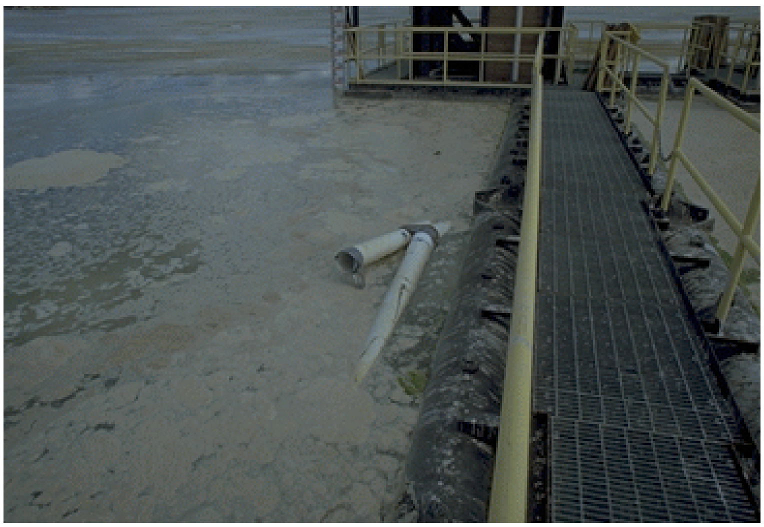

Figure 18. Lateral Pipelines Pulled Apart at Joints.
Nov 19, 1999; t = +207 days; Pond Level = 132.5 ft msl
[12/16/99: 20]

Figure 19. Repaired Elbows at Lateral Pipeline Joints.
Nov 24, 1999; t = +212 days; Pond Level = 132.5 ft msl
[12/27/99: 7]

Figure 20. Repaired Elbows under Catwalk.
May 29, 2001; t = +773 days; Pond Level = 135.8 ft msl
[07/20/01: 5]

Figure 21(a). Geodrain Installation Completed.
Apr 26, 1999; t = 0 days; Pond Level = 125.8 ft msl
[06/08/99: 7]

Figure 21(b). Geodrain Installation Viewed from East Embankment.
Apr 26, 1999; t = 0 days; Pond Level = 125.8 ft msl
[06/08/99: 18 (enlargement)]

Figure 22. Northern Geodrain Test Section from the Embankment Crest at the Catwalk Facing North.

Figure 22(a). Feb 17, 1999; t = –68 days
Pond Level = 118.5 ft msl [04/12/99: 2]

Figure 22(b). Apr 05, 1999; t = –21 days
Pond Level = 124.1 ft msl [04/12/99: 34]

Figure 22(c). Apr 05, 1999; t = –21 days
Pond Level = 124.1 ft msl [04/12/99: 38]

Figure 22(d). Apr 06, 1999; t = –20 days
Pond Level = 124.4 ft msl [04/14/99: 3]

Figure 22(e). Apr 06, 1999; t = –20 days
Pond Level = 124.4 ft msl [04/14/99: 11]

Figure 22(f). Apr 07, 1999; t = –19 days
Pond Level = 124.4 ft msl [04/14/99: 32]

Figure 22(g). May 28, 1999; t = +32 days
Pond Level = 127.7 ft msl [06/21/99: 11]

Figure 22(j). Aug 25, 1999; t = +121 days
Pond Level = 129.9 ft msl [09/29/99: 15]

Figure 22(h). Jun 30, 1999; t = +65 days
Pond Level = 128.9 ft msl [07/08/99: 23]

Figure 22(k). Oct 18, 1999; t = +175 days
Pond Level = 131.3 ft msl [11/30/99: 1]

Figure 22(i). Aug 02, 1999; t = +98 days
Pond Level = 129.5 ft msl [09/03/99: 15]

Figure 22(l). Dec 17, 1999; t = +235 days
Pond Level = 132.4 ft msl [12/27/99: 32]

Figure 22(m). Jan 12, 2000; t = +261 days
Pond Level = 132.5 ft msl [01/21/00: 17]

Figure 22(n). Feb 16, 2000; t = +296 days
Pond Level = 134.5 ft msl [02/25/00: 31]

Figure 22(o). Mar 14, 2000; t = +323 days
Pond Level = 135.6 ft msl [04/06/00: 18]

Figure 22(p). Apr 07, 2000; t = +347 days
Pond Level = 137.5 ft msl   [04/24/00: 8]

Figure 22(q). Apr 20, 2000; t = +360 days
Pond Level = 137.5 ft msl   [05/22/00: 7]

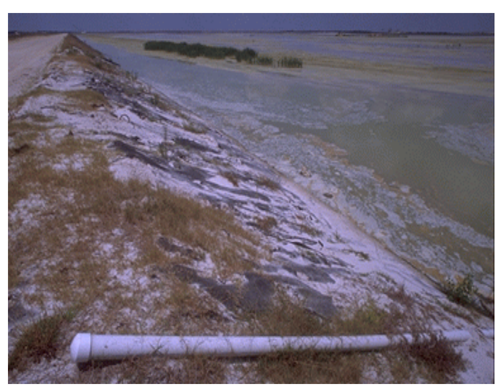

Figure 22(r). May 12, 2000; t = +382 days
Pond Level = 138.5 ft msl [05/22/00: 36]

Figure 22(s). Jun 07, 2000; t = +408 days
Pond Level = 138.0 ft msl [07/13/00: 17]

Figure 22(t). Jun 29, 2000; t = +430 days
Pond Level = 137.7 ft msl [08/02/00: 19]

Figure 22(u). Jul 19, 2000; t = +450 days
Pond Level = 137.0 ft msl [08/02/00: 34]

Figure 22(v). Aug 16, 2000; t = +478 days
Pond Level = 136.8 ft msl [08/25/00: 29]

Figure 22(w). Sep 25, 2000; t = +518 days
Pond Level = 137.0 ft msl [11/08/00: 17]

Figure 22(x). Oct 30, 2000; t = +553 days
Pond Level = +135.4 ft msl [11/08/00: 23]

Figure 22(y). Nov 09, 2000; t = +563 days
Pond Level = 136.4 ft msl [12/27/00: 27]

Figure 22(bb). Mar 23, 2001; t = +697 days
Pond Level = 136.0 ft msl [03/30/01: 23]

Figure 22(z). Dec 15, 2000; t = +599 days
Pond Level = 135.2 ft msl [02/06/01: 1]

Figure 22(cc). Apr 20, 2001; t = +725 days
Pond Level = 137.0 ft msl [06/08/01: 14]

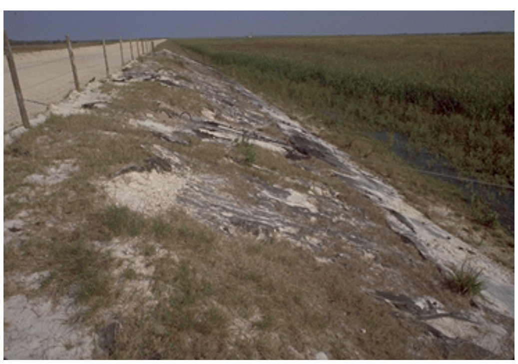

Figure 22(aa). Feb 22, 2001; t = +668 days
Pond Level = 136.9 ft msl [03/14/01: 32]

Figure 22(dd). May 29, 2001; t = +764 days
Pond Level = 135.9 ft msl [06/08/01: 36]

Figure 22(ee). Jul 03, 2001; t = +799 days
Pond Level = 135.5 ft msl [07/20/01: 32]

Figure 23. Northern Geodrain Test Section from the Toe Drain at the Catwalk Facing North.

Figure 23(a). Apr 06, 1999; t = –20 days
Pond Level = 124.4 ft msl [04/14/99: 4]

Figure 23(d). Apr 06, 1999; t = –20 days
Pond Level = 124.4 ft msl [04/14/99: 13]

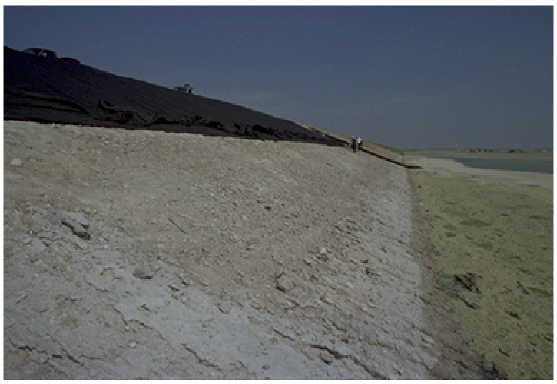

Figure 23(b). Apr 06, 1999; t = –20 days
Pond Level = 124.4 ft msl [04/14/99: 5]

Figure 23(c). Apr 06, 1999; t = –20 days
Pond Level = 124.4 ft msl [04/14/99: 9]

Figure 23(e). Apr 07, 1999; t = –19 days
Pond Level = 124.4 ft msl [04/14/99: 18]

Figure 23(f). Apr 07, 1999; t = –21 days
Pond Level = 124.4 ft msl [04/14/99: 19]

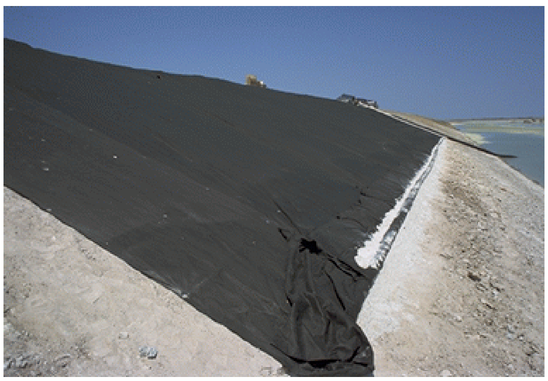

Figure 23(g). Apr 07, 1999; t = –21 days
Pond Level = 124.4 ft msl [04/14/99: 25]

Figure 23(h). May 03, 1999; t = +7 days
Pond Level = 128.1 ft msl [06/08/99: 22]

Figure 23(i). May 28, 1999; t = +32 days
Pond Level = 127.7 ft msl [06/21/99: 12]

Figure 23(j). Jun 06, 1999; t = +41 days
Pond Level = 128.1 ft msl [06/21/99: 24]

Figure 23(k). Jun 30, 1999; t = +65 days
Pond Level = 128.9 ft msl [07/08/99: 34]

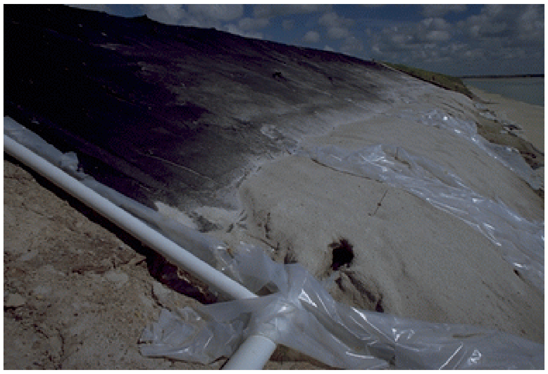

Figure 23(l). Jul 16, 1999; t = +81 days
Pond Level = 128.9 ft msl [07/31/99: 36]

Figure 23(m). Aug 25, 1999; t = +121 days
Pond Level = 129.9 ft msl [09/29/99: 19]

Figure 23(n). Sep 17, 1999; t = +144 days
Pond Level = 130.2 ft msl [10/05/99: 2]

Figure 23(o). Oct 18, 1999; t = +175 days
Pond Level = 131.3 ft msl [11/30/99: 4]

Figure 23(p). Nov 19, 1999; t = +207 days
Pond Level = 132.5 ft msl [12/16/99: 18]

Figure 23(q). Dec 17, 1999; t = +235 days
Pond Level = 132.4 ft msl [12/27/99: 33]

Figure 23(r). Jan 12, 2000; t = +261 days
Pond Level = 132.5 ft msl [01/21/00: 18]

Figure 23(u). Mar 28, 2000; t = +337 days
Pond Level = 137.2 ft msl [04/24/00: 2]

Figure 23(s). Feb 16, 2000; t = +296 days
Pond Level = 134.5 ft msl [02/25/00: 32]

Figure 23(v). Apr 07, 2000; t = +347 days
Pond Level = 137.5 ft msl [04/24/00: 9]

Figure 23(t). Mar 14, 2000; t = +323 days
Pond Level = 135.6 ft msl [04/06/00: 19]

Figure 23(w). Apr 20, 2000; t = +360 days
Pond Level = 137.5 ft msl [05/22/00: 8]

Figure 23(x). May 12, 2000; t = +382 days
Pond Level = 138.5 ft msl [05/22/00: 37]

Figure 23(aa). Jun 29, 2000; t = +430 days
Pond Level = 137.7 ft msl [08/02/00: 20]

Figure 23(y). May 23, 2000; t = +393 days
Pond Level = 138.3 ft msl [06/02/00: 29]

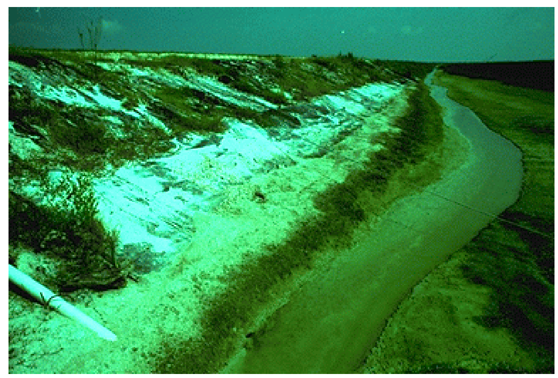

Figure 23(bb). Jul 19, 2000; t = +450 days
Pond Level = 137.0 ft msl [08/02/00: 35]

Figure 23(z). Jun 07, 2000; t = +408 days
Pond Level = 138.0 ft msl [07/13/00: 18]

Figure 23(cc). Aug 16, 2000; t = +478 days
Pond Level = 136.8 ft msl [08/25/00: 30]

Figure 23(dd). Sep 25, 2000; t = +518 days
Pond Level = 137.0 ft msl [11/08/00: 18]

Figure 23(ee). Oct 30, 2000; t = +553 days
Pond Level = 135.4 ft msl [11/08/00: 24]

Figure 23(ff). Nov 09, 2000; t = +563 days
Pond Level = 136.4 ft msl [12/27/00: 30]

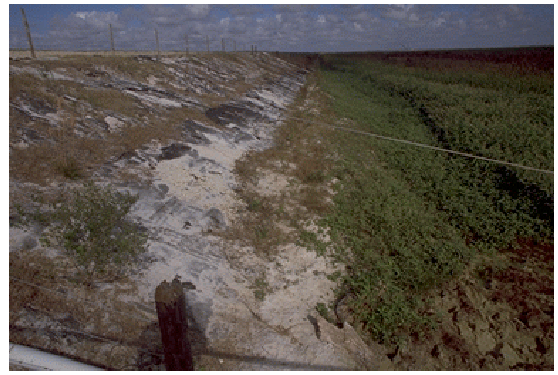

Figure 23(gg). Dec 15, 2000; t = +599 days
Pond Level = 135.2 ft msl [02/06/01: 2]

Figure 23(hh). Feb 22, 2001; t = +668 days
Pond Level = 136.9 ft msl [03/14/01: 31]

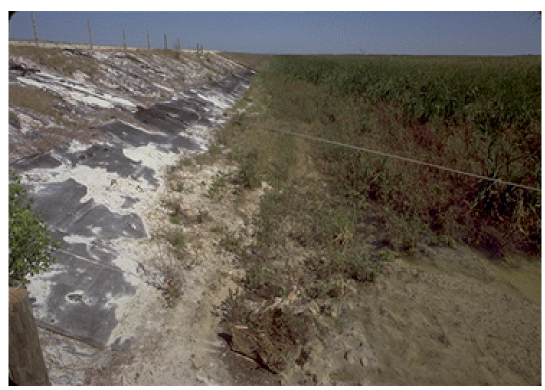

Figure 23(ii). Mar 23, 2001; t = +697 days
Pond Level = 136.0 ft msl [03/30/01: 24]

Figure 23(jj). Apr 20, 2001; t = +725 days
Pond Level = 137.0 ft msl [06/08/01: 15]

Figure 23(kk). May 29, 2001; t = +764 days
Pond Level = 135.9 ft msl [06/08/01: 37]

Figure 23(mm). Jul 03, 2001; t = +799 days
Pond Level = 135.5 ft msl [07/20/01: 33]

Figure 23(ll). Jun 07, 2001; t = +773 days
Pond Level = 135.8 ft msl [07/20/01: 18]

Figure 24. Spillway from the Catwalk Facing East.

Figure 24(a). Jan 26, 1999; t = –90 days
Pond Level = 114.9 ft msl [03/01/99: 5]

Figure 24(b). Mar 09, 1999; t = –48 days
Pond Level = 120.6 ft msl [04/12/99: 17]

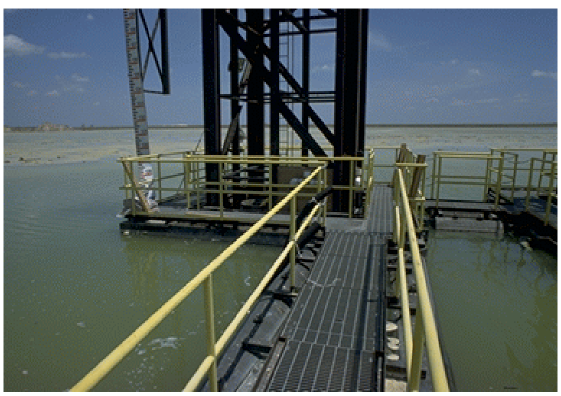

Figure 24(c). Apr 14, 1999; t = –12 days
Pond Level = 124.9 ft msl [04/28/99: 22]

Figure 24(d). Apr 20, 1999; t = –6 days
Pond Level = 125.6 ft msl [04/28/99: 35]

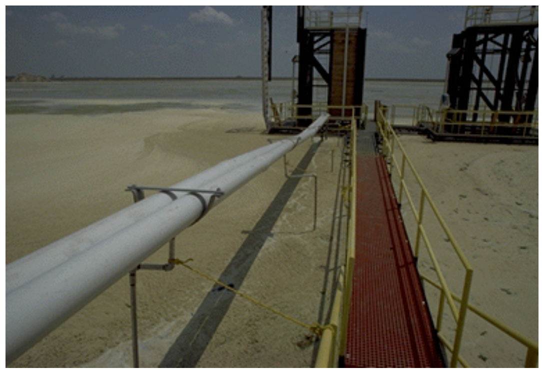

Figure 24(e). Apr 26, 1999; t = 0 days
Pond Level = 125.8 ft msl [06/08/99: 10]

Figure 24(f). Jun 30, 1999; t = +65 days
Pond Level = 128.9 ft msl [07/08/99: 22]

Figure 24(g). Oct 18, 1999; t = +175 days
Pond Level = 131.3 ft msl [11/30/99: 2]

Figure 24(j). Nov 23, 1999; t = +211 days
Pond Level = 132.5 ft msl [12/27/99: 2]

Figure 24(h). Nov 11, 1999; t = +199 days
Pond Level = 132.0 ft msl [12/16/99: 15]

Figure 24(k). Nov 24, 1999; t = +212 days
Pond Level = 132.5 ft msl [12/27/99: 5]

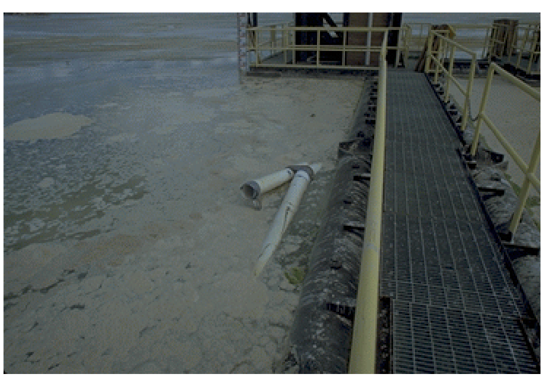

Figure 24(i). Nov 19, 1999; t = +207 days
Pond Level = 132.5 ft msl [12/16/99: 20]

Figure 24(l). Dec 17, 1999; t = +235 days
Pond Level = 132.4 ft msl [12/27/99: 34]

Figure 24(m). Jan 12, 2000; t = +261 days
Pond Level = 132.5 ft msl [01/21/00: 20]

Figure 24(p). Mar 14, 2000; t = +323 days
Pond Level = 135.6 ft msl [04/06/00: 20]

Figure 24(n). Feb 16, 2000; t = +296 days
Pond Level = 134.5 ft msl [02/25/00: 33]

Figure 24(q). Mar 28, 2000; t = +337 days
Pond Level = 137.2 ft msl [04/06/00: 35]

Figure 24(o). Feb 24, 2000; t = +304 days
Pond Level = 135.1 ft msl [03/15/00: 20]

Figure 24(r). Apr 07, 2000; t = +347 days
Pond Level = 137.5 ft msl [04/24/00: 10]

Figure 24(s). Apr 20, 2000; t = +360 days
Pond Level = 137.5 ft msl [05/22/00: 9]

Figure 24(v). Jun 07, 2000; t = +408 days
Pond Level = 138.0 msl [07/13/00: 19]

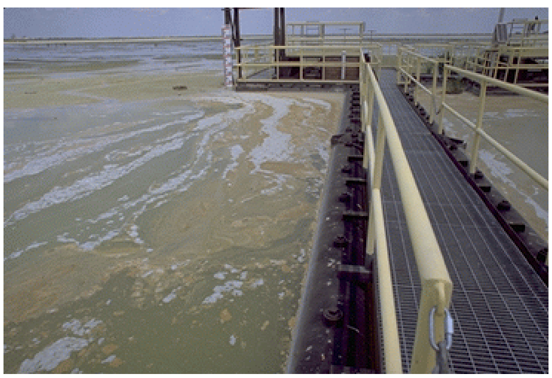

Figure 24(t). May 12, 2000; t = +382 days
Pond Level = 138.5 ft msl [06/02/00: 1]

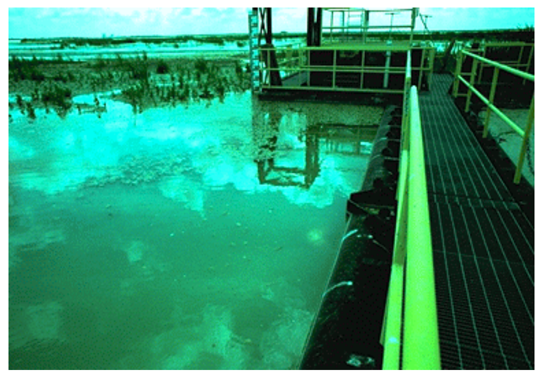

Figure 24(w). Jun 29, 2000; t = +430 days
Pond Level = 137.7 ft msl [08/02/00: 21]

Figure 24(u). May 23, 2000; t = +393 days
Pond Level = 138.3 ft msl [06/02/00: 31]

Figure 24(x). Jul 19, 2000; t = +450 days
Pond Level = 137.0 ft msl [08/25/00: 1]

Figure 24(y). Aug 16, 2000; t = +478 days
Pond Level = 136.8 ft msl [08/25/00: 31]

Figure 24(bb). Nov 09, 2000; t = +563 days
Pond Level = 136.4 ft msl [12/27/00: 32]

Figure 24(z). Sep 25, 2000; t = +518 days
Pond Level = 137.0 ft msl [11/08/00: 19]

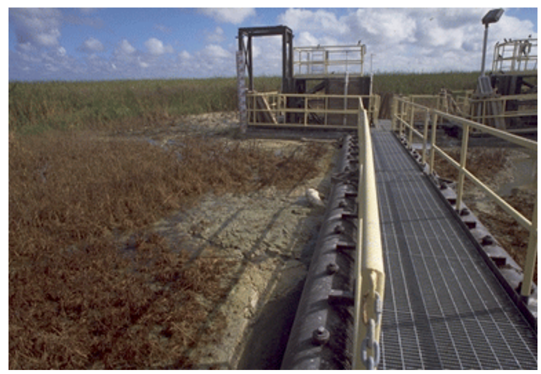

Figure 24(cc). Dec 15, 2000; t = +599 days
Pond Level = 135.2 ft msl [02/06/01: 3]

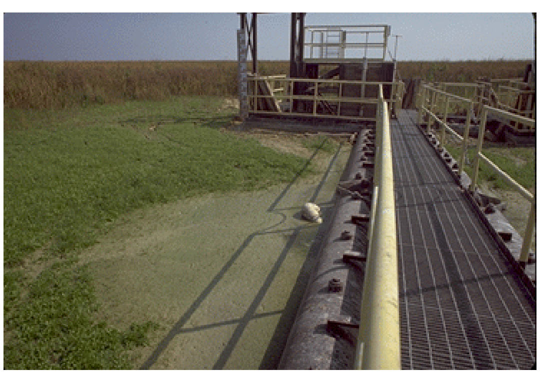

Figure 24(aa). Oct 30, 2000; t = +553 days
Pond Level = 135.4 ft msl [11/08/00: 25]

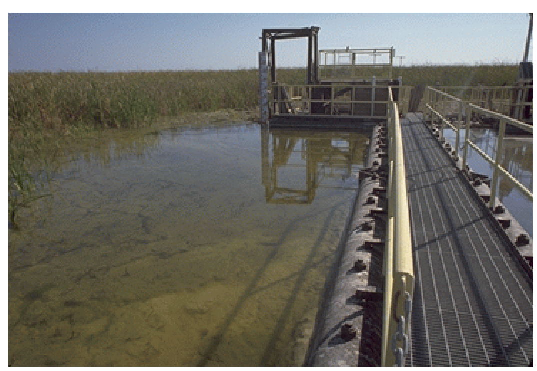

Figure 24(dd). Feb 22, 2001; t = +668 days
Pond Level = 136.9 ft msl [03/14/01: 30]

Figure 24(ee). Mar 23, 2001; t = +697 days
Pond Level = 136.0 ft msl [03/30/01: 25]

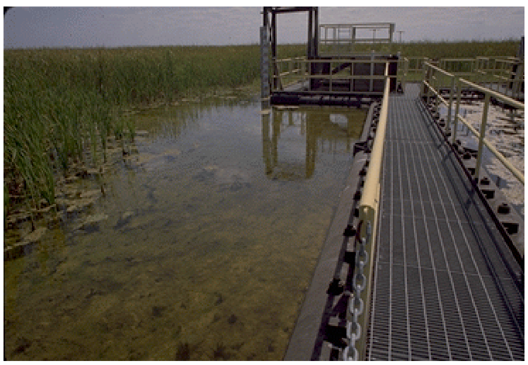

Figure 24(ff). Apr 20, 2001; t = +725 days
Pond Level = 137.0 ft msl [06/08/01: 16]

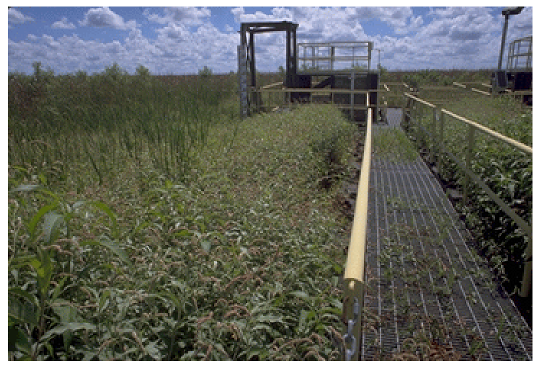

Figure 24(hh). Jul 03, 2001; t = +799 days
Pond Level = 135.5 ft msl [07/20/01: 34]

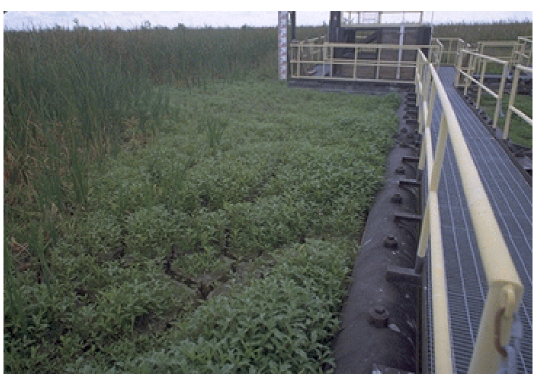

Figure 24(gg). May 29, 2001; t = +764 days
Pond Level = 135.9 ft msl [07/20/01: 4]

Figure 25. Northern Geodrain Test Section from the Spillway Facing West.

Figure 25(a). Apr 06, 1999; t = –20 days
Pond Level = 124.4 ft msl [04/14/99: 8]

Figure 25(b). Apr 07, 1999; t = –19 days
Pond Level = 124.4 ft msl [04/14/99: 33]

Figure 25(c). Apr 14, 1999; t = –12 days
Pond Level = 124.9 ft msl [04/28/99: 16]

Figure 25(d). Apr 26, 1999; t = 0 days
Pond Level = 125.8 ft msl [06/08/99: 13]

Figure 25(e). May 28, 1999; t = +32 days
Pond Level = 127.7 ft msl [06/21/99: 13]

Figure 25(f). Jun 06, 1999; t = +41 days
Pond Level = 128.1 ft msl [06/21/99 22]

Figure 25(g). Jun 11, 1999; t = +46 days
Pond Level = 127.8 ft msl [06/21/99: 34]

Figure 25(h). Jun 30, 1999; t = +65 days
Pond Level = 128.9 ft msl [07/08/99: 35]

Figure 25(i). Jul 16, 1999; t = +81 days
Pond Level = 128.9 ft msl [07/31/99: 35]

Figure 25(j). Aug 02, 1999; t = +98 days
Pond Level = 129.5 ft msl [09/03/99: 19]

Figure 25(k). Aug 25, 1999; t = +121 days
Pond Level = 129.9 ft msl [09/29/99: 22]

Figure 25(l). Sep 17, 1999; t = +144 days
Pond Level = 130.2 ft msl [10/05/99: 3]

Figure 25(m). Oct 18, 1999; t = +175 days
Pond Level = 131.3 ft msl [11/30/99: 5]

Figure 25(p). Dec 17, 1999; t = +235 days
Pond Level = 132.4 ft msl [12/27/99: 36]

Figure 25(n). Nov 11, 1999; t = +199 days
Pond Level = 132.0 ft msl [12/16/99: 17]

Figure 25(q). Jan 12, 2000; t = +261 days
Pond Level = 132.5 ft msl [01/21/00: 21]

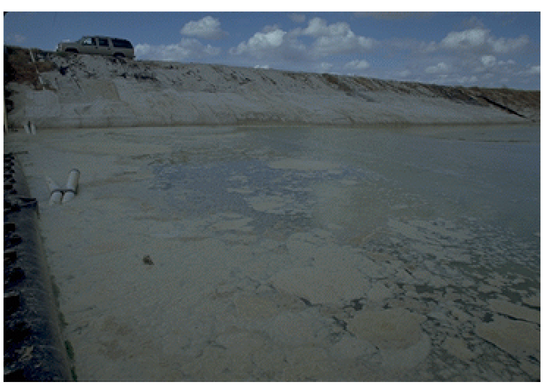

Figure 25(o). Nov 19, 1999; t = +207 days
Pond Level = 132.5 ft msl [12/16/99: 21]

Figure 25(r). Mar 14, 2000; t = +323 days
Pond Level = 135.6 ft msl [04/06/00: 21]

Figure 25(s). Apr 07, 2000; t = +347 days
Pond Level = 137.5 ft msl [04/24/00: 12]

Figure 25(v). Jun 29, 2000; t = +430 days
Pond Level = 137.7 ft msl [08/02/00: 25]

Figure 25(t). May 12, 2000; t = +382 days
Pond Level = 138.5 ft msl [06/02/00: 3]

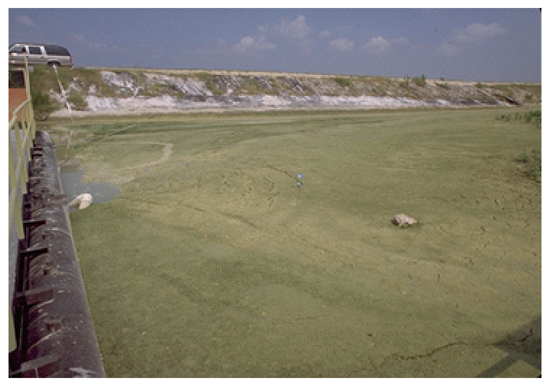

Figure 25(w). Jul 19, 2000; t = +450 days
Pond Level = 137.0 ft msl [08/25/00: 4]

Figure 25(u). May 23, 2000; t = +393 days
Pond Level = 138.3 ft msl [06/02/00: 35]

Figure 25(x). Aug 16, 2000; t = +478 days
Pond Level = 136.8 ft msl [08/25/00: 32]

Figure 25(y). Sep 25, 2000; t = +518 days
Pond Level = 137.0 ft msl [11/08/00: 21]

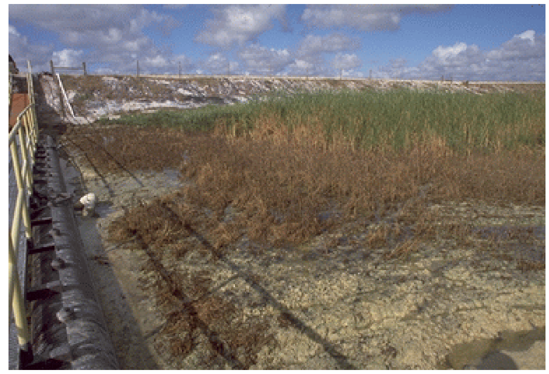

Figure 25(bb). Dec 15, 2000; t = +599 days
Pond Level = 135.2 ft msl [02/06/01: 5]

Figure 25(z). Oct 30, 2000; t = +553 days
Pond Level = 135.4 ft msl [11/08/00: 27]

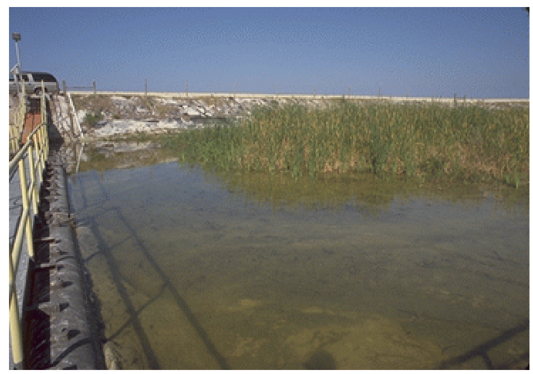

Figure 25(cc). Feb 22, 2001; t = +668 days
Pond Level = 136.9 ft msl [03/14/01: 27]

Figure 25(aa). Nov 09, 2000; t = +563 days
Pond Level = 136.4 ft msl [12/27/00: 35]

Figure 25(dd). Mar 23, 2001; t = +697 days
Pond Level = 136.0 ft msl [03/30/01: 28]

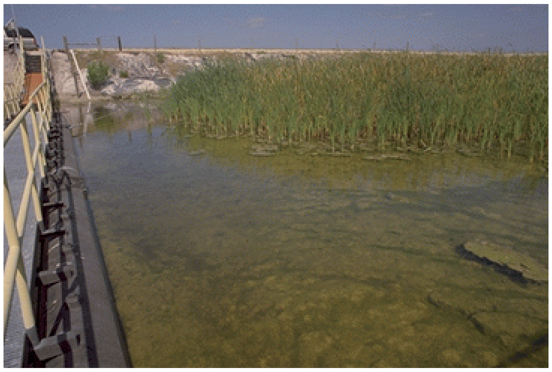

Figure 25(ee). Apr 20, 2001; t = +725 days
Pond Level = 137.0 ft msl [06/08/01: 17]

Figure 25(ff). May 29, 2001; t = +764 days
Pond Level = 135.9 ft msl [07/20/01: 6]

Figure 25(gg). Jul 03, 2001; t = +799 days
Pond Level = 135.5 ft msl [07/31/01: 5]

Figure 26. Southern Geodrain Test Section from the Longitudinal Conveyance Pipeline at the Catwalk Facing South.

Figure 26(a). Apr 07, 1999; t = –19 days
Pond Level = 124.4 ft msl [04/14/99: 26]

Figure 26(b). Apr 14, 1999; t = –12 days
Pond Level = 124.9 ft msl [04/28/99: 15]

Figure 26(c). Apr 20, 1999; t = –6 days
Pond Level = 125.6 ft msl [04/28/99: 30]

Figure 26(d). Dec 17, 1999; t = +235 days
Pond Level = 132.5 ft msl [01/21/00: 4]

Figure 26(e). Feb 16, 2000; t = +296 days
Pond Level = 134.5 ft msl [02/25/00: 26]

Figure 26(g). Mar 14, 2000; t = +323 days
Pond Level = 135.6 ft msl [04/06/00: 24]

Figure 26(f). Feb 24, 2000; t = +304 days
Pond Level = 135.1 ft msl [03/15/00: 19]

Figure 26(h). Mar 28, 2000; t = +337 days
Pond Level = 137.2 ft msl [04/24/00: 1]

Figure 26(i). Apr 07, 2000; t = +347 days
Pond Level = 137.5 ft msl [04/24/00: 15]

Figure 26(k). May 12, 2000; t = +382 days
Pond Level = 138.5 ft msl [06/02/00:5]

Figure 26(j). Apr 20, 2000; t = +360 days
Pond Level = 137.5 ft msl [05/22/00: 13]

Figure 26(l). Jun 07, 2000; t = +408 days
Pond Level = 138.0 ft msl [07/13/00: 26]

Figure 26(m). Jun 29, 2000; t = +430 days
Pond Level = 137.7 ft msl [08/02/00: 26]

Figure 26(o). Aug 16, 2000; t = +478 days
Pond Level = 136.8 ft msl [08/25/00: 34]

Figure 26(n). Jul 19, 2000; t = +450 days
Pond Level = 137.0 ft msl [08/25/00: 6]

Figure 26(p). Sep 25, 2000; t = +518 days
Pond Level = 137.0 ft msl [11/08/00: 23]

Figure 26(q). Oct 30, 2000; t = +553 days
Pond Level = 135.4 ft msl [11/08/00: 29]

Figure 26(s). Dec 15, 2000; t = +599 days
Pond Level = 135.2 ft msl [02/06/01: 7]

Figure 26r. Nov 09, 2000; t = +563 days
Pond Level = 136.4 ft msl [12/27/00: 29]

Figure 26t. Feb 22, 2001; t = +668 days
Pond Level = 136.9 ft msl [03/14/01: 25]

Figure 26(u). Mar 23, 2001; t = +697 days
Pond Level = 136.0 ft msl [03/30/01: 29]

Figure 26(w). May 29, 2001; t = +764 days
Pond Level = 135.9 ft msl [07/20/01: 9]

Figure 26(v). Apr 20, 2001; t = +725 days
Pond Level = 137.0 ft msl [06/08/01: 19]

Figure 26(x). Jul 03, 2001; t = +799 days
Pond Level = 135.5 ft msl [07/31/01: 9]

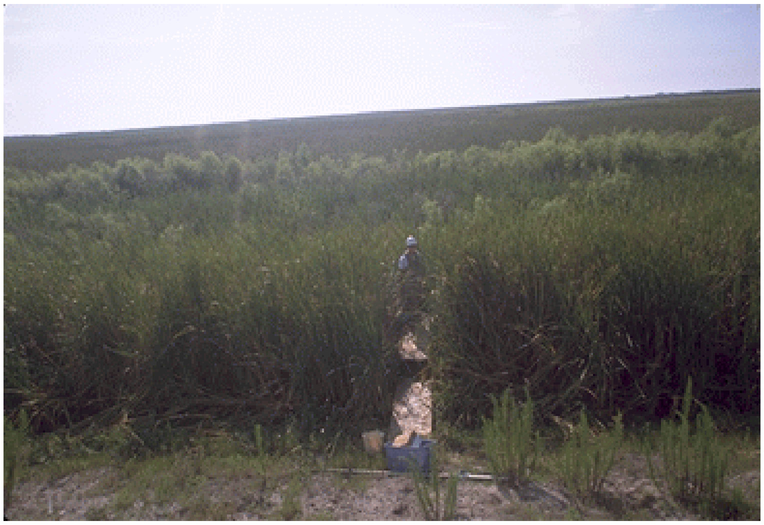

Figure 27. Performing Vane Shear Tests and Obtaining Piston Tube Samples of Clay.
Jun 07, 2001; t = +773 days; Pond Level = 135.8 ft msl
[07/20/01: 19]

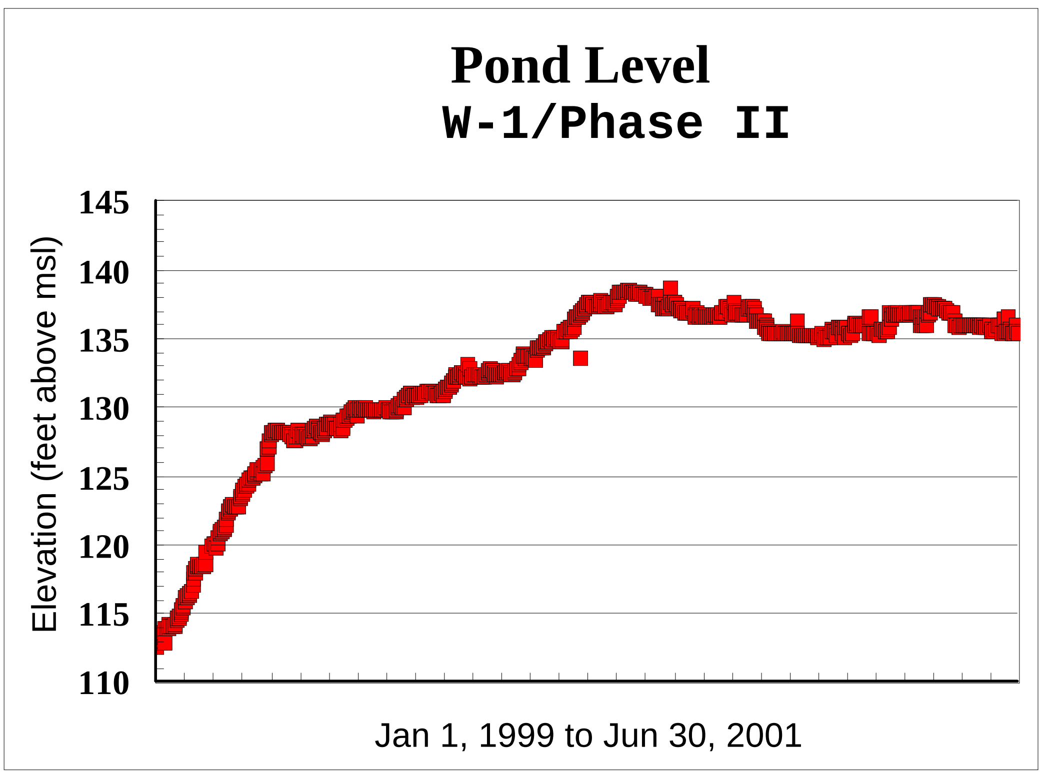

Figure 28. Daily Pond Level.

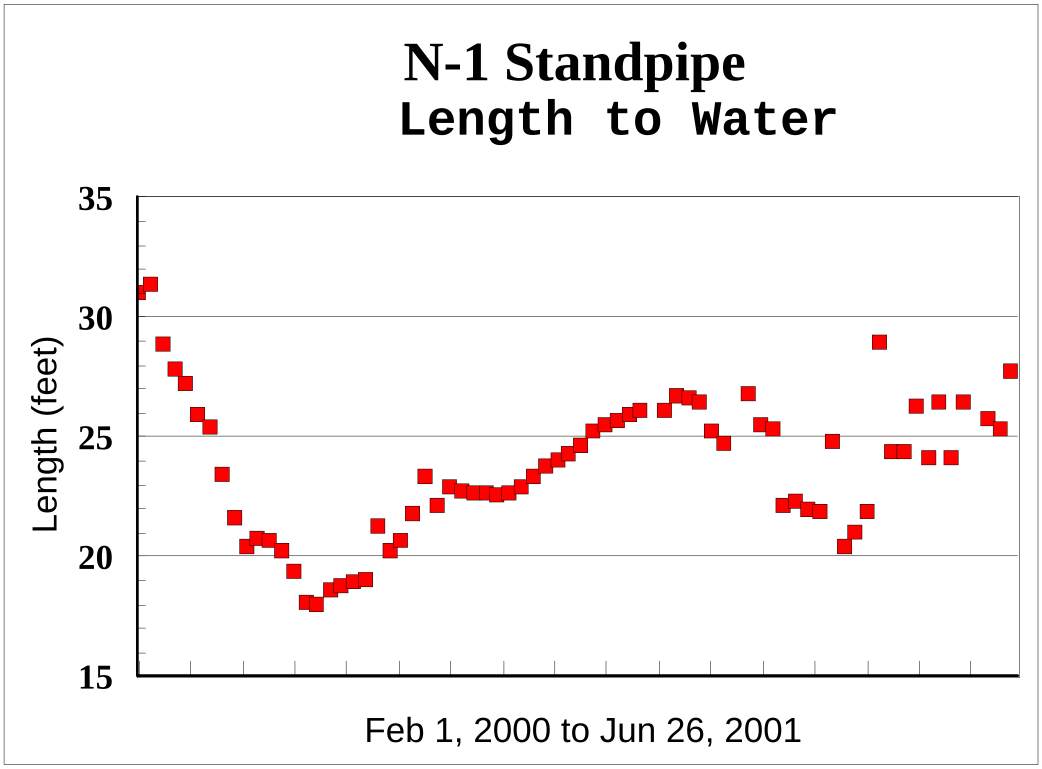

Figure 29. Weekly Length to Water in N-1 Standpipe.

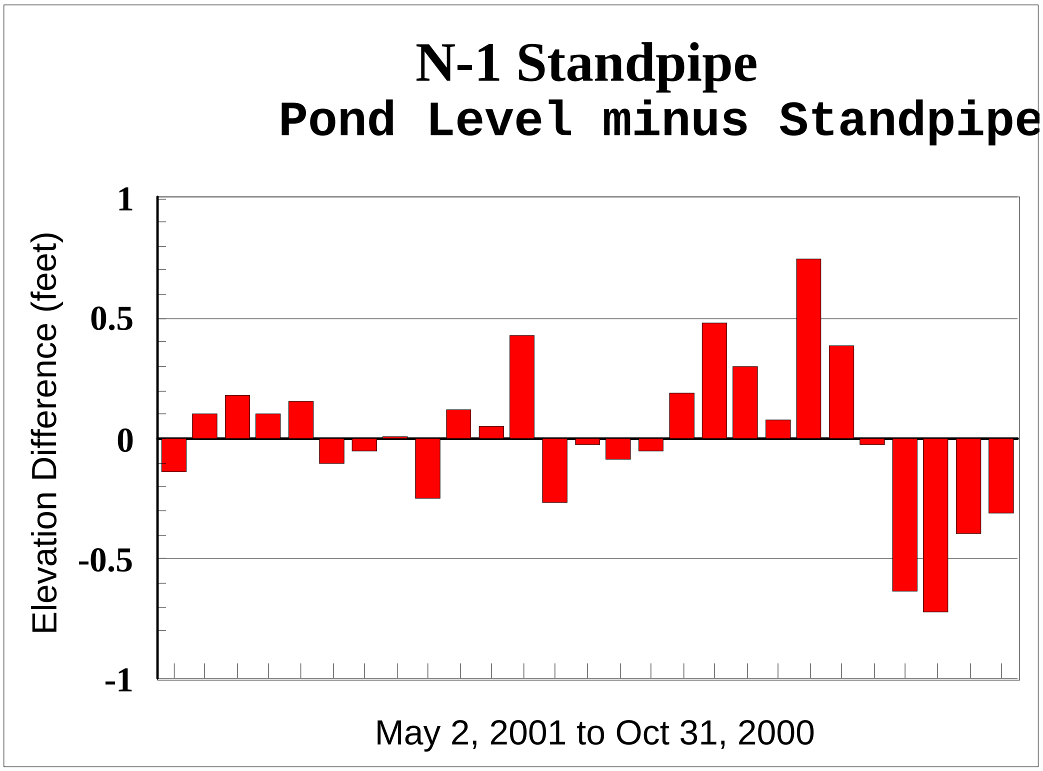

Figure 30. Elevation Difference between Pond Level and N-1 Standpipe.

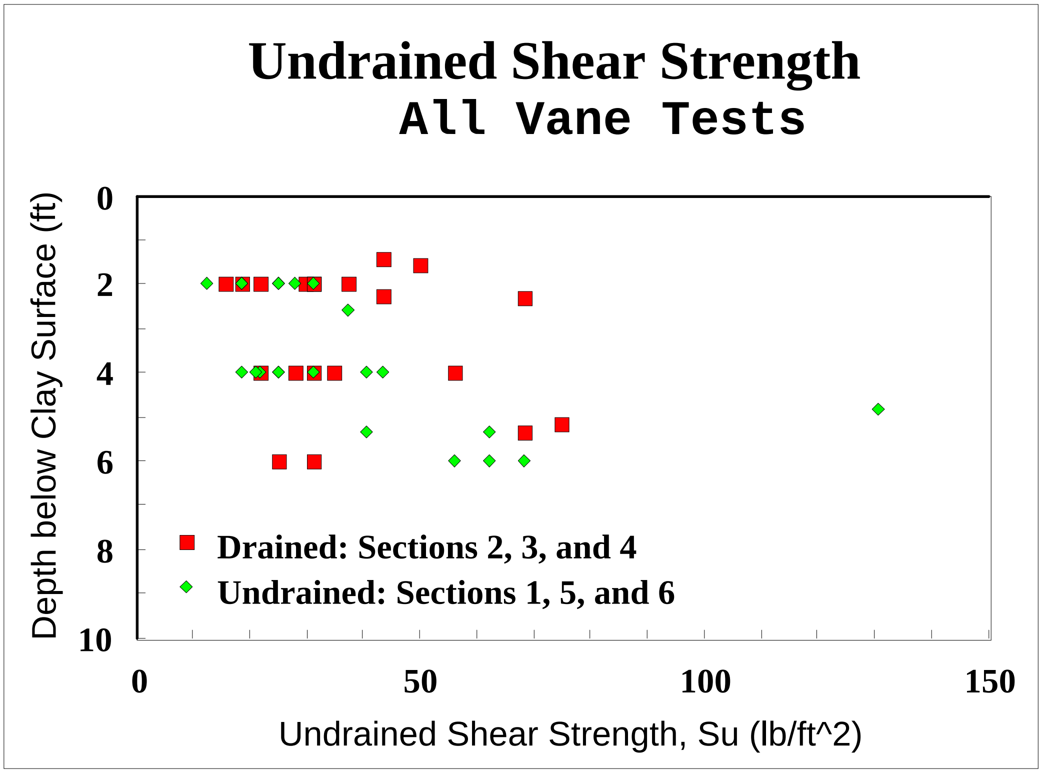

Figure 31. In Situ Vane Shear Strength of Clay.

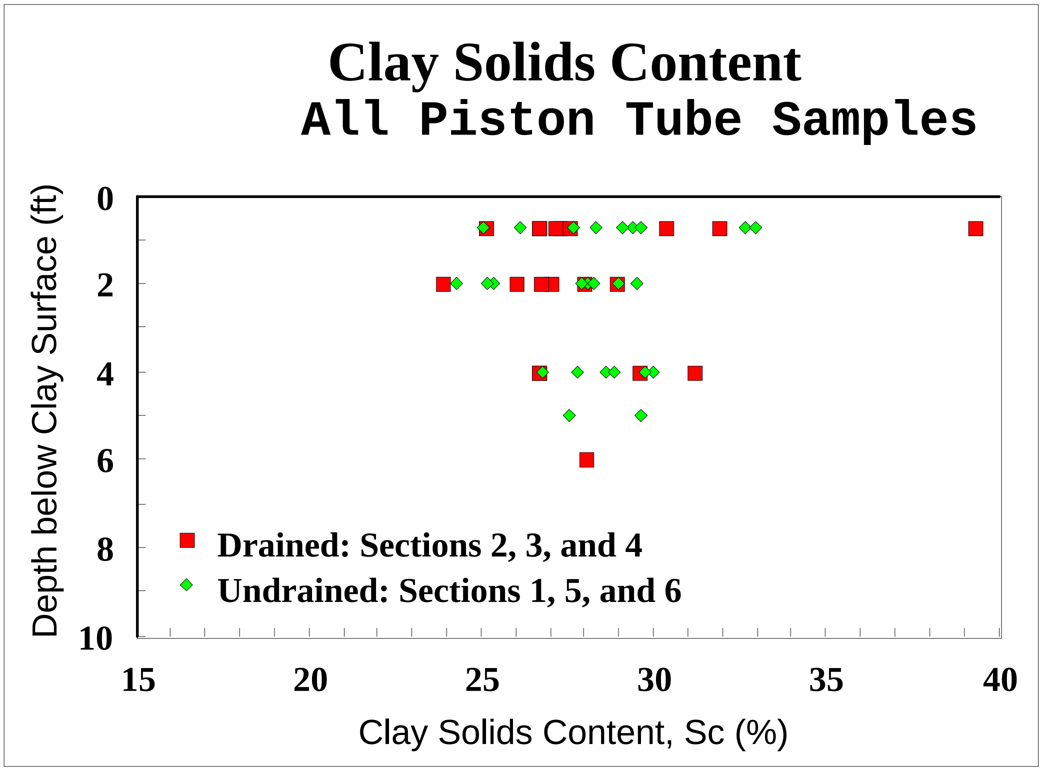

Figure 32. Clay Solids Contents from Piston Tube Samples.

Table 1. Photographic Documentation.

Time[1]		Number of Photographs		
Date	(Days)	W-1/Phase I	W-1/Phase II	Photo CD Number
Jul 09, 1998	-291	6		08/13/98
Aug 11, 1998	-258	18		08/19/98
Sep 17, 1998	-221	13	4	09/24/98
		2		11/30/98
Oct 21, 1998	-187	26	3	11/30/98
Nov 19, 1998	-158	5		11/30/98
		8	2	01/07/99
Dec 23, 1998	-124	14	2	01/07/99
		10	6	01/29/99
Jan 26, 1999	-90	14	12	03/01/99
Feb 17, 1999	-68		1	03/01/99
		6	3	04/12/99
Mar 09, 1999	-48	4	4	04/12/99
Apr 05, 1999	-21		6	04/12/99
			1	04/14/99
Apr 06, 1999	-20		13	04/14/99
Apr 07, 1999	-19		21	04/14/99
Apr 08, 1999	-18		2	04/14/99
Apr 14, 1999	-12		11	04/28/99
Apr 18, 1999	-8		6	04/28/99
Apr 20, 1999	-6		7	04/28/99
Apr 26, 1999	0		12	06/08/99
May 03, 1999	+7		6	06/08/99
May 28, 1999	+32		11	06/21/99
Jun 06, 1999	+41		10	06/21/99
Jun 11, 1999	+46		5	06/21/99
Jun 30, 1999	+65	1	29	07/08/99
Jul 16, 1999	+81		3	07/31/99
			10	08/06/99
Aug 02, 1999	+98	3	11	09/03/99
Aug 25, 1999	+121		11	09/29/99
		2	5	09/29/99
Sep 17, 1999	+144		4	09/29/99
		2	18	10/05/99
Oct 18, 1999	+175		4	10/25/99
			11	11/30/99

[1]Time = 0 corresponds to Apr 26, 1999, which is when the geodrain installation was completed.

Table 1. (Cont.) Photographic Documentation.

Time[1] Date	(Days)	Number of Photographs W-1/Phase I	W-1/Phase II	Photo CD Number
Nov 11, 1999	+199		3	12/16/99
Nov 19, 1999	+207		6	12/16/99
Nov 23, 1999	+211		3	12/27/99
Nov 24, 1999	+212		4	12/27/99
Dec 17, 1999	+235		11	12/27/99
			11	01/21/00
Jan 12, 2000	+261		19	01/21/00
Feb 16, 2000	+296		19	02/25/00
			18	03/15/00
Feb 24, 2000	+304		3	03/15/00
Mar 14, 2000	+323		21	04/06/00
Mar 28, 2000	+337		3	04/06/00
			2	04/24/00
Apr 07, 2000	+347		23	04/24/00
Apr 20, 2000	+360		19	05/22/00
May 12, 2000	+382		6	05/22/00
			13	06/02/00
May 23, 2000	+393		11	06/20/00
Jun 07, 2000	+408		19	07/13/00
Jun 29, 2000	+430		16	08/02/00
Jul 19, 2000	+450		6	08/02/00
			11	08/25/00
Aug 16, 2000	+478		10	08/25/00
			9	11/08/00
Sep 25, 2000	+518		21	11/08/00
Oct 03, 2000	+553		21	11/08/00
			3	12/27/00
Nov 09, 2000	+563		21	12/27/00
Dec 15, 2000	+599		3	12/27/00
			17	02/06/01
Feb 22, 2001	+668		21	03/14/01

[1]Time = 0 corresponds to Apr 26, 1999, which is when the geodrain installation was completed.

Table 1. (Cont.) Photographic Documentation.

Time[1]		Number of Photographs		
Date	(Days)	W-1/Phase I	W-1/Phase II	Photo CD Number
Mar 23, 2001	+697		17	03/30/01
			2	06/08/01
Apr 20, 2001	+725		14	06/08/01
May 29, 2001	+764		4	06/08/01
			15	07/20/01
Jun 07, 2001	+773		5	07/20/01
Jul 03, 2001	+799		9	07/20/01
			20	07/31/01

[1]Time = 0 corresponds to Apr 26, 1999, which is when the geodrain installation was completed.

Table 2. Atterberg Limits of Clay.

Composite Sample	Liquid Limit LL (%)	Plastic Limit PL (%)	Plasticity Index PI = LL – PL (%)
1	206	54	152
2	211	54	157
3	203	50	153