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DEVELOPMENT AND EVALUATION OF A RAPID CLAY-DEWATERING (FIPR-DIPR) PROCESS AS A RECLAMATION TECHNIQUE

Prepared by
Hassan El-Shall

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Phosphate Research

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DEVELOPMENT AND EVALUATION OF A RAPID CLAY-DEWATERING PROCESS (FIPR/DIPR) PROCESS AS A RECLAMATION TECHNIQUE

FINAL REPORT

FIPR # 93-02-93R

Submitted by

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August 1995

DISCLAIMER

PERSPECTIVE

By Patrick Zhang
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The mining and beneficiation of phosphate rock produces large quantities of phosphatic clays. Approximately one ton of clay is generated for each ton of phosphate rock product. Nearly 100,000 tons per day of waste clays are currently produced by the phosphate mines in Florida. The waste clays create one of the most difficult disposal problems in the mining industry. The standard disposal method requires constructing huge settling ponds, tieing up a great amount of water and large acreages of land which otherwise could be used for intensive agriculture, construction or recreation. As of November 30, 1994, 84,218 acres of unreclaimed clay settling areas had accumulated in central Florida.

Because of their colloidal nature and finely divided size, the phosphatic clays settle extremely slowly. Mechanical dewatering or chemical treatment processes are too expensive. Development of a rapid dewatering/consolidation/reclamation technique has been one of FIPR's major research priorities since its inception. Enhancing the consolidation process has three major benefits: 1) accelerating the water reuse process so that water loss by evaporation could be reduced, 2) maximizing the storage capacity of clay settling ponds, therefore limiting the number of new ponds needed, and 3) speeding up the reclamation process, thus restoring lands to a productive use more quickly. In July 1993, the FIPR Board approved funding for the project "Evaluation of FIPR/DIPR Process as a Reclamation Technique Phase I". This project is an extension of an in-house project (FIPR 91-02-086) that resulted in the FIPR/DIPR process.

The FIPR/DIPR process involves flocculating the phosphatic clay suspensions with a polymer, strengthening the flocks with a fibrous material (waste paper pulp), and separating the flocks from water by screening. Two possible approaches for utilizing this technique in the reclamation process have been proposed: using it on fresh slurry to eliminate the need to construct new settling ponds, or treating pre-settled clays from active settling ponds to increase the storage capacity.

Although the process does not appear to be an economically attractive alternative to the present impounding technique, it has found application in the clay industry as well as for cleaning the organic muck from lakes. It should be pointed that the economic evaluation in this project did not consider the benefits of the rapid reuse of water and more productive utilization of the lands which otherwise would be occupied by clay slurry for many years. Too, there may be future mining sites where the public will not allow construction of large clay settling ponds, so that the only viable alternative would be to employ a FIPR/DIPR type technology.

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Executive Summary

Since its inception, the Florida Institute of Phosphate Research (FIPR) has been pursuing an economical, practical, and environmentally-sound technique for dewatering phosphatic clays. In-house research has shown that when small amounts of fibrous materials and flocculant are mixed with a phosphatic clay slurry, very rapid dewatering of the clays occurs. The clay solids form a mass that continues to release water when pressed. Clay solids content of up to 25% can be obtained by simply rolling the clay mass on a screen. After squeezing or pressing the mass, solids contents of up to 50% can be obtained.

This report consists of two parts. Part one gives a chronological account of the development work leading to a new process for rapidly dewatering waste slurries, particularly phosphatic clays (FIPR/DIPR). Part two reports on an evaluation of different disposal options using the developed process or a modified version of it.

1. Process Development:

Settling tests

The data suggest that a 5% level fiber of addition enhanced the initial settling rate of the flocculated slurry. At higher fiber content (15%), however, the settling rate decreased.

Vacuum filtration tests

The data indicate that faster filtration can be obtained with the addition of fibers. However, addition of more than 10% of fiber impedes the filtration rate. The percent solids in the filter cake suggests that fibrous material does produce drier cakes at addition levels of less than 10% of the weight of dry clays.

Screen dewatering tests

The tests show that 50% of the flocculated clays will pass through the screen unless fibrous material is added. The fibrous material obviously strengthens the flocs, allowing more solids to be retained on the screen (up to 99% depending on the amount of fiber). In addition, up to a 12% solid content can be obtained in the dewatered clays. This is a significant considering the fact that the starting slurry contained only 2.0% solids. A longer retention time on the screen was found to yield higher solids contents. In addition, pressing these solids leads to further dewatering. It is important to note that such mechanical pressing cannot be applied to clays not containing fiber.

Centrifuge testing

The feed contained very, very fine solids with an average weight diameter of 8.0 microns. Naturally, filtration and/or centrifugation of unflocculated samples would be a difficult task (as is reported in the literature). However, flocculation of such clays in the presence of fibers was found to accelerate dewatering.

a) Solid Bowl Decanter Test

The results suggest that cakes of better than 19% solids can be obtained. Also, the solids content and recovery can both be increased as the force and retention times are increased. A perforate bowl centrifuge was used to measure the maximum cake dryness.

b) Perforate Bowl Solids Dewatering Test

The data indicate that a one-minute retention time will give more than 35% clay solids in the product. It is worthwhile to mention here that such a high percentage can only be obtained after decades of natural settling in Florida's clay disposal areas. However, the economics of using centrifuges to achieve a consolidation level of +35% solids is not realistic. The low capacities of such machines would make the capital costs unbearable. Further research was directed to static dewatering screens.

Small-scale Continuous Agitation-Flocculation Tests

The data suggest the following:

1. Solids recovery increases as the polymer concentration and fiber addition increase. On the other hand, higher solids in the clay slurry lead to a decrease in recovery.

2. Polymer consumption increases as fiber and/or clay solid contents increase. Interestingly enough, as the polymer concentration is increased, its consumption decreases.

3. Clays can be dewatered instantaneously, with an increase in solids content from 2.2% up to 22% using static screens.

4. Close examination of the polymer consumption levels, however, indicate that such levels are too high to be economically for waste tailings such as phosphatic clays. Also, such levels were significantly higher than the consumption data developed in the batch tests.

The last observation lead us to investigate why the continuous tests required such a high polymer consumption. Visual examination of floc formation in the agitation-flocculation tank indicated that floc disintegration was also taking place in the same tank.

Pilot Plant Tests

Based on the above observations, we decided to investigate different ways of mixing, including on-line static mixers. Such research efforts resulted in the design of a pilot plant unit using on-line mixers.

The pilot unit was used to test the rapid dewatering process on clays from different mines. Polymers from various suppliers were tested.

The data indicate that Percol 156 is one of the more effective polymers. Thus, further work was carried out with this polymer at different feed solid contents.

The data suggest that polymer addition as low as 0.7 lb/ton of clay may be effective in producing a dewatered product of 15% solids content. Increasing the amount of fiber addition to 10%, however, did not produce a significant improvement in product solids content. Polymer requirements were also higher, as shown in Table 10.

Using two stages of screening and belt pressing the pilot plant was operated on clays from a different mine in Florida. The results showed that phosphatic clays may be dewatered to levels approaching 50% solids content using the FIPR/DIPR process. However, belt presses would only be economic with higher value clay products. Nevertheless, reasonably high solid content clays can be obtained by using only static screens.

Sand/clay Mix

Limited pilot plant testing with the addition of sand (dry or wet) on the screen was conducted to test sand/clay mix. The results have indicated that wet sand can be dewatered on the screen and that it mixes with the floculated clay/fiber mix and continues to dewater as it rolls down the screen. Dry sand addition on the screen produced similar results. It is important to note that the amount of sand added (sand/clay ratio) is not critical since a ratio of 0.5 was used and the dewatered product contained over 47% solids by weight. The amount of fiber used was 3.0% of the dry weight of clay and polymer (Percol 156) addition was 0.5 lb/ton of clays. The product seemed fluid enough to be pumpable. Nevertheless, the fluidity and pumpability of sand/clay mixes need to be evaluated.

Seepage Induced Consolidation Tests

a. Column tests: A 2^3 factorial design was used to test the effect of the following variables: A (polymer dosage; 0.5 to 1.0 lb/ton), B (pulp dosage; 3 to 6% dry fiber to dry weight of clay), and C (type of polymer; Percol 156 and a Percol 156/Drimax 1235 blend at 9/1 ratio). Drimax 1235 is a surfactant used to enhance drainage through the sand layer.

The data suggest that the surfactant shortens the drainage time. Also a product of 26% solids might be obtained in a reasonably short drainage time with the lowest level of polymer and fiber addition. These data were confirmed in larger scale (drum tests).

b. Drum tests: In these tests the flocculated/fibered clays were deposited on a layer of sand in 55 gallon drums. After two hours of settling, clear water was decanted from the top of the drums until the clay surface appeared. The water was then left to drain through the bottom sand layer and samples were taken for solids analyses. The results confirm the small scale (column) consolidation tests and indicate that higher % solids can be obtained.

The "AQUARIUM"

In order to test on a bench scale the proposition that it might be feasible to dewater a clay/polymer/fiber mix over a substratum of tailings sand in a mine cut, we fabricated a 2 X 6 foot plywood box with a wooden separator at one end. A three inch layer of phosphate tailings sand was deposited on the bottom, with an inch opening between the compartments to allow the water to drain laterally through the sand to the right side of the box where it could be drained off into a barrel. The box was filled with the clay/polymer/fiber mix and allowed to settle. After the clay had drained and dewatered to such an extent that it was shrinking away from the sides of the box (at about a 25% solids content), a 3 to 4 inch layer of slurried tailing sands was distributed on top of the consolidated clays. The important point was whether or not the clay layer would stop water penetration. In one test fiber was omitted from the clay/polymer mix placed over a layer of consolidated clays. The drainage was painfully slow. However, when the recommended amount of fiber was included, the water penetrated the clay layer and drained off rapidly.

In another run, after standing for 48 hours under a surcharge of sand, the bottom layer of clay analyzed 48% solids (Figure 13). Subsequent layers of clay and sand were deposited, and it became obvious that as the lower layers of clays shrank, they allowed freer drainage of the water through the lower sand layers.

PROPOSITIONS FOR LARGE SCALE APPLICATIONS OF THE FIPR/DIPR PROCESS

The following options may be considered as possible disposal methods for clays treated by the FIPR/DIPR process, or modified versions of it.

Option A) - Mining Cut (pit) Disposal

The mine cut is separated into two sections by a cofferdam, as shown in the illustration, with the smaller right hand portion acting as a water reservoir from which the recovered water can be recycled to the washer using a floating pump. Large (22 inch) pipes are placed in the cofferdam wall with the left hand end buried in a two-foot layer of tailings sand. The clay/polymer/fiber slurry is pumped onto a floating barge to break the hydraulic force, and the flocculated mixture distributes itself over the sand throughout the mine cut. The water flows into the sand layer and through the pipes buried in the cofferdam to the right hand portion of the cut where the water is pumped back to the washer. After the water has drained from the clays and they have dewatered to the point of shrinking, cracking and pulling away from the sides of the mine cut, dewatered sand tailing are pumped onto the barge and distributed as uniformly as possible by moving the barge from one end of the cut to the other. The surcharge of sand squeezes additional water out of the clay layer (>40% solids), and the pit is then ready for a second filling with clay/polymer/fiber mix. Drainage time on the field level with a much higher hydraulic head will have to be determined experimentally, but pilot results suggest 48 to 60 hours will be adequate. After the pit has been filled to the maximum level practical with the sandwiched clay and sand, overburden would be bulldozed over the top to complete the reclamation process.

Because rapid dewatering of the clay suspension can be observed immediately after the polymer and fiber are added, logic would say that one should remove as much water as possible at the washer in order to save pumping costs. Pumping a 15% solids slurry to a mine cut, which may be miles away from the washer, is certainly preferable to pumping a 3% slurry. One problem, yet to be evaluated, is how much degradation the flocs undergo while being pumped long distances. The suggestion has been made that only half the polymer be added at the washer, with the other half to be added at the mine cut. A second issue, yet to be demonstrated, is the distribution of the tailings slurry (50+% solids) across the consolidated clays. This will undoubtedly require multiple introduction points along the mine cut, as the tailings will not flow readily. The logistics of moving waste newsprint to the washer will be substantial. One might estimate that a 3 million ton per year mine would produce roughly 3 million tons of clay solids. If the fiber dosage is in the range of 3 to 5%, it would require 90,000 to 150,000 tons of waste newsprint annually or 300 to 500 tons/day. The paper would have to be slurried and pulped in recycle water before mixing with the polymer and clay. All materials would be mixed with in-line static mixing devices. The polymer would have to be prepared as a dilute solution, then further diluted before mixing with the fiber and clays. A 3 million ton operation would require a million pounds of polymer/year.

Option B) -_ Median Strip

A second possible dewatering scenario involves utilizing the median strip between two parallel mine cuts as a clay dewatering area. The median strip would be sloped slightly and dammed at the top and ends to allow water to drain into the topmost mine cut (#2). About two feet of slurried tailing sands would be deposited onto the median, and the transport water allowed to drain into cut #2. Treated clay mix (clay / polymer / fiber) would then be pumped onto the sand layer. The water would quickly drain through the tailings into cut #2 where it would be recycled to the washer. The drained and air-dried clay layer atop the sand tailings would then be bulldozed into cut #l. This process would be repeated until cut #l was filled with the dewatered sand/clay material. Overburden would then be pushed over the top to complete the reclamation. Cut #2 would then be filled in the same manner, using cut #3 as a temporary water reservoir.

The median strip scenario would have the disadvantage of co-mingling the clay and tailings, which might make future treatment of the clays (to recover P_2O_5 values) more difficult.

Option C) - Sand mix with FIPR/DIPR product

In this option sand tailings are dewatered as currently done, but on the top of the static screens. The cyclone underflow (dewatered sand) flows on the screens to mesh with the flocculated FIPR/DIPR mix. Both sand and flocculated clays will undergo dewatering on the screens. Actually, the sand will help in retaining fines on the screens. The sand clay mix is then pumped at high % solid content (> 45%) to the mine cut.

OTHER ISSUES

Recycle water quality

On a small scale the quality of recovered water has been excellent. Bench flotation tests, using water recycled several times, has shown a slight increase in flotation performance if anything. A polishing filter would probably not be necessary in a field operation.

Degradation of the newsprint and its environmental effects

The intimate mixing of paper fibers and clay will result in the ultimate biodegradation of the paper, though under anaerobic conditions (from recent reports of sampled landfills) the fiber might last for some time.

Tests were conducted to test the possibility of contamination of underground water from metals that may be in the ink and the organic products that may result from the biodegradation of the fiber. Four leaching columns were set where clay, flocculated clay, flocculated clay plus fiber were deposited, and drainage water was collected over a period of four months, then sent to an environmental laboratory for analyses for both inorganic and organic "EPA Priority Pollutants". The data indicate the presence of flocculant and/or fiber does not increase the elemental content of the water. Organic priority pollutants are found to be less than the EPA standards for drinking water as indicated in the EPA regulations.

Potential environmental advantages

The FIPR/DIPR process appears to offer a number of potential advantages to the environment, though these will have to await large scale practice for quantification:

a. Water use reduction through avoiding the solar evaporation experienced with large volume waste clay ponds.

b. Elimination or significant reduction of the consequences of a dam failure/threat to water supplies and property.

c. More rapid reclamation of some of the mine cuts.

d. Reduce the acreage devoted to clay settling areas.

e. Returning more reclaimed acres to the tax roles/providing more options for habitat creation.

f. Though not an environmental consideration, consolidating the clays in re-minable seams might allow the industry to recover the phosphate values in future years (mine cut option only), if that were practical/economical.

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f. Though not an environmental consideration, consolidating the clays in re-minable seams might allow the industry to recover the phosphate values in future years (mine cut option only), if that were practical/economical.

FIPR/DIPR DISPOSAL ANALYSIS

As mentioned above, previous work completed at FIPR has identified two suggested disposal alternatives for the FIPR/DIPR: mine cut disposal and median strip disposal. During this project, GMC and BCI's personnel met with mining and reclamation personnel from several of the mining companies to describe the two disposal alternatives for the FIPR/DIPR process. Comments from the companies were instrumental in developing the FIPR/DIPR disposal method included in the economic comparison with dilute clay disposal.

INDUSTRY COMMENTS

Mine Cut Disposal

- Placing alternating two foot layers of sand and clay mix would not be practical in the field and would be very expensive.
- Operational control would be hard to achieve given the typical 24 hour a day operating schedule currently employed at the mines.
- Deposition of clay/pulp/paper mix in cuts has the possibility of spilling to adjacent areas.

Median Strip Disposal

- Placing clay/paper/pulp mix in two foot layers would not be practical in the field given the large quantity of clay produced per hour.
- Operational control would be hard to achieve given 24 hour a day schedule.
- This method would require intensive manpower and field equipment.
- The possibility of spilling clay/pulp/paper mix into adjacent areas was also a concern.

Low Embankment Disposal

Based on comments received from the mining industry, BCI developed a low embankment disposal method. This method involves building an embankment of sufficient height to store the FIPR/DIPR mix with the required five foot freeboard required by FDEP Chapter 62-672. The basic characteristics of the low embankment disposal method are listed below.

- Large areas of mined-out areas are selected for construction of an engineered embankment within which FIPR/DIPR clay mix would be deposited.
- The FIPR/DIPR mix would be generated at a facility constructed at the beneficiation plant and the mix would be pumped to the low embankment.
- Clear water would be returned from the FIPR/DIPR disposal areas to the hydraulic ditch as is now done.
- Currently sized motors and pipelines are assumed to be sufficient to pump the FIPR/DIPR mix.

The requisite characteristics of this disposal method based on the interviews are listed below.

- Construction and operational methods are similar to those now employed.
- Operational requirements are minimal.

- This method avoids intensive manpower and field equipment required in the two other FIPR/DIPR disposal methods discussed.
- This method maintains the water storage capacity of the current clay disposal method.

Evaluation of Low embankment Disposal Alternative

Using the consolidation parameters measured by BCI from one consolidation test and BCI's proprietary finite strain consolidation program FLINZ2, computer analyses were completed to compare a mine scenario of clay and FIPR/DIPR mix disposal. The analysis simulated a three year fill of a clay settling area and the ultimate consolidation conditions. The fill reflects 2.9 MT (dry weight basis) of clay produced per year. Consolidation simulations for the FIPR/DIPR clay included 2.987 MT per year reflect the paper and pulp added to the clay. The analyses included deposition into an area with 967 acres of effective storage area, with a 40 foot fill height for the Restricted Plow Consolidation (absorbtion) clay sample.

Input parameters for the computer programs include settling area geometry, flow rate, filling time, initial clay solids, and the engineering properties of the clay including specific gravity, compressibility parameters, and permeability parameters. The modeling using the RFC parameters indicate that the clay sample has a fill height of 40 feet and the clay, polymer, pulp sample has a fill height of 30 feet. Ultimate heights are 13 feet for the clay sample and 17 feet for the clay, polymer and pulp sample. Since the permeability parameters govern how quickly consolidation occurs, the clay, polymer and pulp mix, with its better permeability characteristics will settle faster. The four foot difference in ultimate height indicates the clay sample has better compressibility characteristics.

CONCLUSIONS REGARDING LOW EMBANKMENT DISPOSAL ALTERNATIVE

- One Restricted Plow Consolidation test was completed in the BCI laboratory on FIPR/DIPR mix and untreated clay. Consolidation analyses based on consolidation parameters derived from the limited data indicate the FIPR/DIPR clay mix shows improved consolidation in the short term due to improved permeability. Ultimately, the dilute clay consolidates to a higher percent solids than the FIPR/DIPR mix due to better compressibility characteristics.

- The cost of polymer ($1.5 million/year) and paper ($0.9 million/year) represent about 85 percent of the additional annual operating costs for the FIPR/DIPR process.

- Cost reductions identified for the FIPR/DIPR process include $0.5 million per year in reduced settling area construction. Implementation of the process include operating costs of $2.78 million per year and capital costs of over $0.9 million.

- Cost of paper could be higher (as much as $20/ton) to remote beneficiation sites with long haul distances from paper sources.

- Eliminating the embankment would still not produce net cost savings for the FIPR/DIPR process compared with conventional clay disposal.

- Additional research would be justified if cost reductions in the two additives, paper pulp and polymer, are identified.

- Alternative process or disposal methods for the FIPR/DIPR mix such as sand/clay mix and dewatering on the screen would be required to justify large-scale implementation.

PART I
Process Development

1. INTRODUCTION

During beneficiation of Florida's phosphatic ores, the fines fraction (-150 mesh) is separated by cyclones as a dilute (3-5% solids by weight) aqueous slurry. The solids are a mixture of clay minerals, silica sand, apatites, and other finely divided minerals. This slurry (commonly called phosphatic clays) is pumped into large impoundment areas for natural settling. However, because of the colloidal nature and slow consolidation characteristics of such clays, large above-ground storage areas are required. In order to place these clays, together with the sand tailings (from the flotation process), back into the original mine cut without building above-ground dams, the clays would have to be dewatered to over 47% solids by weight. Unfortunately, decades are needed for clays to dewater to such a high solids level in conventional settling areas. Thus, a huge volume of water and large areas of land are tied-up by impounding these clays for a long period.

Since the 1950's, the problems associated with phosphatic clay disposal have stimulated research efforts to find economical and practical methods for dewatering and consolidating phosphatic clays. Various schemes have been proposed over the years, with a few marginally viable disposable methods. These techniques are documented in the literature (1-21). Among the published art one finds the use of polymers to flocculate the solids, followed by solid-liquid separation device(s). Actually, polymer flocculation was practiced by Estech (a now defunct Florida phosphate miner) to flocculate the clays followed by thickening in a high capacity enviro-clear thickener. The company achieved its goals for disposal of their waste clays, as described by Raden (13,17) and Barnett (19). However, their technique has not received wide acceptance in the industry because of the relatively high capital cost of the thickener and relatively high operating cost due to polymer consumption. Estech's costs were offset by the cost savings in pumping clays and water to and from their settling areas, located near the beneficiation plant. Such distance is relatively larger in other mines.

Polymer flocculation followed by dewatering on a static screen and/or a rotating trommel was proposed and tested by the U.S. Bureau of Mines (13). Their results indicated a high percent solids content in the dewatered product could be obtained by using polyethylene oxide as the flocculating polymer. This polymer (PEO) produced strong flocs that could be mechanically dewatered on screens. However, due to its cost and its specificity toward some clays, the process has not been practiced by the industry. Nevertheless, such work inspired us to look for a substitute flocculant (in lieu of PEO) that might be of more reasonable cost and would be capable of flocculating a wide suite of clays.

After screening a large number of flocculants we concluded that polyacrylamide polymers were most promising. However, the flocs formed were not of sufficient strength and would break up readily when handled. The addition of a fibrous material (cellulosic fibers or other fibers) was found to help in forming much larger and stronger flocs, as shown in Figure 1.

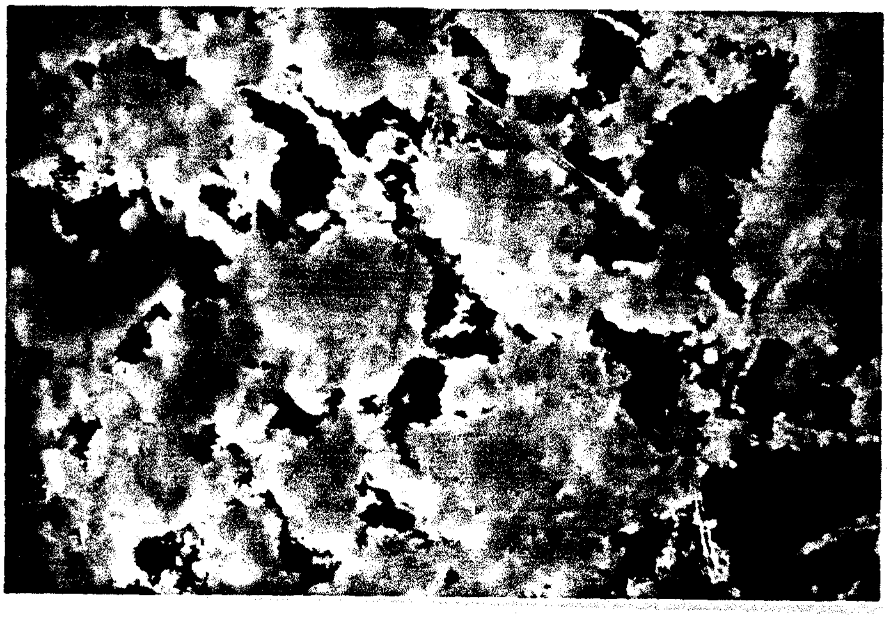

Figure 1: Photomicrograph of flocculated clays attached to fibers

A research effort was initiated to investigate the effect of fibrous material on the flocculation and dewatering of phosphatic clays. Several dewatering (solid/liquid) techniques were investigated, including sedimentation thickening; filtration; centrifugation; dewatering on screens; and seepage-induced dewatering and consolidation.

2. EXPERIMENTAL

1. Material

Phosphatic clay slurries from two different mines and of different solids content were used in this study. Flocculants evaluated included Percol 156 from Allied Colloids, Nalco 7877, Arrmaz 856 E and 957 G. A solution of 0.05% by weight flocculant was utilized for all the clays. Newsprint was used as a source of fibrous material.

2. Methodology

2.1. Sedimentation tests: Sedimentation tests were conducted in 1000 ml graduated cylinders. After the required amount of fiber was pulped with the clay (in a kitchen blender), the clay slurry was transferred to the cylinder and the required amount of polymer was added. Then, the cylinder was inverted ten times to assure complete polymer mixing and to allow flocculation to take place. Immediately after setting the cylinder upright on a flat surface, the height of the descending interface was recorded together with the elapsed time. A control test was conducted without the use of pulp.

2.2. Filtration tests: Clay slurry (100 ml) was flocculated in a 500 ml beaker with (and without) fibrous material. Flocculation was achieved by mixing the polymer solution with the clay slurry by pouring the slurry from one beaker to another ten times. The flocculated slurry was then filtered, using a 12.5 cm dia. Buchner funnel and an aspirator (creating 0.5 ATM of vacuum). Whatman #41 filter paper was the filter medium. The filtrate volume was measured in a graduated cylinder and recorded as a function of filtration time.

2.3. Dewatering on a screen: Plastic screen (10 mesh) was used to dewater 200 ml flocculated clay slurry samples in the presence (and absence) of fibrous material. Flocculation was conducted as described above. The flocculated slurry was then poured onto the screen for dewatering. After clear water stopped draining through the screen, the percent solids and percent solids recovery on the screens were determined.

2.4. Small-scale continuous centrifugation tests: A five-gallon clay sample was flocculated in the presence of fiber and sent to Bird Machine Company to conduct the following tests:

a. Solid bowl decanter test.

Solid bowl decanter performance was evaluated by metering a sample into a basket centrifuge at differing rates and gravitational levels. The supernate, which reports as an overflow stream, was analyzed for percent suspended solids. The cake which was compacted on the bowl wall, was analyzed for percent total solids. The expected percent solids, capture (recovery) and cake consistency over the centrifuge operating range were determined. These data also showed an optimal retention time and gravitational force for this application.

b. Perforate bowl dewatering test.

The perforate bowl is used to measure the maximum cake dryness possible with a given product. A thickened sample of feed is prepared to simulate the settled solids from a decanter centrifuge. This thickened material (mud) is then spun in a perforated basket with an open cloth liner to measure the consistency of the cake as a function increasing dewatering times and various gravitational levels.

2.5. Small-scale continuous agitation-flocculation and screen dewatering tests: The calculated amount of fiber was added to the clay slurry in a small agitated tank (2.0 minutes retention time at a speed of 75 rpm), while the polymer solution was continuously added at the top using a metering pump. The rate of polymer addition was preset, depending on the polymer concentration, clay percent solids, flow rates, etc., as determined during preliminary testing. The flocculated slurry flowed by gravity (through a stand pipe) to another agitated tank where the speed of agitation was much slower (25 rpm). Gentle agitation promotes floc growth. The flocculated pulp was then pumped to a hydrosieve where dewatering took place. Further dewatering was achieved on an inclined static screen (1.5 meters in length). A flow diagram showing the sequence of this continuous process is given in Figure 2.

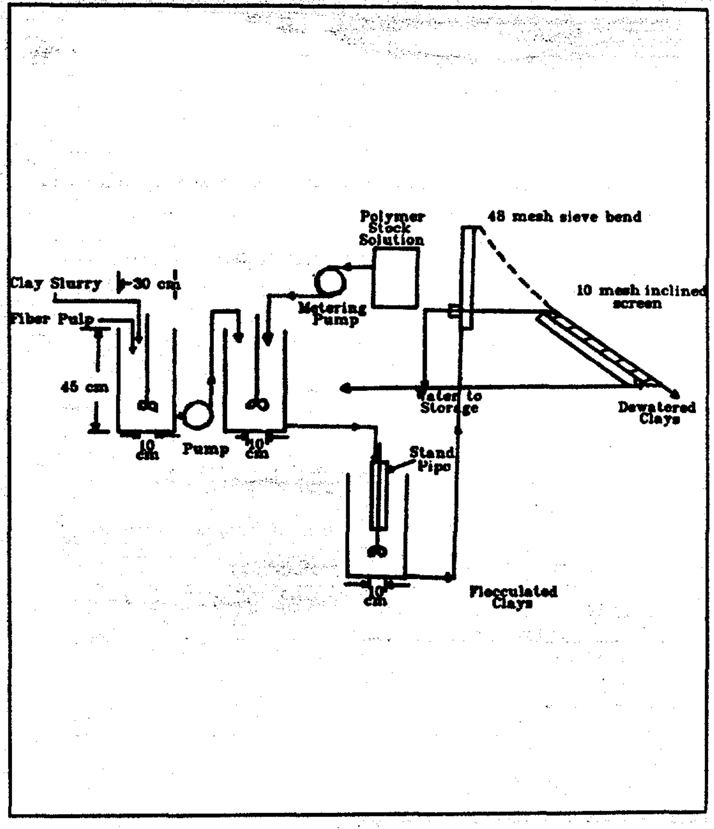

Figure 2: Flow diagram of continuous agitation - flocculation process

The set-up shown in Figure 2 was used to test the effect of variables such as clay solids content, polymer concentration, and the level of addition of fibers. A 2^3 factorial design was used, as shown below:

Run #	(Nalco 7877) Polymer	Clay Solid Weight Content,	Fiber/Clay %
8	0.10	2.2	0.0
7	1.00	2.2	0.0
6	0.10	4.4	0.0
5	1.00	4.4	0.0
4	0.10	2.2	5.0
3	1.00	2.2	5.0
2	0.10	4.4	5.0
1	1.00	4.4	5.0

2.6. Pilot Plant: A pilot unit was constructed and mounted on a trailer so that it could be conveniently moved from one mine site to another. A flow diagram of the pilot process is shown in Figure 3. The dewatering screens were used either as a single or double stage screening.

2.7. Seepage dewatering and consolidation: In these tests, phosphatic clay slurries were poured onto a layer of sand (- 35 + 150 mesh) at the bottom of a 6" diameter cylinder fitted with a discharge valve on the side (1" from the bottom). The valve permitted removal of the water that seeped through the sand layer.

Larger scale tests were conducted using 55 gallon drums. In certain cases, water was also decanted from the top and a 1" sand cap was placed on top of the clays to promote further clay consolidation.

3. RESULTS AND DISCUSSION

Several dewatering (solids/liquid separation) techniques were investigated:

3.1. **Settling tests:** The mathematical model described in an earlier report (23) was used to analyze the data obtained in the absence and presence of 5% and 15% by weight of dry clays of fibrous news print pulp. The following first order kinetics were found to give an

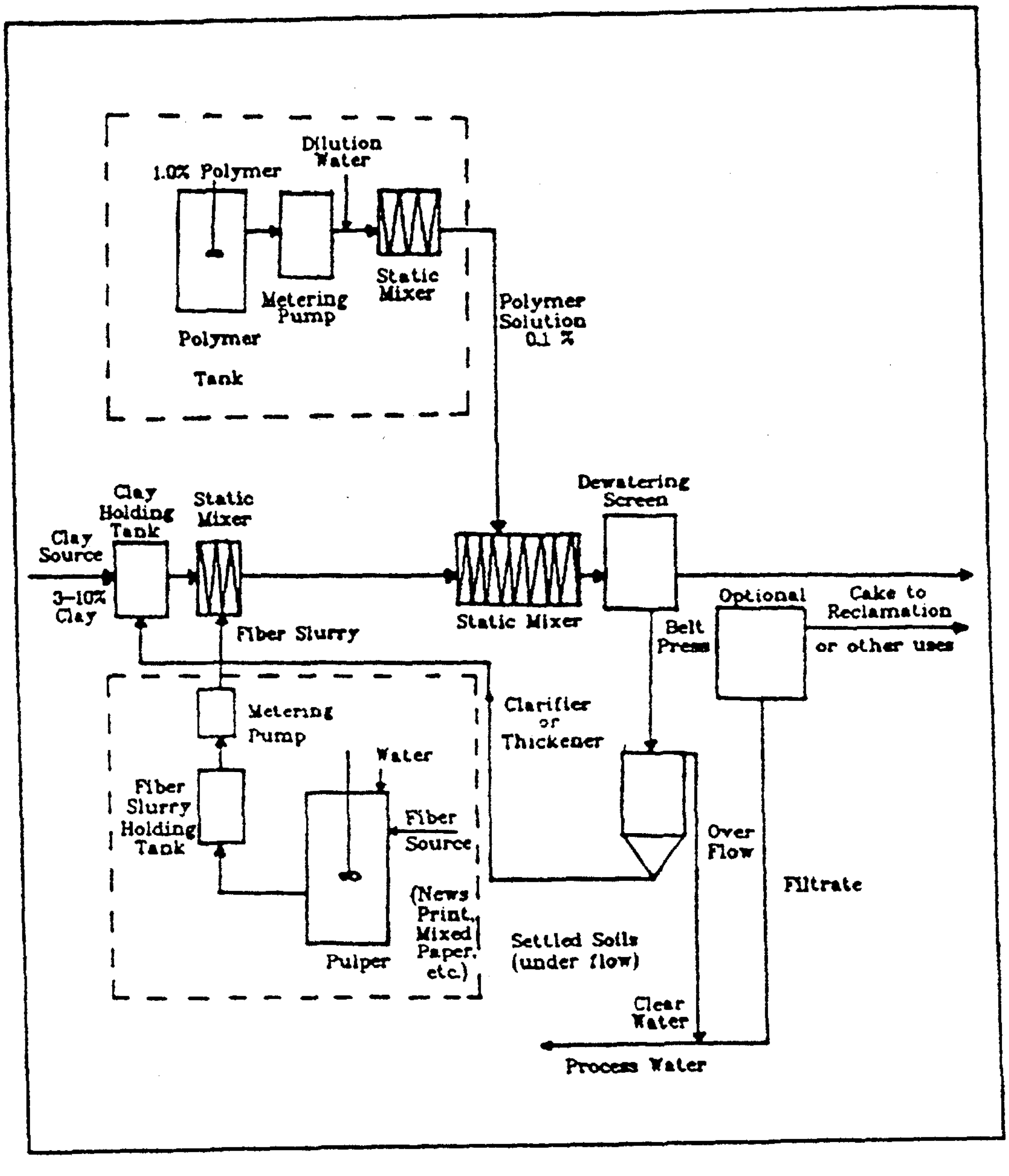

Figure 3. Flow diagram of the pilot plant of FIPR/DIPR process

data:

$$H_t = H_O \exp - kt + H_\infty[1\text{-}\exp\text{-}kt]$$

where

H_t = Height of interface (cm) at time = t
H_o = Initial height (cm) of slurry (at t=o)
H_∞ = Height of interface (cm) at infinite time (ultimate height)
t = Settling time, min
k = Rate constant, min^{-1}

The kinetic parameters for these tests are listed in Table 1.

Table 1. Kinetic parameters of the settling of flocculated phosphatic clays in presence and absence of fibrous material (0.8 lb/ton Percol 156 used as flocculant).

% fiber (based on dry clay weight)	k, min-1	H_∞, cm
0	0.129	13.7
5	0.154	14.1
15	0.13	15.9

The data in Table 1 and in Figure 4 suggest that the 5% level of addition of fiber enhanced the initial settling rate of the flocculated slurry. At higher fiber content (15%), however, the settling rate decreased. This may be explained by the stacking of fibers in a form leading to the increase in the drag force, hindering gravitational settling. The same mechanism has been used to explain the slow settling behavior of attapulgite (fibrous) clays. The results lead to the conclusion that gravitational settling is not the determining mechanism with high fiber containing clay slurries.

3.2. Vacuum filtration tests: Filtration time was recorded as a function of volume of collected filtrate from flocculated slurries in presence and absence of fibrous material. The data shown in Table 2 and Figure 5 indicate that faster filtration can be obtained with the addition of fibers. However, addition of more than 10% of fiber impedes the filtration rate. The percent solids in the filter cake, (See Table 3), suggests that fibrous material does produce drier cakes at addition levels of less than 10% of the weight of dry clays.

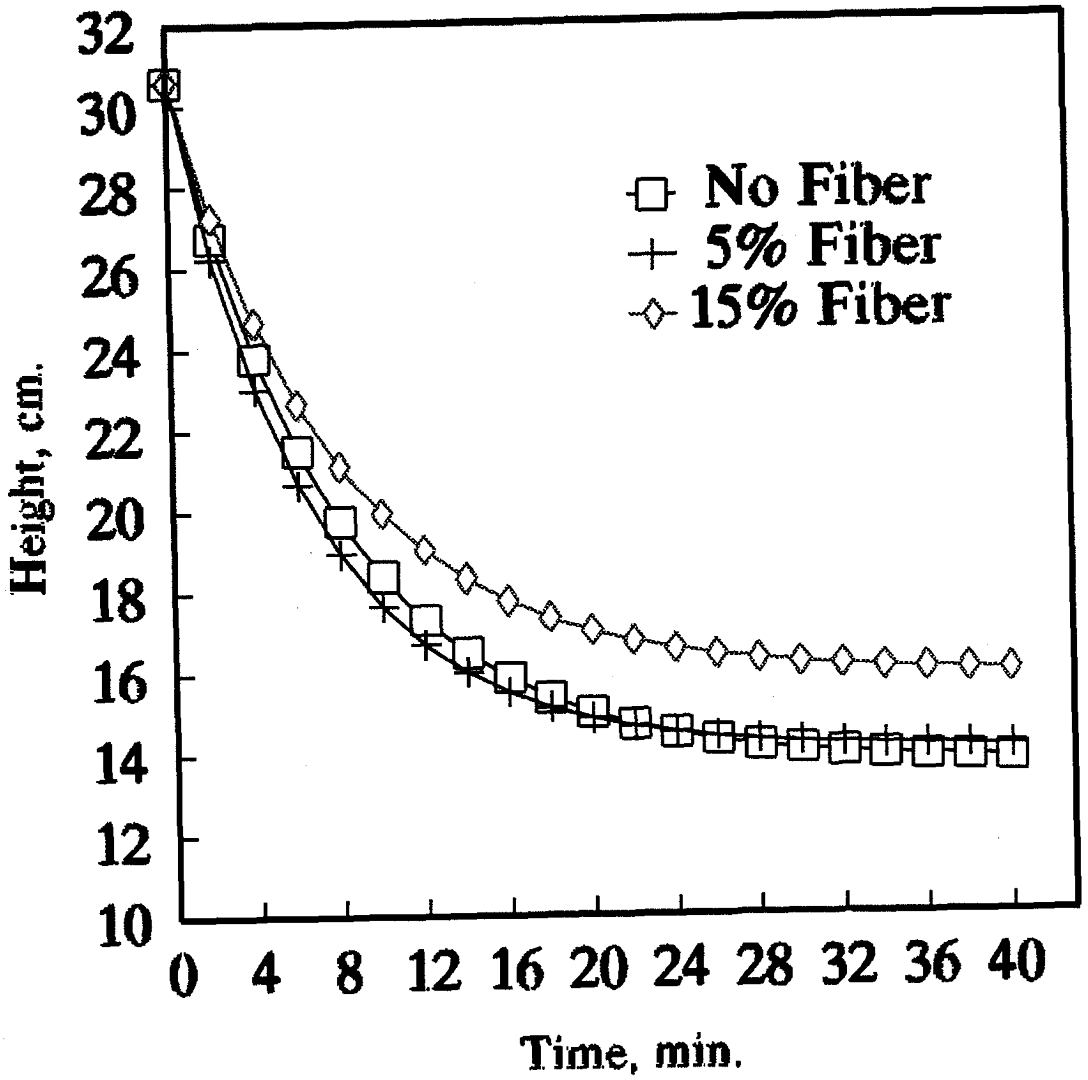

Figure 4. Effect of fibrous material on Sedimentation of flocculated phosphatic clays.

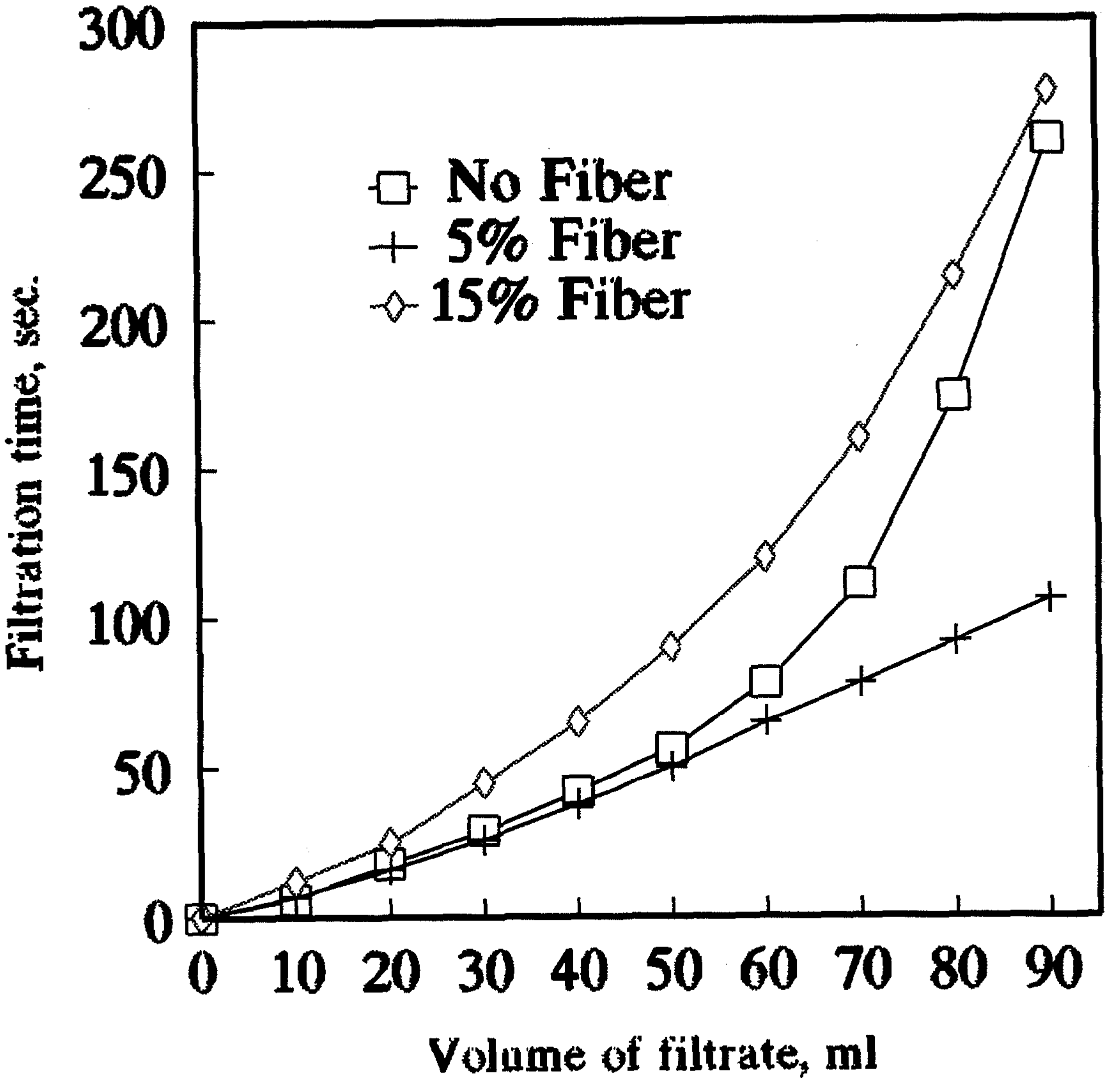

Figure 5. Effect of fibrous material on filtration time of flocculated phosphatic clays.

Table 2. **Time (seconds) required for vacuum filtration of flocculated phosphatic clays in the presence of differing amounts of fibrous material. (0.8 lb/ton Percol 156 is used as flocculant).**

Vol of Filtrate ml	Time in seconds to filter volume shown			
	0% fiber	5% fiber	10% fiber	15% fiber
10	6	6	7	12
20	18	14	16	25
30	29	20	23	45
40	42	24	31	65
50	56	31	40	90
60	78	38	57	120
70	111	47	64	160
80	174	65	83	214
90	260	106	107	276

Table 3. **Solids content in filter cakes as a function of fiber addition (0.8 lb/ton percol 156 flocculant, 105 sec filtration time)**

Fiber to dry clay wt%	Cake solids content wt%
0	6.6
5	20.4
10	20.4
15	5

The decrease in filtration rate at high fiber content could be attributed to blinding of the media caused by precipitation of the fiber. On the other hand, lower levels of fiber addition helps prevent the fine particles from reaching and blinding the media, especially in the early part of the filtration cycle. Only thin cakes can be obtained. Filtration was dropped from further consideration as a dewatering technique for flocculated phosphatic clays containing fibrous material.

3.3. Screen dewatering tests: The floccs obtained in the presence of fibrous material reached as large as 12 mm in size (see Figure 1). Thus, it was decided to test dewatering on screens. The drained water and the retained (dewatered) clays were analyzed for solids content and the data given in Table 4.

Table 4. Results of screen dewatering tests (0.8 lb/ton Percol 156 was used as flocculant)

Fiber addition (% of dry clay)	Solids recovered on screen, wt%	Solid content of the dewatered solids, wt%
0	50	7
5	95	12
10	97	12
15	99	14

These results show that 50% of the flocculated clays will pass through the screen unless fibrous material is added. The fibrous material obviously strengthens the flocs, allowing more solids to be retained on the screen (up to 99% depending on the amount of fiber). In addition, up to a 12% solid content can be obtained in the dewatered clays. This is a significant considering the fact that the starting slurry contained only 2.0% solids. Larger retention time on the screen was found to yield higher solids contents. In addition, pressing these solids can lead to further dewatering (See figure 6). It is important to note that such mechanical pressing cannot be applied to clays not containing fiber.

3.4. Centrifuge tests: These tests were conducted by Bird Machine Company on a fiber-flocculated phosphatic clay sample, as in the beaker tests described above with the exception that the percent solids in the treated slurry was 5.93%. The size distribution on the clays, as determined by the L&N Microtrac Particle Size analyzer, is given in Table 5.

The data indicate very fine solids with an average weight diameter of 8.0 microns. Naturally, filtration and/or centrifugation of unflocculated samples would be a difficult task (as is reported in the literature). However, flocculation of such clays in the presence of fibers was found to accelerate dewatering.

Figure 6. Photograph of squeezed clays

Table 5. **Particle size distribution of phosphatic clay feed for centrifuge testing**

Size, Microns	Cumulative Weight % Passing
27.0	100.0
19.0	91.3
13.0	77.7
9.4	60.6
6.6	40.7
4.7	29.7
3.3	16.2
2.4	6.4

a) Solid Bowl Decanter Test

These tests were conducted under different gravitation forces and for different periods. The data obtained at 18 sec. retention time, as a function of gravitational force, are shown in figures 7 and 8.

The results suggest that cakes of better than 19% solids can be obtained. Also, the solids content and recovery can both be increased as the force and retention times are increased (See Figure 9). A perforate bowl centrifuge was used to measure the maximum cake dryness, as discussed in the next paragraph.

b) Perforate Bowl Solids Dewatering Test

A thickened sample of feed was prepared to simulate the settled solids in a decanter centrifuge. This thickened material was spun in a perforated basket with an open cloth liner to measure the consistency of the cake with increasing dewatering times and at various gravitational levels. The results of these tests are shown in Table 6 and Figure 10.

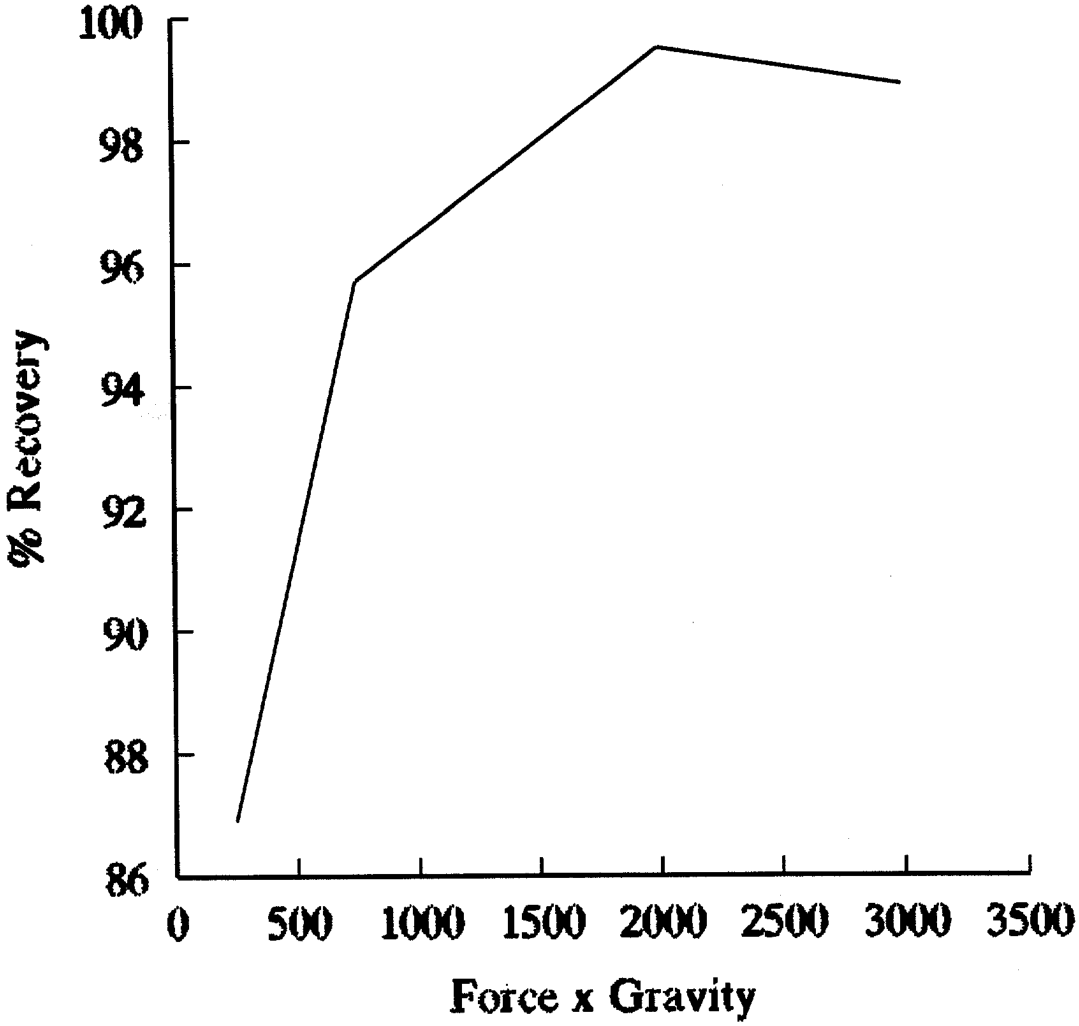

Figure 7. Solid Bowl Decanter Test % Recovery vs. Gravitational level

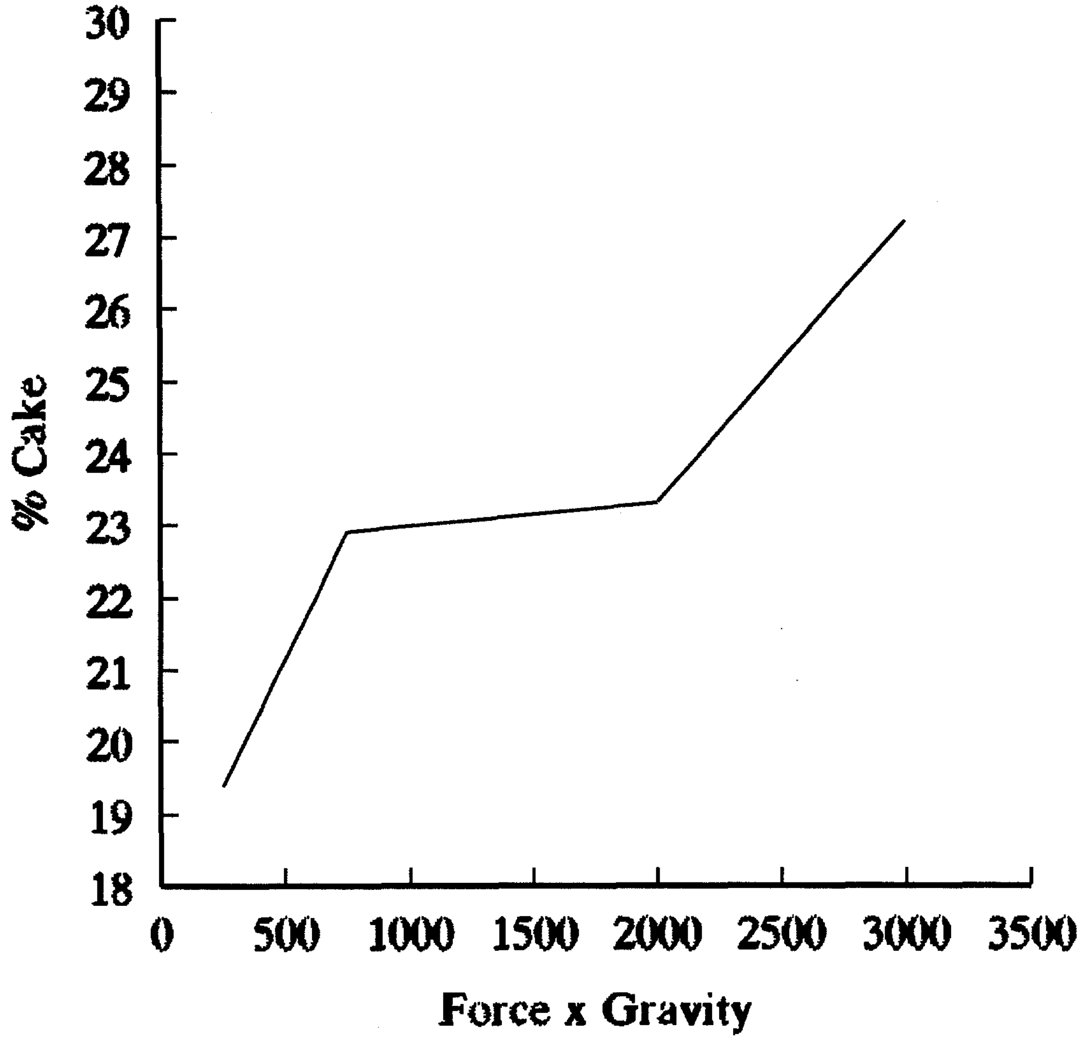

Figure 8. Solid Bowl Decanter Test % Cake solids vs. Gravitational level

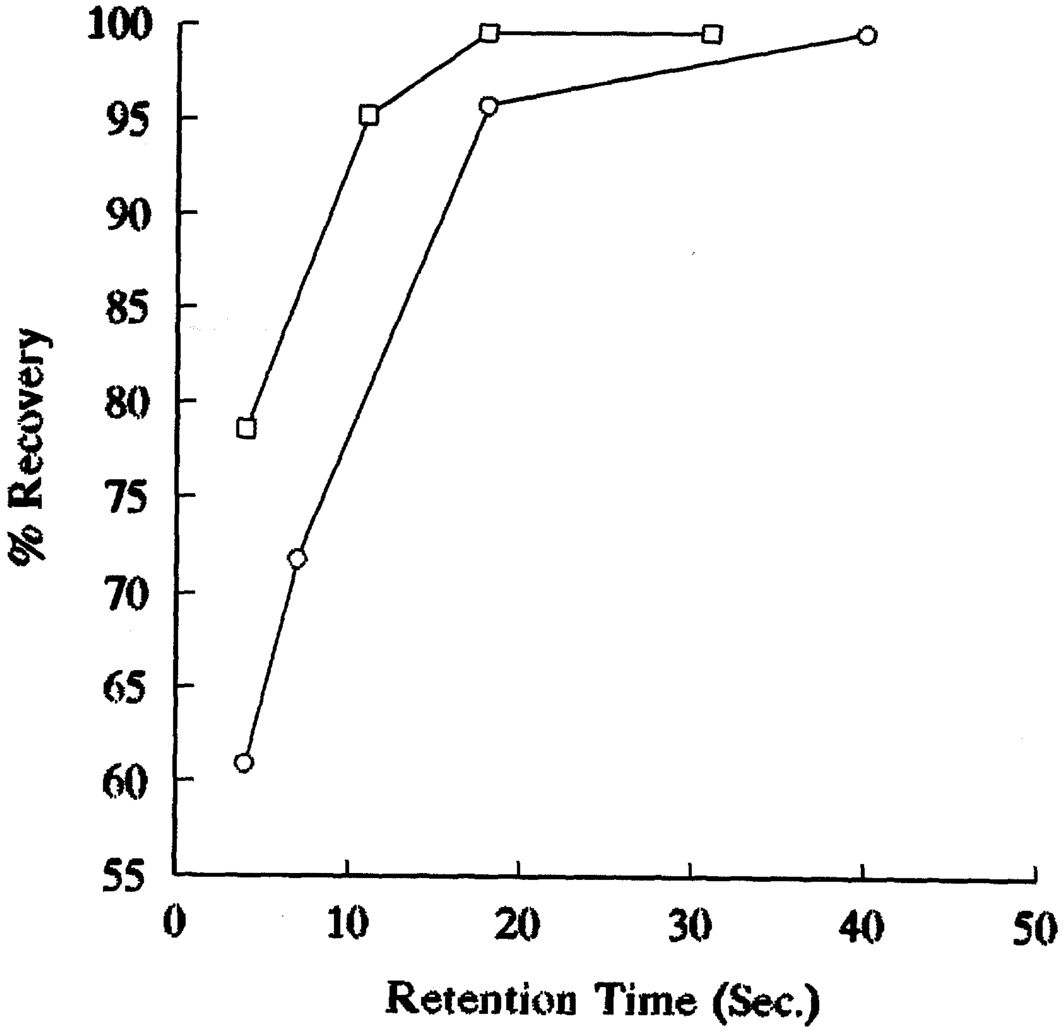

Figure 9. Solid Bowl Decanter Test % Recovery vs. Retention time

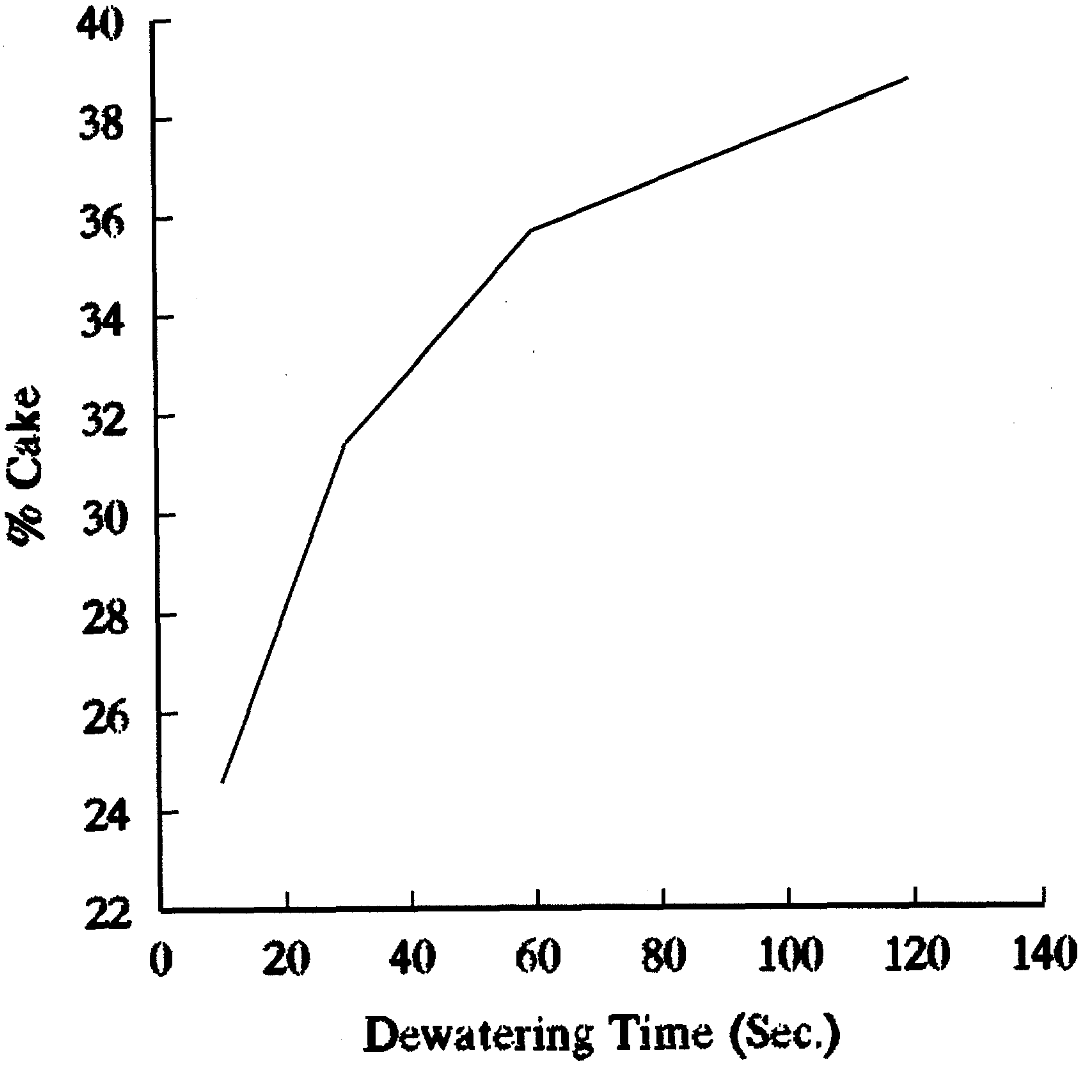

Figure 10. Perforate Bowl Dewatering Test % Cake solids vs. Dewatering time.

Table 6. **Results of perforate bowl solids dewatering test as a function of time (force = 1000 G)**

% solids in:				
Feed	20.00	20.00	20.00	20.00
Cake	24.60	31.40	35.70	38.40
Effluent	0.20	0.20	0.20	0.20
% recovery	99.80	99.60	99.60	99.50
Dewatering Time (sec.)	10.00	30.00	60.00	120.00

The data indicate that a one-minute retention time will give more than 35% solids in the product. It is worthwhile to mention here that such a high percentage can only be obtained after years of natural settling in Florida's clay disposal areas. However, the economics of using centrifuges to achieve a consolidation level of +35% solids is not realistic. The low capacities of such machines could make the capital costs unbearable. Further research was directed to static dewatering screens, as discussed below.

3.5. Small-scale Continuous Agitation-Flocculation Tests: The experimental set-up in Figure 1 was used to test the effect of different parameters on the performance of the dewatering process. The 2^3 factorial design was used to evaluate the effect of polymer concentration, clay solids content and level of fiber addition. The measured responses included the percentage of solids recovered on the screens and the polymer consumption (in lb/ton of dewatered solids) on the inclined screen as shown in Table 7.

Using Yate's Algorithm, effects of the studied parameters on the measured responses are calculated, leading to the following equations:

$$Y_1 \text{ (Solids Recovery, \%)} = 58 + 12.0X_1 + 13.25X_2 - 3.75X_3 + 0.25X_1X_2 + 1.25X_1X_3 + 2.0X_2X_3 = 4.5X_1X_2X_3$$

$$Y_3 \text{ (Polymer Consumption, Kg/t)} = 1.25 - 0.10X_1 + 0.80X_2 + 0.275X_3 - 0.05X_1X_2 + 0.075X_1X_3 + 0.375X_2X_3 + 0.075X_1X_2X_3$$

Where: X_1, X_2, X_3 are coded parameters: % polymer concentration; % clay solids; fiber to clay ratio, respectively.

Table 7. **Continuous Agitation Flocculation Tests**

Run #	Solids Recovery %	Clay Solid Weight Content, %	Nalco 7877 Polymer lb/ton
8	35	15.0	1.3
7	66	18.0	1.1
6	67	18.0	3.7
5	79	16.0	2.4
4	30	15.0	0.7
3	48	17.0	0.9
2	52	15.0	5.9
1	87	22.0	5.9

The data suggest the following:

1. Solids recovery increases as the polymer concentration and fiber addition increase. On the other hand, higher solids in the clay slurry lead to a decrease in recovery.

2. Polymer consumption increases as fiber and/or clay solid contents increase. Interestingly enough, as the polymer concentration is increased, its consumption decreases.

3. Clays can be dewatered instantaneously, with an increase in solid content from 2.2% up to 22% using static screens.

4. Close examination of the polymer consumption levels, however, indicate that such levels are too high to be economically used to treat waste tailings such as phosphatic clays. Also, such levels were significantly higher than the consumption data developed in the batch tests.

The last observation lead us to investigate why the continuous tests require such a high polymer consumption. Visual examination of floc formation in the agitation-flocculation tank has indicated that floc disintegration is also taking place in the same tank.

3.6. Pilot Plant Tests: Based on the above observations, it was decided to investigate different ways of mixing, including on-line static mixers. Such research efforts have resulted in the design of a pilot plant unit using on-line mixers as shown in Figure 3.

The pilot unit was used to test the rapid dewatering process on clays from different mines. Polymers from various suppliers were tested. Using 6.0% fiber to the weight of dry clays, the following results (See table 8) were obtained from one of the Florida operating mines.

Table 8. **Data of pilot plant testing of the rapid dewatering process on clay from plant A using 6.0% fiber.**

% solids in feed	% solids in product (single screen)	polymer	
		type	lb/ton
1.8	14.0	AMP856	2.9
2.4	15.0	AMP957G	2.3
2.8	15.0	PERCOL156	1.1
3.0	16.0	NALC7877	2.5

These data indicated that Percol 156 is one of the most effective polymers. Thus, further work was carried out at different feed solid contents as shown in Table 9.

Table 9. **Pilot plant data of the rapid dewatering process using Percol 156 and clays from plant A using 6% fiber.**

% solids in feed		% solids in product		polymer consumption lb/ton	
	Average		Average		Average
1.2	2.5	15.0	15.0	0.7	0.54
1.5		14.0		1.2	
1.8		15.0		1.5	
2.3		14.0		1.3	
2.4		14.0		1.5	
3.3		15.0		0.9	
3.6		11.0		1.0	
3.9		18.0		1.4	

The data suggest that as low as 0.7 lb/ton of polymer may be effective in producing a dewatered product of 15% solids content.

Increasing the amount of fiber addition to 10%, however, did not produce a significant improvement in product solids content. Polymer requirements were also higher, as shown in Table 10.

Table 10. **Pilot plant data of the rapid dewatering process using Percol 156 and clays from mine A, at 10.0% fiber addition**

% solids in feed		% solids in product		polymer consumption lb/ton	
	Average		Average		Average
1.3	2.2	13.0	15.0	1.8	0.68
1.5		15.0		1.6	
1.7		14.0		1.6	
1.8		15.0		1.5	
2.1		14.0		1.5	
2.7		18.0		1.3	
4.0		16.0		1.0	

(10% Fiber added)

Using two stages of screening and belt press, the pilot plant was operated on clays from a different mine in Florida. The results are given in Table 11.

Table 11. **Pilot plant tests of rapid clay dewatering process using Nalco 7877 and clays from mine B**

%Solids in feed	% Solids in product			Polymer (Nalco 7877), lb/ton
	First screen	Second screen	Belt press*	
3	16	20	45	0.82
4	14	19	50	0.86
5	14	21	48	0.62
6	24	32	47	0.55

* The belt press is used to maximize the dewatering.

The results in Table 11 suggest that phosphatic clays may be dewatered to levels approaching 50% solids content using the FIPR/DIPR process. However, belt presses would only be economic with higher value clay products. Nevertheless, reasonably high solid content clays can be obtained by using only static screens.

3.7. **Sand/clay Mix:** Limited pilot plant testing with the addition of sand (dry or wet) on the screen was conducted to test sand/clay mix. The results indicated that wet sand can be dewatered on the screen and get mixed with the FIPR/DIPR mix and the product continues to dewater as it rolls down the screen. Dry sand addition on the screen produced similar results. It is important to mention that amount of sand addition (sand/clay) ratio is not critical since a ratio of 0.5 was used and the dewatered product contained over 47% solids by weight. The amount of fiber used was 3.0% of the dry weight of clay and polymer (Percol 156) addition was 0.5 lb/ton of clays.

The product seemed fluid enough to be pumpable. Nevertheless, the fluidity and pumpability of the sand/clay mix need to be evaluated.

3.8. Seepage Induced Consolidation Tests

a. Column tests

A 2^3 factorial design was used to test the effect of the following variables: A (polymer dosage; 0.5 to 1.0 lb/ton), B (pulp dosage; 3 to 6% dry fiber to dry weight of clay), and C (type of polymer; Percol 156 and a Percol 156/Drimax 1235 blend at 9/1 ratio). Drimax 1235 is a surfactant used to enhance drainage through the sand layer. The results are summarized in table 12.

The data in Table 12 suggest that the surfactant lowers the drainage time. A higher solids product was obtained when higher levels of polymer and fiber were used. Nevertheless, the data of run #5 indicates a product of 26% solids might be obtained in a reasonably short drainage time with the lowest level of polymer and fiber addition. These data were confirmed in larger scale (drum tests) below.

b. Drum tests

In these tests the flocculated/fibered clays were deposited on a layer of sand in 55 gallon drums. After two hours of settling, clear water was decanted from the top of the drums until the clay surface appeared. The water was then left to drain through the bottom sand layer and samples were taken for solids analyses as shown in table 13.

Table 12. **Results of 2^3 statistical design experiments of column seepage consolidation tests.**

Run #	Variable			Drainage time	% solids by weight in product
	A	B	C	minutes	
1	-	-	-	120+	23
2	+	-	-	120+	25
3	-	+	-	120+	24
4	+	+	-	120+	26
5	-	-	+	12	26
6	+	-	+	8	26
7	-	+	+	28	26
8	+	+	+	6	28

Table 13. **Seepage induced consolidation of phosphatic clays in 55 gallon drums.**

Drum #	Feed % solids	Reagent type & design	Fiber %	% solids in Product			
				24hrs	92hrs	96hrs	Remarks
1	1.7	Percol 156 1.0 lb/tn	6.0	28	28	29	
2	1.7	Percol 156 Drimex 1235 (9:1) 1.0 lb/tn	6.0	27	27	28	Faster rate than #1
3	1.5	Percol 156 Drimex 1235 (9:1) 0.5 lb/tn	3.0	34	37	40	Faster rate than #1 slower than #2

The results in Table 13 confirm the small scale (column) consolidation tests and indicate that higher

% solids can be obtained.

Field testing of the above technique (with and without sand capping) will be needed to confirm the practicality of the FIPR/DIPR process as a clay consolidation and reclamation technique.

3.9. The "AQUARIUM": In order to test on a bench scale the proposition that it might be feasible to dewater a clay/polymer/fiber mix over a substratum of tailings sand in a mine cut, we fabricated a 2 X 6 foot plywood box with a wooden separator at one end. A three-inch layer of phosphate tailings sand was deposited on the bottom, with one-inch opening between the compartments to allow the water to drain laterally through the sand to the right side of the box where it could be drained off into a barrel. The box was filled with the clay/polymer/fiber mix and allowed to settle. Figures 11 and 12 show the progression of the liquid and clay interfaces over a 24-hour period. After the clay had drained and dewatered to such an extent that it was shrinking away from the sides of the box (at about a 25% solids content), a 3 to 4 inch layer of slurried tailing sands was distributed on top of the consolidated clays. The important point of whether or not the clay layer would stop water penetration can be shown in Figure 13. In the first case fiber was omitted from the clay/polymer mix placed over a layer of consolidated clays and the drainage was painfully slow. However, when the recommended amount of fiber was included, the water penetrated the clay layer and was drained off rapidly.

In another run, after standing for 48 hours under a surcharge of sand, the bottom layer of clay analyzed 48% solids. Subsequent layers of clay and sand were deposited, and it became obvious that as the lower layers of clays shrank, they allowed drainage of the water through the lower sand layers.

4. PROPOSITIONS FOR LARGE SCALE APPLICATIONS OF THE FIPR/DIPR PROCESS

To those familiar with past efforts to "solve" the waste clay problem, it is well understood that the real test of any experimental process is: "Can it be done on a large scale where one is handling 20 to 80,000 gallons/minute?" Many clever processes have been developed on a laboratory or pilot scale that were simply overwhelmed by the problems of moving and handling the volumes of materials involved in the field. The following are proposed options that may be considered as possible disposal methods for clays treated by the developed process or modified versions of it.

4.1. Option A) - Mining Cut (pit) Disposal: Figures 14a, b, and c depict the concept of simultaneously dewatering the clays and reclaiming the mine cut. The mine cut is separated into two sections by a cofferdam, as shown in the illustration, with the smaller right hand portion acting as a water reservoir from which the recovered water can be recycled to the washer using a floating

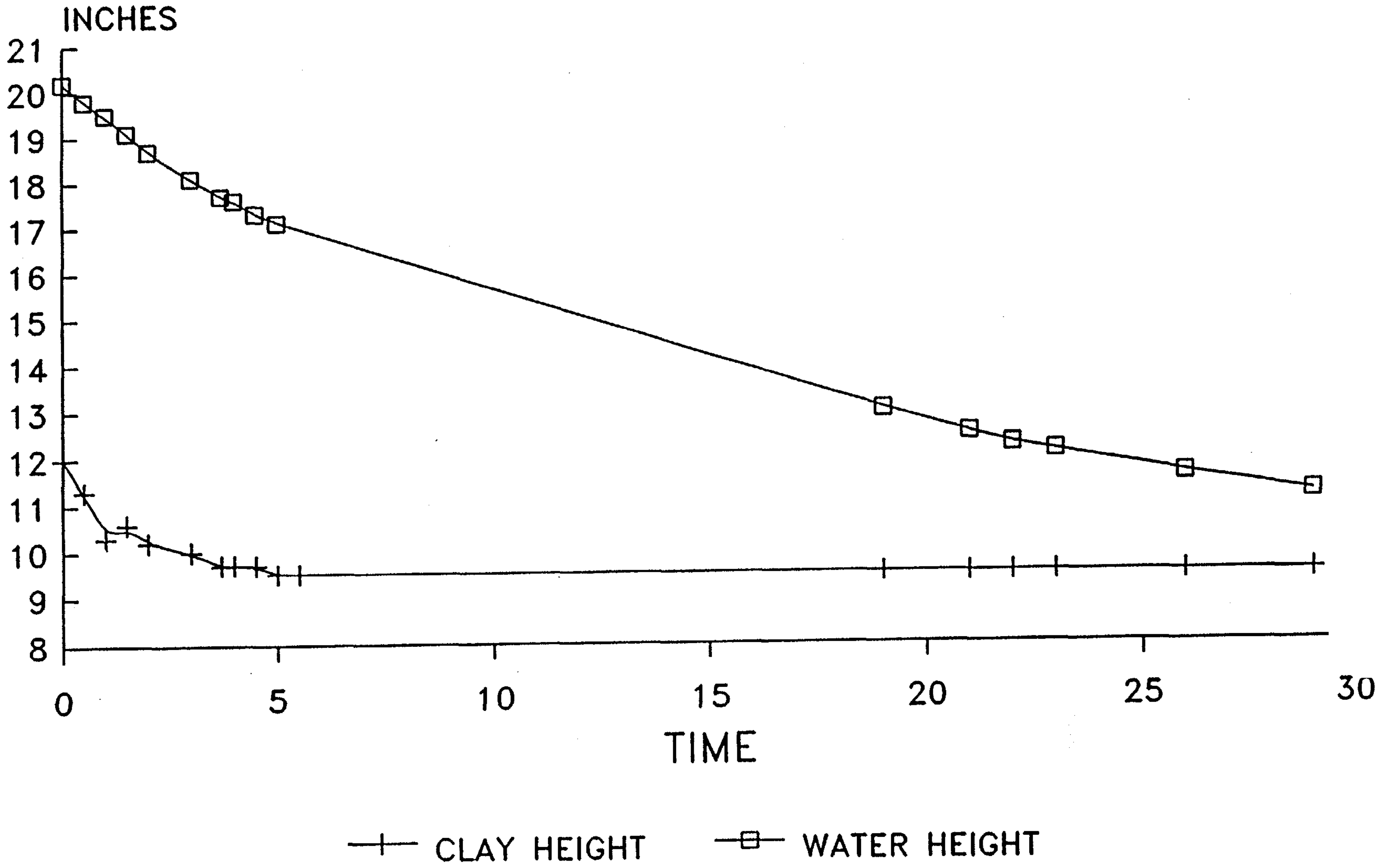

Figure 11. Effect of lower pulp addition on progression of water drainage and clay settling in the aquarium

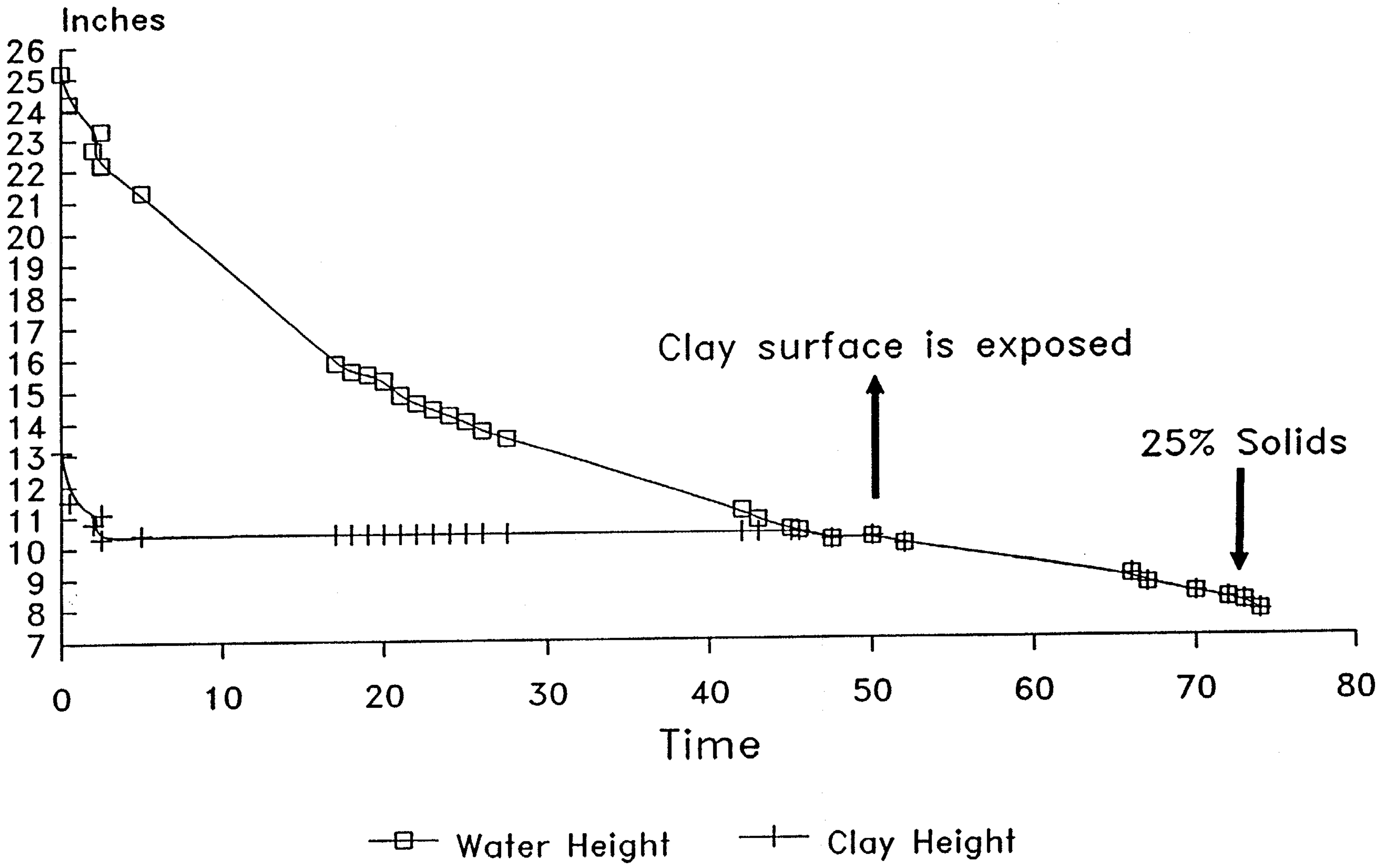

Figure 12. Effect of higher pulp addition on progression of water drainage and clay settling in the aquarium

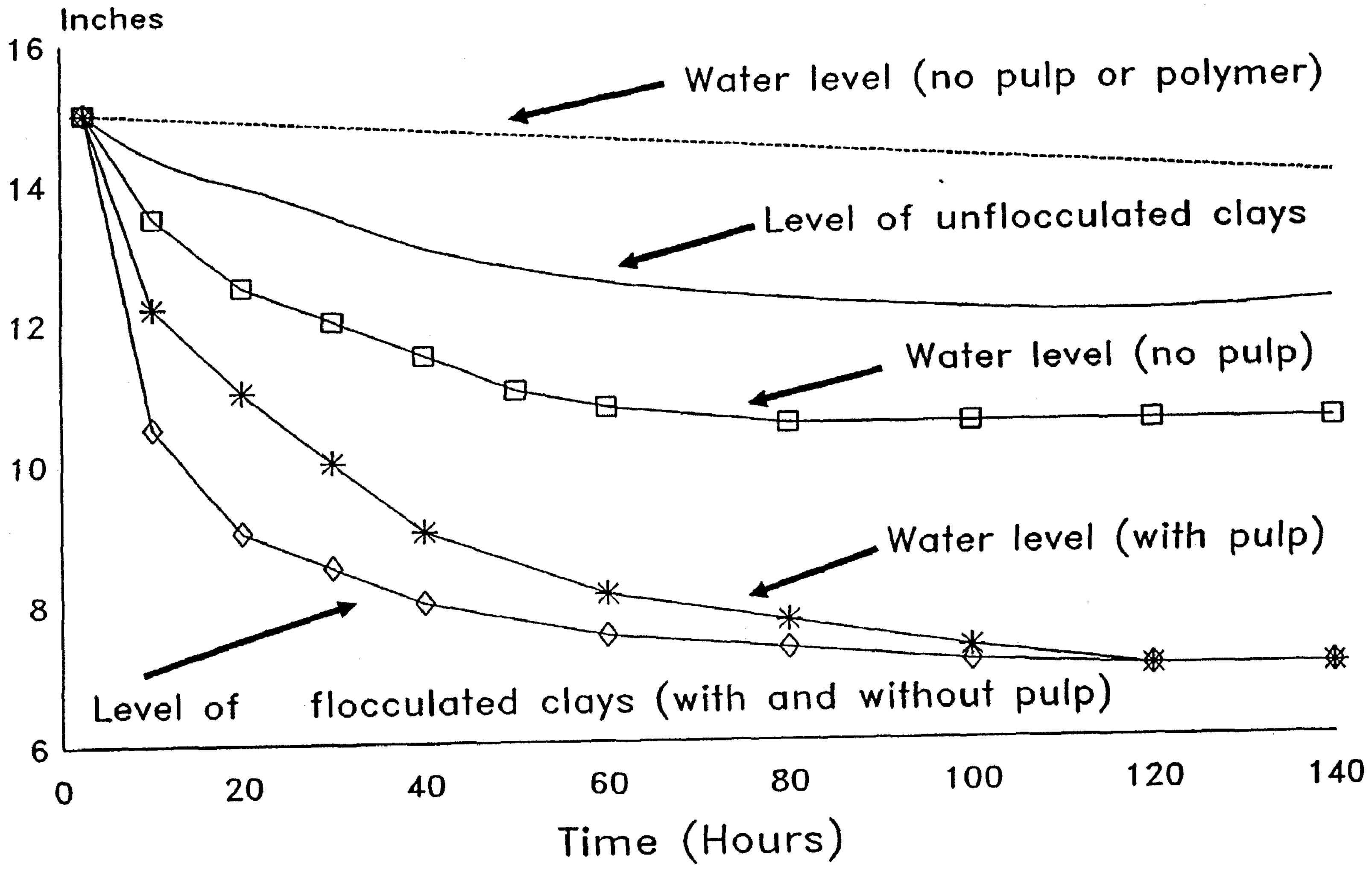

Figure 13. Impact of fiber addition on water drainage rate as compared to clays without pulp

Option "A" - Mining Cut (pit) Disposal

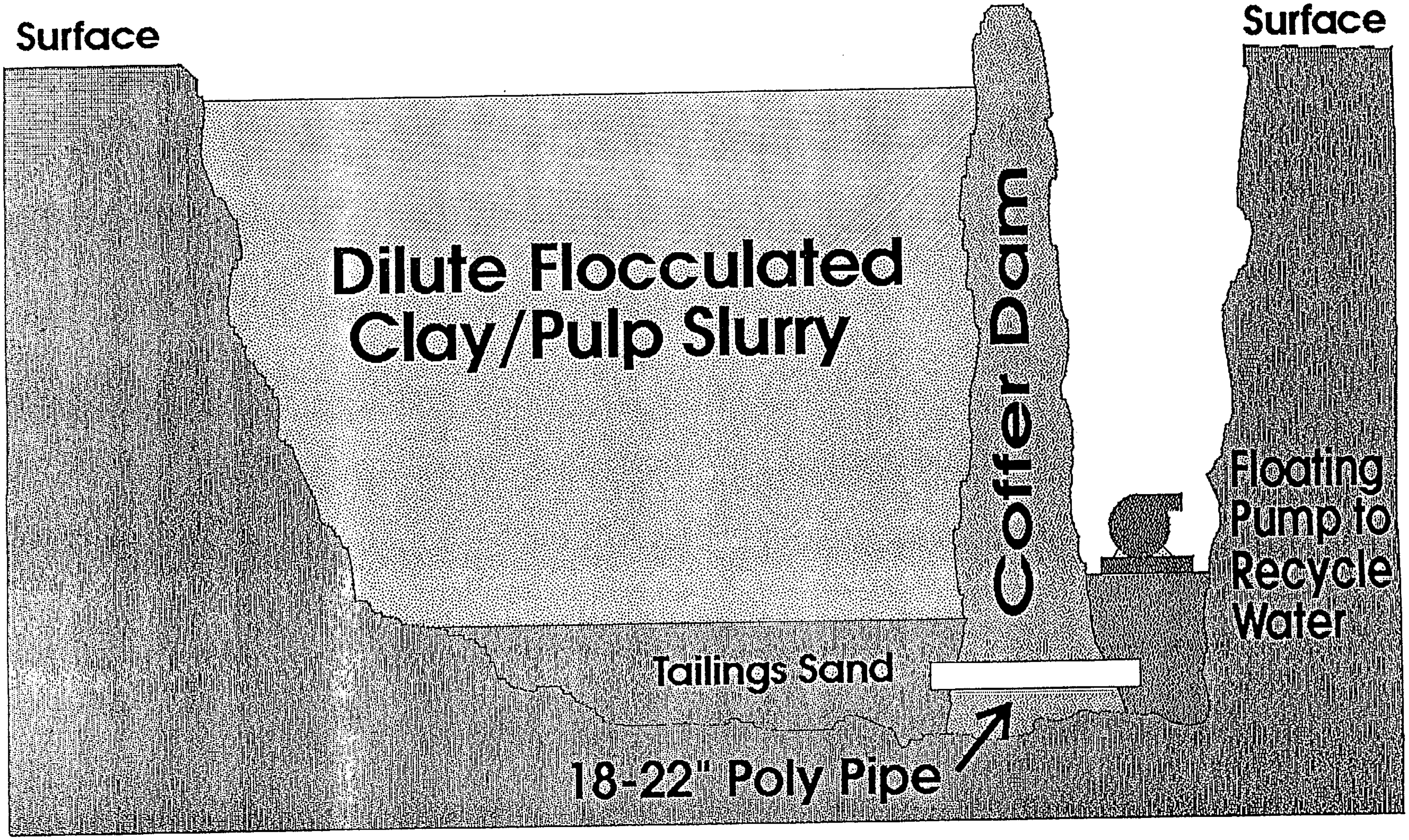

Figure 14a. Scenario of mine cut disposal of FIPR/DIPR mixture

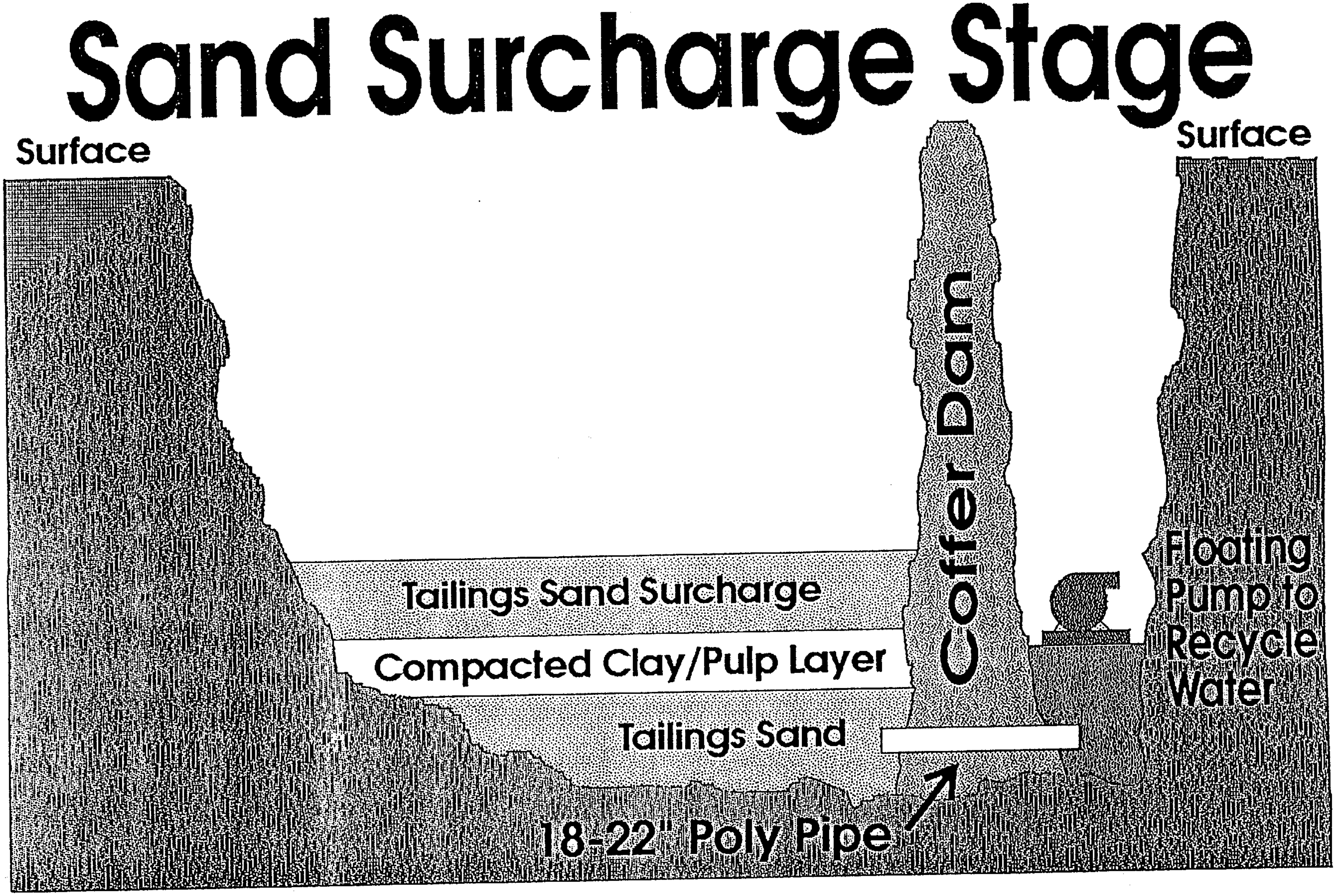

Figure 14b. Scenario of mine cut disposal of FIPR/DIPR mixture

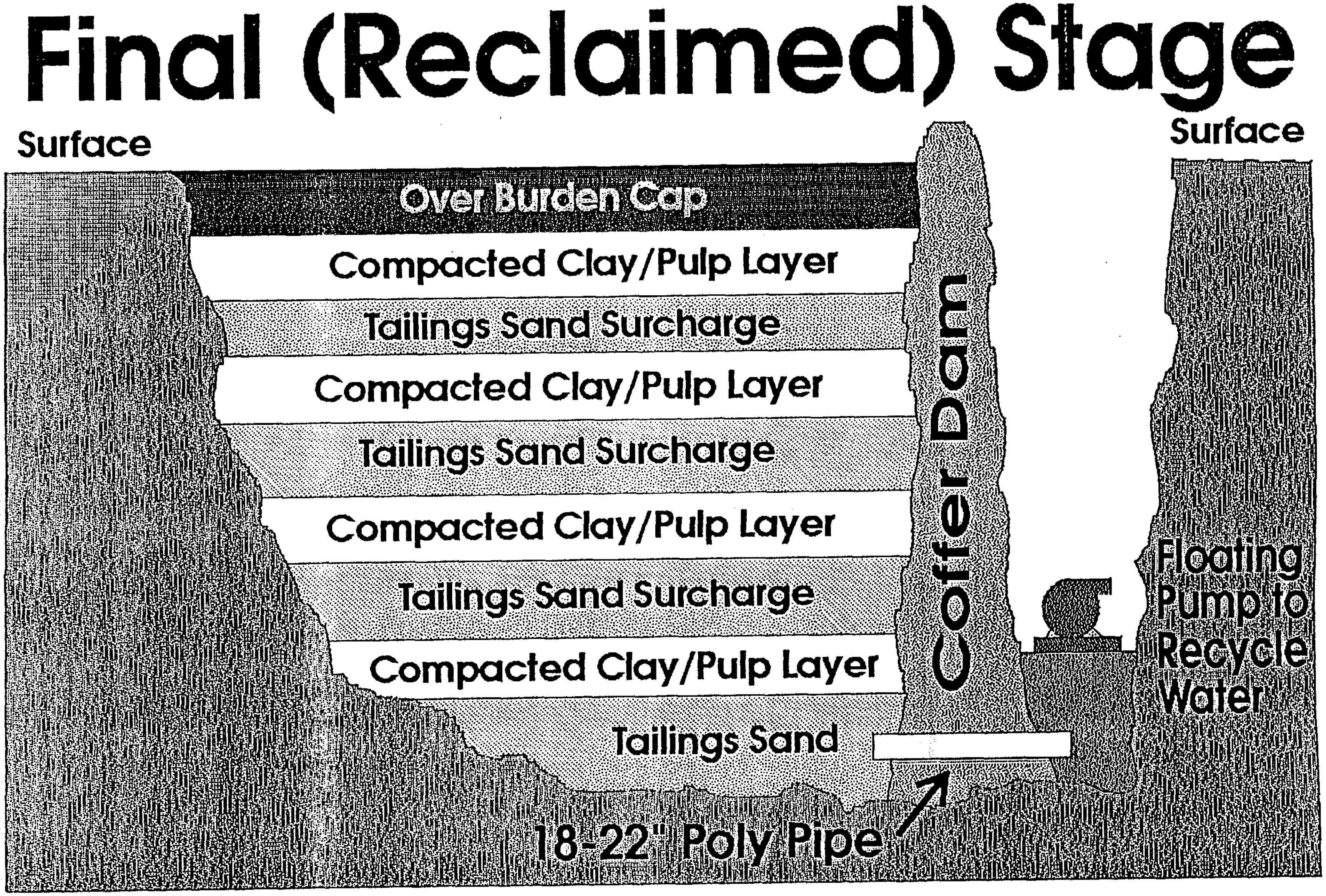

Figure 14c. Scenario of mine cut disposal of FIPR/DIPR mixture

pump. Large (22 inch) pipes are placed in the cofferdam wall with the left hand end buried in a two-foot layer of tailings sand. The clay/polymer/fiber slurry is pumped onto a floating barge to break the hydraulic force, and the flocculated mixture distributes itself over the sand throughout the mine cut. The water flows into the sand layer and through the pipes buried in the cofferdam to the right hand portion of the cut where the water is pumped back to the washer. After the water has drained from the clays and they have dewatered to the point of shrinking, cracking and pulling away from the sides of the mine cut, dewatered sand tailing are pumped onto the barge and distributed as uniformly as possible by moving the barge from one end of the cut to the other. The surcharge of sand squeezes additional water out of the clay layer (>40% solids), and the pit is then ready for a second filling with clay/polymer/fiber mix. Drainage time on the field level with a much higher hydraulic head will have to be determined experimentally, but pilot results suggest 48 to 60 hours. After the pit is filled to the maximum practical level with the sandwiched clay and sand, overburden would be bulldozed over the top to complete the reclamation process.

Because rapid dewatering of the clay suspension can be observed immediately after the polymer and fiber are added, logic would say that one should remove as much water as possible at the washer in order to save pumping costs. Pumping a 15% solids slurry to a mine cut, which may be miles away from the washer, is certainly preferable to pumping a 3% slurry. One problem, yet to be evaluated, is how much degradation the flocs undergo while being pumped long distances. The suggestion has been made that only half the polymer be added at the washer, with the other half to be added at the mine cut. A second issue, yet to be demonstrated, is the distribution of the tailings slurry (50+% solids) across the consolidated clays. This will undoubtedly require multiple introduction points along the mine cut, as the tailings will not flow readily. The logistics of moving waste newsprint to the washer will be substantial. One might estimate that a 3 million ton mine would produce roughly 3 million tons of clay solids. If the fiber dosage is in the range of 3 to 5%, it would require 90,000 to 150,000 tons of waste newsprint annually or 300 to 500 tons/day. The paper would have to be slurried and pulped in recycle water before mixing with the polymer and clay. All materials would be mixed with in-line static mixing devices. The polymer would have to be prepared as a dilute solution, then further diluted before mixing with the fiber and clays. A 3 million ton operation would require a million pounds of polymer/year.

4.2. Option B) - Median Strip: A second possible dewatering scenario involves utilizing the median strip between two parallel mine cuts as a clay dewatering area. Figures15 a, b, and c show this concept. The median strip would be sloped slightly and dammed at the top and ends to allow water to drain into the topmost mine cut (#2). About two feet of slurried tailing sands would be deposited onto the median, and the transport water allowed to drain into cut #2. Treated clay mix (clay/polymer/fiber) would then be pumped onto the sand layer. The water would quickly drain through the tailings into cut #2 where it would be recycled to the washer. The drained and air-dried clay layer atop the sand tailings would then be bulldozed into cut #l. This process would be repeated until cut #1 was filled with the dewatered sand/clay material. Overburden would then be pushed over the top to complete the reclamation. Cut #2 would then be filled in the same manner, using cut #3 as a temporary water resevoir.

Option "B" - Median Strip

(Plan View)

Step 1

Figure 15a. A scenario of median strip disposal of FIPR/DIPR mixture

Option "B" - Median Strip

(Plan View)

Step 2

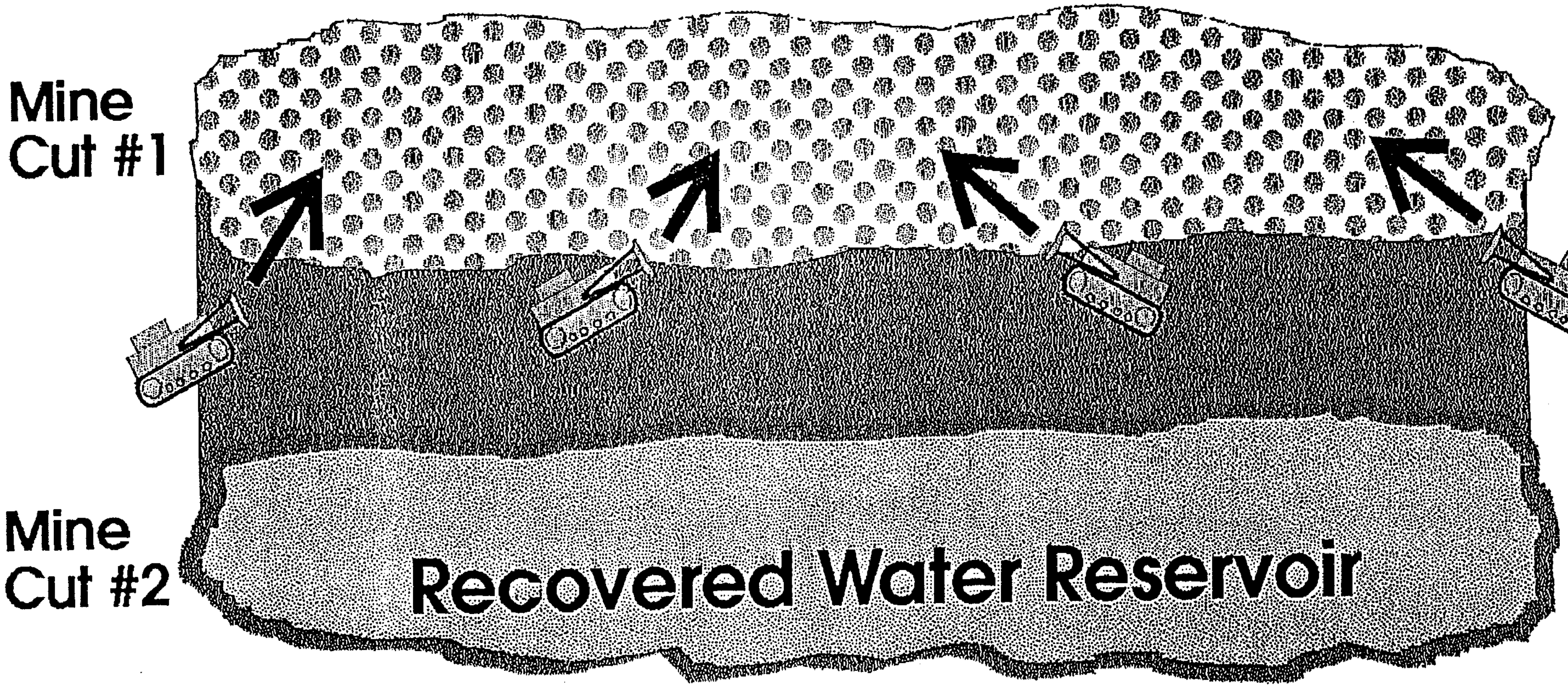

Figure 15b. A scenario of median strip disposal of FIPR/DIPR mixture

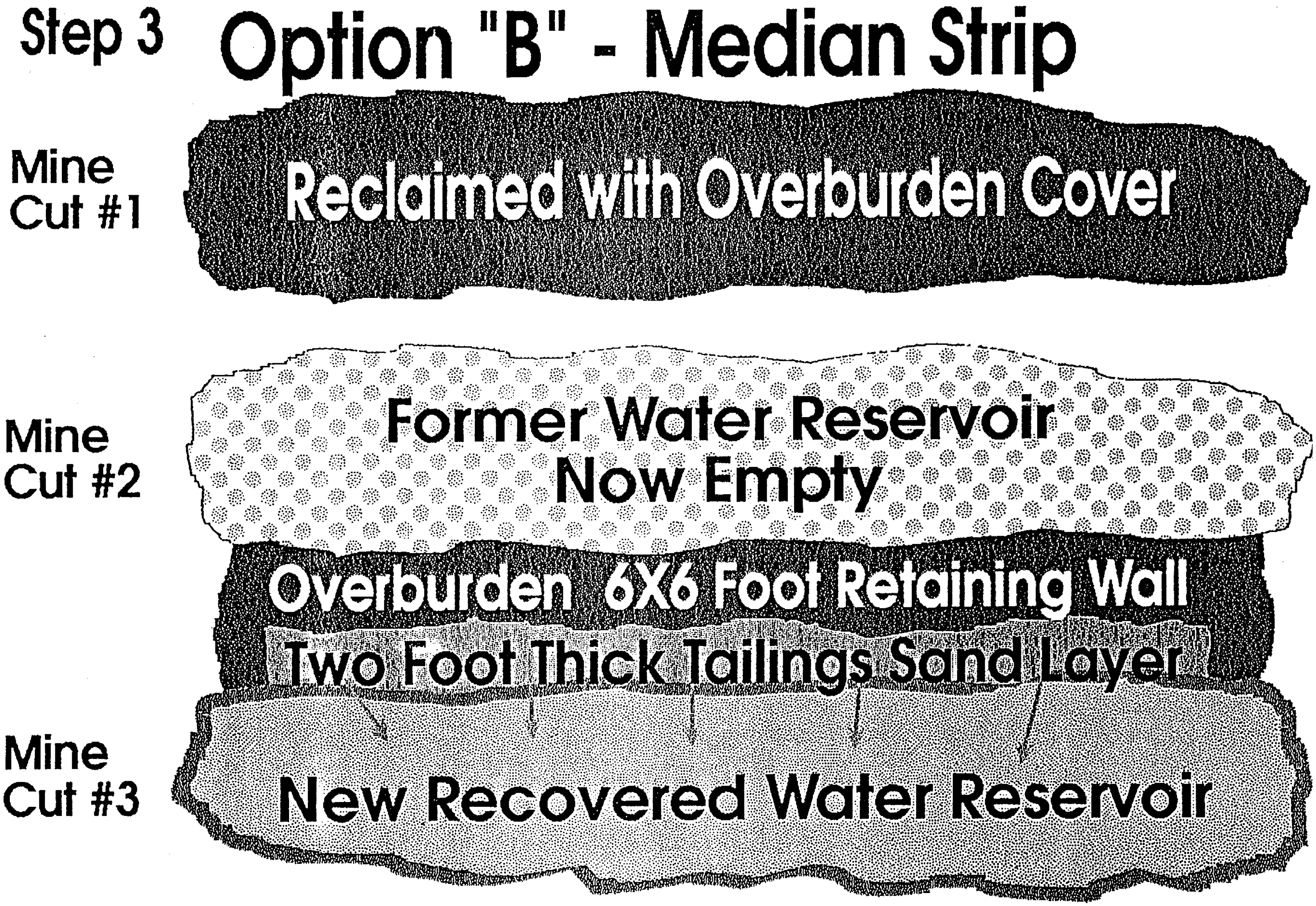

Figure 15c. A scenario of median strip disposal of FIPR/DIPR mixture

The median strip scenario would have the disadvantage of co-mingling the clay and tailings, which might make future treatment of the clays (to recover P_2O_5 values) more difficult.

4.3. Option C) - Sand mix with FIPR/DIPR product: In this option sand tailings are dewatered as currently done, but on the top of the static screens. The cyclone underflow (dewatered sand) flows on the screens to meet the flocculated FIPR/DIPR mix. Both sand and flocculated clays will undergo dewatering on the screens. Actually, the sand will help in retaining fines on the screens. The sand clay mix is then pumped at high % solid content to (> 45%) to the mine cut.

5. OTHER ISSUES

5.1. Recycle Water Quality

On a small scale the quality of recovered water has been excellent. Bench flotation tests, using water recycled several times, has shown a slight increase in flotation performance if anything. A polishing filter would probably not be necessary in a field operation.

5.2. Reclamation Approval

Because the proposed clay sandwich method of reclamation has not been practiced, the Florida DEP would have to evaluate and approve such a method. Hydrologic behavior will have to be investigated. The clay/sand mix of the median strip scenario has already been sanctioned by the DEP.

5.3. Degradation of the newsprint and its environmental effects

The intimate mixing of paper fibers and clay will result in the ultimate biodegradation of the paper, though under anaerobic conditions (from recent reports of sampled landfills) the fiber might last for some time.

Test were conducted to test possibility of contamination of underground water from metals that may be in the ink and the organic products that may result from the biodegradation of the fiber. Four leaching columns were set where clay, flocculated clay, flocculated clay plus fiber were deposited and draining water was collected over a period of four months then sent to environmental laboratory for analyses for both inorganic and organic “EPA Priority Pollutants”. The results are given in Appendix A. The data indicate the presence of flocculant and/or fiber does not increase the elemental content of the water. Organic priority pollutants are found to be less than the EPA standards for drinking water.

5.4. Potential environmental advantages

The FlPR/DIPR process appears to offer a number of potential advantages to the environment, though these will have to await large scale practice for quantification:

a. Water use reduction through avoiding the solar evaporation experienced with large volume waste clay ponds.

b. Elimination or significant reduction of the consequences of a dam failure/threat to water supplies.

c. More rapid reclamation of some of the mine cuts.

d. Faster recovery of thousands of acres of land that would be tied up in waste clay storage ponds for years.

e. Returning more reclaimed acres to the tax roles/providing more options for habitat creation.

f. Consolidating the clays in re-minable seams should the industry be forced to recover the phosphate values in future years (mine cut option only).

6. ECONOMICS

The failure of many previous clay-consolidation schemes has been economic. The industry simply can't afford to pay more for waste clay disposal than they are now experiencing with long-term storage in above grade ponds. The rule of thumb is that we can't afford to spend more than $1 per ton of clay solids for any process. If the FIPR/DIPR process uses 5% fiber (@ $10/ton) and 0.5 lbs of polymer (@ $0.90/lb), materials cost would be $0.95/ton of clay solids....just under the arbitrary limit. At 3% fiber the cost would be $0.75/ton. Some capital costs would be necessary for polymer mixing and paper pulping, but the process would look very attractive if it were given credit for the reclamation accomplished. Because every phosphate miner evaluates his costs differently, assigning some incremental costs to the mining operation, others to dam building and clay storage, to reclamation and yet additional costs to the maintenance of dams and reclaimed lands....it becomes a major task to evaluate the FIPR/DIPR process economically. Therefore, FIPR granted funds to GMC and BCI to evaluate the process as a reclamation technique. The idea was to evaluate the sand / clay sandwich disposal in a mine cut as proposed above. However, BCI, based on industry's comments evaluated a different version as shown below.

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PART II

FIPR/DIPR PROCESS AS A RECLAMATION TECHNIQUE: EVALUATION OF DIFFERENT SCENARIOS

1. INTRODUCTION

This work is conducted by Bromwell and Carrier, Inc. (BCI) of Lakeland, Florida. The study included an evaluation of the consolidation behavior, disposal alternatives and costs of implementing the process.

Initial project work included meeting with mining and reclamation personnel from several of the mining companies. The purpose of the meetings was to describe two disposal alternatives for the FIPR/DIPR process, obtain input from the industry on the practicality of the two methods, and solicit alternative disposal alternatives. Comments were received from Cargill Fertilizer, Inc., IMC/Agrico, Mobil, OxyChem, and USAC.

Consolidation testing was completed on untreated clay and clay treated with polymer and pulp using the restricted flow consolidation (RFC) test in the BCI laboratory. Results of laboratory testing allowed BCI to develop consolidation parameters and to predict the behavior of clay and FIPR/DIPR mix.

The project scope included interviewing mine engineering personnel from the various phosphate mining companies in Florida. Upon completing the initial interviews, we determined that for proprietary reasons the mines were not willing to release detailed cost figures which would allow us to evaluate three mines. BCI did, however receive considerable input and critique of the two proposed FIPR/DIPR disposal methods. Based on the input from the mines, we developed a disposal scenario for the FIPR/DIPR process that was thought to be realistic by the industry. This was the basis for completing an economic comparison of dilute clay disposal and disposal of the FIPR/DIPR pulp and polymer clay mix.

Based on the consolidation parameters developed for the clay and FlPR/DIPR mix, we have analyzed dilute clay disposal in conventional clay settling areas and FIPR/DIPR mix in low embankment areas built around mined-out cuts, Our economic analysis included comparison of equipment, operating and labor costs. Based on our analyses of the consolidation behavior, depositional alternatives and economics, we have made recommendations regarding additional work to be completed on the FIPR/DIPR process.

2. CLAY CONSOLIDATION TESTING AND MODELING

Consolidation parameters were developed to compare the consolidation behavior of phosphatic clay and phosphatic clay after treatment with the FIPR/DIPR process. FIPR tested the two materials using a centrifuge in an earlier project. The original scope of work for this project included testing the two materials using the Seepage Induced Consolidation (SIC) test. Due to equipment problems at FIPR with the SIC test, BCI completed two restricted flow consolidation tests to evaluate the consolidation behavior of treated and untreated clay samples. Test methods and the results for the tests are discussed below.

Clay consolidation is a function of two physical properties - permeability and compressibility. Compressibility characteristics dictate the amount of consolidation, and the permeability controls the rate at which consolidation takes place. Parameters have been derived from restricted flow consolidation tests and centrifuge tests as discussed in Sections 2.1 and 2.2 of this report. The compressibility and permeability relationships used for the analysis to predict consolidation behavior are listed below.

Compressibility

$$e = A\bar{\sigma}^{B}$$

Permeability

$$k = Ce^{D}$$

Where:

e = Clay Void Ratio (volume of voids ÷ volume of solids)
$\bar{\sigma}$ = Effective Stress (pounds per square foot)
k = Permeability (feet per day)
A, B, C and D = parameters determined by testing

The parameters A, B, C, and D are input variables for one-dimensional finite difference computer programs developed by BCI specifically for analyzing finite strain non-linear consolidation of mineral waste slurries.

2.1. Centrifuge Testing

Consolidation testing using a centrifuge was completed on unflocculated and flocculated clay samples. Test results are listed below for the four consolidation parameters A, B, C and D. Figures 2.1 and 2.2 include plots of compressibility and permeability.

TABLE 2.1
Consolidation Parameters from Centrifuge Test

Consolidation Parameter	Clay Sample	Clay, Polymer, & Pulp Sample
A (psf)	62.1	80.0
B	-0.35	-0.80
C (Feet per day)	6.84×10^{-10}	4.75×10^{-8}
D	5.84	4.36

2.2. Restricted Flow Consolidation Testing

BCI received one, five-gallon bucket of clay and polymer/pulp/clay mix in our laboratory. Laboratory tests completed on each sample included solids content (moisture determination), percent minus No. 150-mesh sieve, Atterberg limits testing and restricted flow consolidation test. The test procedures and results are discussed in the following sections.

Soils Laboratory Testing

A percent minus No. 150-mesh sieve test was completed on each sample in order to determine if any coarse fraction material was mixed with the clay. Test results indicate that 100 percent of the solids from all samples passed through the No. 150-mesh sieve.

An Atterberg limits test measures the plasticity of a soil or mineral waste. The moisture content range over which the clay exhibits plastic behavior is termed the plasticity index (PI). The Atterberg limits test defines the following three parameters.

- Liquid Limit (LL): The water content* above which a clay behaves as a liquid and below which it behaves as a plastic material.
- Plastic Limit (PL): The water content* above which a clay behaves as a plastic material and below which it behaves as a semi-solid.
- Plasticity Index (PI): The liquid limit minus the plastic limit (PI = LL - PL).

$$* \; water\ content = \frac{weight\ of\ water}{weight\ of\ solids} \times 100$$

Table 2.2 summarizes the results of the Atterberg limits tests. Atterberg limits tests were completed in accordance with ASTM D854 on a composite clay sample from each of the 15 drill holes completed for the study. The PI values for samples from each drill hole ranged between 96 and 243 (Table 2.2).

TABLE 2.2
Atterberg Limits Test Results

Sample Identification	Minus 200 Sieve (%)	Liquid Limit (LL)	Plastic Limit (PL)	Plasticity Index (PI)
Clay	97	211	47	164
Clay, Polymer and Pulp	96	200	59	141

Restricted Flow Consolidation Test

consolidated under very low gradients created by restricted flow of water through the sample. The clay slurry sample is placed in a cylindrical chamber approximately 70 millimeters in height and 70 millimeters in diameter which is pressurized using water pressure and a piston. The piston is sealed by O-rings to prevent water above the piston from contacting the clay sample below the piston. An adjustable micro-flow valve is connected to the bottom of the chamber which allows for a minute flow of water from the sample. This flow creates a very small gradient across the sample which is measured by pore pressure transducers at the top and bottom of the sample. Pressures are also recorded for the supplied water pressure above the piston. Measurements of the volume of water entering the chamber with time provides continual monitoring of the sample height change and the flow rate of pore water out of the sample.

Once the test is completed, typically in four to six days, all pressures on the sample are relieved and the clay sample is removed from the chamber. The compressed sample is measured to determine the final height, and oven dried. Final solids content and void ratio are calculated based on the dry total weight. Final solids contents are generally greater than 65 percent, which correspond to final sample heights of about 8 to 10 millimeters. Data collected from the RFC test can be evaluated by means of a computer spreadsheet to determine the void ratio at any time during the test, as well as the effective stress and permeability values that correspond with that void ratio.

Results of the two RFC tests are summarized below and in the attached graphs of effective stress versus void ratio (Figure 2.3) and permeability verses void ratio (Figure 2.4). Based on the best-fit lines of the data presented in the graphs, consolidation parameters were developed for the two samples. The RFC consolidation parameters are listed in Table 2.3 below. Consolidation parameters for the clay are similar to other phosphatic clay samples we have tested as shown in Figures 2.5 and 2.6.

TABLE 2.3
Consolidation Parameters from RFC Test

Consolidation Parameter	Clay Sample	Clay, Polymer, & Pulp Sample
A (psf)	25.5	44.4
B	-0.27	-0.34
C (Feet per day)	1.86×10^{-6}	4.63×10^{-7}
D	3.73	4.66

2.3 Consolidation Modeling Comparison

Compressibility and permeability plots for different clays are included as Figures 2.1 to 2.6. For compressibility plots, consolidation parameters that plot lower on the graph represent better compressibility clays. That is, at a given stress level they will exhibit a lower void ratio, and therefore a higher solids content.

Permeability parameters that plot lower (and to the right) on the void ratio vs. permeability graphs represent clays with better permeability characteristics. They will have a greater permeability at the same void ratio and clay solids and so will consolidate more quickly. The following section summarize results of consolidation modeling using laboratory derived parameters.

Using the consolidation parameters listed above and BCI's proprietary finite strain consolidation program FLINZ2, computer analyses were completed to compare the laboratory test results. The parameter comparison analyses included a one year fill at 5,000 tons which is a typical rate for clay deposition. Consolidation simulations for the FIPR/DIPR clay included 5,150 tons per year reflect the paper added to the clay.

Input parameters for the computer programs include settling area geometry, flow rate, filling time, initial clay solids, and the engineering properties of the clay including specific gravity, compressibility parameters, and permeability parameters. The consolidation analyses were for a three year period into an area with 967 acres of effective storage area.

Results of the computer analyses are shown in Table 2.4 below. The modeling using the RFC parameters indicate that after a one year fill at 5,000 tons per acre, the clay sample has a fill height of 19 feet and the clay, polymer, pulp sample has a fill height of 30 feet. Ultimate heights are 13 feet for the clay sample and 17 feet for the clay, polymer and pulp sample. Since the permeability parameters (C and D in Table 2.1) govern how quickly consolidation occurs, the clay, polymer and pulp mix has better permeability characteristics. The four foot difference in ultimate height indicates the clay sample has better compressibility characteristics. Copies of the computer output are included in Appendix B.

TABLE 2.4
Consolidation Parameter Comparison

Sample Type	Laboratory Test Method	End of Fill Clay Height Clay Solids	Ultimate Clay Height Clay Solids
Clay	RFC	27 Feet 13 percent	13 Feet 24 percent
FIPR/DIPR Mix	RFC	19 Feet 18 percent	17 Feet 20 percent
Clay	Centrifuge	32 Feet 11 percent	22 Feet 15 percent
FIPR/DIPR Mix	Centrifuge	23 Feet 15 percent	7 Feet 41 percent

Results of the computer analyses using the centrifuge parameters are also shown in Table 2.4. Modeling the parameter comparison scenario using the centrifuge data indicate that the clay sample has a fill height of 32 feet and the clay, polymer, pulp sample has a fill height of 23 feet. Ultimate heights are 22 feet for the clay sample and 7 feet for the clay, polymer and pulp sample. Parameters derived from the centrifuge test indicate the FIPR/DIPR mix has very good compressibility parameters (A and B in Table 2.1) which control the ultimate height. The 15 foot difference in ultimate height reflects the steep slope of the centrifuge compressibility curve for the FIPR/DIPR mix.

Figure 2.7 also shows the first two years of quiescent consolidation once deposition has stopped. The clay only sample consolidates more quickly, and the height difference is only 2 feet (31.5 feet vs. 28.5 feet) after two years of quiescent consolidation. The consolidation analyses indicate the ultimate or final conditions reflect a continuation of the rapid consolidation of the clay. The clay, polymer, and pulp sample has a predicted ultimate height of 25 feet and the clay sample has an ultimate height of 20.5 feet. So, the clay sample will have more consolidation and have an ultimate height approximately 4.5 feet lower than the clay, polymer and pulp sample. Output summaries of the four consolidation model runs are included in Appendix B.

3. FIPR/DIPR DISPOSAL ANALYSIS

Previous work completed at FIPR has identified two suggested disposal alternatives for the FIPR/DIPR: mine cut disposal and median strip disposal. During this project,GMC and BCI's personnel met with mining and reclamation personnel from several of the mining companies to describe the two disposal alternatives for the FIPR/DIPR process. Comments from the companies were instrumental in developing the FIPR/DIPR disposal method included in the economic comparison with dilute clay disposal.

3.1. Industry Comments

Task 2 of the BCI scope of work included interviewing engineering staff from the various phosphate mining companies in Florida. The intent was to collect clay disposal cost figures that would allow us to compare FIPR/DIPR disposal with the currently employed method at three mines. Upon completing the initial interviews, it was determined that cost accounting methods at each operating company differed sufficiently to preclude the researchers in accurately comparing disposal costs among mines. In addition, for proprietary reasons the mines were not willing to release the detailed cost figures.

The following mines were interviewed and had the following comments.

Cargill (John Schmedeman and Tom Myers)

- Cargill was interested in how the process could be incorporated into sand/clay mix disposal.
- Incorporating wood and vegetation fiber from clearing activities intrigued the Cargill mine personnel.

IMC/Agrico (Ken Williams and Jeff Drum)

- Primary clays at IMC well below our target of 3 to 4 percent solids.
- Did not anticipate IMC/Agrico would agree to uncontrolled use of a mine cut for clay mix deposition.
- Suggested alternate method of building one or more sides of an embankment with sand to allow for underdrainage of clay/polymer/pulp mix.
- Operational realities are that clay deposition areas are used to store water.

Mobil (Ted Nichols and John Ellington)

- Mobil has looked at polymer flocculant tests in the past and found them to be costly.
- Mobil thought implementation of this method would require an integrated mine and disposal plan best done at mine start-up.
- Implementation would only occur if the new disposal method added value or reduced costs.

OxyChem (Clayton Jones)

- OxyChem utilizes gravity flow deposition of clay and the proposed method would involve pumping FIPR/DIPR mix.

USAC (Charles Hammill)

- Implementation of any new clay disposal area was not planned due to the shutdown of the Rockland Mine in July 1994.
- USAC thought industries current methods of reclaiming clay settling areas dewatered areas quickly (N-3 at Agrico).

The input and critique of the two proposed FIPR/DIPR disposal methods as received from the mine personnel is included in sections 3.2 and 3.3. Based on the input from the mines, BCI developed the FIPR/DIPR disposal scenario discussed in section 3.4 that was the basis for completing an economic comparison of dilute clay disposal and disposal of the FIPR/DIPR pulp and polymer clay mix.

Based on the consolidation parameters developed for the clay and FIPR/DIPR mix, BCI's researchers have analyzed dilute clay disposal in conventional clay settling areas and FIPR/DIPR mix in low embankment areas built around mined-out cuts. The economic analysis included comparison of equipment, operating and labor costs. Based on BCI's analyses of the consolidation behavior, depositional alternatives and economics, they have made recommendations regarding additional work to be completed on the FIPR/DIPR process.

3.2. Mine Cut Disposal

The first disposal method developed by FIPR includes depositing alternating layers of tailings sand and clay/polymer/fiber slurry in a mine cut. This scenario includes a cofferdam that separates the disposal area from a sump from which decant water is pumped (Figure 3.1). The advantage of this method, which was demonstrated in the laboratory, is that the tailings sand imposes a stress on the mix that accelerates consolidation and provides a preferred drainage path for water produced from consolidation of the mix.

Comments regarding mine cut disposal from mine personnel include:

- Placing alternating two foot layers of sand and mix would not be practical in the field and would be very expensive.
- Operational control would be hard to achieve given the typical 24 hour a day operating schedule currently employed at the mines.
- Deposition of clay/pulp/paper mix in cuts has the possibility of spilling to adjacent areas.

3.3. Median Strip Disposal

The other dewatering option scenario proposed by FIPR utilizes the overburden pile between two adjacent mine cuts as a dewatering area. Slurried clay/paper/pulp mix would be pumped to the overburden pile which had been sloped toward one cut. Water from the mix would flow down the slope into one cut and the dewatered mix would then be pushed to the adjacent cut. Figure 3.2 illustrates s plan view of this disposal method. The process would be repeated and then the process would shift over one mine spoil row.

Comments from the mine personnel regarding median strip disposal include:

- Placing clay/paper/pulp mix in two foot layers would not be practical in the field given the large quantity of clay produced per hour.
- Operational control would be hard to achieve given 24 hour a day schedule.
- This method would require intensive manpower and field equipment.
- The possibility of spilling clay/pulp/paper mix into adjacent areas was also a concern.

3.4. Low Embankment Disposal

Based on comments received from the mining industry, BCI developed a low embankment disposal method. This method involves building an embankment of sufficient height to store the FIPR/DIPR mix with the required five foot freeboard required by FDEP Chapter 17-673. The basic characteristics of the low embankment disposal method are listed below.

- Large areas of mined-out areas are selected for construction of an engineered embankment within which FIPR/DIPR clay mix would be deposited.
- The FIPR/DIPR mix would be generated at a facility constructed at the beneficiation plant and the mix would be pumped to the low embankment.
- Clear water would be returned from the FIPR/DIPR disposal areas to the hydraulic ditch as is now done.
- Currently sized motors and pipelines are assumed to be sufficient to pump the FIPR/DIPR mix.

The requisite characteristics of this disposal method based on the interviews are listed below.

- Construction and operational methods are similar to those now employed.
- Operational requirements are minimal.
- This method avoids intensive manpower and field equipment required in the two other FIPR/DIPR disposal methods discussed.
- This method maintains the water storage capacity of the current clay disposal method.
- This method increases the acreage of settling areas and therefore increases the liability of the most difficult reclamation type.
- Doubles the volume of material to dispose of, i.e., clay plus fiber.

3.5. Evaluation of Disposal Alternatives

Using the consolidation parameters listed above and BCI's proprietary finite strain consolidation program FLINZ2, computer analyses were completed to compare a mine scenario of clay and FIPR/DIPR mix disposal. The analysis simulated a three year fill of a clay settling area and the ultimate consolidation conditions. The fill reflects 2.9 MT (dry weight basis) of clay produced per year. Consolidation simulations for the FIPR/DIPR clay included 2.987 MT per year reflect the paper and pulp added to the clay. The analyses included deposition into an area with 967 acres of effective storage area, which represented a 40 foot fill height for the RFC clay sample.

Input parameters for the computer programs include settling area geometry, flow rate, filling time, initial clay solids, and the engineering properties of the clay including specific gravity, compressibility parameters, and permeability parameters. Results of the computer analyses are shown in Table 3.1 below. The modeling using the RFC parameters indicate that the clay sample has a fill height of 40 feet and the clay, polymer, pulp sample has a fill height of 30 feet. Ultimate heights are 21 feet for the clay sample and 26 feet for the clay, polymer and pulp sample. Since the permeability parameters (C and D in Table 2.1) govern how quickly consolidation occurs, the clay, polymer and pulp mix has better permeability characteristics. The five foot difference in ultimate height indicates the clay sample has better compressibility characteristics. Copies of the computer output are included in Appendix C.

TABLE 3.1
Fill Height and Ultimate Height Data

Sample Type	Laboratory Test Method	End of Fill Clay Height Clay Solids	Ultimate Clay Height (feet) Clay Solids (%)
Clay	RFC	40 Feet 15 Percent	21 Feet 27 Percent
FIPR/DIPR Mix	RFC	30 Feet 20 Percent	26 Feet 23 Percent
Clay	Centrifuge	54 Feet 11 Percent	33 Feet 18 Percent
FIPR/DIPR Mix	Centrifuge	40 Feet 15 Percent	9 Feet 50 Percent

Results of the computer analyses using the centrifuge parameters are also shown in Table 3.1. Modeling the same clay deposition scenario using the RFC parameters indicate that the clay sample has a fill height of 39 feet and the clay, polymer, pulp sample has a fill height of 40 feet. Ultimate heights are 3 1 feet for the clay sample and 9 feet for the clay, polymer and pulp sample. Parameters derived from the centrifuge test indicate the FIPR/DIPR mix has very good compressibility ultimate height indicates the clay sample has better compressibility characteristics.

4. COST COMPARISONS

Based on the storage volume requirements determined for dilute clay and FIPR/DIPR mix disposal, we have compared the costs for each method. Our economic analysis included comparison of equipment, operating and labor costs. Listed below are some of the basic process assumptions common to both clay disposal scenarios.

Common to Both Scenarios

- Annual clay production is 3.0 million tons of solids per year.
- The beneficiation plant operates 7,072 of 8,320 available hours.
- Clay from beneficiation plant is at 3 percent solids by weight.
- Pumping distance to disposal area is one mile.
- Electricity cost is $0.05 per kilowatt hour.
- Clay production rate is about 425 dry tons per hour.

4.1. Process Description

Dilute Clay Disposal

The dilute clay disposal scenario includes the following assumptions.

- Clay is pumped at 3 percent solids.
- Discharge point is 40 feet higher in elevation than pump at beneficiation plant.
- Clay input to pump from a tank or above-ground sump.
- Positive feed to horizontal pump.
- Average flow rate is 66,560 gallons per minute.

FIPR/DIPR Clay Disposal

The FIPR/DIPR clay disposal process is described below.

- Clay, polymer, and pulp are mixed adjacent to the beneficiation plant and pumped to the disposal area.
- The FIPR/DIPR mix process will include a polymer mixing station, paper storage and pulping unit, tanks and pumps.
- Disposal will include pumping the entire mix to disposal areas.
- Paper pulp will be slurried with dilute clay to 6 percent fiber solids.
- Paper pulp rate is 60 pounds per ton of clay and paper cost is $10 per ton of paper.
- Polymer rate is 0.5 pound per ton of clay.

The FIPR/DIPR process involves 66,560 gallons per minute (gpm) of clay slurry containing 3 percent clay solids pumped from a tank or above ground sump at the beneficiation plant. Polymer and fiber are added to the clay solids to produce a mixture with improved consolidation characteristics.

Fiber Slurry Preparation

Fiber slurry containing 6 percent fiber solids is produced in a continuous pulper. The fiber source is assumed to be all newsprint. The equipment consists of a conveyor and unbaler which removes bales from the newsprint and delivers it to the pulper. The pulper is fed with about 12.7 tons per hour of newsprint and a side stream of 1564 gpm of clay slurry to produce 1615 gpm of 6 percent solids fiber slurry. The pulper operates continuously.

This type of pulper has some limitations. Some large fiber flakes will be produced and the maximum consistency is 6 percent solids. However, for this application this is not a problem. The fiber slurry is fed to a high efficiency static mixer where it is combined with the main clay slurry stream.

Polymer Preparation

Dry polymer is received in drums and fed to a bin. Polymer is metered from the bin to a mixing tank where it is dissolved in process water to form a 0.5 percent by weight polymer solution. The polymer handling system is supplied by the polymer supplier. Polymer solution is fed at about 85 gpm to a second high efficiency static mixer where it is mixed with the clay slurry and fiber mixture.

The flocculated clay and fiber slurry is pumped by the existing pumping system to the disposal area.

Low Embankment Disposal

- This scenario includes disposing clay in an embankment designed for higher initial solids typical of the FIPR/DIPR process.
- Preliminary embankment heights of 30 feet will be modified based on laboratory consolidation tests on the FIPR/DIPR mix.
- Low embankments have single drainage through the top of the clay mix.

TABLE 4.1
Equipment List

ITEM	NO.	DESCRIPTION
1102	1	Pulp Pump T - Horizontal Centrifugal C - 1940 gpm M - 28 percent Chrome Iron D - 200 HP
1101	1	Polymer Pump T - Horizontal Centrifugal C - 100 gpm M - Cast Iron D - 25 HP
1301	1	Pulper T - Continuous Pulper C - 12.7 tph Paper S - 36 m^3 M - 304L SS D - 400 HP
1601	1	Static Mixer T - Static Mixer C - 67,000 gpm S - 48" M - FRP
2501	1	Polymer System Comprising Screw Feeder & Hopper Blower/Venturi Ejector Disperser Tank w/Agitator Transfer Pump Storage Tank

4.2. Economic Cost Comparison

The economic analysis compared conventional dilute clay disposal with the FIPR/DIPR process where the polymer (flocculant) and fiber are added at the beneficiation plant and the entire clay, fiber and polymer mix is pumped to the disposal area. Costs for the two clay additives are listed below.

Polymer (flocculant)	$1 per pound
Fiber (newsprint)	$10 per ton delivered

Capital Cost Estimate

Estimated capital costs for the FIPR/DIPR process equipment are included in Table 4.2. The most expensive piece of equipment is the fiber pulper which has an estimated cost of $240,500. The total delivered equipment cost for the five major components is $367,000 (Table 4.2). The estimated capital cost for the FIPR/DIPR process including installation, engineering and a 15 percent contingency is $933,000. Table 4.2 includes all the installation and instrumentation costs.

Operating Cost Estimate

Estimated operating costs are summarized in Table 4.3. The estimated operating cost for the FIPR/DIPR system is about $2.78 million per year or $0.93 per ton of clay solids. The cost of polymer ($1.5m/year) and paper ($0.9m/year) represent about 85 percent of the FIPR/DIPR annual operating costs. A breakdown of labor costs is included in Table 4.4.

There is a fraction of a percent increase in volume to be pumped, which is insignificant in the operating costs.

Cost Savings

The savings for the FIPR/DIPR system considered are reduced dam construction costs. The cost for the conventional system is estimated to be $3.1 m every three years for a dam height of 30 ft. For the FIPR/DIPR case the dam height required is only 20 ft. The cost incurred every three years is $1.6m. Thus, the savings in dam costs is only $1.5m every three years or $0.5m annually.

TABLE 4.2
Equipment Cost Estimate

Item	Description	Vendor	Cost
1101	Polymer Pump	Nagle	6,600
1102	Pulp Pump	Nagle	42,400
1301	Fiber Pulper	Fiberprep/Aikwa 36	240,500
1601	Static Mixer	Koch	39,500
2501	Polymer System	Allied Colloids	38,000
Total			**367,000**

Item	Factor	Cost
Delivered equipment cost		$367,000
Installed equipment cost	1.35	$495,000
Piping	0.15	$55,000
Instrumentation	0.10	$37,000
Electrical	0.10	$37,000
Total physical plant cost		$624,000
Engineering & construction	0.30	$187,000
Contingency	0.15	$122,000
Total Plant Cost		**$933,000**

Table 4.3
Operating Costs

	Unit/t clay	Unit	$/unit	$/t	$/y
Direct operating costs					
Raw materials					
Polymer	0.5	lb	1	0.5	1,500,000
Paper	0.03	t	10	0.3	900,000
Subtotal				**0.8**	**2,400,000**
Utilities					
Process Water	12	gal	0.001	0.012	35,984
Power	0.9	kWh	0.05	0.044	131,893
Subtotal				**0.056**	**167,877**
Direct Labor & Supervision					
Labor				0.041	122,640
Supervision				0.005	15,600
Subtotal				**0.046**	**138,240**
Plant Maintenance					
Labor				0.003	8,840
Material (5 percent of equipment cost)				0.006	18,350
Subtotal				**0.009**	**27,190**
Operating supplies (20 percent of plant maintenance)					
Subtotal direct operating cost				**0.911**	**2,733,307**
Indirect Costs					
Administration (15 percent of direct labor)					20,736
Subtotal indirect costs				**0.007**	**20,736**
Fixed charges					
Taxes & insurance (3 percent of plant cost)					27,990
Subtotal fixed charges				**0.009**	**27,990**
Total operating cost				**0.927**	**2,782,003**

TABLE 4.4
Labor Costs

Labor	Shifts/day	$/h	hourly	Annual Cost
Plant operation				
Unloader/Operator	4	14	8760	122640
Total				122640
Supervision				
Superintendent	0.25	30	520	15600
Total				15600
Maintenance				
Mechanic	0.25	17	520	8840
Total				8840

Economic Evaluation

Based on the estimates of capital and operating costs for the FIPR/DIPR process, no detailed economic evaluation is necessary. The savings from the system are only $0.5m per year compared with operating costs of $2.78m per year and capital costs of over $0.9m.

5. CONCLUSIONS

This project has addressed several aspects of disposing phosphatic clay using a mixture of flocculant and paper pulp to improve the consolidation behavior of the material. The project scope was defined based on the previous work completed by FIPR on the process. The FIPR/DIPR mix does consolidate more rapidly than untreated phosphatic clay. Preliminary cost estimates for implementing the FIPR/DIPR process indicates that it is significantly more expensive than conventional dilute clay disposal. Our testing and analyses have identified the following conclusions regarding the behavior of the FIPR/DIPR clay mix.

- One Restricted Flow Consolidation test was completed in the BCI laboratory on FIPR/DIPR mix and untreated clay. Consolidation analyses based on consolidation parameters derived from the limited data indicate the FIPR/DIPR clay mix shows improved consolidation in the short term due to improved permeability. Ultimately, the dilute clay consolidates to a higher percent solids than the FIPR/DIPR mix due to better compressibility characteristics.

- The accelerated consolidation of the FIPR/DIPR mix does result in a smaller required clay storage volume when compared with conventional clay consolidation.

- The cost of polymer ($1.5m/year) and paper ($0.9m/year) represent about 85 percent of the additional annual operating costs for the FIPR/DIPR process.

- Cost reductions identified for the FIPR/DIPR process include $0.5m per year in reduced settling area construction. Implementation of the process include operating costs of $2.78m per year and capital costs of over $0.9m.

- Cost of paper could be higher (as much as $20/ton) to remote beneficiation sites with long haul distances from paper sources.

- Eliminating the embankment would still not produce net cost savings for the FIPR/DIPR process compared with conventional clay disposal.

6. RECOMMENDATIONS

BCI's consolidation test results, computer modeling of clay and mix deposition and economic comparison indicates the FIPR/DIPR process results in improved initial consolidation of phosphatic clay. This would allow construction of lower embankments, since the embankment height is driven by the dilute, low percent solids clay typical of the early phase of consolidation. Our economic evaluation shows the cost of implementing the FIPR/DIPR process by pumping dilute paper, pulp and clay would be much greater than the savings resulting from a lower profile clay settling area embankment.

Due to the economic implications of these results, BCI recommends that no additional testing of this disposal method be completed until fundamental changes are made in the economics. Specific ways the economics could change are listed below.

- Alternative process or disposal methods for the FIPR/DIPR mix would be required to justify large-scale implementation.

- Additional research would be justified if cost reductions in the two additives, paper pulp and polymer, are identified.

- The FIPR/DIPR process may have a specific application for phosphatic clay disposal based on environmental, permit or reclamation considerations that override the high costs.

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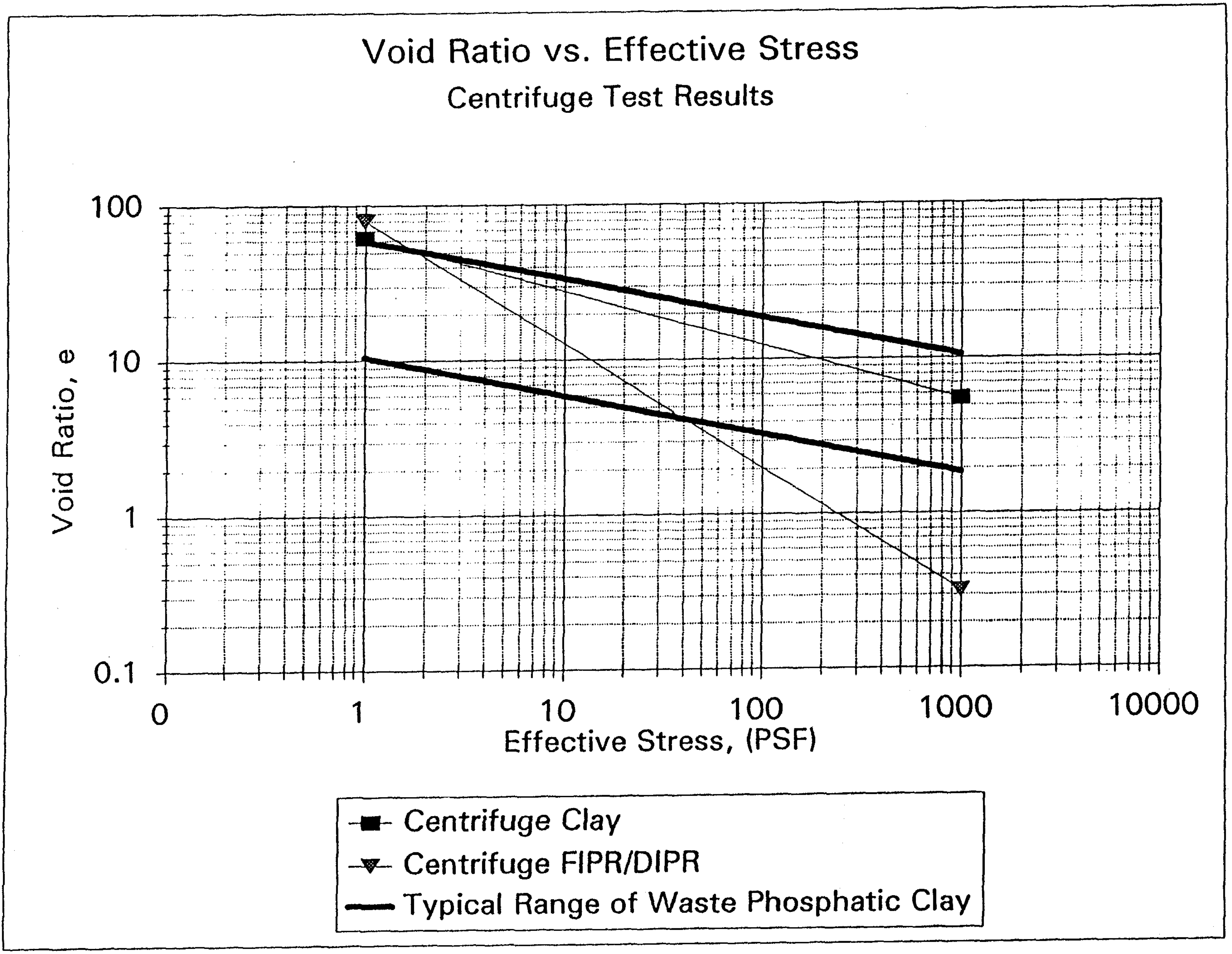

Void Ratio vs. Effective Stress
Centrifuge Test Results
Void Ratio, e
100
10
1
0.1
0
1
10
100
1000
10000
Effective Stress, (PSF)
■ Centrifuge Clay
▼ Centrifuge FIPR/DIPR
— Typical Range of Waste Phosphatic Clay

FIGURE 2.1

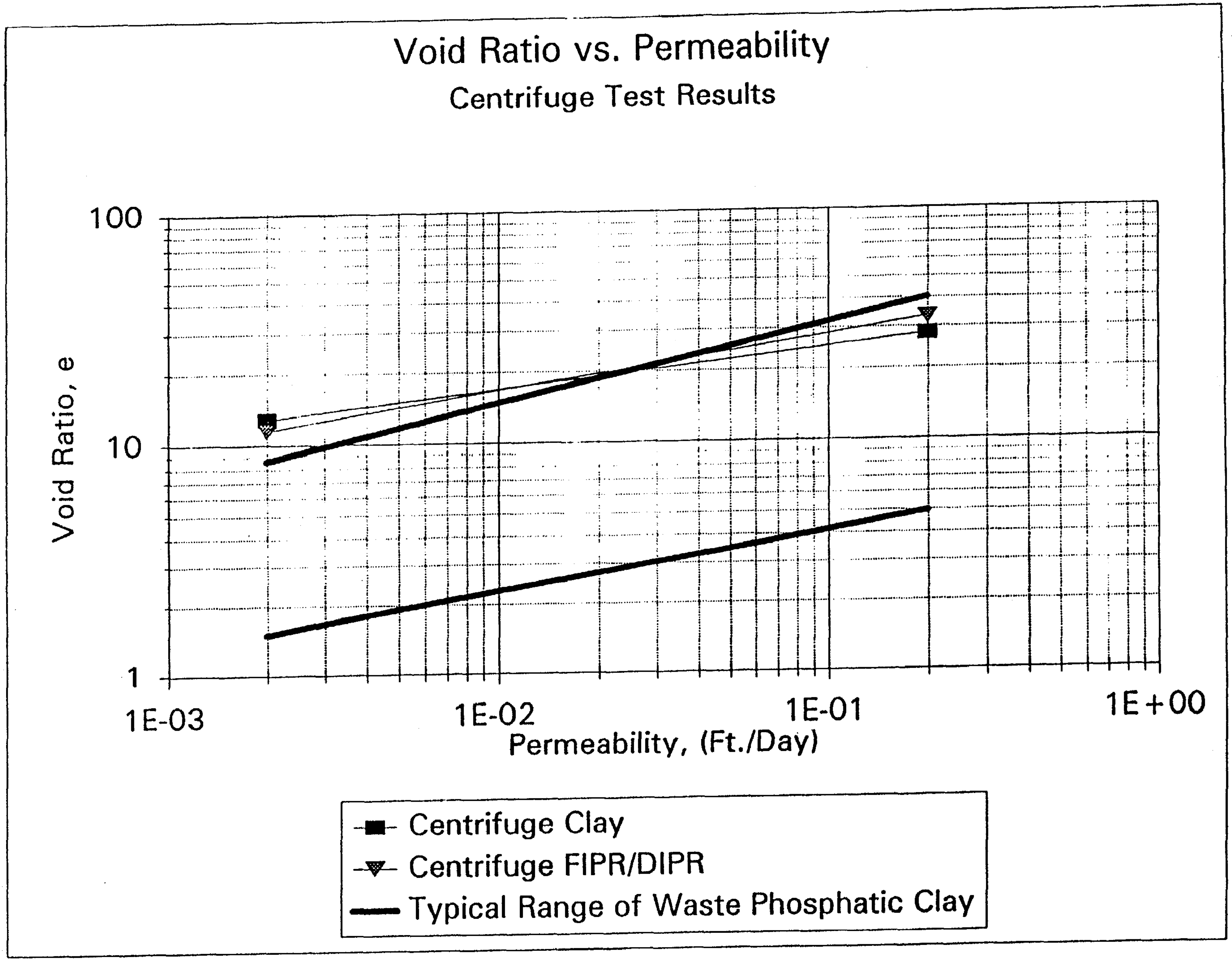
Void Ratio vs. Permeability
Centrifuge Test Results
100
10
1
Void Ratio, e
1E-03
1E-02
1E-01
1E+00
Permeability, (Ft./Day)
Centrifuge Clay
Centrifuge FIPR/DIPR
Typical Range of Waste Phosphatic Clay

FIGURE 2.2

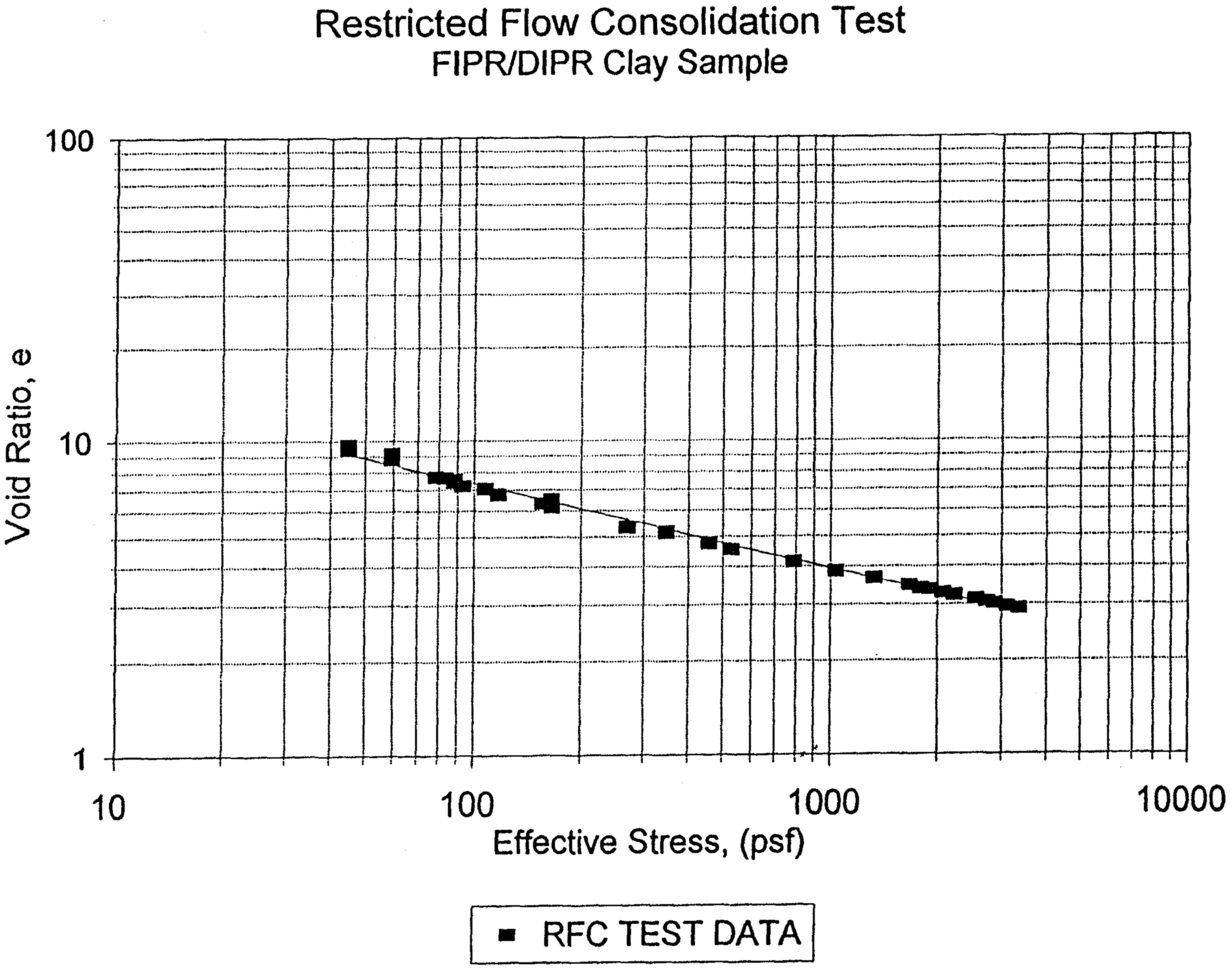
Restricted Flow Consolidation Test
FIPR/DIPR Clay Sample
Void Ratio, e
100
10
1
10
100
1000
10000
Effective Stress, (psf)
■ RFC TEST DATA

Figure 2.3a

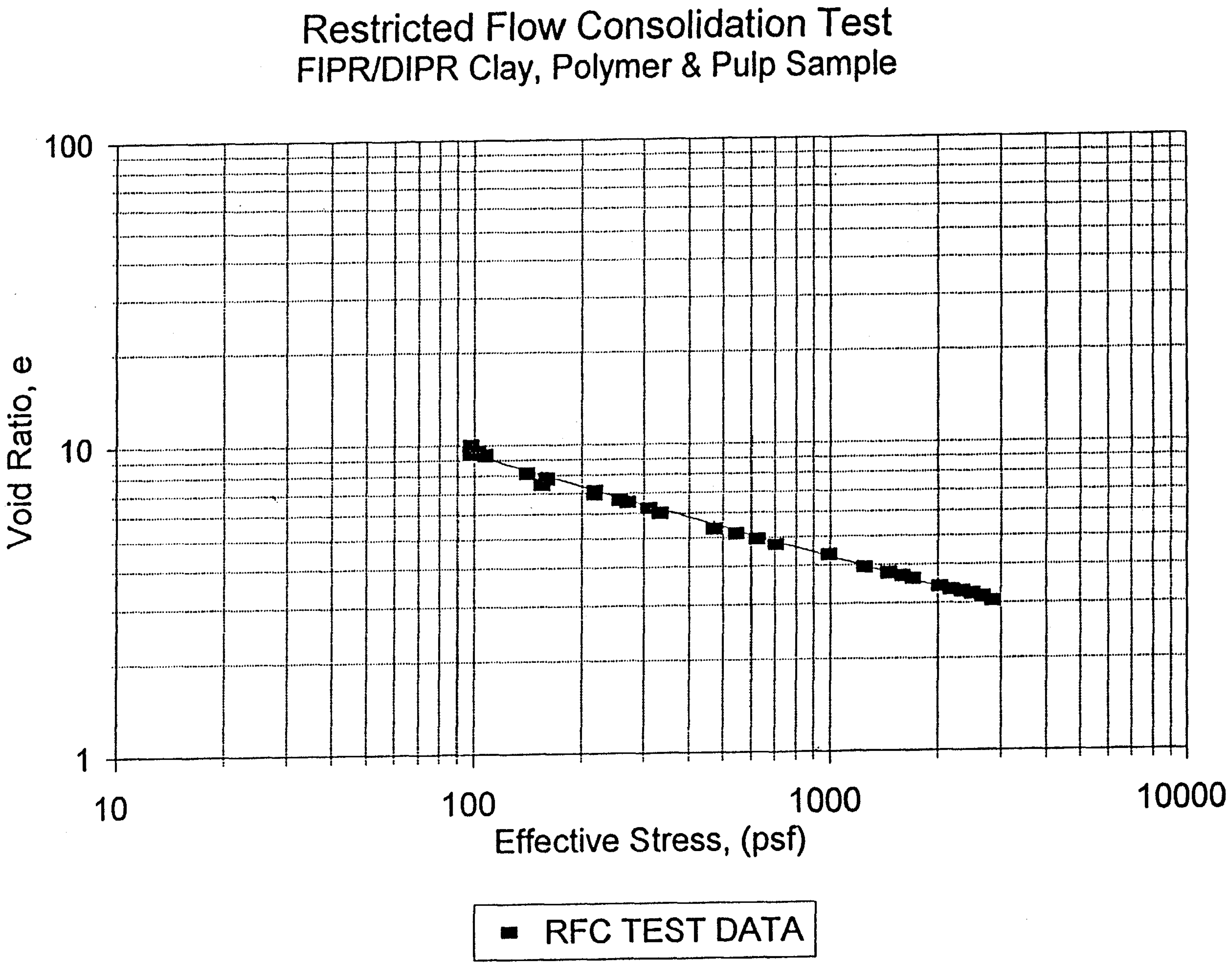
Restricted Flow Consolidation Test
FIPR/DIPR Clay, Polymer & Pulp Sample
Void Ratio, e
100
10
1
10
100
1000
10000
Effective Stress, (psf)
■ RFC TEST DATA

Figure 2.3b

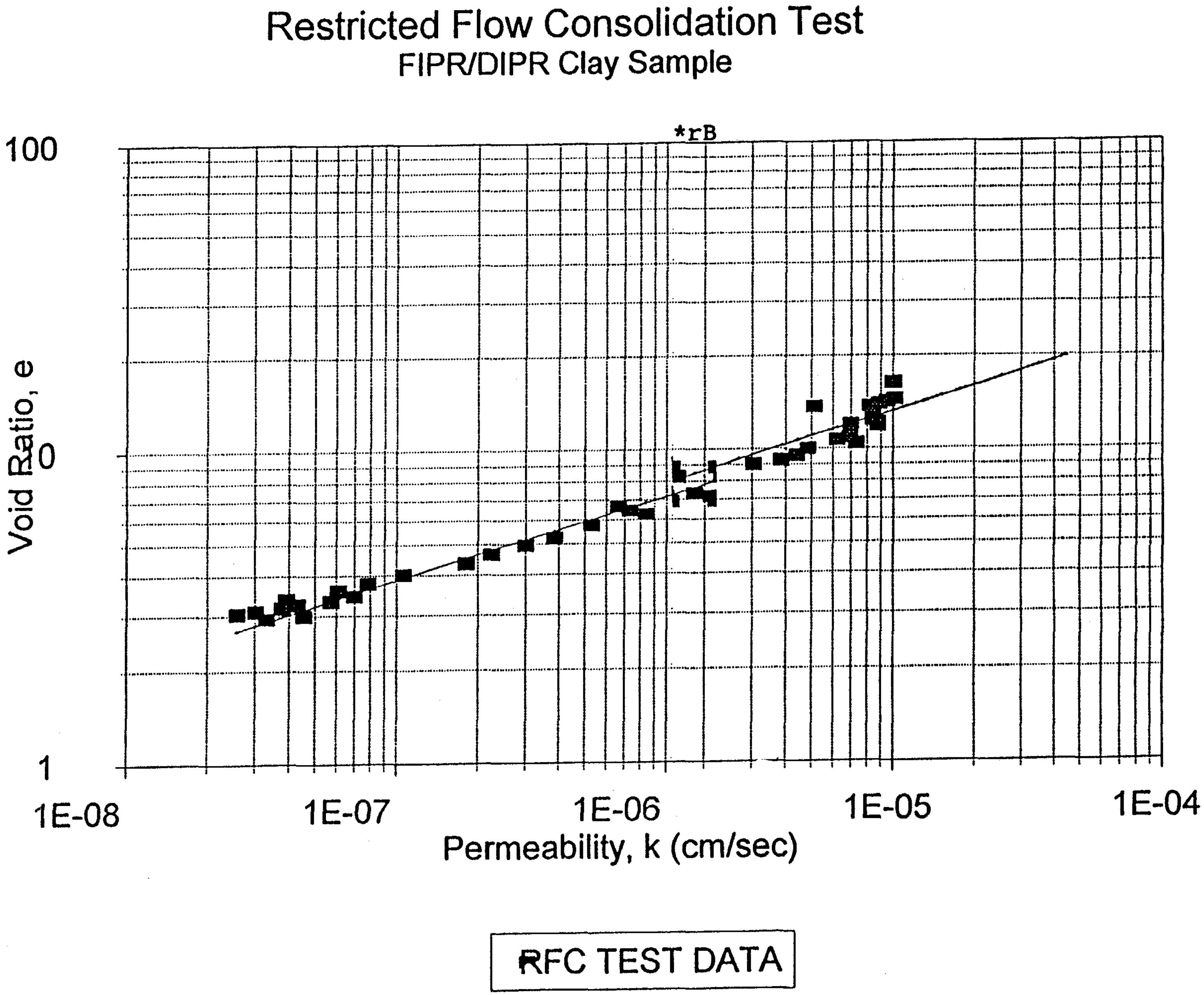
Restricted Flow Consolidation Test
FIPR/DIPR Clay Sample
*rB
100
10
1
Void Ratio, e
1E-08
1E-07
1E-06
1E-05
1E-04
Permeability, k (cm/sec)
RFC TEST DATA

Figure 2.4a

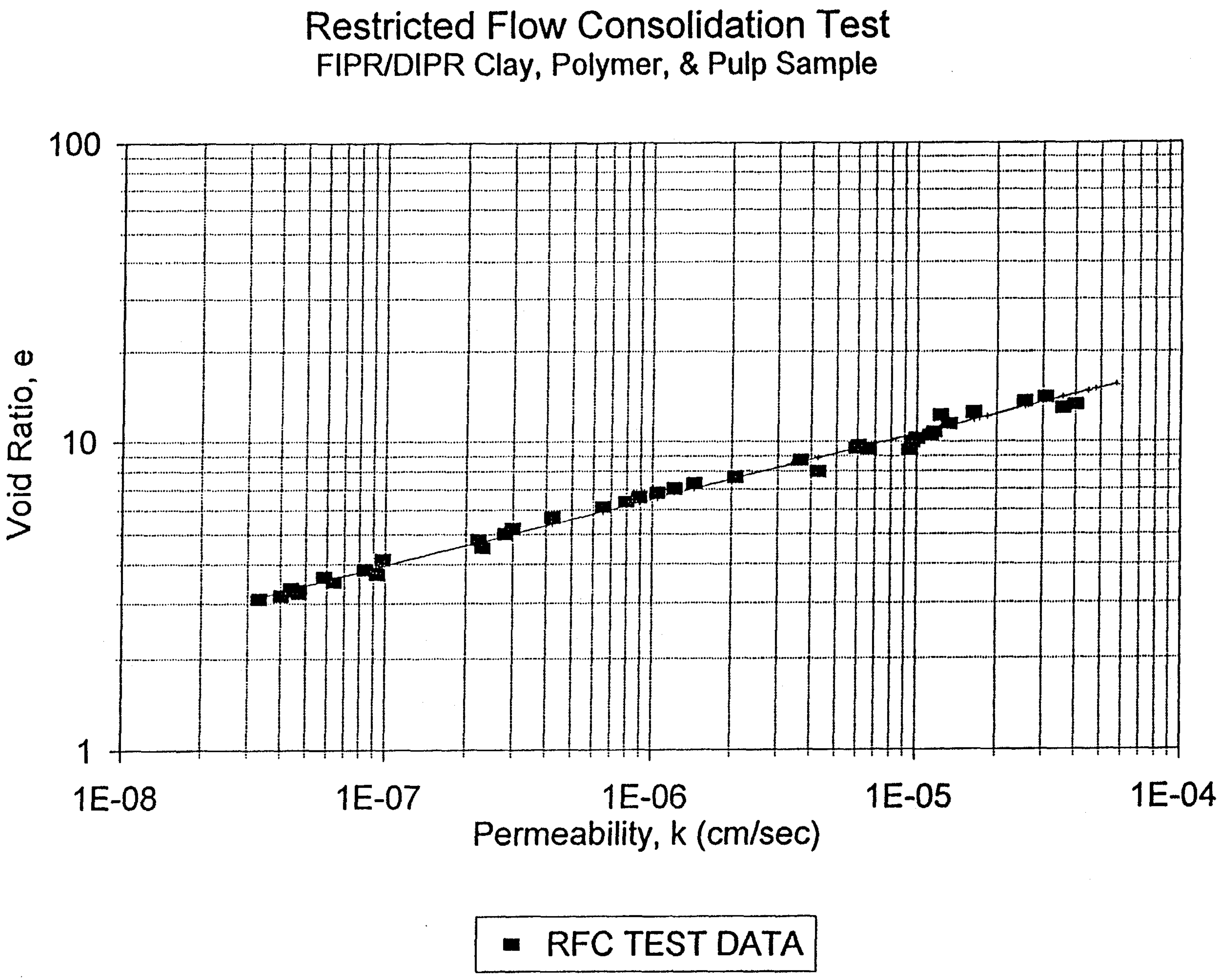
Restricted Flow Consolidation Test
FIPR/DIPR Clay, Polymer, & Pulp Sample
100
10
1
Void Ratio, e
1E-08
1E-07
1E-06
1E-05
1E-04
Permeability, k (cm/sec)
■ RFC TEST DATA

Figure 2Ab

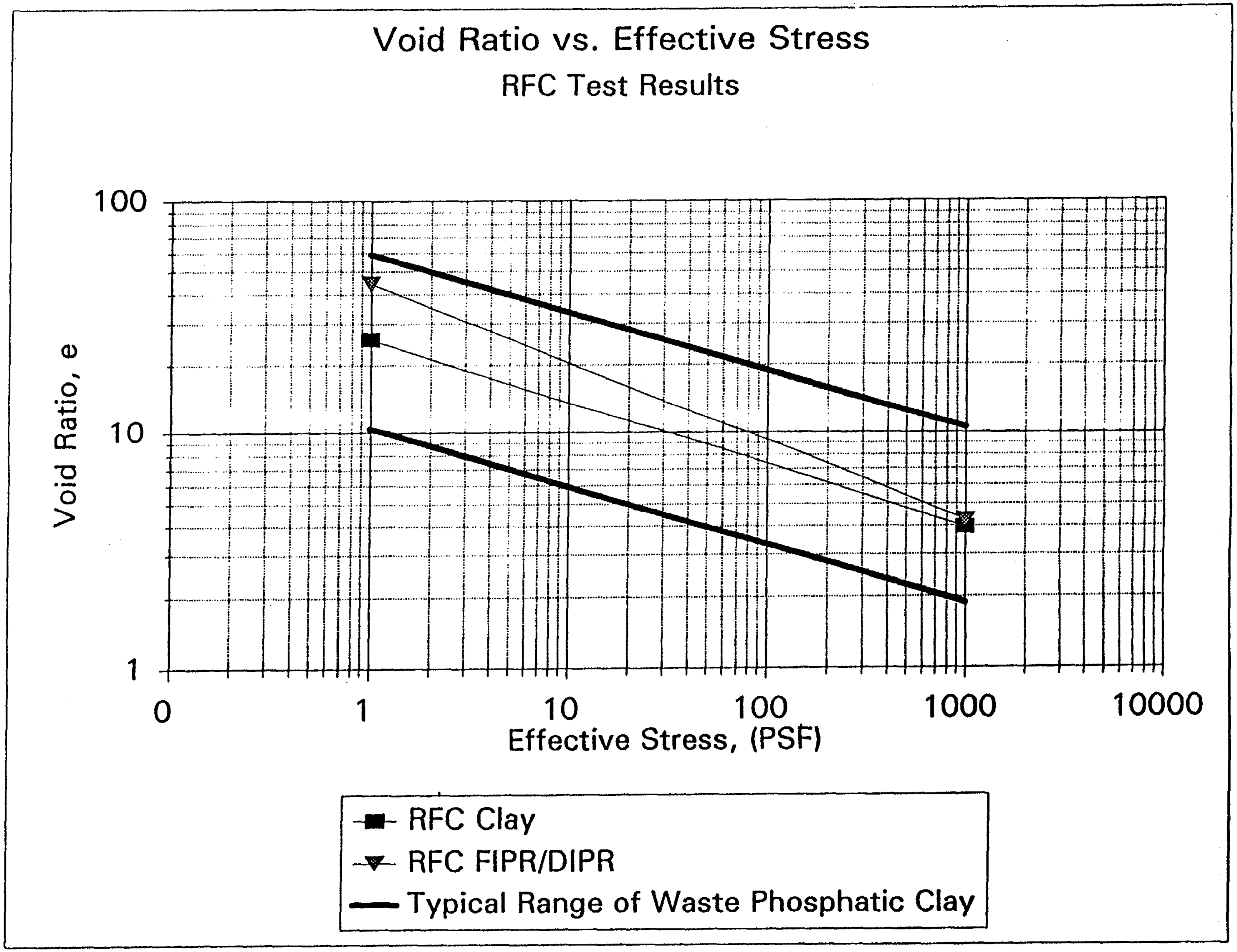
Void Ratio vs. Effective Stress
RFC Test Results
Void Ratio, e
100
10
1
0
1
10
100
1000
10000
Effective Stress, (PSF)
■ RFC Clay
▼ RFC FIPR/DIPR
Typical Range of Waste Phosphatic Clay

FIGURE 2.5

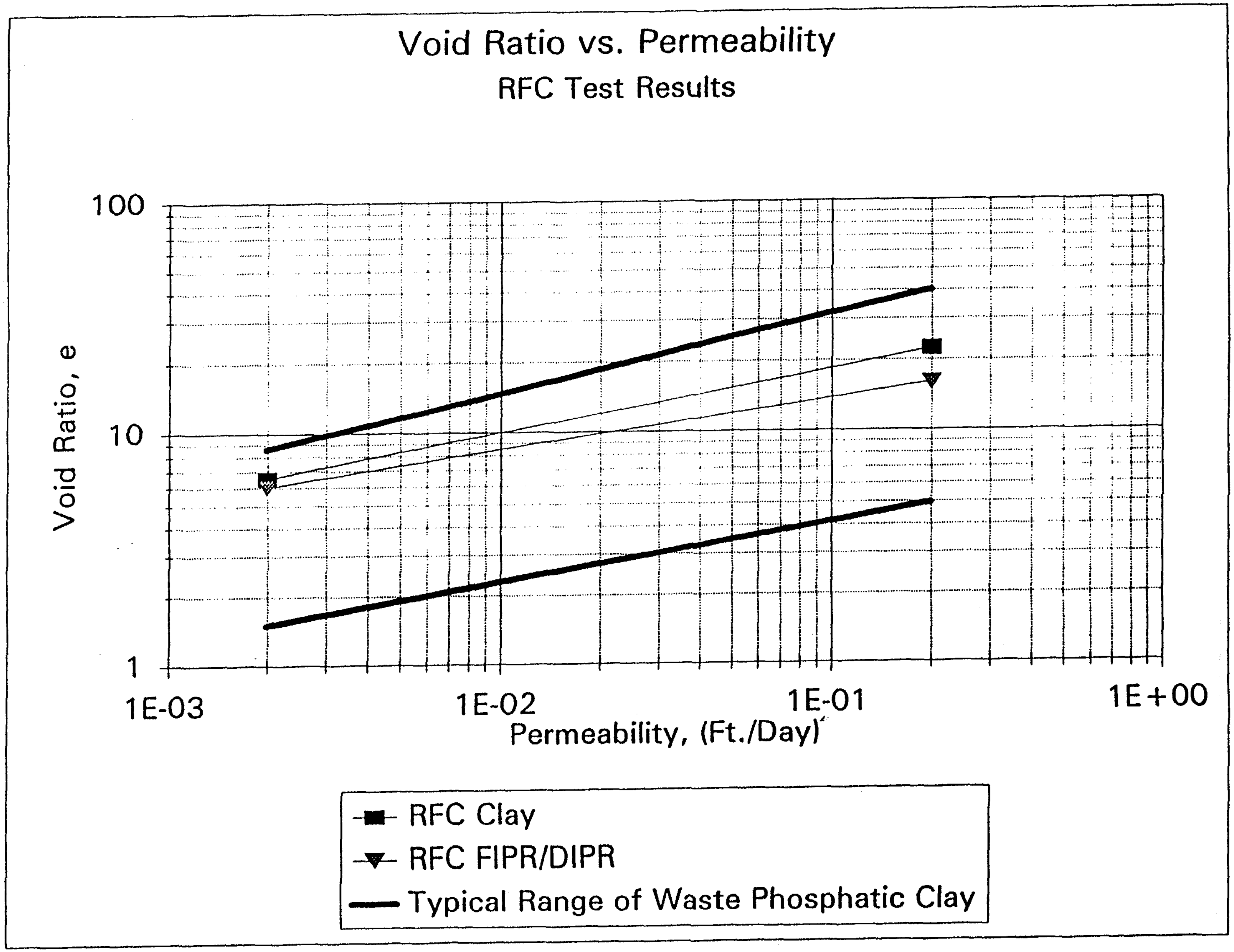
Void Ratio vs. Permeability
RFC Test Results
Void Ratio, e
100
10
1
1E-03
1E-02
1E-01
1E+00
Permeability, (Ft./Day)
RFC Clay
RFC FIPR/DIPR
Typical Range of Waste Phosphatic Clay

FIGURE 2.6

Option "A" - Mining Cut (pit) Disposal

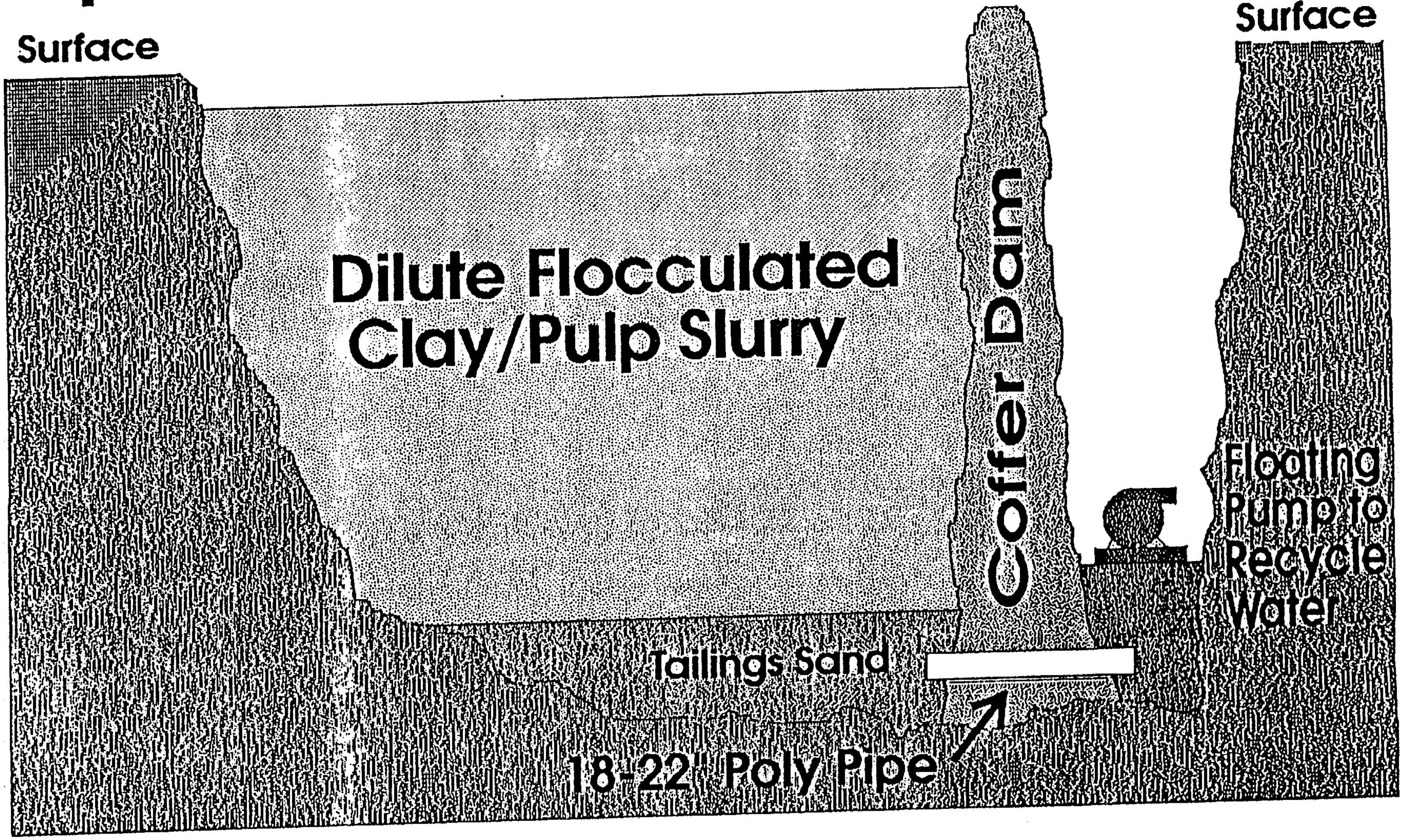

Figure 3.1

Option "B" - Median Strip

(Plan View)

Step 1

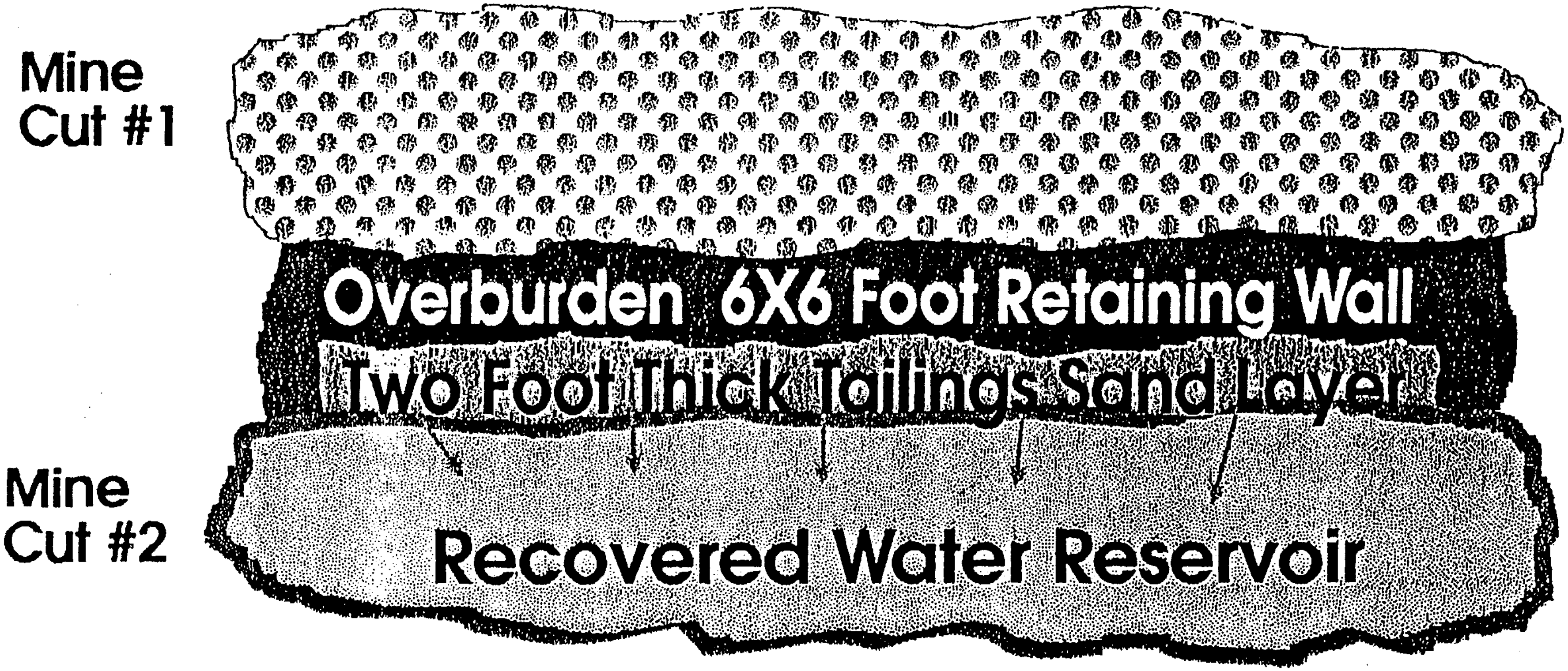

Figure 3.2

APPENDIX A
ANALYSES FOR PRIORITY POLLUTANTS

ENVIROLAB

Environmental Certification
HRS #E83079

ENVIROLAB
1032 U.S. Highway One, North
P.O. Box 468
Ormond Beach, Florida 32175
(904) 672-5668
Fax (904) 673-4001
Drinking Water Certification
HRS #83160

GLOBAL MARKETING & CONSULTING
2009 PALADIN CT.
VALRICO,FL 33594
ATT:HASSAN EL-SHALL

Submission #: 9407000025
Date Received: 07/01/94
Date Reported: 07/28/94

Client PO Number:
Project Number:
Project:

Order Number: 57182
Date Sampled: 06/29/94
Client Sample Number: 1
Sample Description: COLUMN 1

Method	Component	Units	Result	Analyst	Date Analyzed	Date Prepared
206.2	ARSENIC	MG/L	0.001	BB	07/12/94	
208.1	BARIUM	MG/L	<0.05	AKM	07/11/94	
213.1	CADMIUM	MG/L	<0.005	BB	07/13/94	
218.1	CHROMIUM	MG/L	<0.02	AKM	07/11/94	
239.1	LEAD	MG/L	<0.02	BB	07/13/94	
245.1	MERCURY	MG/L	<0.0002	AKM	07/15/94	
270.2	SELENIUM	MG/L	<0.002	BB	07/11/94	
272.1	SILVER	MG/L	<0.01	BB	07/13/94	

Order Number: 57183
Date Sampled: 06/29/94
Client Sample Number: 2
Sample Description: COLUMN 2

Method	Component	Units	Result	Analyst	Date Analyzed	Date Prepared
206.2	ARSENIC	MG/L	0.002	BB	07/12/94	
208.1	BARIUM	MG/L	<0.05	AKM	07/11/94	
213.1	CADMIUM	MG/L	<0.005	BB	07/13/94	
218.1	CHROMIUM	MG/L	<0.02	AKM	07/11/94	
239.1	LEAD	MG/L	<0.02	BB	07/13/94	
245.1	MERCURY	MG/L	<0.0002	AKM	07/15/94	
270.2	SELENIUM	MG/L	<0.002	BB	07/11/94	
272.1	SILVER	MG/L	<0.01	BB	07/13/94	

ENVIROLAB

Environmental Certification
HRS #E83079

ENVIROLAB
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Fax (904) 673-4001
Drinking Water Certification
HRS #83160

GLOBAL MARKETING & CONSULTING
2009 PALADIN CT.
VALRICO,FL 33594
ATT:HASSAN EL-SHALL

Submission #: 9407000025
Date Received: 07/01/94
Date Reported: 07/28/94

Client PO Number:
Project Number:
Project:

Order Number: 57190
Date Sampled: 06/29/94
Client Sample Number: 3
Sample Description: COLUMN 3 & 4

Method	Component	Units	Result	Analyst	Date Analyzed	Date Prepared
206.2	ARSENIC	MG/L	0.001	BB	07/12/94	
208.1	BARIUM	MG/L	<0.05	AKM	07/11/94	
213.1	CADMIUM	MG/L	<0.005	BB	07/13/94	
218.1	CHROMIUM	MG/L	<0.02	AKM	07/11/94	
239.1	LEAD	MG/L	<0.02	BB	07/13/94	
245.1	MERCURY	MG/L	<0.0002	AKM	07/15/94	
270.2	SELENIUM	MG/L	<0.002	BB	07/11/94	
272.1	SILVER	MG/L	<0.01	BB	07/13/94	
624	1,1,1-TRICHLOROETHANE	UG/L	<1	VG	07/11/94	
624	1,1,2,2-TETRACHLOROETHANE	UG/L	<1	VG	07/11/94	
624	1,1-DICHLOROETHANE	UG/L	<1	VG	07/11/94	
624	1,2-DICHLOROBENZENE	UG/L	<1	VG	07/11/94	
624	1,2-DICHLOROPROPANE	UG/L	<1	VG	07/11/94	
624	1,4-DICHLOROBENZENE	UG/L	<1	VG	07/11/94	
624	BENZENE	UG/L	<1	VG	07/11/94	
624	BROMOFORM	UG/L	<1	VG	07/11/94	
624	CARBON TETRACHLORIDE	UG/L	<1	VG	07/11/94	
624	CHLOROETHANE	UG/L	<1	VG	07/11/94	
624	CHLOROMETHANE	UG/L	<1	VG	07/11/94	
624	DIBROMOCHLOROMETHANE	UG/L	<1	VG	07/11/94	
624	METHYLENE CHLORIDE	UG/L	<1	VG	07/11/94	
624	TOLUENE	UG/L	<1	VG	07/11/94	
624	TRANS-1,3-DICHLOROPROPENE	UG/L	<1	VG	07/11/94	
624	TRICHLOROFLUOROMETHANE	UG/L	<2.0	VG	07/11/94	
624	1,1,2-TRICHLOROETHANE	UG/L	<1	VG	07/11/94	
624	1,1-DICHLOROETHENE	UG/L	<1	VG	07/11/94	
624	1,2-DICHLOROETHANE	UG/L	<1	VG	07/11/94	
624	1,3-DICHLOROBENZENE	UG/L	<1	VG	07/11/94	
624	2-CHLOROETHYLVINYLETHER	UG/L	<1	VG	07/11/94	
624	BROMODICHLOROMETHANE	UG/L	<1	VG	07/11/94	
624	BROMOMETHANE	UG/L	<1	VG	07/11/94	
624	CHLOROBENZENE	UG/L	<1	VG	07/11/94	

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HRS #83160

GLOBAL MARKETING & CONSULTING
2009 PALADIN CT.
VALRICO,FL 33594
ATT:HASSAN EL-SHALL

Submission #: 9407000025
Date Received: 07/01/94
Date Reported: 07/28/94

Client PO Number:
Project Number:
Project:

Order Number: 57190
Date Sampled: 06/29/94
Client Sample Number: 3
Sample Description: COLUMN 3 & 4

Method	Component	Units	Result	Analyst	Date Analyzed	Date Prepared
624	CHLOROFORM	UG/L	<1	VG	07/11/94	
624	CIS-1,3-DICHLOROPROPENE	UG/L	<1	VG	07/11/94	
624	ETHYLBENZENE	UG/L	<1	VG	07/11/94	
624	TETRACHLOROETHENE	UG/L	<1	VG	07/11/94	
624	TRANS-1,2-DICHLOROETHENE	UG/L	<1	VG	07/11/94	
624	TRICHLOROETHENE	UG/L	<1	VG	07/11/94	
624	VINYL CHLORIDE	UG/L	<1	VG	07/11/94	
624	DICHLORODIFLUOROMETHANE	UG/L	<1.0	VG	07/11/94	
625	1,2,4-TRICHLOROBENZENE	UG/L	<5.0	RM	07/11/94	07/05/94
625	1,3-DICHLOROBENZENE	UG/L	<5.0	RM	07/11/94	07/05/94
625	2,4,6-TRICHLOROPHENOL	UG/L	<5.0	RM	07/11/94	07/05/94
625	2,4-DIMETHYL PHENOL	UG/L	<5.0	RM	07/11/94	07/05/94
625	2,4-DINITROTOLUENE	UG/L	<5.0	RM	07/11/94	07/05/94
625	2-CHLORONAPHTHALENE	UG/L	<5.0	RM	07/11/94	07/05/94
625	2-METHYL-4,6-DINITROPHENOL	UG/L	<5.0	RM	07/11/94	07/05/94
625	3,3-DICHLOROBENZIDINE	UG/L	<10	RM	07/11/94	07/05/94
625	4-BROMOPHENYLPHENYLETHER	UG/L	<5.0	RM	07/11/94	07/05/94
625	4-CHLOROPHENYLPHENYLETHER	UG/L	<5.0	RM	07/11/94	07/05/94
625	ACENAPHTHYLENE	UG/L	<5.0	RM	07/11/94	07/05/94
625	ANTHRACENE	UG/L	<5.0	RM	07/11/94	07/05/94
625	BENZIDINE	UG/L	<10	RM	07/11/94	07/05/94
625	BENZO(A)PYRENE	UG/L	<5.0	RM	07/11/94	07/05/94
625	BENZO(GHI)PERYLENE	UG/L	<5.0	RM	07/11/94	07/05/94
625	BIS(2-CHLOROETHOXY)METHANE	UG/L	<5.0	RM	07/11/94	07/05/94
625	BIS(2-CHLOROISOPROPYL)ETHER	UG/L	<5.0	RM	07/11/94	07/05/94
625	BUTYL BENZYL PHTHALATE	UG/L	<5.0	RM	07/11/94	07/05/94
625	CHRYSENE	UG/L	<5.0	RM	07/11/94	07/05/94
625	DI-N-BUTYL PHTHALATE	UG/L	<5.0	RM	07/11/94	07/05/94
625	DIBENZO(A,H)ANTHRACENE	UG/L	<5.0	RM	07/11/94	07/05/94
625	DIETHYL PHTHALATE	UG/L	<5.0	RM	07/11/94	07/05/94
625	FLUORENE	UG/L	<5.0	RM	07/11/94	07/05/94
625	HEXACHLOROBENZENE	UG/L	<5.0	RM	07/11/94	07/05/94

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HRS #83160

GLOBAL MARKETING & CONSULTING
2009 PALADIN CT.
VALRICO,FL 33594
ATT:HASSAN EL-SHALL

Submission #: 9407000025
Date Received: 07/01/94
Date Reported: 07/28/94

Client PO Number:
Project Number:
Project:

Page 4

Order Number: 57190
Date Sampled: 06/29/94
Client Sample Number: 3
Sample Description: COLUMN 3 & 4

Method	Component	Units	Result	Analyst	Date Analyzed	Date Prepared
625	HEXACHLOROCYCLOPENTADIENE	UG/L	<5.0	RM	07/11/94	07/05/94
625	INDENO(1,2,3-CD)PYRENE	UG/L	<5.0	RM	07/11/94	07/05/94
625	N-NITROSODI-N-PROPYLAMINE	UG/L	<5.0	RM	07/11/94	07/05/94
625	N-NITROSODIPHENYLAMINE	UG/L	<5.0	RM	07/11/94	07/05/94
625	NITROBENZENE	UG/L	<5.0	RM	07/11/94	07/05/94
625	PENTACHLOROPHENOL	UG/L	<5.0	RM	07/11/94	07/05/94
625	PHENOL	UG/L	<5.0	RM	07/11/94	07/05/94
625	1,2-DICHLOROBENZENE	UG/L	<5.0	RM	07/11/94	07/05/94
625	1,4-DICHLOROBENZENE	UG/L	<5.0	RM	07/11/94	07/05/94
625	2,4-DICHLOROPHENOL	UG/L	<5.0	RM	07/11/94	07/05/94
625	2,4-DINITROPHENOL	UG/L	<5.0	RM	07/11/94	07/05/94
625	2,6-DINITROTOLUENE	UG/L	<5.0	RM	07/11/94	07/05/94
625	2-CHLOROPHENOL	UG/L	<5.0	RM	07/11/94	07/05/94
625	2-NITROPHENOL	UG/L	<5.0	RM	07/11/94	07/05/94
625	4-CHLORO-3-METHYLPHENOL	UG/L	<5.0	RM	07/11/94	07/05/94
625	4-NITROPHENOL	UG/L	<5.0	RM	07/11/94	07/05/94
625	ACENAPHTHENE	UG/L	<5.0	RM	07/11/94	07/05/94
625	BENZO(A)ANTHRACENE	UG/L	<5.0	RM	07/11/94	07/05/94
625	BENZO(B)FLUORANTHENE	UG/L	<5.0	RM	07/11/94	07/05/94
625	BENZO(K)FLUORANTHENE	UG/L	<5.0	RM	07/11/94	07/05/94
625	BIS(2-CHLOROETHYL)ETHER	UG/L	<5.0	RM	07/11/94	07/05/94
625	DI(2-ETHYLHEXYL)PHTHALATE	UG/L	<5.0	RM	07/11/94	07/05/94
625	DI-N-OCTYL PHTHALATE	UG/L	<5.0	RM	07/11/94	07/05/94
625	DIMETHYL PHTHALATE	UG/L	<5.0	RM	07/11/94	07/05/94
625	FLUORANTHENE	UG/L	<5.0	RM	07/11/94	07/05/94
625	HEXACHLOROBUTADIENE	UG/L	<5.0	RM	07/11/94	07/05/94
625	HEXACHLOROETHANE	UG/L	<5.0	RM	07/11/94	07/05/94
625	ISOPHORONE	UG/L	<5.0	RM	07/11/94	07/05/94
625	N-NITROSODIMETHYLAMINE	UG/L	<5.0	RM	07/11/94	07/05/94
625	NAPHTHALENE	UG/L	<5.0	RM	07/11/94	07/05/94
625	PHENANTHRENE	UG/L	<5.0	RM	07/11/94	07/05/94
625	PYRENE	UG/L	<5.0	RM	07/11/94	07/05/94

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ATT:HASSAN EL-SHALL

Submission #: 9407000025
Date Received: 07/01/94
Date Reported: 07/28/94

Client PO Number:
Project Number:
Project:

Order Number: 57190
Date Sampled: 06/29/94
Client Sample Number: 3
Sample Description: COLUMN 3 & 4

Method	Component	Units	Result	Analyst	Date Analyzed	Date Prepared
625	1-METHYLNAPHTHALENE	UG/L	<5.0	RM	07/11/94	07/05/94
625	2-METHYLNAPHTHALENE	UG/L	<5.0	RM	07/11/94	07/05/94
625	1,2-DIPHENYLHYDRAZINE	UG/L	<5.0	RM	07/11/94	07/05/94
8270	BIS(CHLOROMETHYL)ETHER	UG/L	<5	RM	07/11/94	07/05/94
8270	1,2-DIPHENYLHYDRAZINE	UG/L	<5	RM	07/11/94	07/05/94

Frank Guzman
F. Guzman Vice-President

QC ACCEPTABLE

JUL 28 1994

R.A. ELEFRITZ, SR.

APPENDIX B
CLAY CONSOLIDATION PARAMETER COMPARISON MODEL OUTPUT

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                              FLINZ2

              TIME RATE OF CONSOLIDATION DURING FILLING
                    SUBMERGED, ONE-WAY DRAINAGE
                          DILUTE SLURRY
                     (WITH PSEUDO-SURCHARGE)


REVISION 0: JAN 01, 1980    FS
REVISION 5: DEC 31, 1993   WDC


              SETTLING POND AREA =   1.(ACRES)
              BASE ELEVATION =   .0(FT)
              MAX. HEIGHT = 100.0(FT)
              CLAY SOLIDS INFLOW RATE =   5000.(TON/YR)
              DISCHARGE CLAY SOLIDS CONTENT =10.0(%)
              SAND:CLAY RATIO = .0
              MAX. FILLING TIME = 1.00(YRS)


              SPECIFIC GRAVITY OF SOLIDS =2.80
              PORE-FLUID DENSITY =62.4(PCF)

              VOID RATIO =25.5000(EFF. STRESS)** -.2700
              PERM. = .1860E-05(VOID RATIO)** 3.7300
                  NOTE* EFF. STRESS IN PSF
                        PERM. IN FT/DA

              IMMEDIATE CLAY SOLIDS CONTENT =10.0(%)
              MAX. PERM. =10.000(FT/DA)
              MIN. EFF. STRESS =  .00(PSF)


      TIME=  365.0(DA)= 1.00(YR)    HEIGHT = 26.8(FT)
       AVG S=12.6(%)   AVG ST=12.6(%)      AVG EC=19.41   AVG ET=19.41
                 CLAY     TOTAL                                 EXCESS
                SOLIDS   SOLIDS    CLAY    TOTAL                 PORE
         DEPTH  CONTENT  CONTENT   VOID    VOID    ELEV.        PRESS.
          (FT)    (%)      (%)     RATIO   RATIO    (FT)         (FT)
         *****  *******  *******   *****   *****   *****        ******
            .0    10.0     10.0    25.20   25.20    26.8            .0
           4.3    10.0     10.0    25.15   25.15    22.5            .3
           8.6    10.2     10.2    24.59   24.59    18.3            .6
          12.6    10.9     10.9    22.90   22.90    14.2            .9
          16.4    12.1     12.1    20.39   20.39    10.4           1.2
          19.7    13.8     13.8    17.53   17.53     7.2           1.4
          22.5    16.0     16.0    14.68   14.68     4.4           1.7
          24.8    18.7     18.7    12.17   12.17     2.0           1.8
          26.8    21.5     21.5    10.20   10.20      .0           1.9

              ****** FILLING TIME HAS BEEN REACHED ******

            ****** TIME RATE ANALYSIS IS COMPLETED ******
                PREDICTED EQUILIBRIUM CONDITIONS:
                   FINAL HEIGHT = 13.1(FT)
                   FINAL AVG S =23.7(%)
                   ADDITIONAL SETTLEMENT TO BE EXPECTED =13.7(FT)
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                              FLINZ2

             TIME RATE OF CONSOLIDATION DURING FILLING
                  SUBMERGED, ONE-WAY DRAINAGE
                         DILUTE SLURRY
                    (WITH PSEUDO-SURCHARGE)


REVISION 0: JAN 01, 1980    FS
REVISION 5: DEC 31, 1993   WDC

            SETTLING POND AREA =    1.(ACRES)
            BASE ELEVATION =    .0(FT)
            MAX. HEIGHT = 100.0(FT)
            CLAY SOLIDS INFLOW RATE =   5150.(TON/YR)
            DISCHARGE CLAY SOLIDS CONTENT =15.0(%)
            SAND:CLAY RATIO = .0
            MAX. FILLING TIME = 1.00(YRS)


            SPECIFIC GRAVITY OF SOLIDS =2.76
            PORE-FLUID DENSITY =62.4(PCF)

            VOID RATIO =44.4000(EFF. STRESS)** -.3400
            PERM. = .4630E-06(VOID RATIO)** 4.6600
                 NOTE* EFF. STRESS IN PSF
                       PERM. IN FT/DA

            IMMEDIATE CLAY SOLIDS CONTENT =15.0(%)
            MAX. PERM. =10.000(FT/DA)
            MIN. EFF. STRESS =  .00(PSF)


   TIME=  365.0(DA)= 1.00(YR)   HEIGHT = 18.6(FT)
    AVG S=18.0(%)   AVG ST=18.0(%)      AVG EC=12.57   AVG ET=12.57
                  CLAY     TOTAL                                 EXCESS
                 SOLIDS    SOLIDS    CLAY    TOTAL               PORE
        DEPTH   CONTENT   CONTENT    VOID    VOID      ELEV.    PRESS.
         (FT)     (%)       (%)      RATIO   RATIO      (FT)     (FT)
        *****   *******   *******    *****   *****     *****    ******
           .0     15.0      15.0     15.64   15.64      18.6        .0
          2.8     15.7      15.7     14.80   14.80      15.9        .2
          5.4     16.4      16.4     14.02   14.02      13.2        .5
          7.9     17.2      17.2     13.28   13.28      10.7        .7
         10.3     18.0      18.0     12.55   12.55       8.3        .9
         12.6     18.9      18.9     11.82   11.82       6.0       1.1
         14.7     19.9      19.9     11.10   11.10       3.9       1.2
         16.7     21.0      21.0     10.38   10.38       1.9       1.3
         18.6     22.2      22.2      9.67    9.67        .0       1.3

            ****** FILLING TIME HAS BEEN REACHED ******

          ****** TIME RATE ANALYSIS IS COMPLETED ******
               PREDICTED EQUILIBRIUM CONDITIONS:
                  FINAL HEIGHT = 16.6(FT)
                  FINAL AVG S =20.0(%)
                  ADDITIONAL SETTLEMENT TO BE EXPECTED = 2.1(FT)
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                            FLINZ2

            TIME RATE OF CONSOLIDATION DURING FILLING
                  SUBMERGED, ONE-WAY DRAINAGE
                         DILUTE SLURRY
                   (WITH PSEUDO-SURCHARGE)


REVISION 0: JAN 01, 1980    FS
REVISION 5: DEC 31, 1993   WDC


            SETTLING POND AREA =    1.(ACRES)
            BASE ELEVATION =    .0(FT)
            MAX. HEIGHT = 100.0(FT)
            CLAY SOLIDS INFLOW RATE =   5000.(TON/YR)
            DISCHARGE CLAY SOLIDS CONTENT =10.0(%)
            SAND:CLAY RATIO = .0
            MAX. FILLING TIME = 1.00(YRS)


            SPECIFIC GRAVITY OF SOLIDS =2.80
            PORE-FLUID DENSITY =62.4(PCF)

            VOID RATIO =62.1000(EFF. STRESS)** -.3500
            PERM. = .6840E-09(VOID RATIO)** 5.8400
                 NOTE* EFF. STRESS IN PSF
                       PERM. IN FT/DA

            IMMEDIATE CLAY SOLIDS CONTENT =10.0(%)
            MAX. PERM. =10.000(FT/DA)
            MIN. EFF. STRESS =  .00(PSF)


  TIME=  365.0(DA)= 1.00(YR)   HEIGHT = 31.9(FT)
   AVG S=10.7(%)   AVG ST=10.7(%)      AVG EC=23.30    AVG ET=23.30
                 CLAY      TOTAL                               EXCESS
                SOLIDS    SOLIDS    CLAY     TOTAL              PORE
        DEPTH  CONTENT   CONTENT    VOID     VOID     ELEV.    PRESS.
         (FT)    (%)       (%)      RATIO    RATIO    (FT)      (FT)
        *****  *******   *******    *****    *****    *****    ******
           .0    10.0      10.0     25.20    25.20     31.9        .0
          4.3    10.0      10.0     25.19    25.19     27.6        .3
          8.6    10.0      10.0     25.14    25.14     23.3        .6
         12.9    10.1      10.1     24.92    24.92     19.0        .9
         17.1    10.3      10.3     24.39    24.39     14.8       1.2
         21.2    10.7      10.7     23.42    23.42     10.7       1.4
         25.1    11.3      11.3     21.94    21.94      6.8       1.7
         28.7    12.3      12.3     19.91    19.91      3.2       1.9
         31.9    13.9      13.9     17.30    17.30       .0       2.0

            ****** FILLING TIME HAS BEEN REACHED ******

          ****** TIME RATE ANALYSIS IS COMPLETED ******
               PREDICTED EQUILIBRIUM CONDITIONS:
                  FINAL HEIGHT = 21.6(FT)
                  FINAL AVG S =15.4(%)
                  ADDITIONAL SETTLEMENT TO BE EXPECTED =10.3(FT)
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                              FLINZ2

             TIME RATE OF CONSOLIDATION DURING FILLING
                   SUBMERGED, ONE-WAY DRAINAGE
                          DILUTE SLURRY
                    (WITH PSEUDO-SURCHARGE)


REVISION 0: JAN 01, 1980    FS
REVISION 5: DEC 31, 1993   WDC


             SETTLING POND AREA =    1.(ACRES)
             BASE ELEVATION =    .0(FT)
             MAX. HEIGHT = 100.0(FT)
             CLAY SOLIDS INFLOW RATE =   5150.(TON/YR)
             DISCHARGE CLAY SOLIDS CONTENT =15.0(%)
             SAND:CLAY RATIO = .0
             MAX. FILLING TIME = 1.00(YRS)


             SPECIFIC GRAVITY OF SOLIDS =2.76
             PORE-FLUID DENSITY =62.4(PCF)

             VOID RATIO =80.0000(EFF. STRESS)** -.8000
             PERM. = .4750E-07(VOID RATIO)** 4.3600
                 NOTE* EFF. STRESS IN PSF
                       PERM. IN FT/DA

             IMMEDIATE CLAY SOLIDS CONTENT =15.0(%)
             MAX. PERM. =10.000(FT/DA)
             MIN. EFF. STRESS =  .00(PSF)


  TIME=  365.0(DA)= 1.00(YR)    HEIGHT = 22.6(FT)
   AVG S=15.2(%)   AVG ST=15.2(%)      AVG EC=15.43    AVG ET=15.43
                 CLAY     TOTAL                                EXCESS
                SOLIDS    SOLIDS     CLAY    TOTAL              PORE
        DEPTH  CONTENT   CONTENT     VOID    VOID    ELEV.     PRESS.
         (FT)    (%)       (%)       RATIO   RATIO    (FT)      (FT)
        *****  *******   *******     *****   *****   *****     ******
           .0    15.0      15.0      15.64   15.64    22.6         .0
          2.9    15.0      15.0      15.64   15.64    19.7         .3
          5.7    15.0      15.0      15.64   15.64    16.8         .6
          8.6    15.0      15.0      15.64   15.64    14.0         .9
         11.4    15.0      15.0      15.64   15.64    11.1        1.2
         14.3    15.0      15.0      15.64   15.64     8.3        1.5
         17.1    15.0      15.0      15.64   15.64     5.4        1.8
         20.0    15.1      15.1      15.56   15.56     2.6        2.1
         22.6    21.0      21.0      10.36   10.36      .0        2.3

             ****** FILLING TIME HAS BEEN REACHED ******

           ****** TIME RATE ANALYSIS IS COMPLETED ******
                PREDICTED EQUILIBRIUM CONDITIONS:
                   FINAL HEIGHT =   6.9(FT)
                   FINAL AVG S =40.6(%)
                   ADDITIONAL SETTLEMENT TO BE EXPECTED =15.6(FT)
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APPENDIX C
CLAY DISPOSAL ANALYSES
MODEL OUTPUT

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                              FLINZ2

           TIME RATE OF CONSOLIDATION DURING FILLING
                  SUBMERGED, ONE-WAY DRAINAGE
                         DILUTE SLURRY
                    (WITH PSEUDO-SURCHARGE)


 REVISION 0: JAN 01, 1980    FS
 REVISION 5: DEC 31, 1993   WDC


           SETTLING POND AREA =1000.(ACRES)
           BASE ELEVATION =    .0(FT)
           MAX. HEIGHT = 100.0(FT)
           CLAY SOLIDS INFLOW RATE =3000000.(TON/YR)
           DISCHARGE CLAY SOLIDS CONTENT =10.0(%)
           SAND:CLAY RATIO = .0
           MAX. FILLING TIME = 3.00(YRS)


           SPECIFIC GRAVITY OF SOLIDS =2.80
           PORE-FLUID DENSITY =62.4(PCF)

           VOID RATIO =25.5000(EFF. STRESS)** -.2700
           PERM. = .1860E-05(VOID RATIO)** 3.7300
               NOTE* EFF. STRESS IN PSF
                     PERM. IN FT/DA

           IMMEDIATE CLAY SOLIDS CONTENT =10.0(%)
           MAX. PERM. =10.000(FT/DA)
           MIN. EFF. STRESS =  .00(PSF)


   TIME= 1095.0(DA)= 3.00(YR)   HEIGHT = 40.0(FT)
    AVG S=15.0(%)   AVG ST=15.0(%)      AVG EC=15.93    AVG ET=15.93
                 CLAY     TOTAL                                 EXCESS
                SOLIDS   SOLIDS    CLAY    TOTAL                 PORE
        DEPTH  CONTENT  CONTENT    VOID    VOID     ELEV.       PRESS.
         (FT)    (%)      (%)      RATIO   RATIO     (FT)        (FT)
        *****  *******  *******    *****   *****    *****       ******
           .0    10.0     10.0     25.20   25.20     40.0           .0
          7.2    11.2     11.2     22.20   22.20     32.8           .5
         13.8    12.2     12.2     20.07   20.07     26.2          1.0
         19.7    13.5     13.5     17.94   17.94     20.3          1.6
         25.0    15.1     15.1     15.76   15.76     15.1          2.1
         29.6    17.1     17.1     13.58   13.58     10.4          2.5
         33.6    19.5     19.5     11.55   11.55      6.4          2.9
         37.1    22.2     22.2      9.80    9.80      3.0          3.2
         40.0    25.0     25.0      8.40    8.40       .0          3.3

           ****** FILLING TIME HAS BEEN REACHED ******

         ****** TIME RATE ANALYSIS IS COMPLETED ******
              PREDICTED EQUILIBRIUM CONDITIONS:
                 FINAL HEIGHT = 20.6(FT)
                 FINAL AVG S =26.7(%)
                 ADDITIONAL SETTLEMENT TO BE EXPECTED =19.5(FT)
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                              FLINZ2

            TIME RATE OF CONSOLIDATION DURING FILLING
                  SUBMERGED, ONE-WAY DRAINAGE
                         DILUTE SLURRY
                    (WITH PSEUDO-SURCHARGE)


REVISION 0: JAN 01, 1980    FS
REVISION 5: DEC 31, 1993   WDC

            SETTLING POND AREA =1000.(ACRES)
            BASE ELEVATION =    .0(FT)
            MAX. HEIGHT = 100.0(FT)
            CLAY SOLIDS INFLOW RATE =3090000.(TON/YR)
            DISCHARGE CLAY SOLIDS CONTENT =15.0(%)
            SAND:CLAY RATIO = .0
            MAX. FILLING TIME = 3.00(YRS)


            SPECIFIC GRAVITY OF SOLIDS =2.76
            PORE-FLUID DENSITY =62.4(PCF)

            VOID RATIO =44.4000(EFF. STRESS)** -.3400
            PERM. = .4630E-06(VOID RATIO)** 4.6600
                 NOTE* EFF. STRESS IN PSF
                       PERM. IN FT/DA

            IMMEDIATE CLAY SOLIDS CONTENT =15.0(%)
            MAX. PERM. =10.000(FT/DA)
            MIN. EFF. STRESS =  .00(PSF)


  TIME= 1095.0(DA)= 3.00(YR)   HEIGHT = 30.1(FT)
   AVG S=19.8(%)   AVG ST=19.8(%)      AVG EC=11.19    AVG ET=11.19
             CLAY     TOTAL                                EXCESS
            SOLIDS   SOLIDS    CLAY    TOTAL                PORE
     DEPTH  CONTENT  CONTENT   VOID    VOID     ELEV.      PRESS.
      (FT)    (%)      (%)     RATIO   RATIO     (FT)       (FT)
     *****  *******  *******   *****   *****    *****      ******
        .0    15.0     15.0    15.64   15.64     30.1          .0
       4.8    16.7     16.7    13.79   13.79     25.3          .4
       9.2    17.9     17.9    12.66   12.66     20.9          .8
      13.3    19.0     19.0    11.76   11.76     16.9         1.2
      17.1    20.1     20.1    10.97   10.97     13.0         1.5
      20.7    21.2     21.2    10.24   10.24      9.4         1.9
      24.0    22.5     22.5     9.53    9.53      6.1         2.1
      27.2    23.8     23.8     8.85    8.85      2.9         2.3
      30.1    25.2     25.2     8.18    8.18       .0         2.4

            ****** FILLING TIME HAS BEEN REACHED ******

          ****** TIME RATE ANALYSIS IS COMPLETED ******
               PREDICTED EQUILIBRIUM CONDITIONS:
                  FINAL HEIGHT = 25.6(FT)
                  FINAL AVG S =22.8(%)
                  ADDITIONAL SETTLEMENT TO BE EXPECTED = 4.5(FT)
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                              FLINZ2

          TIME RATE OF CONSOLIDATION DURING FILLING
                SUBMERGED, ONE-WAY DRAINAGE
                       DILUTE SLURRY
                  (WITH PSEUDO-SURCHARGE)


REVISION 0: JAN 01, 1980    FS
REVISION 5: DEC 31, 1993   WDC


          SETTLING POND AREA =1000.(ACRES)
          BASE ELEVATION =   .0(FT)
          MAX. HEIGHT = 100.0(FT)
          CLAY SOLIDS INFLOW RATE =3000000.(TON/YR)
          DISCHARGE CLAY SOLIDS CONTENT =10.0(%)
          SAND:CLAY RATIO = .0
          MAX. FILLING TIME = 3.00(YRS)


          SPECIFIC GRAVITY OF SOLIDS =2.80
          PORE-FLUID DENSITY =62.4(PCF)

          VOID RATIO =62.1000(EFF. STRESS)** -.3500
          PERM. = .6840E-09(VOID RATIO)** 5.8400
               NOTE* EFF. STRESS IN PSF
                     PERM. IN FT/DA

          IMMEDIATE CLAY SOLIDS CONTENT =10.0(%)
          MAX. PERM. =10.000(FT/DA)
          MIN. EFF. STRESS =  .00(PSF)


  TIME= 1095.0(DA)= 3.00(YR)   HEIGHT = 54.6(FT)
   AVG S=11.3(%)   AVG ST=11.3(%)      AVG EC=22.07   AVG ET=22.07
              CLAY     TOTAL                              EXCESS
             SOLIDS   SOLIDS    CLAY    TOTAL              PORE
      DEPTH  CONTENT  CONTENT   VOID    VOID     ELEV.    PRESS.
      (FT)    (%)      (%)      RATIO   RATIO    (FT)     (FT)
      *****  *******  *******   *****   *****    *****    ******
         .0    10.0     10.0    25.20   25.20    54.6        .0
        7.7    10.0     10.0    25.08   25.08    46.8        .5
       15.4    10.2     10.2    24.72   24.72    39.2       1.1
       22.9    10.4     10.4    24.02   24.02    31.6       1.6
       30.2    10.9     10.9    23.00   23.00    24.4       2.1
       37.1    11.5     11.5    21.64   21.64    17.5       2.5
       43.5    12.3     12.3    19.93   19.93    11.0       3.0
       49.4    13.6     13.6    17.77   17.77     5.2       3.4
       54.6    15.7     15.7    15.04   15.04      .0       3.5

         ****** FILLING TIME HAS BEEN REACHED ******

       ****** TIME RATE ANALYSIS IS COMPLETED ******
             PREDICTED EQUILIBRIUM CONDITIONS:
                FINAL HEIGHT = 32.8(FT)
                FINAL AVG S =17.9(%)
                ADDITIONAL SETTLEMENT TO BE EXPECTED =21.8(FT)
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                             FLINZ2

            TIME RATE OF CONSOLIDATION DURING FILLING
                  SUBMERGED, ONE-WAY DRAINAGE
                         DILUTE SLURRY
                    (WITH PSEUDO-SURCHARGE)


REVISION 0: JAN 01, 1980    FS
REVISION 5: DEC 31, 1993   WDC


            SETTLING POND AREA =1000.(ACRES)
            BASE ELEVATION =   .0(FT)
            MAX. HEIGHT = 100.0(FT)
            CLAY SOLIDS INFLOW RATE =3090000.(TON/YR)
            DISCHARGE CLAY SOLIDS CONTENT =15.0(%)
            SAND:CLAY RATIO = .0
            MAX. FILLING TIME = 3.00(YRS)


            SPECIFIC GRAVITY OF SOLIDS =2.76
            PORE-FLUID DENSITY =62.4(PCF)

            VOID RATIO =80.0000(EFF. STRESS)** -.8000
            PERM. = .4750E-07(VOID RATIO)** 4.3600
                 NOTE* EFF. STRESS IN PSF
                       PERM. IN FT/DA

            IMMEDIATE CLAY SOLIDS CONTENT =15.0(%)
            MAX. PERM. =10.000(FT/DA)
            MIN. EFF. STRESS =  .00(PSF)


  TIME= 1095.0(DA)= 3.00(YR)   HEIGHT = 40.2(FT)
   AVG S=15.3(%)   AVG ST=15.3(%)     AVG EC=15.28   AVG ET=15.28
               CLAY     TOTAL                              EXCESS
              SOLIDS   SOLIDS   CLAY    TOTAL               PORE
        DEPTH CONTENT  CONTENT  VOID    VOID    ELEV.      PRESS.
         (FT)   (%)      (%)    RATIO   RATIO   (FT)        (FT)
        ***** *******  *******  *****   *****   *****      ******
           .0   15.0     15.0   15.64   15.64    40.2          .0
          5.1   15.0     15.0   15.64   15.64    35.1          .5
         10.3   15.0     15.0   15.64   15.64    30.0         1.1
         15.4   15.0     15.0   15.64   15.64    24.8         1.6
         20.6   15.0     15.0   15.64   15.64    19.7         2.2
         25.7   15.0     15.0   15.64   15.64    14.5         2.7
         30.8   15.0     15.0   15.64   15.64     9.4         3.3
         36.0   15.3     15.3   15.31   15.31     4.3         3.8
         40.2   24.6     24.6    8.45    8.45      .0         4.2

            ****** FILLING TIME HAS BEEN REACHED ******

          ****** TIME RATE ANALYSIS IS COMPLETED ******
               PREDICTED EQUILIBRIUM CONDITIONS:
                  FINAL HEIGHT =  9.3(FT)
                  FINAL AVG S =50.1(%)
                  ADDITIONAL SETTLEMENT TO BE EXPECTED =31.0(FT)
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