Stormwater Detention Systems with Effluent Filtration

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STORMWATER DETENTION SYSTEMS WITH EFFLUENT FILTRATION

BY

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ABSTRACT

The growing concern for water quality enhancement of our surface waters has led to changes in detention facility design. Providing a filter media for the effluent water to travel through before discharge into the environment has become an area of interest. Thus, detention facilities may be used for both water quality and quantity control.

Different soil medias were studied for the potential of pollutant removal and infiltration rates usable in design work. Both laboratory and field experimentation were performed.

A computer program was also developed to model stormwater movement through a swale detention system.

This research was performed to examine filter media and to indicate the advisability of designing a combination of detention ponds and berms.

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CHAPTER I

INTRODUCTION

The growing concern for improved water quality in our drinking waters and recreational waters has always been an important aspect of our daily lives. The quality of our lakes and streams have been severely degraded in part due to uncontrolled discharges of stormwater into them. Techniques have been developed to reduce the quantity of stormwater by re-routing their flow into detention/retention facilities. Also, these facilities have the more common application names of ditches or swales, depression areas, detention ponds, perculation ponds, holding areas, and sedimentation ponds. They have been primarily successful for flood control purposes in reducing peak discharges and acting as equalization basins.

In accordance with the Florida Law F.A.C. Chapter 17-25, these ponds are designed to hold the runoff from the first one inch of rainfall. The quality of this water is usually extremely poor, containing various pollutants such as heavy metals, oils, greases and nutrients rich in nitrogen and phosphorus. Since this polluted water is conveniently stored in these detention sites, it only seems logical that this is the place where water quality improvement should occur - before it is discharged into our lakes, streams and estuaries.

The concept of using detention areas for water quality enhancement as well as for flood control purposes would make these facilities valuable pollution control devices. Pollutant removal by filtration of the detention water through a natural soil media mixture would probably be a good addition to these ponds. Using underground filtration systems would also enable these ponds to keep their aesthetic value without having to dredge out these areas completely. With the proper filter media in place, pollution control for water quality improvement would become a second benefit of detention/retention facilities.

Scope and Objectives

The main interest in performing this research is to examine different types of filter media mixtures and report on their effectiveness for pollutant removal. Estimation of exhaustion times will be included as well as permeability rates of these soil mixtures. The purpose of these findings is to aid in the design of a filtration system for detention area ponds.

Basically, the research has been divided into three major areas of concern. Initially, laboratory work on soil columns will be performed to determine favorable soil mixtures. Using the results from this experimentation, a prototype model will be studied based on these filter media types. The prototype model will give an idea of how the filter will work on a more real life situation and help to point out difficulties that were not encountered in the lab.

The final part of this research is to report on the performance of a recently built detention facility with bank filtration system. Based on previous design parameters, this alum sludge and sand filter will be studied to determine its effectiveness. A computer program to model a storm event as it passes through a swale and swale block will also be developed. The purpose of this is to estimate, on an annual basis, how large of a detention system will be required if a swale berm is used.

CHAPTER II

LITERATURE REVIEW

The use of a stormwater retention facility has been primarily based on the design for water quality control. The major design guideline for such a facility has been to divert the runoff from the first one inch of rainfall into the pond. Criteria for this method is based on the "first flush" effect. This concept uses the idea that most of the pollutants in stormwater are present in the first portion of rainfall runoff. Use of this design shows that retainment of the first flush will give a pollutant removal of up to 90 or 95 percent (Wanielista 1979). Thus, retention ponds are holding areas for polluted waters.

Another important stormwater management technique is to detain runoff waters so as to reduce peak discharges. Detention areas or ponds are used to attenuate hydrographs. Designs for detention areas are based on a site specific runoff hydrograph and a detention area discharge hydrograph. The volume difference between these hydrographs determines the size of the detention areas.

The dual use of these ponds as an area for further pollutant removal should be considered since the polluted water is already stored in a convenient area to be treated. This topic has just recently become one of important interest.

Little research has been done in the area of pollutant removal from detention ponds. From the limited studies found in the literature, it seems that there are two possible processes under investigation. One process of removal is based on the sedimentation and bottom containment of pollutants in the detention areas. Additional removal of pollutants may be achieved by filtration of the effluent as it leaves the detention areas.

Nitrogen and Phosphorus Pollution

Undesirable concentrations of nitrogen in water systems has two main pollution reasons involving both health and ecological aspects. Nitrate-nitrogen may become a health hazard. High concentrations in drinking water have been found to cause such symptoms as methemoglobinemia in infants and vitamin A deficiency, reproductive difficulties, and abortions in animals. Thus, this concentration should be kept low, with a maximum established concentration of around 45 mg nitrate per liter (Bolt and Bruggenwert 1967).

The ecological aspect concerning high nitrogen concentrations is the fear of surface water eutrophication. This process causes rapid growth of aquatic plants such as algal blooms. Eutrophication is a natural process which is accelerated by human activities such as discharge of domestic and industrial wastewaters, treated effluents, runoff and leaching of fertilizers. Although the exact reason for eutrophication is not completely understood, it has been accepted that nitrogen and phosphorus concentrations in very low amounts (less than 0.01 mg/l for phosphorus and less than 0.2-0.3 mg/l for nitrogen) may prevent the acceleration of eutrophication.

Studies have shown that phosphate concentrations in surface waters fed with drainage water favor the excessive growth of phytoplankton (Bolt and Bruggenwert 1967). Thus, phosphates are also important in the eutrophication process.

Nitrogen and Phosphorus in the Soil

Using soil as a filter may not retain selected forms of nitrogen such as nitrates, due to their relatively high mobility in the soil. Conversely, phosphates have a comparatively low mobility in the soil so that phosphates reaching ground waters are relatively small. These two contrasting elements may be examined with respect to their relation with the soil. Since the soil provides excellent adsorption sites for phosphates with a high retention capacity, its use for the disposal of nitrogen compounds is rather limited and nitrogen removal hinges on the capacity to provide a medium for denitrification to occur (McLarren 1967).

The major form of nitrogen in the soil is organic nitrogen. This amount can be as high as 90% for top soils. Since organisms generally use the inorganic form of nitrogen, the relationship between the two needs to be shown. Mineralization is the process by which organic nitrogen is converted to inorganic forms. Immobilization is the reverse process. These processes are typically microbial dependent.

Mineralization is the most understood process. Inorganic forms of nitrogen of interest in this study are ammonium-nitrogen (NH_4^+), nitrate-nitrogen (NO_3^-), and nitrite (NO_2^-). The rate at which mineralization occurs is influenced by a number of external conditions. These include temperature, pH, free oxygen and water availability, and the presence of other nutrients. The pathway of nitrogen through the soil is shown in Figure 1. This figure shows that there are a number of reactions which may occur if secondary sewage is spread on the soil. NH_4^+ may revert to NH_3 if pH values are favorable and some NH_3 may be lost due to volatilization. The remaining ammonium will be displaced through the soil subject to a number of adsorption and fixation processes. This would result in an incorporation into the microbial tissue and re-enter into the living organisms which will undergo mineralization and thus increase the inorganic nitrogen concentrations.

The major process left to occur is nitrification, which will only happen if special conditions are met. These conditions include sufficient amounts of nitrifying organisms, sufficient free oxygen, presence of carbon sources, and satisfactory conditions of moisture and temperature. Nitrate ions formed in this process will not be adsorbed since they are highly mobile in the soil.

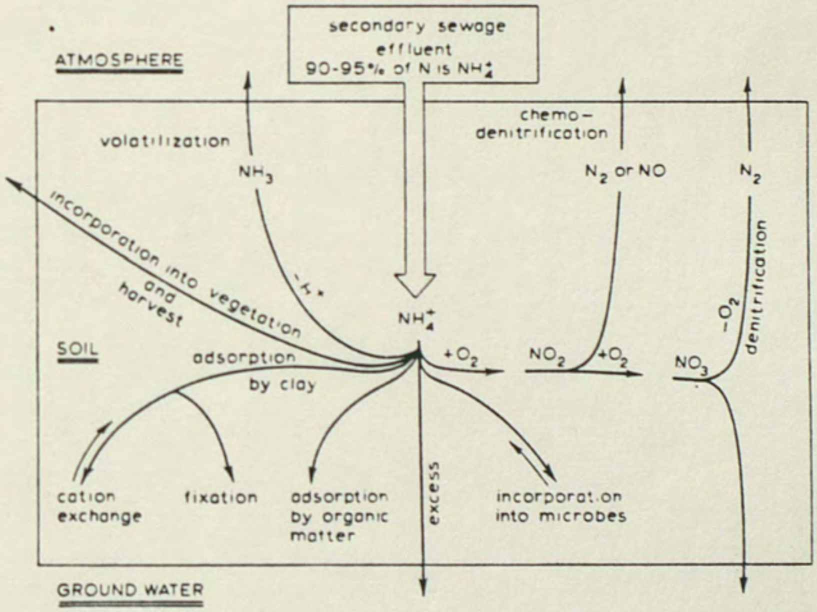


Fig. 1. Transformations of nitrogen in soil, departing from an NH_4^+-nitrogen source (Bolt and Bruggenwert 1976).

Nitrification

The process of nitrification consists of a number of different steps. The first one is the oxidation of ammonium to nitrite which occurs by nitrosomonas bacteria. Nitrite is an intermediate which is further oxidized by nitrobacter to nitrate. If the environment is highly alkaline, there will be an accumulation of nitrite. This is likely due to pH restrictions.

Since nitrification is a microbial process, there are a number of factors which effect it. Optimum temperatures range from 25°C to 30°C. Temperatures out of this range limit this process. Moisture content is also very important. High moisture contents prevent nitrification from occurring due to the lack of oxygen. The optimum condition is to be two-thirds saturation. An increase is found in the nitrification process given ammonium ions are present. In the absence of oxygen denitrification may occur given an energy source. Since denitrification acts on the nitrate ion for nitrogen gas formation, it must follow nitrification. The main conditions for denitrification include prevalence of nitrate, an energy source, reducing conditions, and temperatures above 25°C. Since a high moisture content in the soil may give a decrease in oxygen available, denitrification is possible. Therefore, a moisture content which satisfies nitrification can be applied followed by a complete saturation state to favor denitrification. In natural systems, the conditions for denitrification are poor due to the lack of energy material and denitrifying microorganisms present in the soil.

In summary, excess nitrogen compounds entering the soil create problems when nitrate ions leave the topsoil and reach the receiving water supply. The soil's low capability of retaining nitrogen forms points towards denitrification for nitrogen removal. In order for denitrification to occur, specific environmental conditions need to be presented and, thus, suggest a low possibility of nitrogen removal.

Phosphorus Removal Mechanisms in the Soil

Clay materials have a high affinity for PO_4^{-3} ions showing that there is the existence of chemical bonds between the solid phase and phosphate. This has been shown by experimentations with high PO_4^{-3} ion concentrations. Clay minerals became negatively charged on their edges in the presence of high PO_4^{-3} concentrations, thus, often forming a bond with the phosphate ion. The adsorption capacity is not very large, but depends on the amount of oxides present in the soil. A probable explanation for the strong bonding of PO_4^{-3} with Fe and Al oxides/hydroxides is that there is a coating of Fe-Al oxide/hydroxide on sand grains, found usually in sandy soils. This seems to increase the phosphorus retention in the soil and decrease the mobility of phosphates in the soil.

Sedimentation Processes

Removal of pollutants by sedimentation in detention/retention areas is related to the settleability of suspended particles.

Generally, it has been observed that suspended solids can usually settle in these areas. Major factors which determine pollutant settleability include detention time, basin design, outlet structure design, particle size, and baseflow concentrations (Scherger and Davis 1982).

Detention time is the primary indicator of pollution control capability (AWWA 1981). The difficulty in determining this parameter is due to the unsteady-state situation in a detention pond. Storm events are random and stormwater flows vary from storm to storm. It has been proposed that the detention time be determined on a mass balance basis and calculate how long it remains in the pond (APWA 1981).

Recent studies on a detention basin by Scherger and Davis (1982) showed that there were other pollutants removed besides suspended solids from 10 to 85 percent, TKN reductions of 0 to 50 percent and phosphorus reduction of 0 to 82 percent. These findings show that there is variability in the removal efficiencies. These fluctuations were explained by the fact that most of the nitrogen was in the soluble form and phosphorus was mainly in the insoluble form. A high removal of iron was also noted in this study.

Other studies on removal of pollutants by settleability include those by Whipple and Hunter (1981). Using a total of four composite samples over a period of 32 hours, stormwater was allowed to settle in a 6.0 ft (1.83 m) high, 0.75 ft (22.9 cm) diameter column. The removals observed are given in Table 1.

TABLE 1

STORMWATER POLLUTANT REMOVALS FROM SETTLING COLUMN

Pollutant	Percent Removal Range	Percent Removal Average
Suspended Solids	62 - 73	68
Total Phosphorus	30 - 67	50
Lead	55 - 84	65
Zinc	17 - 36	30
Copper	31 - 58	42
Nickel	20 - 42	30

SOURCE: Whipple and Hunter 1981.

A similar study was performed by Randall et al. (1982) where stormwater was allowed to settle for 48 hours in 4 feet (1.22 m) deep, 5 inch (12.7 cm) diameter columns using a total of 7 runs. Results obtained from this study showed substantial reductions of pollutants including a lead removal of 86 percent and total nitrogen removal of 33 percent. Overall removals from this experiment were slightly greater than that found by Whipple and Hunter (1981). This may be due to the difference in the settling times or the dissolved fractions of pollutants.

Wanielista et al. (1981) conducted settling studies from an urban area. They reported reductions in suspended materials ranging from a high of 52% for TSS to a low of 20% for lead. The use of alum coagulation and detention showed a higher improvement in stormwater quality than when detention was used alone. Alum coagulation gave low reductions of nitrogen and calcium, while TP and TSS showed removals greater than 90%.

The underlying principle for the settleability of pollutants to occur is the detention time of the basin. This time sets the critical settling velocity of the particles. Depending on the particle size, the settling velocity of the particle will determine if it will settle out and be removed or not.

In a study of an extremely long average detention time of approximately 213 days, Harper et al. (1980) found removal of pollutants from Lake Eola, Orlando, Florida. Considered to be basically a detention pond by the descriptions previously given, results obtained from this study showed suspended solids removals of 94.6 percent, TKN removals of 46.9 percent, nitrate nitrogen removals of 61.3 percent and dissolved orthophosphorus removals of 85.7 percent. Mechanisms other than settleability of the pollutants were also believed to be responsible for the high removals. These included the biological use of nitrogen and phosphorus by organisms in the water column.

Based on the concept of particle size distribution, a model has been developed by Ferrara and Salvage (1984), which gives guidelines for detention basin design. It was assumed that particles of a size greater than one micron would be totally removed and partial removal of particles less than this size would occur, based on column studies performance. The basis for this design was that the minimum detention time had to be 9 hours at all times during each storm event. The detention time is based on dividing the volume of water in the basin by the existing flowrate. This implies that for a constant volume situation, the detention time is totally dependent on the flow, such that at lower flows, a high removal should be observed.

Theoretical design parameters have also been put forward by these researchers based on settling velocities and particle size distribution. Generally, the larger particle and the shorter settling velocity would give the best removal. The comparison of theory and actual results portrays the limitations of assuming a uniform particle size distribution. Thus, in real life situations, there are many factors which influence removal capabilities in detention ponds by settling of particles.

Filtration of Effluent

Another method of using detention/retention facilities for water quality enhancement is to add a filter for the effluent water to percolate through before discharge. By filtering the effluent before it leaves the pond, pollutant removal has been possible (Wanielista et al. 1983). Removals of ammonia-N, nitrite-nitrogen, ortho- and total phosphorus were achieved for a filter mixture of 50 percent building sand and 50 percent alum sludge (Wanielista et al. 1982). It was noted that removal efficiencies were dependent on flow rates, such that the lower flows gave a greater reduction for some of the water parameters. Reductions of 90 percent for ortho- and total phosphorus were observed. Other findings of this research was the alteration of nitrogen forms in the effluent waters. The nitrification process was observed to occur since ammonia-nitrogen and nitrite-nitrogen concentrations decreased while nitrate-N concentrations increased. Addition of limerock to the filter media was used to control pH levels. This addition gave lower phosphorus removals, suggesting that the phosphorus removal was a function of detention time (contact with media) since the depth of soil removing phosphorus was decreased.

The above mentioned work of Wanielista was done in an environmental laboratory. Harper et al. (1982) extrapolated these results and designed filters for the Lake Eola Watersheds in Orlando. He observed a phosphorus removal efficiency of about 75% for a filter composed of alum sludge and sand that was 15 inches deep. Another filter which was 24 inches deep had a phosphorus removal efficiency which ranged from 75-92%.

In a separate study with roadside soils, it was found that soils were a major sink for heavy metals (Wanielista and Bell 1978). Further results showed that soils which contained organic matter, clay, minerals, and were of an alkaline nature tended to promote metal removals.

It appears that a soil mixture which contains some clay and organic content is favorable for pollutant removals. Hickok (1980) showed that use of an organic rich soil was capable of removing mainly phosphorus and nitrogen forms from stormwater. In another study, two different soil mixtures were used; one without organics and one with two percent organics (Anderson et al. 1981). The two mixtures: (1) 95% sand, 1% silt, and 4% clay and (2) 89% sand, 5% silt, 4% clay and 2% organics seeded with bermuda grass and loaded with wastewater, showed initial differences in removal efficiencies of phosphorus. The soil with organics initially had a greater phosphorus removal, but as the applications of wastewater increased, the difference in the two removal efficiencies was less obvious. Nitrogen removals for the same study were greater for the mixture with organics (65%) than the mixture without (52%). Nitrate-N concentrations were based on the rate of application of wastewater as was phosphorus.

In a rapid infiltration study with wastewater, high pollutant removals were observed (Dornbush 1981). Using a 4 foot (1.31 m) depth of silty clay loam underlain with saturated coarse gravel, removals of pollutants were recorded. Results from this experiment are given in Table 2. The cation exchange of the soil was 30-43 meq/100 g with an organic content of 10-20 percent and a permeability of 0.2-0.8 in/hr. This study shows that using a wastewater with high pollutant concentrations, a high removal efficiency can be achieved. The next step is to apply this to stormwater.

Another study with intermittent sand filters by Otis (1982) found ortho- and total phosphorus removals of 50 percent. Also, it was found that mixing the sand with calcium, aluminum, or iron

TABLE 2

RESULTS FROM RAPID SAND INFILTRATION STUDY BY DORNBUSH

Pollutant	Percent Removal
Orthophosphorus	85 - 93
Total Phosphorus	85 - 91
Ammonia-Nitrogen	90 - 94
Nitrate-Nitrogen	0
TKN	88.5-91.5

SOURCE: Dornbush 1981

species could improve removals up to 70 to 90 percent. This particular study was with filters which were 2 to 3 feet deep (0.6-0.92 m), and of "granular materials" underlain with collection drains. The disadvantage of using the sand was that the sorption sites were quickly covered with biological film and, thus, had to be replaced often.

Swales

Another water quantity structure which may have some potential for pollutant removals are roadside swales (Wanielista, et al. 1983). Water quality research is now being done in this area by Yousef (1984). It is assumed that under proper design considerations of volume routing, crop cover, site characteristics, swale blocks, and expected removal efficiencies, the effectiveness of pollutant removal by these structures could be determined. Since these swale systems are used to transport stormwater to detention/ retention facilities, a combination of swales and detention ponds could reduce the water pollutant load.

Summary

From the research performed by others, it seems that there are two major ways to remove pollutants from the stormwater once it has entered detention areas. One method is to design the system so that there is an adequate detention time to allow settling of pollutants. Short circuiting of the pollutants must be prevented. Removals for pollutants using this idea are relatively high under ideal conditions. The areas should be carefully designed to include real life interferences. The major drawback with this idea is that it may require a large amount of area, which could be costly.

The second alternative is to use a type of soil filter to remove pollutants as the water leaves the areas. This type of technique is also in the research stage and removal efficiencies cover a wide range of values from 0 to 90 percent removal or more. The type of media that does work best is one which has (1) a variety of natural characteristics, such as silt, clay, organic matter, aluminum, iron, and calcium, (2) a high cation exchange capacity, and (3) a low permeability rate through the soil. This type of pollutant removal requires little extra land area, but will need to be replaced periodically when exhaustion of the media occurs. The best method to remove pollutants would be to have a combination of both methods discussed, if it was economically feasible.

CHAPTER III

LABORATORY EXPERIMENTATION

As previously mentioned in Chapter I, the objectives of this research are to study the removal of pollutants for different filter media types and observe their response to a prototype situation. In the previous chapter, different types of soil mixtures already studied were mentioned. From these studies, it seems that a soil mixture which contained some clay and organics had a better pollutant removal than those without. Other information was that the slower the percolation rate, the greater the pollutant removal, phosphorus removal was primarily due to adsorption processes, and that nitrification was responsible for the variation in nitrogen forms.

Water Quality Analysis

The following parameters were measured on each sample that was collected: nitrate nitrogen, ammonia nitrogen, nitrite nitrogen, total phosphorus, total orthophosphorus, dissolved orthophosphorus, and total Kjeldahl nitrogen. These were all measured according to Standard Methods (1975). Heavy metals were measured for some of the samples. These metals included cadmium, zinc, copper, aluminum, iron, lead, nickel and chromium. Measurements of pH were also taken on some samples. All analyses were performed in the Environmental Engineering Laboratory at the University of Central Florida within the specified time given by the U.S. EPA in Methods for Chemical Analysis of Water and Wastes (1976).

The pH determination was performed using a Corning Model 12 research pH meter with a temperature compensation probe. Orthophosphorus determinations were according to the ascorbic acid method. Total phosphorus was determined using the persulfate digestion-ascorbic acid reduction of phosphomolybdic acid absorbance. The brucine acid method was used in nitrate nitrogen analyses and nitrite nitrogen was determined by azo dye procedures. Ammonia nitrogen was analyzed by filtration followed by phenate determination. Total Kjeldahl nitrogen analyses were performed using acid digestion followed by distillation and acidimetric titration of ammonia.

Determination of heavy metals was through the use of a Spectrometrics Incorporated Spectraspan III Plasma Emission Spectrometer. This analysis consists of concentrating a sample by adding 2 ml of concentrated HNO_3 to 100 ml of sample in a 250 ml Erlenmyer flask and heating it at 95°C until a sample of 10 ml was left. The sample was then diluted with distilled water up to a total volume of 20 ml and stored in a covered polypropylene container until it was measured. It was important that all glassware was previously washed with an acid wash of 1:1 solution of hot HCL followed by 5 rinses with distilled water.

Grain Size Analysis

The distribution of grain size for the two filter media types used in the field experimentation was determined according to a procedure by Lambe (1951). A sample of 500 g was dried overnight at 105°C. After cooling, a set of six sieve pans were weighed and stacked on a shaker, the largest pan being on the top. Sieve sizes ranged from number 10 to number 200, with the latter being the smallest mesh size with an opening of 0.075 mm. The dried sample was added to the top of the pan and the whole stack shaken for 5 minutes. The pans were then reweighed and the percentage passing through each sieve size determined. Since the fine material (finer than size number 200) was not significant, a hydrometer analysis was not performed. Uniformity coefficients were calculated based on plots of percent finer versus sieve size.

Exhaustion Study

By comparing removal efficiencies with time for the water quality parameters, a time when no significant removal was observed was set equal to the exhaustion time. Once this time was found, a table was constructed to find the cumulative amount of flow which passed through the filter per unit surface area of the filter media. This was calculated by multiplying the flowrate by the time interval and divided by the surface area of the filter media. Table 17 in the Appendix shows such a calculation.

Column Set Up

The experimental set up for the laboratory column study is shown in Figure 2. The experiment was performed in the Environmental Engineering Laboratory at the University of Central Florida, Orlando, Florida. A 54-inch (132 cm) long, 4-inch (10.2 cm) diameter plexiglass column was used. The column was cleaned with tap water each time a different soil media was used. The column was held in place by two brackets so that the bottom of the column was a height of about 2½ feet (0.76 m) above the floor. A 1 to 1½ inch (2.54-3.8 cm) layer of large rocks were placed on the inside bottom of the column. These rocks were washed gravel stones of a mean diameter ranging from 1 to 1½ inches (2.54-3.8 cm). On top of this a POLY-Filter GB permeable membrane was placed. This pervious cloth was used to prevent sand from leaching out from the column. Next, the particular soil media was loaded on top of the permeable membrane. When packing the column, it was important to ensure that there were no large pore spaces in the filter media, since this would result in short circuiting of the water. To prevent short circuiting, the media was carefully placed in the column and allowed to settle properly before another layer of soil was placed on top of it. Depths of soil in the column varied from 9 to 36 inches (22.9-91.4 cm) for each experiment. A top 1 inch (2.54 cm) of large rocks was added so that the soil would not erode unevenly due to the influent water.

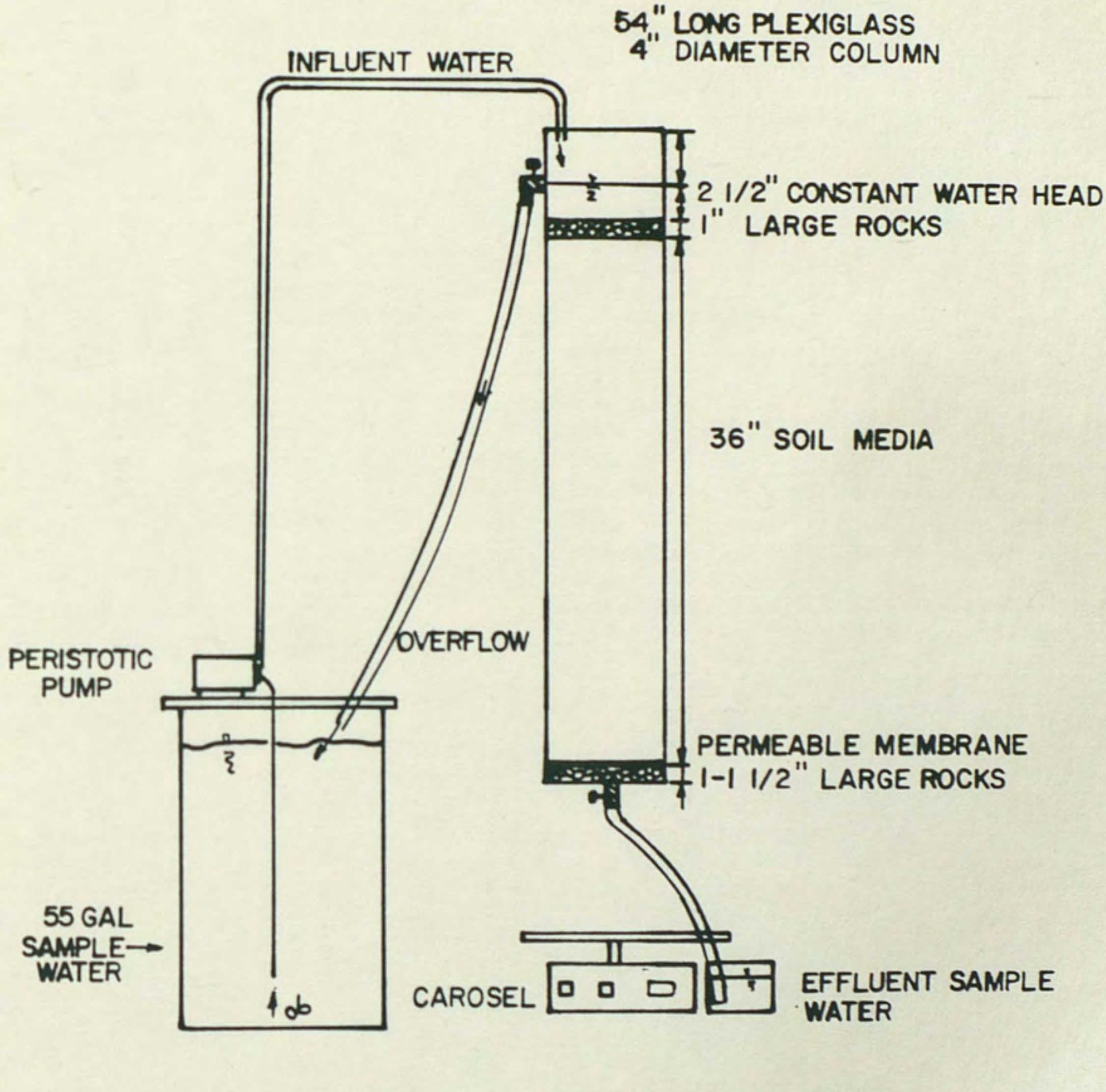


Fig. 2. Experimental set up for laboratory experimentation.

With each soil type, a constant head of water was maintained by the overflow outlet. The overflow was fed back into the raw water by gravity feed. A 55-gallon (208 L) plastic drum was used to hold the raw water. A mixing stone was used in conjunction with an airflow tube into the container to ensure a completely mixed aerated water sample.

The raw water was pumped through a ¼ inch (0.64 cm) tygon tubing up to the head of the column with a Cole-Parmer Instrument Co. peristaltic pump. When the soil sample became saturated with water, the effluent water percolated out of the bottom of the column and into an ELDEX Universal Fraction Collector. This carousel enabled samples to be taken at regular time intervals, automatically, and without supervision. The set up was such that as many samples as necessary could be taken at any regular time frame.

Grab samples were taken of the raw influent water at the beginning of the run, and at a later time if the experiment operated for more than four hours. Grab samples were also taken of the effluent water from the volume obtained from each time period. Samples were taken in clean 1 liter plastic bottles and refrigerated until water quality analyses were performed on them.

Composition of Raw Water

The raw water used for the column study was composed to simulate stormwater runoff. The first water used was taken from Lake Jessup, a eutrophic lake with a high algal content. Due to the high nitrogen concentration of this water it was not used in any other experiments since it was not typical of stormwater. Except where noted, tap water was used in conjunction with phosphorus, nitrogen, and heavy metal chemicals. Detention pond sediments which were rich in nutrients were also added to this mixture. These components were thoroughly mixed 24 hours before the beginning of the experiment to enable complete mixing of the chemicals. Water quality characteristics of this water are given in Table 3.

Composition of Column Soil Media

A total of 6 different soil type mixtures were used in this study. In each case a certain percentage of each soil component was measured by volume and evenly mixed with each of the other soil components. Organic content of the soils were judged by visual and textural characteristics. Mixing was performed manually to ensure a totally homogeneous mixture.

The soil mixtures used are listed in Table 4. The fine sand used in this experiment was obtained from Kissimmee, Florida, near the shore of Lake Tohopekaliga. This area was chosen since it had both dry and wet areas and the sands were extremely dry, suggesting good filtration. The sand was of fine grade, almost silt-like and white in color. The top soil in this area appeared to be rich in organics and was also used in the soil

TABLE 3

RAW WATER CHARACTERISTICS FOR COLUMN STUDY

Water Parameter	Concentration (mg/l)
Total Phosphorus	0.72 - 1.5
Total Orthophosphorus	0.67 - 1.4
Dissolved Orthophosphorus	0.58 - 1.4
Nitrite Nitrogen	0.001 - 0.26
Nitrate Nitrogen	0.02 - 1.9
Ammonia Nitrogen	<0.01 - 0.35
Total Kjeldahl Nitrogen	0.01 - 2.5
Dissolved Metals	
Cd	0.002 - 0.003
Zn	0.007 - 0.049
Cu	0.002 - 0.49
Al	0.075 - 0.143
Fe	0.028 - 0.102
Pb	0.028 - 0.045
Ni	0.002 - 0.005
Cr	0.003 - 0.004

TABLE 4

SOIL TYPE MIXTURES FOR COLUMN STUDY

Media #	Date	Depth (inches)	Water	Mixture
1	3/2/83	36	Lake Jessup	62% fine sand 26% clay 12% organic soil*
2	3/15/83	9	Tap	10% organic soil 10% clay 40% fine sand 40% gravel
3	3/18/83 3/25/83 4/6/83 4/15/83	36	Constructed	10% organic soil 10% clay 40% fine sand 40% gravel
	5/11/83	36	Constructed	45% gravel 45% fine sand 10% organic soil
4	5/17/83	28	Constructed	50% builders sand 50% site sand with some organics
5	5/18/83	36	Constructed	100% concrete sand
6	5/23/83	20	Constructed	50% concrete sand 50% fine sand

* Organic materials estimated by texture and visual observation in topsoil obtained from shores of Lake Tohopekaliga, Kissimmee, Florida.

mixtures. The top soil was approximately 65% sand and 35% organic humus material as determined by visual and texture inspection.

The clay used was an orange-red colored roadway construction clay composed of roughly 80% clay and 20% sand, as determined by a settling test on the clay. Gravel pieces used ranged in an average diameter size of 1.0 to 1.5 inches (2.54 to 3.8 cm) and was similar to that used in the top and bottom parts of the column. It was rinsed five times with tap water to remove any unwanted substances. Site sand was taken from the Maitland Interchange part of Interstate 4, north or Orlando, Florida. This soil was composed mainly of sand, but also contained some organics. Builders sand and typical concrete sands were also used in this experiment. It should be noted that the percentages of the different soil components given in Table 4 were calculated based on the above information.

Column Results

The first filter type (#1) was not successful. The permeability of the media was very slow, about 0.14 in/hr and for this reason further studies were not performed with this type of media. The reason for the low filtration rate was believed to be due to the small pore size of the soil mixture. To improve permeability, less clay was used and more gravel was added in the next soil mixture.

The second filter media composed of 10% organics, 10% clay, 40% fine sand and 40% gravel was initially only run at a depth of

9 inches (22.9 cm). High removals of phosphorus and orthophosphorus were recorded. Results from this experimental run are in Table 5. The permeability of the soil was about 4.0 in/hr, taken over a time period of 4.5 hours. The permeability was seen to slightly decrease during the experiment from an initial of 4.3 in/hr to a final rate of 3.6 in/hr. These results show that there was little nitrogen removal. In this run, the raw water was tap water and the influent values for the various water parameters are as shown in the table.

Another experiment was run on this same type of filter media, since the results looked favorable. A 36-inch (91.4 cm) deep column was used next and the results from this run are given in Table 6. The longer duration of this experiment (about 40 hours) and the larger amount of soil used tend to give similar results to those used in the previously discussed experiment. The permeability of this column was less than the shorter column. Previous samples had been fairly clear in appearance, but after 25 hours of running the experiment, a yellow effluent was observed. Phosphorus was probably removed by adsorption processes with the clay particles in the soil. There were no heavy metals measured in this experiment.

TABLE 5

RESULTS FOR SOIL TYPE #2:
10% ORGANIC SOIL, 10% CLAY, 40% FINE SAND, 40% GRAVEL*
9" DEPTH

Water Parameter	Influent Concentration (mg/1)	Percent Removal Range	Percent Removal Average
Total Phosphorus	1.010	91.3-94.5	93.4
Total Orthophosphorus	0.919	95.2-98.8	97.6
Dissolved Orthophosphorus	0.868	95.4-99.0	97.8
Ammonia-nitrogen	0.349	0	0
Nitrite-nitrogen	0.0098	64.6-91.7	81.6
Nitrate-nitrogen	1.883	0-20.4	6.7
Total Kjeldahl nitrogen	2.517	0-47.1	29.4

* 1. 9 inch depth with 4 samples taken over a 4.5 hour period.

2. Samples taken on 3/15/83.

3. Permeability (in/hr): 3.6 - 4.3, avg. 3.97

TABLE 6

RESULTS FOR SOIL TYPE #2:
10% ORGANIC SOIL, 10% CLAY, 40% FINE SAND, 40% GRAVEL*
36" DEPTH

Water Parameter	Influent Concentration Range (mg/1)	Influent Concentration Average (mg/1)	Percent Removal Range (%)	Percent Removal Average (%)
TP	0.72-1.03	0.923	76.3-92.0	86.4
TOP	0.67-1.03	0.876	93.8-94.2	95.2
DOP	0.67-1.03	0.821	94.5-96.1	95.1
NH_3	<0.010-0.349	0.104	0-20.4	1.5
NO_2	0.0008-0.0023	0.0036	0-1.0	~0
NO_3	0.015-1.883	0.629	0-91.7	29
TKN	0.10-2.52	0.805	0-47.1	10

* 1. 36 inch depth with 14 samples taken over a 40 hour period.

2. Samples taken on 3/18/83, 3/25/83, 4/6/83, 4/15/83.

3. pH influent: 5.80 - 7.05, avg. 6.08
pH effluent: 5.60 - 6.51, avg. 5.94

4. Permeability: 2.3 - 4.0 in/hr, avg. 3.3 in/hr

5. Exhaustion Volume/Area (gal/ft^2): > 160

Due to the colored effluent in the last filter mixture, the clay particles were minimized and the next filter type was a mixture of 45% fine sand, 45% washed gravel and 10% organics. The 36 inch (91.4 cm) column showed an increase in the permeability, due to the larger pore areas from the gravel present. This run was 4 hours long and showed phosphorus removals, but no nitrogen removals. Heavy metals that were removed were lead and chromium at 20% and 31% removals, respectively. Table 7 summarizes these results.

The 50/50 mixture of concrete and site sands had similar results to the previous one. Table 8 lists this data. The permeability of this sand mixture was much higher than any of the others, averaging around 12.8 in/hr. There were also a larger number of heavy metals removed including cadmium, aluminum, iron, lead and nickel. The influent water characteristics were slightly higher for this experiment than the previous one, suggesting that the low removals encountered with nitrogen may be a result of the higher initial concentrations.

The mixture of 100% concrete sand showed the highest permeability, about 43 in/hr. Table 9 gives the results from this run. Phosphorus removal dropped from previous experiments, most

TABLE 7

RESULTS FOR SOIL TYPE #3:
45% GRAVEL, 45% FINE SAND, 10% ORGANIC SOIL*

Water Parameter	Influent Concentration (mg/1)	Percent Removal Range	Percent Removal Average
TP	1.194	53.2-73.1	62
TOP	1.150	85.5-93.9	87.6
DOP	1.149	88.3-94.6	89.7
NH_3	<0.01	0	0
NO_2	0.0011	0	0
NO_3	0.038	0	0
TKN	--	-	-
Dissolved Metals			
Cr	0.004	0-75	31
Pb	0.032	0-31	20

* 1. 36 inch depth with 5 samples taken over a 40 hour period.

2. Samples taken on 5/11/83.

3. Permeability 7.8 in/hr.

TABLE 8

RESULTS FOR SOIL TYPE #4:
50% BUILDERS SAND, 50% SITE SAND WITH SOME ORGANICS*

Water Parameter	Influent Concentration (mg/l)	Percent Removal Range	Percent Removal Average
TP	1.188	52.9-97.2	85.8
TOP	1.184	97.0-98.6	97.9
DOP	1.095	97.0-98.5	97.8
NH_3	<0.010	0	0
NO_2	0.1356	5.5-7.9	6.7
NO_3	0.263	0-5.7	4.0
TKN	0.011	0	0
Dissolved Metals			
Cd	0.002	0-50	25
Al	0.079	21.5-40.5	29.8
Fe	0.102	70.6-77.5	74.3
Pb	0.043	27.9-37.2	34.3
Ni	0.003	0-33.3	25

* 1. 28 inch depth with 5 samples taken over a 4 hour period.

2. Samples taken on 5/17/83.

3. pH: Influent 7.22
   Effluent 6.66

4. Permeability: 12-13 in/hr, avg. 12.8 in/hr

TABLE 9

RESULTS FOR SOIL TYPE #5:
100% BUILDERS SAND

Water Parameter	Influent Concentration (mg/1)	Percent Removal Range	Percent Removal Average
TP	1.242	16-86	53.0
TOP	1.132	16-96.6	57.0
DOP	1.110	25-97.5	59.1
NH_3	<0.010	0	0
NO_2	0.1144	7.2-31.0	13.2
NO_3	1.134	6.3-10.5	7.8
TKN	0.180	0-69	45.9

* 1. 36 inch depth with 5 samples taken over 2 hours.

2. Samples taken on 5/18/83.

3. pH: Influent 7.05
   Effluent 6.79

4. Permeability: 36-47 in/hr, avg. 42.7 in/hr.

likely due to the decrease in adsorption sites in the absence of clay. TKN showed a marked removal with nitrification occurring with the other nitrogen forms.

The last filter media used 50/50 mixture of concrete and fine sand had very low removal of all water parameters. The permeability was averaging around 14 in/hr and other pertinent data are found in Table 10. The longer run time of 20 hours and the low sample volume, showed that the first samples taken 1 hour after the start had the higher removals than those taken at the later time.

Summary

The objective of this experimentation was to study a filter media which would give favorable pollutant removals and a satisfactory infiltration rate. The reason for the second requirement was to develop a media which would have a high permeability when used in the field and allow stormwater to percolate through without a large amount of standing water in the detention structure.

Based on the results obtained to satisfy these objectives, the most favorable soil type was the #2 filter mixture composed of 10% organics, 10% clay, 40% fine sand, and 40% gravel. This media had a permeability of about 3.5 in/hr which was slow enough to allow contact of pollutants with particles in the soil and nitrogen forms to change due to nitrification.

TABLE 10

RESULTS FOR SOIL TYPE #6:
50% CONCRETE SAND, 50% FINE SAND*

Water Parameter	Influent Concentration Range (mg/l)	Influent Concentration Average (mg/l)	Percent Removal Range (%)	Percent Removal Average (%)
TP	1.507-1.558	1.533	3.9-16.0	10
TOP	1.285-1.431	1.358	4.9-18.1	11.5
DOP	1.286-1.380	1.333	4.3-18.4	11.4
NH_3	0.0002-0.115	0.058	0	0
NO_2	<0.0001-0.0002	0.0001	0	0
NO_3	0.940-0.954	0.947	1-1.70	0.85
TKN	0.366-0.515	0.441	31.1-36.9	34.0

* 1. 20 inch depth with 4 samples taken over 20 hours.

2. Samples taken on 5/23/83 and 5/24/83.

3. pH: Influent 7.05
   Effluent 6.78

4. Permeability: 7.4-20.6 in/hr, avg. 14.0 in/hr.

The exhaustion value of the soil type #2 was found to be in excess of 160 gallons of stormwater per square foot of soil media. This value indicates that 160 gallons of stormwater could be run over one square foot of filter media before the removal of pollutants was significantly decreased. Water passed through the filter in excess of these values would result in poorer effluent qualities. The low value of these numbers suggests that if they were used in the field, they would need to be replaced periodically.

The results from this experimentation also indicate that if clay or organic matter is present in the soil media, the removal of pollutants is increased. With regard to the results obtained from the experiment which contained zero organic materials (soil types #5 and #6), there is a much lower removal of all pollutants except TKN.

CHAPTER IV

FIELD EXPERIMENTATION

Experimental Set Up

To model the filter media studied in the laboratory, a prototype model was constructed. Using a large box, the performance of the filter media was observed on a larger scale than the column study.

The box was constructed of plywood with inside dimensions of 2 feet (0.61 m) deep by 7 feet (2.1 m) long and 2.6 feet (0.79 m) wide, a total volume of 33.7 cu ft (944 L). The inside of the box was fiberglassed to make it waterproof and prevent deterioration of the wood. Figure 3 shows this set up.

A filter pipe served as the permeable membrane in the box. This 18 foot (5.5 m) long, 6 inch (15.2 cm) diameter, PVC Larson Drainage system slotted pipe was placed on the bottom of the box in an "hour-glass" pattern. The pipe was covered with a filter cloth and at one end connected to the outflow pipe of the box.

The pipe was then carefully covered with a coarse type of sand to a specific depth. The rest of the box was covered with the soil media. The purpose of the coarse sand was to simulate the large rocks used in the column experiment and to prevent any unnecessary leaching of smaller sand particles into the permeable

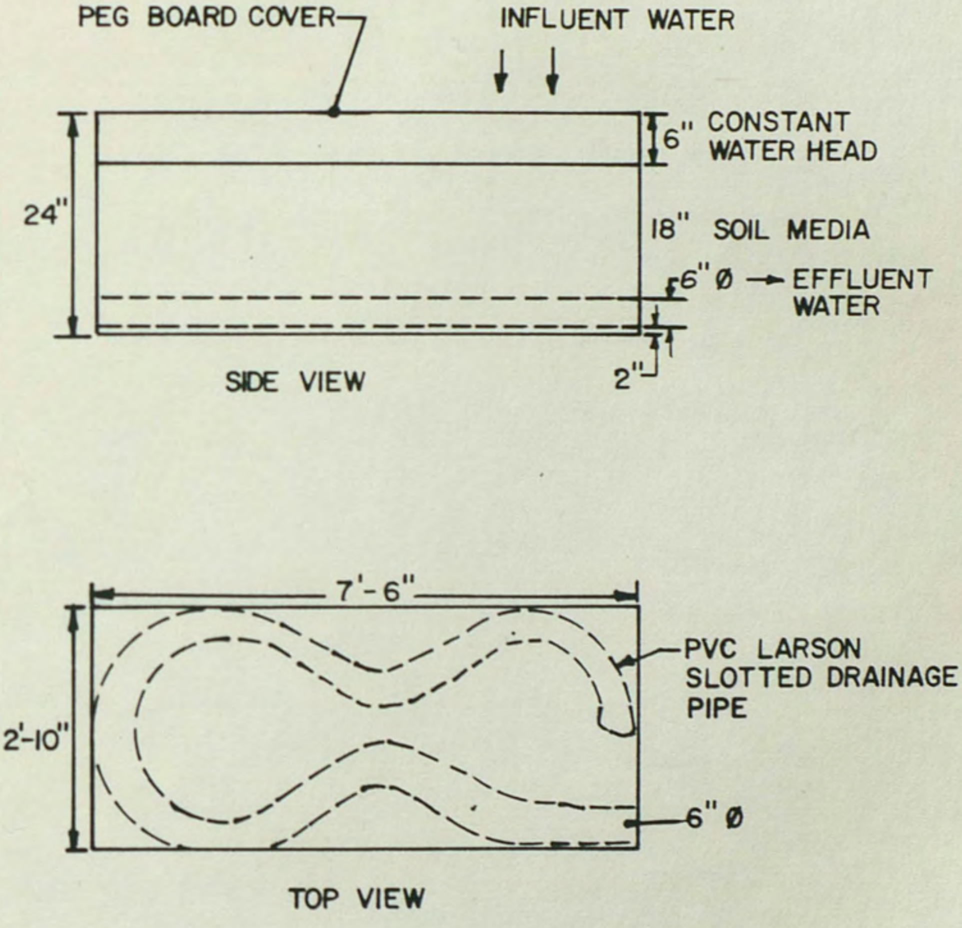


Fig. 3. Set up for field experimentation, top and side views.

membrane. The top of the box was covered with a peg board. This enabled an even spread of the influent water over the sand media (similar to the purpose of the large rocks in the column study), as well as keeping unwanted debris from entering the box.

Site Location

The site of the experimentation of the prototype was a culvert connected to the west pond at the Maitland Interchange on Interstate 4, just north of Orlando, Florida. A site location of this area is illustrated in Figure 4. The water used to run through the filter was pumped out of this culvert. Since the water quality of this culvert was very clean, it was necessary to spike the water with pollutants before it entered the filter media. This was achieved by dripping a concentrated amount of heavy metals, nitrogen and phosphorus into the influent water as it was pumped up from the culvert. A Cole-Parmer Instrument Co. peristaltic pump was used to supply a constant rate of the pollutant mixture to the sump pump intake area via a ¼ inch (6.4 mm) tygon tube. Calculations for the pollutant dosage were based on an approximated flowrate through the filter media and a goal concentration of pollutants in the influent water. The raw water concentrations used in this experiment are summarized in Table 11.

The water was pumped to the head of the filter box using a sump pump and a 2 inch (5.08 cm) diameter PVC pipe. This set up had a valve in it so that the flow could be controlled as it came

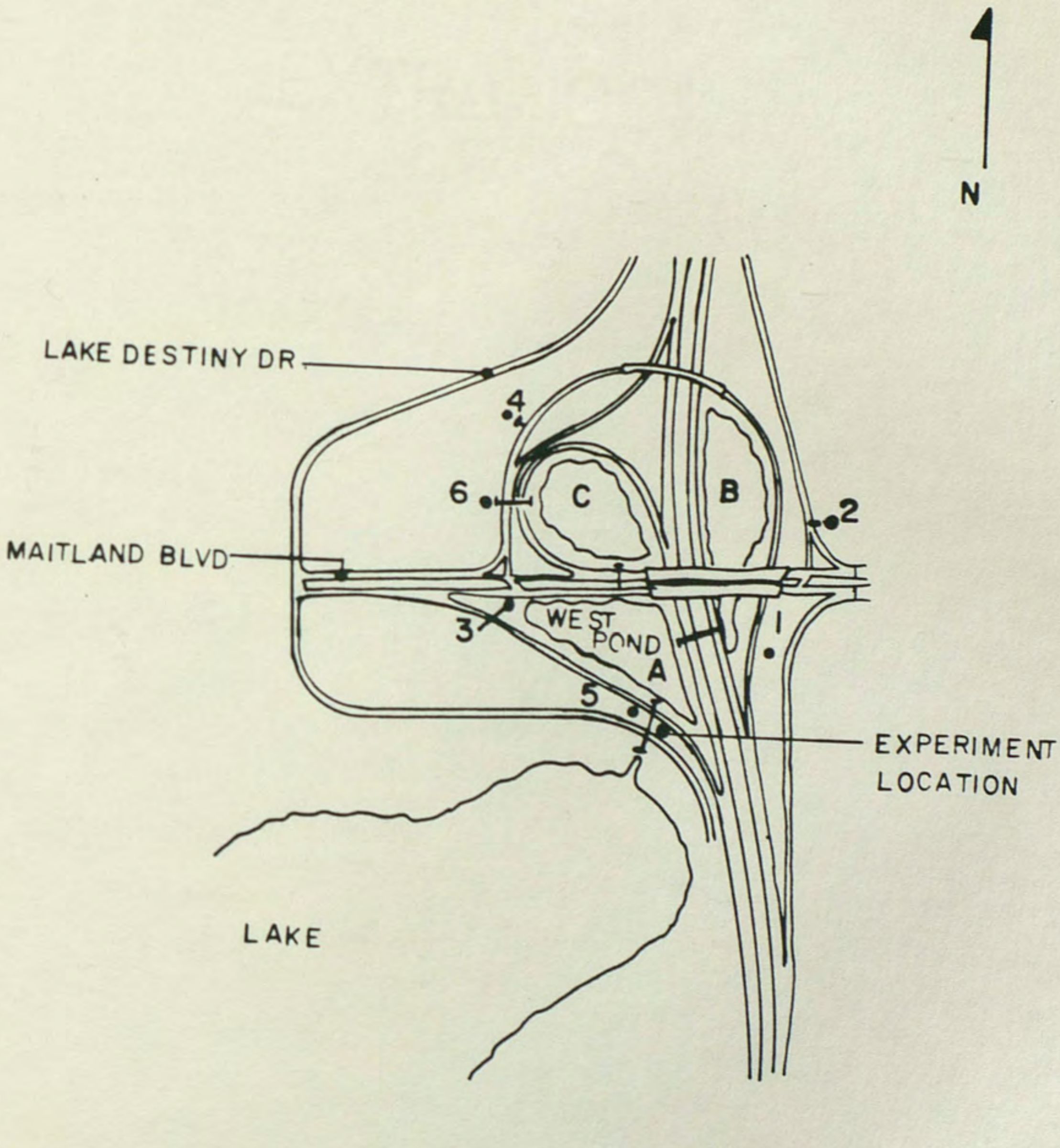


Fig. 4. Site location of field experimentation, Maitland Interchange, Florida.

TABLE 11

RAW WATER QUALITY PARAMETERS FOR FILTER BOX EXPERIMENT FOR ALL SAMPLES

Water Parameter	Concentration Range (mg/1)	Concentration Average (mg/1)
TP	0.061-0.462	0.118
TOP	0.026-0.132	0.053
DOP	0.022-0.096	0.043
Nitrites	0.001-0.003	0.001
Nitrates	0.002-0.561	0.263
Ammonia	0.01-0.090	0.030
TKN	0.475-0.882	0.652
Dissolved Metals		
Cd	0-0.005	0.002
Zn	0.009-0.018	0.012
Cu	0.015-0.030	0.022
Al	0.011-0.119	0.063
Fe	0.019-0.284	0.161
Pb	0.009-0.078	0.037
Ni	0.005-0.014	0.008
Cr	0.003-0.011	0.006

Sample size = 88

out of the pipe. This detail is illustrated in Figure 5. When the influent water filled up the top of the filter box, it was allowed to flow over the side of the box. The influent flow to the filter box was controlled so that a constant amount of water was allowed to spill over the side of the box. This was kept so that there was a constant head of 6 inches (15.2 cm) of water on the top of the filter media. The time for the water to percolate through the filter media was much faster than that observed in the lab, and may be the reason why our influent pollutant removal values were lower than expected (see Table 11).

Sampling Procedure

Water effluent samples were taken as soon as the water emerged from the outflow pipe. Generally, these first samples were a pinkish-orange color, which lasted for about two minutes of the total flow time. This was likely due to the leaching of clay particles through the filter cloth openings. The color of the effluent became clear within the first three minutes of the run. Flow measurements were taken using a 5 gallon (18.9 L) bucket and timing how long it took to fill up. Grab samples were taken of the effluent water samples over a period of hours at regular intervals with 1 liter plastic sampling bottles and brought back to the lab to be analyzed.

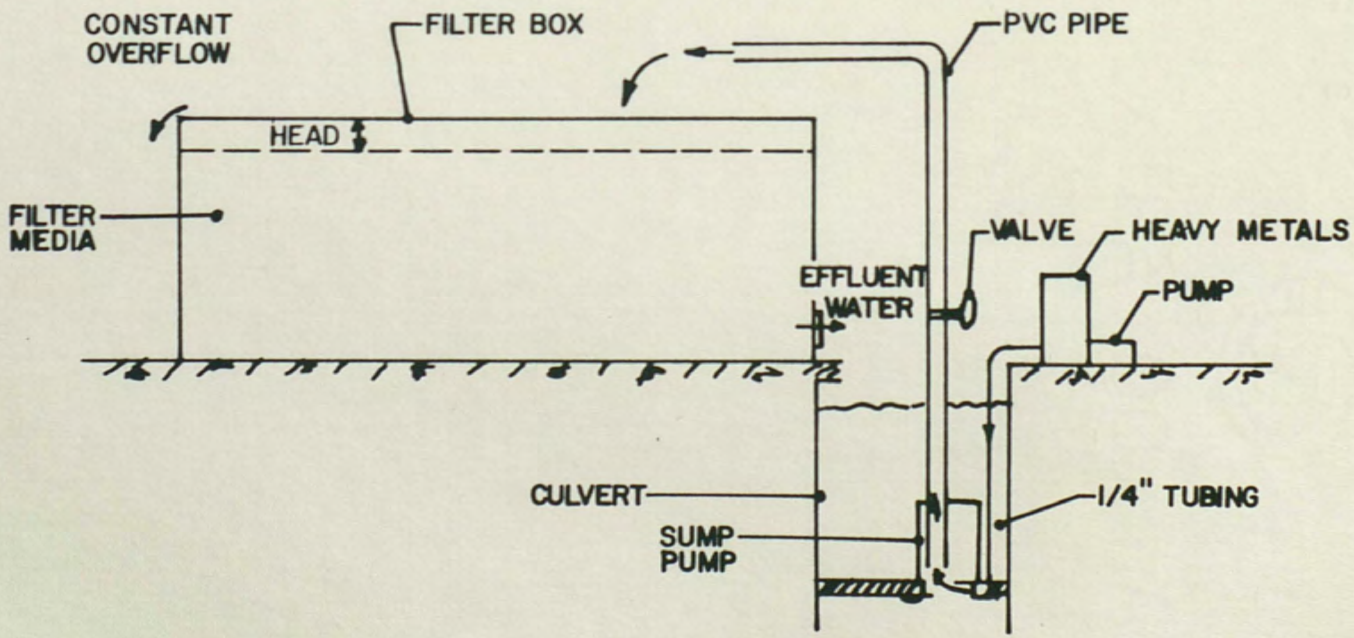


Fig. 5. Experimental set up for field experiment at Maitland, Florida.

Results of Prototype Experimentation

The field experiment was an extension of the laboratory work and was used to observe the response of the larger system to the favorable filter medias found in the column study.

The influent water parameter concentrations for the two filter media are presented in Tables 12 and 13 . This data shows that the influent concentrations of various water parameters were very similar in all cases except nitrate-nitrogen, which was almost 4 times greater for the second filter type. All other concentrations were within a reasonable range of each other.

Removal efficiencies for the first filter media are given in Table 12. Overall removals were low for all water parameters given, ranging from 13.1% for nitrite-N to 39.7% for nitrate-N. Likewise, removals for the second filter type are summarized in Table 13. Again, removal efficiencies were on the low side, ranging from 6.4% for DOP to 30.2% for ammonia-N. Heavy metals were also measured for this experiment and removals were recorded for Ni, Pb and Cr, ranging from 21.5% for Cr to 45.2% for Ni. Heavy metals were not measured for the first experiment.

Grain Size Analysis

Table 17 in the Appendix contains the results from the grain size analysis obtained for the concrete sand and the mixed filter media number 1. Uniformity coefficients were 3.06 and 4.80, respectively. Data is also given for the underdrain sands used in

TABLE 12

RESULTS FOR FIRST FILTER MEDIA FOR PROTOTYPE EXPERIMENT
AT MAITLAND INTERCHANGE, MAITLAND, FLORIDA*

Water Parameter	Influent Concentrations		Effluent Concentrations		Percent Removal	
	Range (mg/1)	Average (mg/1)	Range (mg/1)	Average (mg/1)	Range (%)	Average (%)
TP	0.086-0.463	0.143	0.028-0.096	0.058	1.2-92.6	26.8
TOP	0.036-0.132	0.056	0.015-0.066	0.045	0-88.6	29.3
DOP	0.031-0.096	0.045	0.009-0.048	0.030	0-90.6	26.0
NH_3-N	<0.01-0.048	0.027	<0.01-0.108	0.039	0-100	29.4
NO_2-N	<0.001-0.001	<0.001	<0.001-1.24	0.311	0-47.5	13.1
NO_3-N	0-0.167	0.109	0-0.206	0.070	0-75	39.7
TKN	0.588-0.781	0.686	0.550-0.716	0.617	4.9-20.3	13.5
pH		6.81	6.46-6.6	6.52		

* 1. Filter media makeup: 60% concrete sand and 40% site sand

2. Sample Dates: 6/1, 6/6, 6/7, 6/15, and 6/21/83 (25 samples in 10 hour time span)

3. Permeability: 3.2-5.3 gpm; 14.3-23.7 in/hr

4. Exhaustion Volume/Area (gal/ft^2): >107

5. Some organic materials present as judged by color and texture (less than 10% organics)

TABLE 13

RESULTS FOR SECOND FILTER MEDIA FOR PROTOTYPE EXPERIMENT AT MAITLAND INTERCHANGE, MAITLAND, FLORIDA*

Water Parameter	Influent Concentrations		Effluent Concentrations		Percent Removal	
	Range (mg/1)	Average (mg/1)	Range (mg/1)	Average (mg/1)	Range (%)	Average (%)
TP	0.074-0.132	0.093	0.046-0.804	0.135	0-54	17
TOP	0.029-0.084	0.050	0.029-0.804	0.141	0-30	19
DOP	0.022-0.082	0.045	0.021-0.184	0.052	0-29	6
NH_3-N	<0.01-0.09	0.033	<0.010-0.732	0.067	0-100	30
NO_2-N	0.0008-0.002	0.0015	0.0006-0.0323	0.004	0-46	18
NO_3-N	0.207-0.561	0.416	0.219-0.551	0.317	0-46	20
TKN	0.475-0.882	0.612	0.385-0.939	0.555	0-33	17
Ni	0.003-0.009	0.007	0-0.009	0.004	33-90	45
Pb	0.009-0.051	0.024	0.008-0.058	0.023	0-72.5	27
Cr	0.003-0.011	0.006	0.001-0.016	0.006	0-61	22

* 1. Filter media makeup: 33% coarse sand, 66% finer grain sand

2. Sample dates: 6/28, 6/30, 7/5, 7/8, 7/12, and 7/13/83 (63 samples over 33 hours)

3. Permeability: 15-30 gpm; 71-143 in/hr

4. Exhaustion volume/area (gal/ft^2): ~1077

the second filter box. Values for the upper and underdrain filter data was given by standard sand analysis data. The data was plotted on a percent finer versus sieve size scale to obtain these values. These are shown in Figures 10 through 13. These plots show that the sands were fairly well graded, since a coefficient of 2 or greater means that the soil is well graded and less than 2 means the soil is uniform (Lambe 1969).

Exhaustion Study

The exhaustion volume per area was calculated for each soil type. The first media had a value of 107 gallons of stormwater per square foot of soil media, while the second media was 10 times greater at a value of 1077 gallons of stormwater per square foot soil media. For the first filter type, this means that exhaustion was reached by the fifth day of experimentation. After this time, water quality decreased as shown in Table 17 in the Appendix. The second media had a much longer exhaustion rate. The calculation of the exhaustion volume could be the reason for the large difference in value. Since the second filter media had overall lower pollutant removals than the first, the decrease in this percent removal would be less obvious, that is not as great as the first media. If this decline was more spread out, this could account for the larger value. These values were given mainly for comparison purposes.

Summary

It is interesting to note that the results of this experimentation gave an overall lower pollutant removal than that observed in the laboratory. The major difference in this comparison is that the permeability in the prototype experiment was a lot greater than the column studies, ranging from 14.3 in/hr to a maximum of 143 in/hr. The permeability maximum value in the column experiment was 47 in/hr.

The percent removals for the second media are lower than the first by about 30%. Although this is not based on statistical analysis, this could be due to two reasons. First, the second media had little organic matter in it and according to the column results, organic material in the soil media tended to increase pollutant removals. The second reason could be due to the infiltration rate. The difference in the permeabilities of the two media types is quite large. Permeability of the second media was about five times or more greater than the first media. It might be expected that this would greatly effect the pollutant removals of the second media. The reduced contact time available for pollutants and sand particles may have had an effect of lower removal of pollutants by adsorption processes. In other words, the pollutants just passed through the media without much contact.

CHAPTER V

LEE VISTA PROJECT

Site Location

The Lee Vista Project is located just north of the Orlando International Airport, Orlando, Florida. Figure 6 gives the general location of this area. The project itself consists of several thousand acres and is to be developed into hotels and other accommodations. Presently, two hotels are finished in this project. The site of this study was on Lake Lorri, overlooked by the Mariott Hotel. Lake Lorri is a small, recently built detention pond. It serves as the major detention facility for a number of road ways. There is one main inlet to the detention facility located on its west side, as indicated in Figure 7. The only outflow from this pond is via an underdrain system located on the southern shore of the pond. One of the prime functions of this detention facility is to serve as a cleanup area for the stormwater before it enters Lake Michelle and eventually waters of the state.

It is recognized that the data collected at the existing filtration system is very limited. However, to complete the intention of this research, this limited data will be presented in the hope that further studies will expand on this data base.

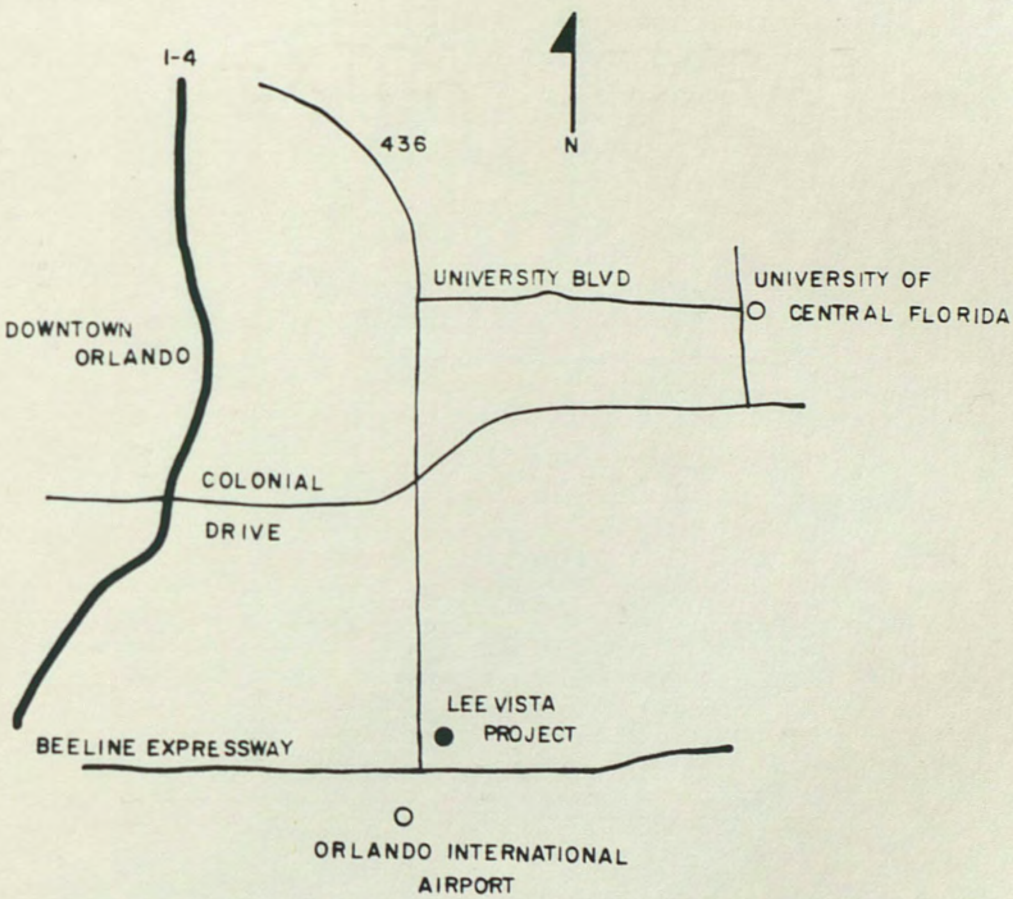
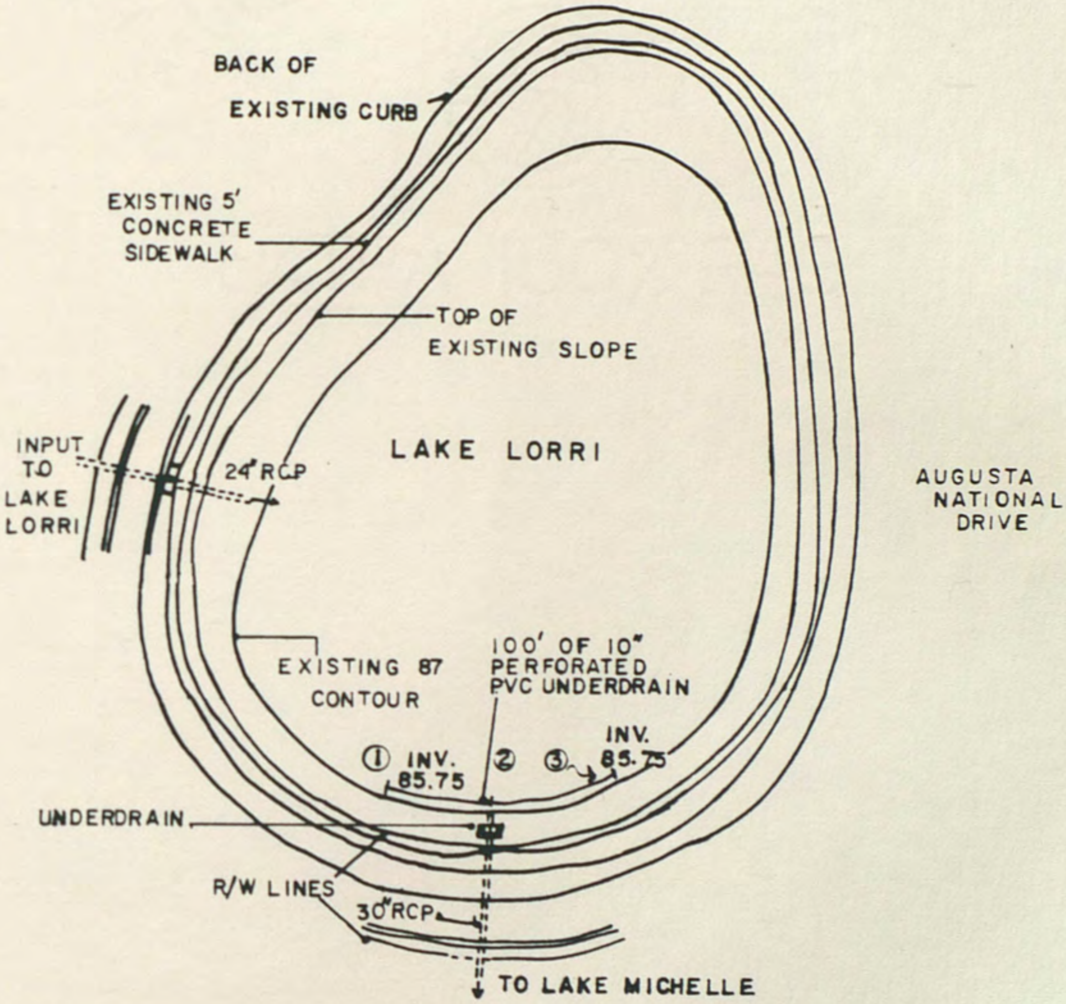


Fig. 6. Site of existing filtration system, Lee Vista, Florida.



Maximum Depth: 15 feet
Average Size: 1.5 acres
Watershed Size: 40.5 acres

Fig. 7. Location of filtration bank on Lake Lorri, Lee Vista, Florida.

Embankment Drainage System

The drain system in use in this pond is composed of a thoroughly mixed combination consisting of 60% alum sludge, 15% quartz sand (DOT Specs. 902-1.3), and 35% gravel (DOT Specs. 901-2). As mentioned in Chapter II, there have been experiments run on an alum sludge and sand filter under laboratory settings. These studies (Wanielista, et al. 1980) showed good pollutant removals. The major difference in the soil mixture of the Lake Lorri drain system and their research was the use of gravel instead of sand. Gravel was used to achieve a high infiltration rate in the system.

The underdrain pipe is a 10 inch (25.4 cm) perforated PVC (DOT Specs. 948-4.5) pipe wrapped in a filter cloth. A total length of 100 ft (30.5 m) of pipe was used. This pipe was then covered with the described filter media and gravel. A detailed drawing of the system is shown in Figure 8. The major purpose of this part of the study was to acknowledge any changes in water quality parameters as the water was filtered through the pipe.

Sampling Procedures

A total of 22 water samples were taken at Lake Lorri over a period of four sampling dates. At the time of the samplings, the banks of the lake had not been entirely sodded and runoff into the lake was not fully retained by the loose sand on the pond banks. These samples were taken at different weather and flow conditions. The first sample of 8/30/83 was taken when the pond had just started

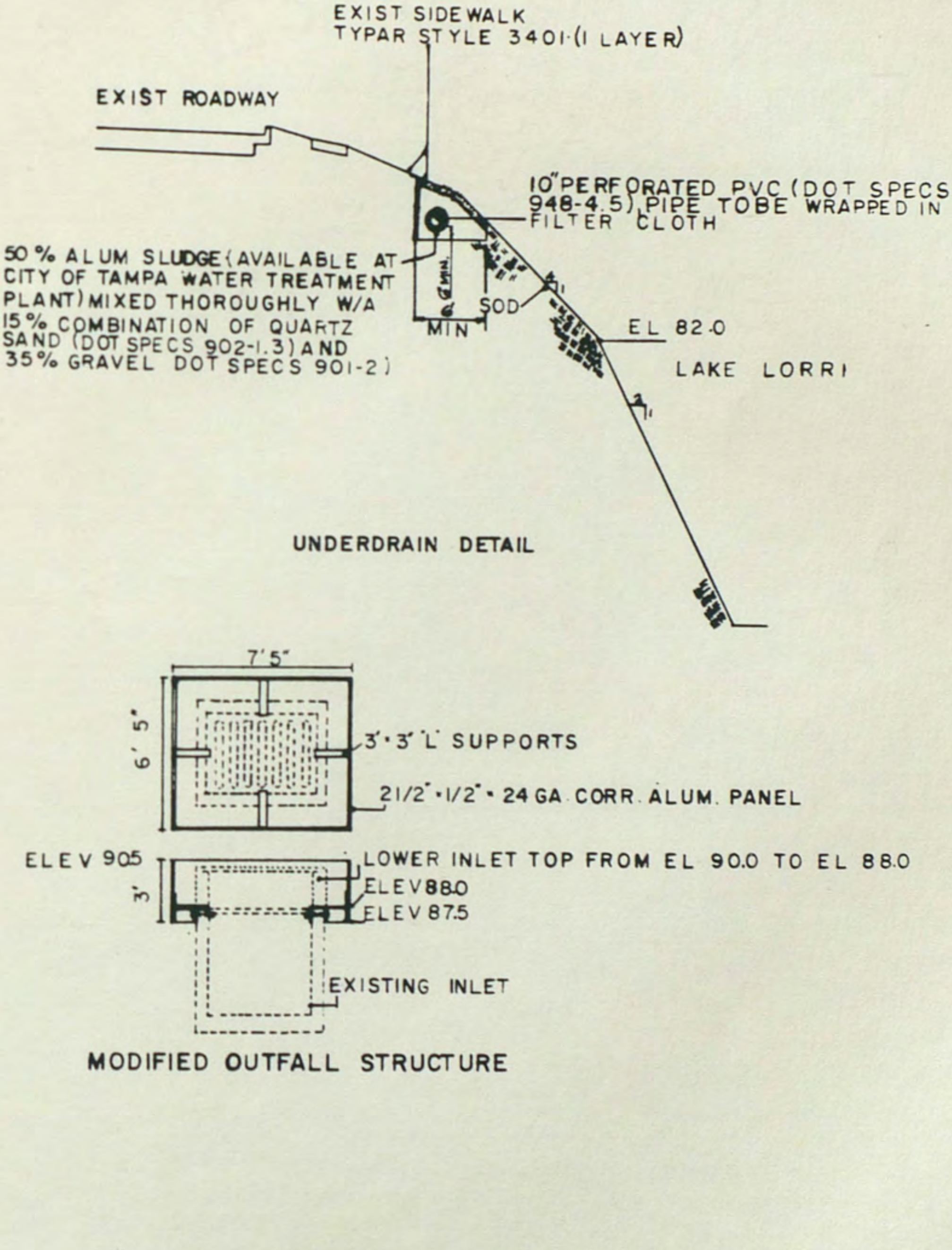


Fig. 8. Underdrain detail and modified outfall structure.

to flow over the top of the filter bank, thus a low flow was observed. The later sampling dates were taken after a storm event had occurred and the last two samples were taken close together during a week which was very rainy.

Samples of the pond were taken at three different locations about 3 ft (0.91 m) in front of the underdrain system. These sampling sites are indicated as 1, 2, and 3 on Figure 7. The samples were taken with clean, one liter plastic sampling bottles from the pond surface from the underdrain pipe. Effluent water samples were taken over a time period of 30 minutes.

The flow of the filtered water was estimated with a 5 gallon (18.9 L) bucket and second-hand watch. The major reason for this measurement was for comparison purposes only. One liter water samples of the discharge water were taken at a noted time interval. One liter plastic sample bottles, which were allowed to overflow three times, were used. Heavy metals were only measured for the first sample date. Total phosphorus was not measured for the last two sample dates, and TKN was only measured for the third sampling date. All other water quality parameters were measured as before.

Results

Effluent water values also had a range of values, the largest being ammonia nitrogen, and the smallest with dissolved orthophosphorus. This data is observed in Table 14. The range of total

TABLE 14

RESULTS FOR LAKE LORRI, LEE VISTA, ORLANDO, FLORIDA*

Water Parameter	Detention Pond Water		Effluent Water		Percent Removals	
	Range (mg/1)	Average (mg/1)	Range (mg/1)	Average (mg/1)	Range (%)	Average (%)
TP	0.096-0.155	0.123	0.086-0.131	0.100	9.7-15.1	14.3
TOP	0.020-0.043	0.032	0.022-0.043	0.033	0-29	7.3
DOP	0.008-0.041	0.020	0.014-0.032	0.019	0-61	20.2
NH_3-N	0.017-0.170	0.094	0.046-0.514	0.145	0-100	45.6
NO_2-N	0.0007-0.0019	0.0014	0.0007-0.031	0.010	0-29.4	6.4
TKN	0.843-0.905	0.894	0.679	0.679	-	24

* Number of samples = 22

orthophosphorus was the same for both influent and effluent values. Also, orthophosphorus, both dissolved and total, did not change much in the average value for both the raw and effluent water qualities.

The overall ranges of pollutant removals show a large variation from zero removal to 100 percent removal for ammonia nitrogen. These results are given in Table 14 and reflect the difference in the values of the tables just previously discussed. For dissolved orthophosphates, there seemed to be an increase in the percent removal as flowrate increased, while the trend was reversed for ammonia nitrogen. Another observation is that the average effluent concentrations were lower for nitrite nitrogen as the flowrate increased; a difference of about 95%. These are only trends and tend not to be general for each water quality parameter.

Summary

The capability of some filter media to remove certain water quality parameters was previously shown in the laboratory experimentation. Depending on the soil type and influent water concentrations, various types of removals were observed. It should be noted that the filter system at Lake Lorri was designed for a high infiltration rate. Similar to the column experimentation, when a high infiltration rate was desired, gravel was used as part of the mixture. With this higher permeability of the soil, the contact time of pollutants with soil particles is shorter. With regard to the field experimentation (Chapter IV), a higher flowrate tended to decrease pollutant removal. The results from this limited study on Lake Lorri gave similar findings.

From the few water samples taken from Lake Lorri, a variation in the water quality characteristics of the pond were found. These findings are summarized in Table 14. Raw water characteristics varied by as much as 90% for ammonia-nitrogen and as little as 7% for TKN.

CHAPTER VI

COMPUTER PROGRAM

A computer program model was developed which enabled a storm event to pass through a series of swales and berms and into a detention pond. The program is interactive and has the option of using canned data or the user's own input. The storm event runoff is calculated using SMADA (Stormwater Management and Design Aid) for various conditions. The outflow hydrograph developed in SMADA is then routed through a swale. The discharge from the swale berm is based upon a stage-discharge relationship and overflow is given by the weir equation. Water pollutant removals may also be calculated based on the soil media type. Discharge from the swale is then routed to another swale or a detention pond. Figure 9 shows this concept. Outflow from the detention pond is also based on a discharge-stage relationship. A flowchart of this program is given in the Appendix in Figure 14.

One year's worth of data for rainfall from the Orlando International Airport, Orlando, Florida was run through this program. Based on 12 acres with a rational coefficient of 0.3 and a time of concentration of 20 minutes, the rainfall was routed through two swales and berms before reaching the detention pond.

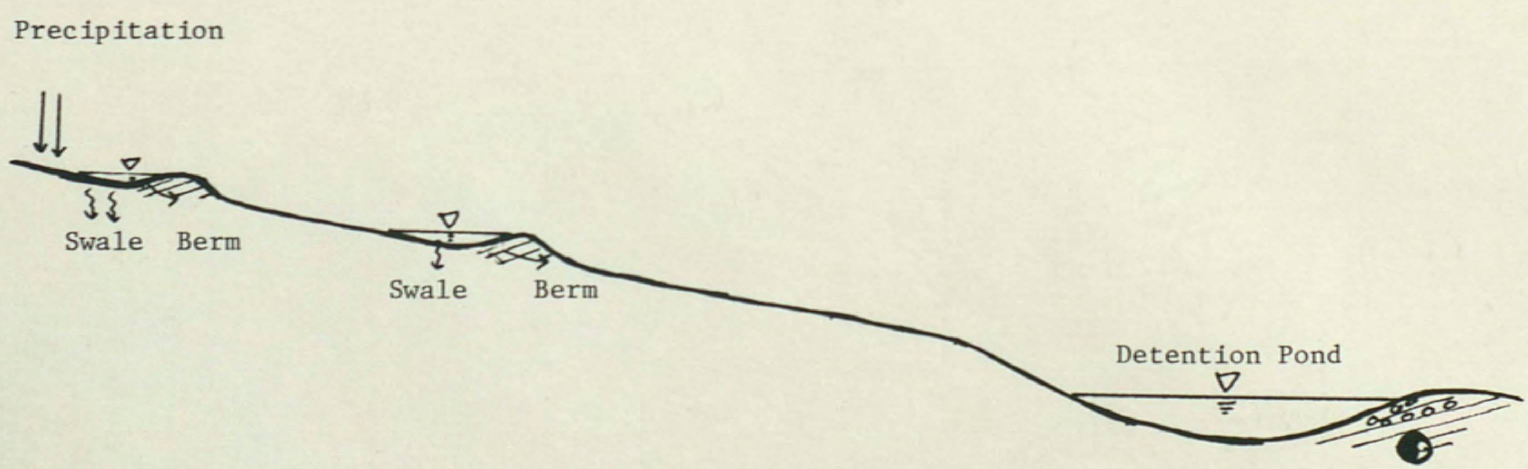


Fig. 9. Sequence of swales, swale berms and detention pond for computer modeling.

The assumption was made that all detention areas are dry before a storm event.

Results

The data obtained from the year's worth of rainfall showed a very low discharge from the first berm. For this reason, a second swale was not used and the detention pond was sized on this reduced flow. These results are given in Table 15. These results showed that routing the storm through a swale and allowing filtration through a berm enabled a smaller detention pond to be needed.

From this model, it appears that the use of a swale and berm system in this sense was a small detention pond. This showed that the total volume of runoff was significantly reduced and predicted a much smaller detention pond. Further study of these results need to be applied to field situations. Thus, incorporating on-site water storage and filtration by such structures seems to have a positive effect in reducing the overall size of detention ponds.

TABLE 15

RESULTS FOR ANNUAL RAINFALL OF
125 STORMS FROM COMPUTER MODEL

Precipitation (in)	Cubic Feet	Number of Storms
< 0.25	< 10,890	101
0.26-0.50	10,891-21,780	4
0.51-0.75	21,781-32,670	4
0.76-1.00	32,671-43,560	3
1.01-1.25	43,561-54,450	2
1.26-1.50	54,451-65,340	4
> 1.50	> 65,340	7

Runoff from Berm #1 (in)	Cubic Feet	Number of Events
< 0.0010	< 44	106
0.001-0.0030	45-130	6
0.0031-0.0050	131-218	3
0.0051-0.0070	219-305	6
0.0071-0.0090	306-392	2
> 0.0090	> 392	2

CHAPTER VII

FINDINGS

Due to the growing concern for improved quality of our water resources, this research was performed to study the possibility of using filtration of stormwater through a soil media to remove pollutants. Various soil medias were examined for pollutant removal, specifically phosphorus and nitrogen forms. Filtration rates through these soils were also important since this is a necessary parameter for design work.

From the laboratory experimentation, it was found that a mixture of 10 percent organics, 10 percent clay, 40 percent fine sand, and 40 percent gravel gave the most favorable results. High phosphorus removals were observed (in excess of 90 percent) as well as changes in nitrogen forms. The permeability of this mixture was also favorable.

As the composition of the soil medias were changed, there were noted differences in pollutant removals. With a media like #4 (50% builder's sand and 50% site sand with some organics), there was a higher phosphorus removal in comparison to samples with a lower sand percentage. On the other hand, the 100% builder's sand had a significantly lower phosphorus removal, possibly due to the higher infiltration rate and less contact time of pollutant particles with sand grains for adsorption to occur.

It was also noted that soil medias which had little or no organic content also had a much lower removal of phosphorus.

The difference in laboratory and field experimentation results could be due to a number of factors including:

1. difference in influent water quality - Phosphorus values for the lab experiment were slightly greater than the field experimentation.

2. difference in ambient air temperatures - The field experiment was exposed to daily fluctuations in temperature. The average ambient temperatures were also greater than that in the laboratory since the experiment was run during the summer. The laboratory experiment was constantly air-conditioned. This may effect the evaporation rate in the soils.

3. slightly different soils were used in the field and manual mixing of the filter media may not have made a homogeneous mixture as was in the laboratory due to the amount of soil that was used.

4. loss due to scale up of the experiments and not as a controlled environment as in the laboratory.

The removal of phosphates was possible with some of the soil medias studied. Removals were not as high as recorded in other research, but this may be explained by the lower phosphorus content found in stormwater than in sewage effluents.

Exhaustion times for some of the soil medias were calculated and can be used to estimate effective operational time for the media.

The limited data collected on the Lake Lorri infiltration system suggests that there is room for much more research. These results do not indicate much removal of pollutants. This could be a result of a few factors. One is that the high removals reported in the literature dealing with alum band filters were not achieved since gravel was used in the filter media instead of sand, giving it a very high infiltration rate. Other reasons may be that the soils are not settled enough yet and that there is much short circuiting or the lack of sand in the soil mixture has removed possible adsorption sites for pollutants. Also, the quality of the alum sludge is suspect and certainly not uniform in residual alum. In any case, more studies need to be carried out on this facility.

With the basic computer model written on a microcomputer, it was found that it was possible to simulate a combination system of swale berms and a detention pond to effectively control runoff.

CHAPTER VIII

CONCLUSIONS

Based on the findings of this research, a few conclusions have been reached.

1. In accordance with the laboratory and field work, it appears that the infiltration rate of stormwater through a soil media is a major factor in possible pollutant removal. At very high infiltration rates, there is an overall reduced pollutant removal than at a lower rate.

2. Organics and sand tend to increase the removal of pollutants. There seems to be, however, a point where too great an organic content has an inhibiting effect on pollutant removal. In soil medias with a high sand content, phosphorus removals were observed to be high if the permeability was not too great.

3. From the computer model, results indicated that use of swales and swale blocks as a routing system of stormwater before it entered a detention pond greatly reduced the size of the pond and increased overall water volume reduction.

4. The most favorable type of soil media to use is one which has:

(a) some organic and clay

(b) sand particles

(c) an infiltration rate which is not too high
to prevent adsorption

CHAPTER IX

RECOMMENDATIONS

The following recommendations are given in the hope that future research will benefit from this study.

1. The study of swale berms in aiding stormwater quantity and quality control seems to have a high possibility in this area. Thus, swales would act like miniature detention ponds with a filtration berm.

2. Studies should be conducted to determine if denitrification is possible by allowing the system to detain water for a longer time to achieve an anaerobic environment for denitrification.

3. As part of the design of filtration systems, maintenance of the media should be included. It is inevitable that the soil media will need to be changed and replaced since pollutant particles will fill up adsorption sites.

4. Develop experiments with methods of recharge of the phosphorus adsorption sites by doses of Fe, Al, or Ca cations to study if regeneration of the soil media could be achieved in this manner.

5. Find the optimum infiltration rate for pollutant removal and satisfy design needs.

6. Develop a soil media with a higher exhaustion value.

APPENDIX

TABLE 16

EXHAUSTION VOLUME CALCULATION FOR FIRST MEDIA OF FIELD EXPERIMENT

Date	Time (min)	ΣT (min)	Flow (GPM)	Vol (gal)	Exh. Vol. (gal)	C/Co
6/1	25	25	5.3	132.5	132.5	0.074
6/6	20	45	4.19	83.8	216.3	0.516
	20	65	3.91	78.2	294.5	0.656
	20	85	3.91	78.2	372.7	0.624
	20	105	3.91	78.2	450.9	0.770
6/7	10	115	3.0	30	481.0	1.0
	25	140	3.27	81.8	562.7	1.0
	20	160	3.27	65.4	628.1	0.803
	20	180	3.27	65.4	693.5	1.0
	10	190	3.27	32.7	726.2	0.750
6/15	10	200	4.09	40.9	767.1	0.583
	30	230	4.74	142.2	909.3	0.568
	25	255	5.00	125	1034.3	0.621
	25	280	5.00	125	1160.0	0.907
	25	305	4.87	121.8	1281.1	1.0
	25	330	4.87	121.8	1402.9	0.558
	20	350	4.87	97.4	1500.3	0.605
	20	370	4.87	97.4	1597.6	1.0
	20	390	4.87	97.4	1695.1	1.0
6/21	2	392	4.74	9.7	1704.8	1.0
	30	422	4.74	142.2	1847.0	0.939
	25	447	5.0	125	1971.9	1.0
	25	472	5.0	125	2097.0	1.0
	25*	497	4.87	121.8	2218.8	1.0
	25	522	4.87	121.8	2340.6	0.898
	20	542	4.87	97.4	2438.0	1.0
	20	562	4.74	94.8	2532.8	1.0
	20	582	4.74	94.8	2627.6	1.0

NOTES: Total Exhaustion = Volume for 6 runs + volume of exhaustion
= 6 x 240 gal** + 2219 gal
= 3659 gal

Volume/area = 3659 gal/21.5 ft^2
= 170.2 gal/ft^2

* Exhaustion
** Volume of filter box of surface area 21.5 ft^2

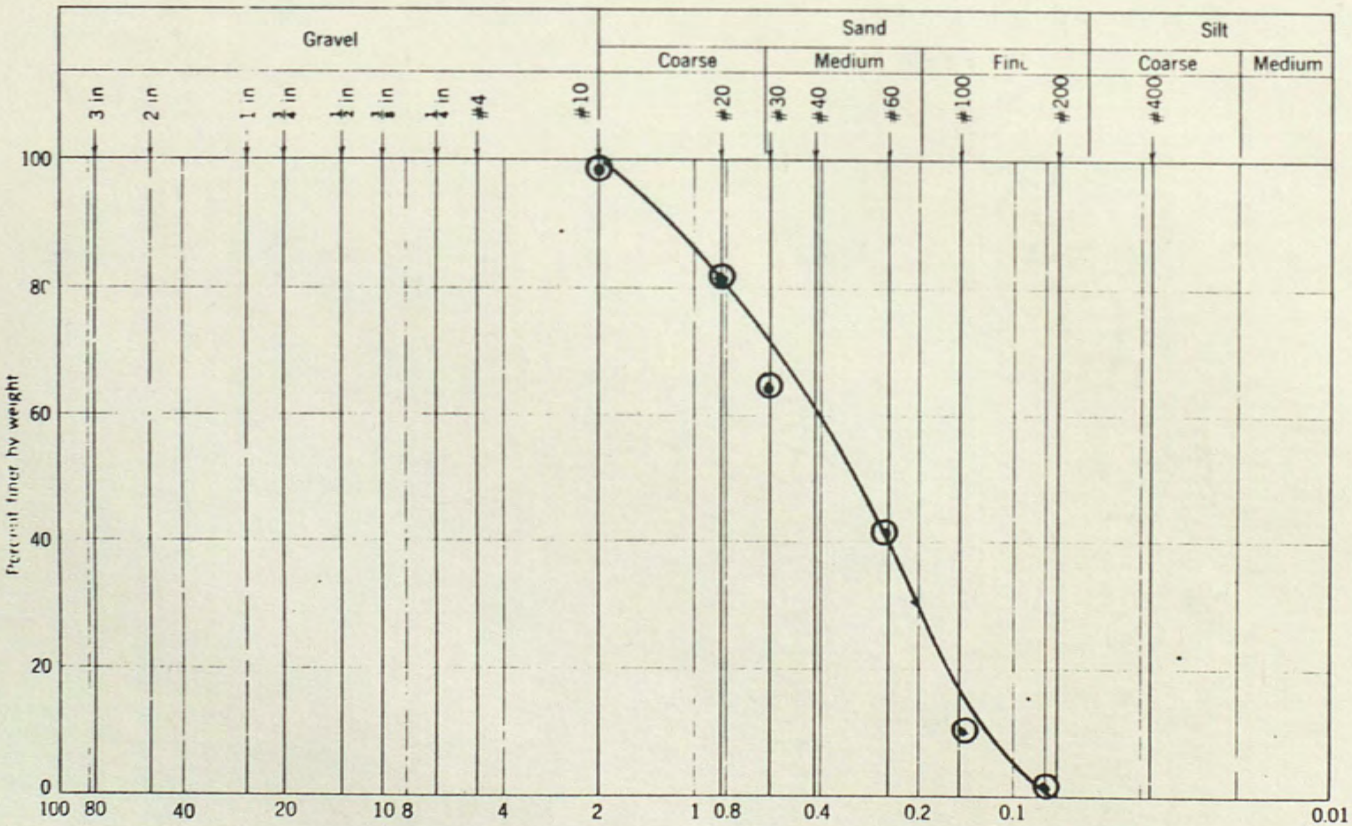


Fig. 10. Sieve analysis for concrete sand (Cu = 3.06; well graded).

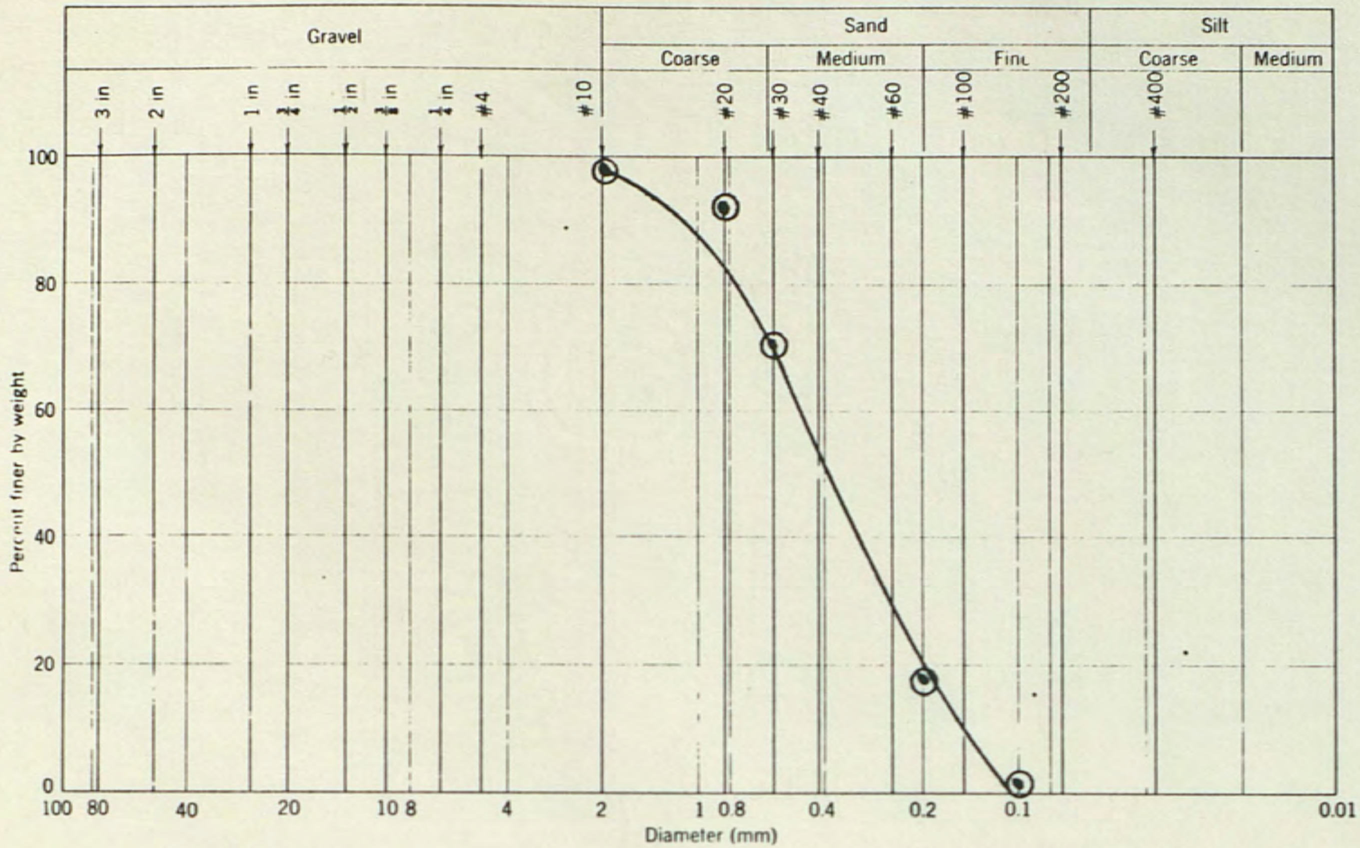


Fig. 11. Sieve analysis of filter box media #1 (Cu = 4.80; well graded).

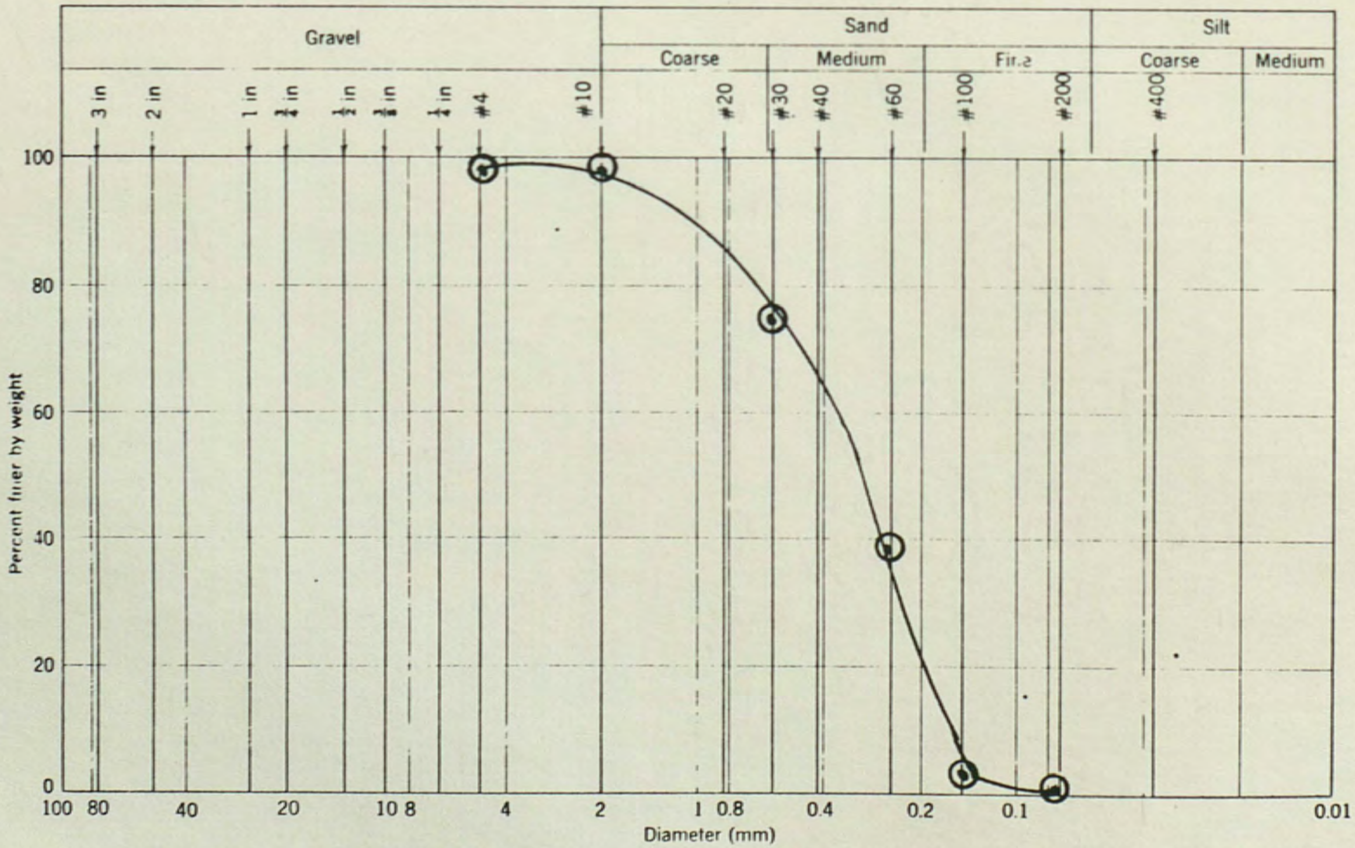


Fig. 12. Sieve analysis for upper sands (Cu = 1.55; uniform).

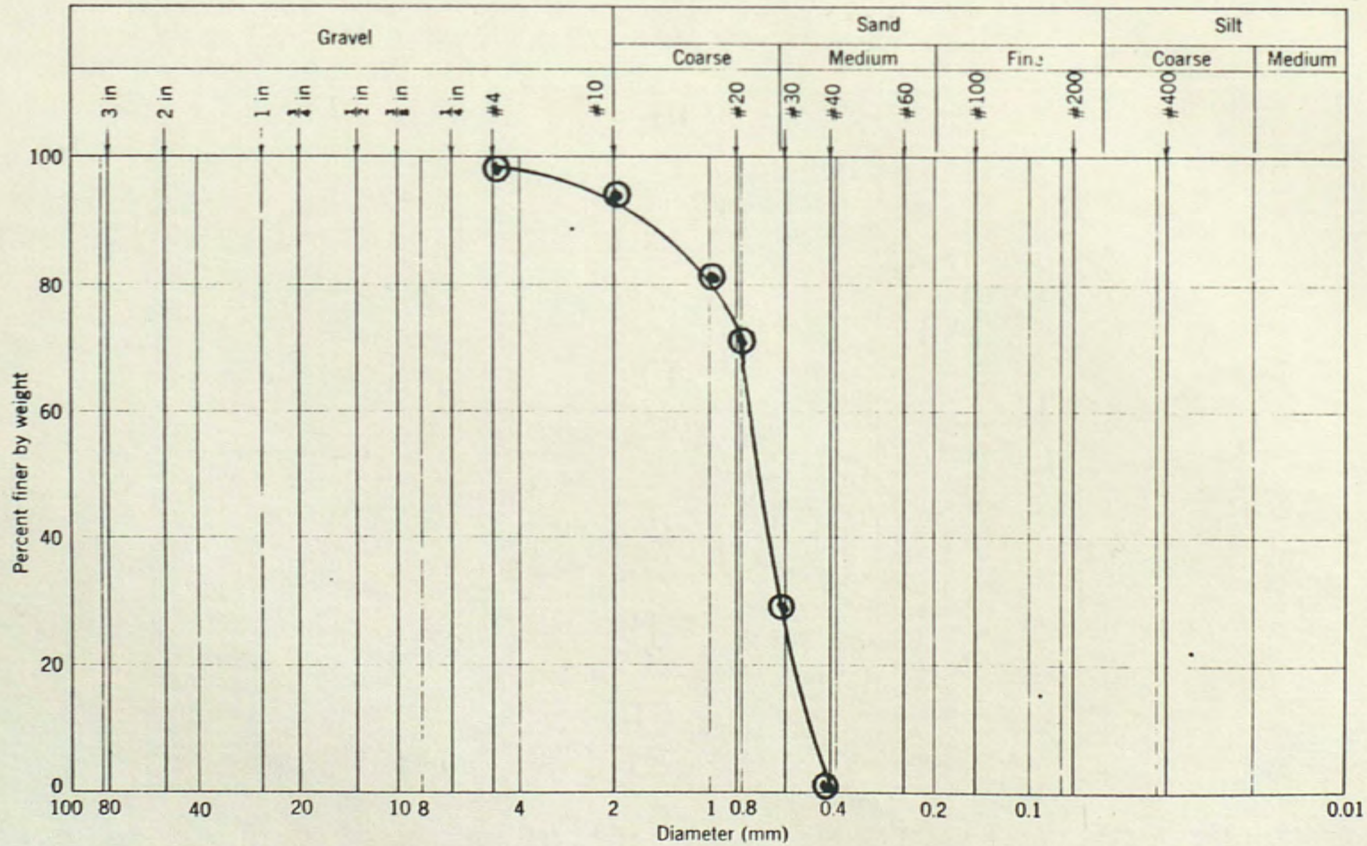


Fig. 13. Sieve analysis for underdrain sands (Cu = 2.85; well graded).

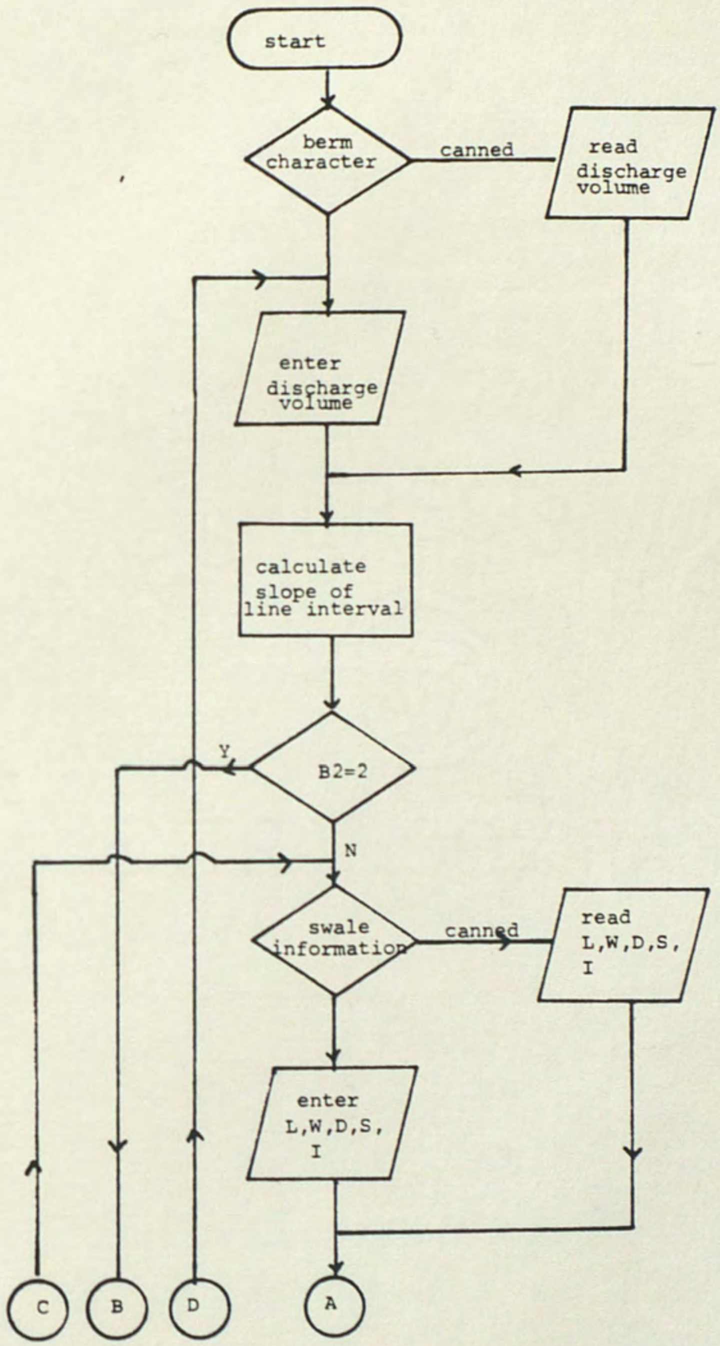


Fig. 14. Flowchart for computer program.

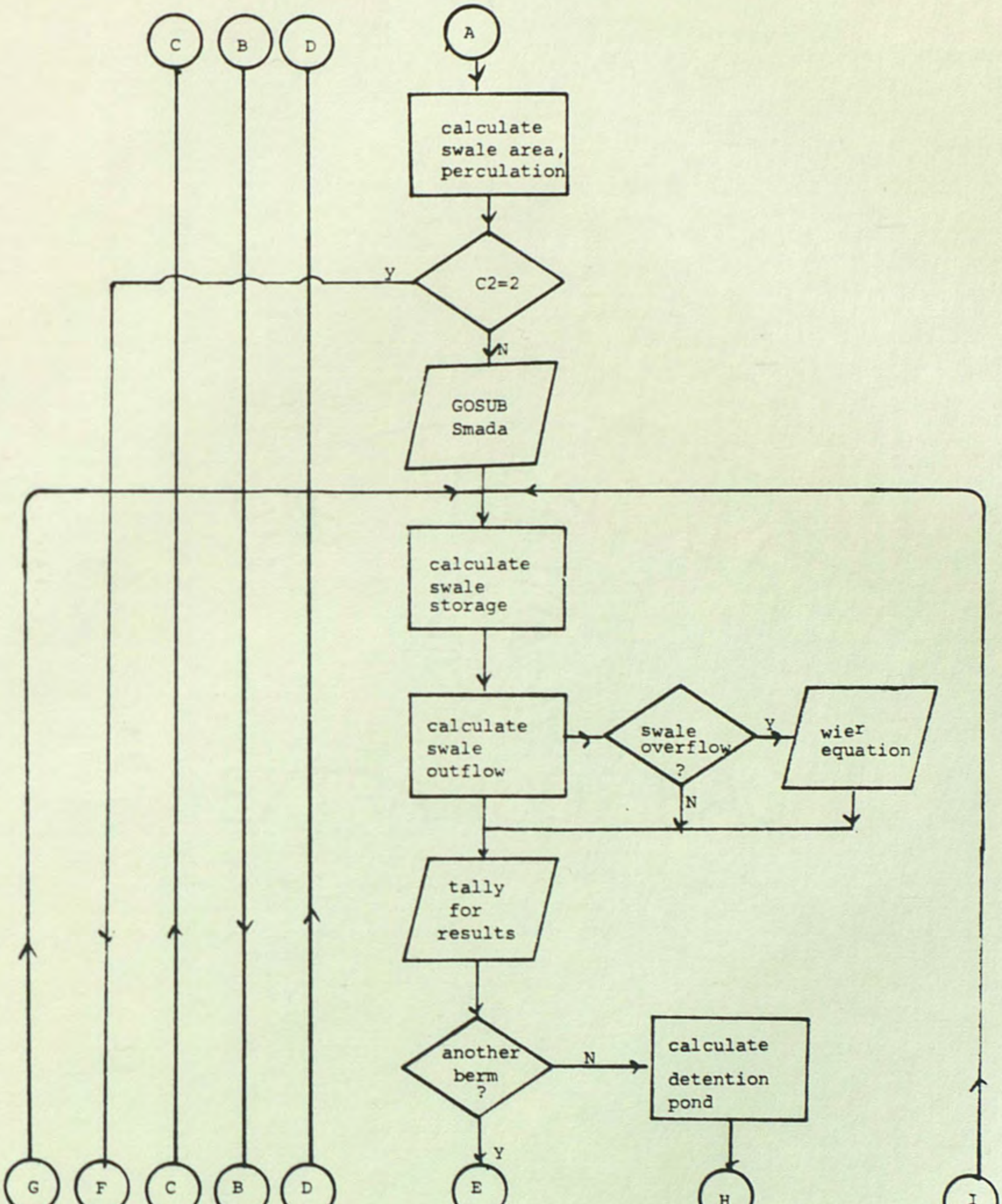


Fig. 14. Continued.

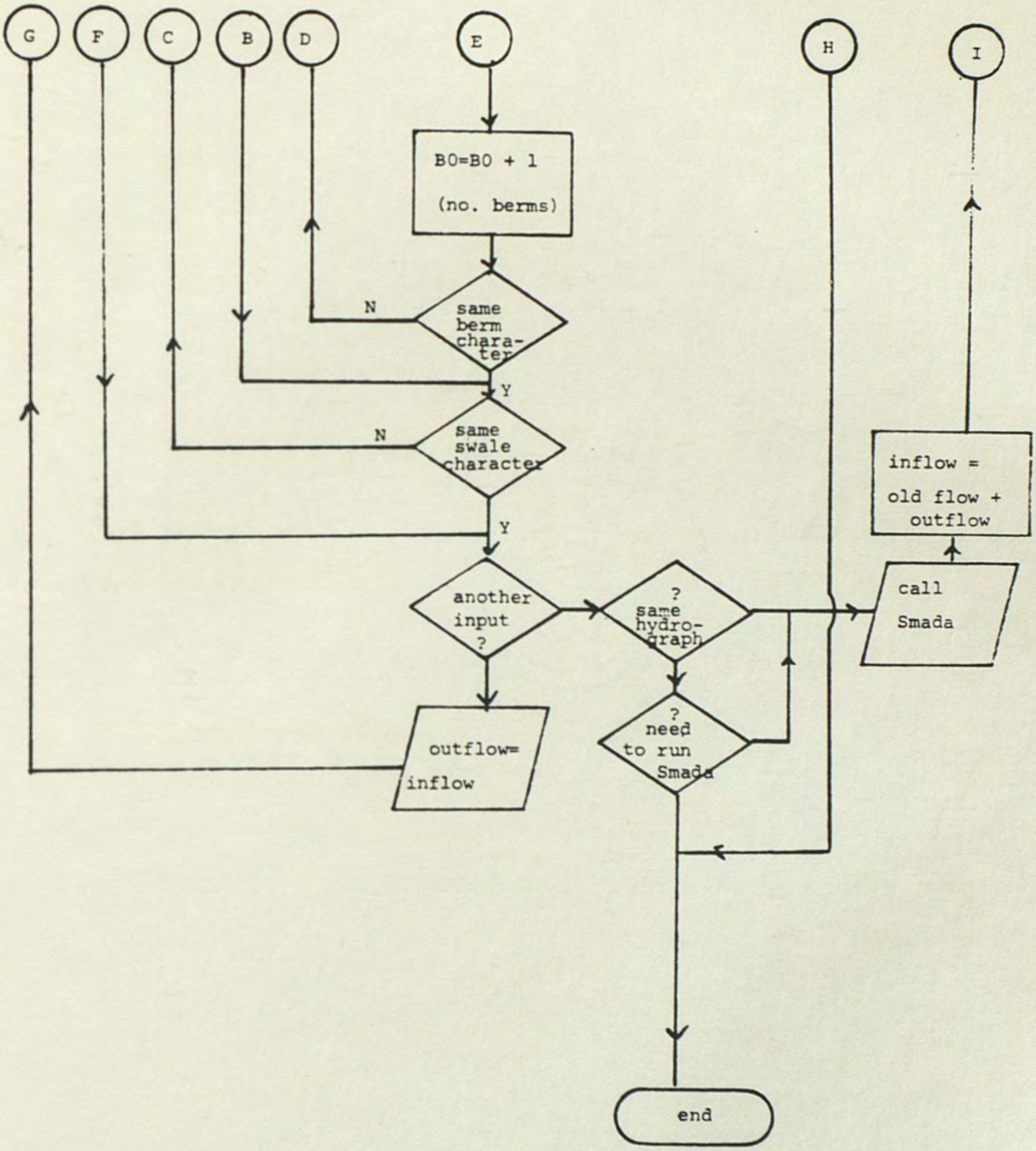


Fig. 14. Continued.

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