Restoration and Protection Techniques

RESTORATION OF LAKE EOLA

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ABSTRACT

Lake Eola is a small land-locked lake in downtown Orlando, Fla. Continual urban stormwater imputs have caused significant deterioration of lake water quality. The lake is characterized by high rates of algal production, a stratified and anaerobic hypolimnion, and periodic fish and duck kills. As a result, a restoration project was begun to restore Lake Eola. Analysis of the contributing watershed indicated that a first-flush effect was present with approximately 90 percent of stormwater pollutant mass contained in the first 1.3 centimeters of excess rainfall. Since an area was not available within the highly urbanized watershed for conventional stormwater management practices, an underground exfiltration system was developed. Stormwater management facilities were constructed and pollutant mass efficiencies estimated. Treatment of stormwater by underground exfiltration was shown to be an attractive economic alternative when compared to traditional forms. An aluminum sulfate-based waste sludge from a drinking water treatment process was shown to be effective in both inactivating anaerobic phosphorus release and in filtrating stormwater to remove phosphorus and heavy metals. Anaerobic phosphorus release was shown to be as high as 1.5 mg-P/m^2/day in Lake Eola sediments. A sediment application of alum sludge at a dose of 7 metric tons/hectare was applied to Lake Eola to minimize this release. Also, two in-line filters were constructed for filtration of stormwater through alum sludge. Actual field removal percentages were estimated for these filters. Monitoring of water quality in Lake Eola will continue to document the success of this restoration project.

INTRODUCTION

Lake Eola is a small land-locked lake located in the heart of downtown Orlando, Florida. The lake receives direct stormwater runoff by way of storm sewers from a watershed of approximately 65 hectares of dense commercial and residential areas surrounding the lake. There are currently 11 active street drains that drain stormwater into the lake with no treatment of any kind. The natural shoreline of the lake has been replaced with a stone wall to prevent flooding of the adjacent parkland, and numerous small patches of rooted emergent macrophytes exist along this wall. The level of the lake is controlled by a drainage well that drains into an underlying artesian aquifer. Physical characteristics of Lake Eola are listed in Table 1.

A summary of stormwater loading rates into Lake Eola for various parameters is listed in Table 2. These continual stormwater inputs have caused a significant deterioration in water quality. With the exception of areas near the shoreline, the bottom of the lake has become covered with an ac-

Table 1. — Physical characteristics of Lake Eola, Florida. (Harper, 1979)

Parameter	Quantity
Average surface area	10.92 hectares
Average volume	$3.30 \times 10^5 m^3$
Mean depth	3.02 m
Maximum depth	6.8 m
Length of shoreline	1417 m
Shoreline development	1.21
Volume development	1.72
Average height above sea level	26.8 m

Table 2. — Summary of stormwater loading rates into Lake Eola (Wanielista et al. 1981)

Parameter	Average loading (kg/yr)	Average stormwater concentration (mg/l)
Suspended solids	54,505	131
BOD_5	5,390	13
COD	39,105	74
TOC	52,030	99
TKN	1,760	3.3
NH_3–N	226	0.43
Orthophosphorus	211	0.51
NO_3–N	816	1.96
Total P	264	0.48
Zinc	204	0.38
Nickel	15.4	0.03
Copper	37.4	0.07
Iron	524	0.99
Lead	234	0.44

cumulation of loose, flocculent, partially decomposed organic matter that is easily disturbed. The loose nature of this material makes it difficult for rooted submergent plants to exist, and no rooted submergent plants of any kind have been seen in Lake Eola. As a result of these decomposition processes, concentrations of dissolved oxygen, although usually at or above saturation near the water surface, drop periodically during the spring and summer months to 1 mg/l or less at depths of 4 meters or greater. In areas near the center of the lake this organic matter, subjected to long periods of anoxic and reducing conditions, has formed into sapropel, complete with the characteristic hydrogen sulfide smell. Floating masses of dead algae and fish and their accompanying odor are a common occurrence in Lake Eola, and the lake has been classified as eutrophic by both the Shannon-Brezonik and Vollenweider trophic state models. In addition, *Salmonella*, *Shigella* and *Clostridium botulinum* have been isolated from the water and shoreline sediments in Lake Eola.

Vertical analyses in Lake Eola indicate that two distinct periods can be observed in terms of water quality. One of these periods is an unstratified condition that occurs mainly during the winter and spring and is characterized for the most part by isograde curves of dissolved oxygen, temperature, pH, ammonia, and ORP with increasing depth (Fig. 1). The stratified period, which occurs in summer and fall, is characterized by decreasing pH, temperature, dissolved oxygen, and ORP with increasing depth. Concentrations of ammonia, total phosphorus, and alkalinity increase significantly near the bottom (Fig. 2).

Lake Eola is a focal point and tourist attraction in downtown Orlando. The surrounding parkland is beautifully landscaped and is used as a site for many social and cultural events throughout the year. Therefore, a restoration project was initiated in 1978 to restore Lake Eola. Estimated benefits of this restoration project are listed in Table 3 (Wanielista et al. 1981).

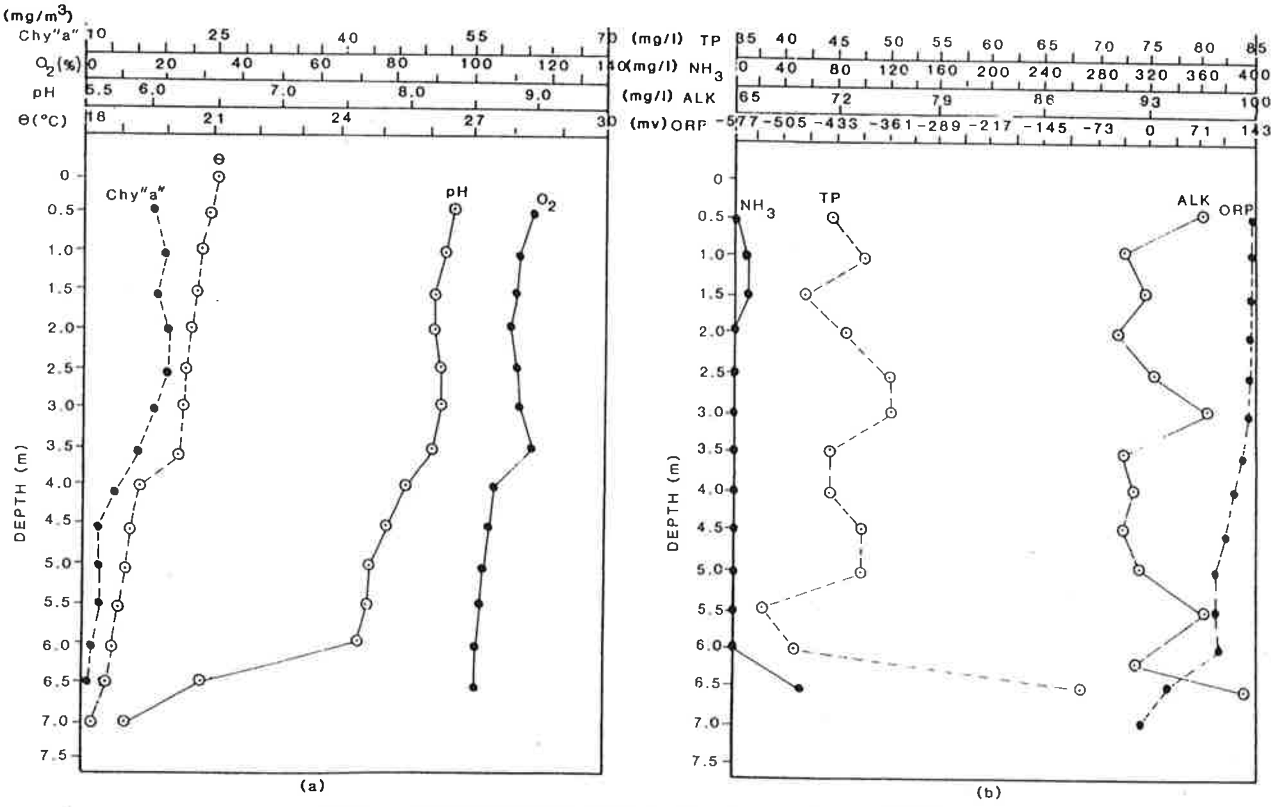


Figure 1.—Physical-chemical depth profiles of Lake Eola on 2/18/82.

PHILOSOPHY OF RESTORATION TECHNIQUES

Since stormwater runoff was determined to be the primary source of pollution entering Lake Eola, management of this source was considered to be essential in restoration of this lake. It was determined through a series of laboratory alga bioassays that phosphorus is the limiting nutrient in Lake Eola during much of the year, and restoration techniques were centered around management of this nutrient. It was determined through analysis of the Shannon-Brezonik and Vollenweider trophic state indices that reducing phosphorus loadings approximately 80 percent would reduce Lake Eola from eutrophic status to a borderline oligotrophic/mesotrophic state.

Analysis of the phosphorus budget in Lake Eola indicated that the two main sources of this element were from stormwater runoff and internal recycling of phosphorus from anaerobic sediments. As seen in Table 2, stormwater runoff contributes an average of 264 kg of phosphorus per year into Lake Eola. Marshall (1980) determined that recycling of phosphorus released from bottom sediments accounted for as much as 25 percent of the phosphorus concentration in the lake at any given time. Atmospheric fallout and groundwater infiltration were found to be insignificant in terms of phosphorus inputs when compared to the previous two sources. Therefore, it became obvious that treatment of both the stormwater runoff entering the lake as well as the bottom sediment would be necessary to begin a restoration of Lake Eola.

Table 3. — Estimated benefits of restoration of Lake Eola.

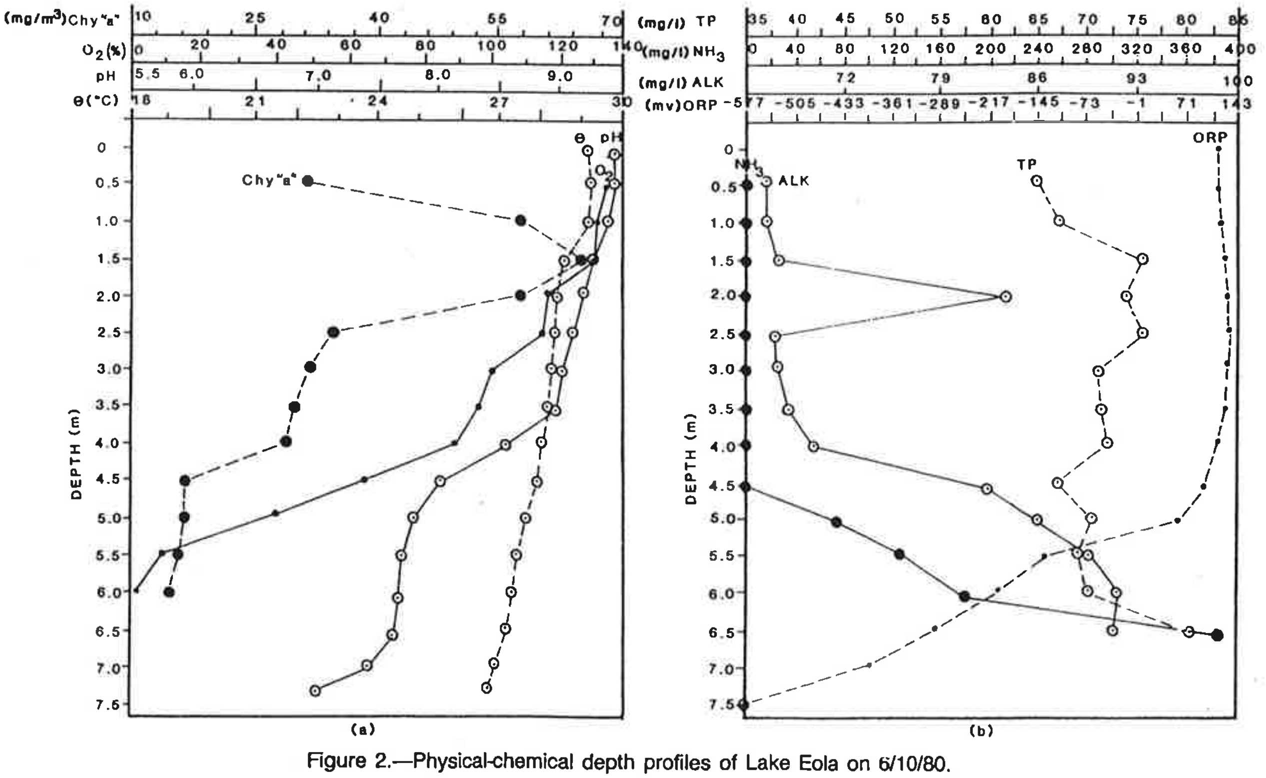
Activity	Approximate frequency/year	Approximate people-visits/yr	$/yr
Music concerts[1]	35	87,500	262,500
Arts/crafts[2]	3	60,000	300,000
Tourist visits[3]	Constant	180,000	90,000
Fish-a-thons[1]	3	3,000	9,000
Food concessions[2]	Constant	—	100,000
Paddle boats[2]	Constant	5,000	20,000
Children's park[1]	Constant	125,000	187,500
Relaxation/aesthetics[1]	Constant	200,000	600,000
Jogging[1]	Constant	50,000	150,000
Land value[4]	Constant	—	600,000
	TOTALS:	710,500	2,319,000

[1] Based on estimated attendance and an expenditure of $3 per person per visit

[2] Based on concession money received by the city of Orlando and an estimated attendance

[3] Grey-line of Orlando estimated visits as a portion of a larger tour

[4] Based on lake-front vs. non-lake-front property tax



(a) (b)

Figure 2.—Physical-chemical depth profiles of Lake Eola on 6/10/80.

TREATMENT BY UNDERGROUND PERCOLATION

Since stormwater runoff was determined to be the primary source of pollution entering Lake Eola, management of this source is essential in restoring this lake. An extensive investigation was conducted of each contributing subwatershed and the loading characteristics of each were defined. During an earlier study (Wanielista et al. 1981), it was determined that a first-flush effect was exhibited by these watersheds, and a large percentage of pollutant mass could be removed by diversion and subsequent retention of first-flush waters. The efficiency of diversion for retention was studied by Wanielista (1977) through extensive simulations of yearly rainfall/runoff events on the Orlando, Florida, area, and the results are listed in Table 4.

Table 4. — Efficiencies of stormwater pollutant mass removal and corresponding diversion volumes for areas exhibiting first-flush effects.

Average annual percent of pollutant mass removed (%)*	Treatment "diversion" volume (centimeters)
99	2.60
95	1.95
90	1.30
80	0.65

* Average of suspended solids, BOD_5, total nitrogen, and total phosphorus.

Therefore, to achieve the desired 80 percent reduction in phosphorus loadings, a diversion of at least the first 0.65 cm of excess rainfall would be necessary. Since the area surrounding Lake Eola is composed of high-density residential and commercial areas, no land area was available for construction of traditional stormwater management structures such as above ground retention basins. As a result, alternative stormwater treatment techniques were required.

After considerable literature research into existing stormwater management methods, it was decided to divert stormwater runoff to underground percolation systems. Perforated aluminum pipe 130 centimeters in diameter with 0.65 cm openings was chosen for percolation. The pipe could be buried several feet under the roadway with a riser pipe extending to a stormwater inlet along the curb. The bottom elevation of the percolation pipe should not be lower than the average anticipated high water table level. Stormwater runoff would be allowed to flow off parking lots and residential areas by gravity sheet flow into the street gutter and be intercepted by the stormwater inlet above the percolation tank. If the volume of rainfall runoff is sufficient to fill the percolation tank, the excess will flow over the inlet, along the gutter, until it intercepts the regular stormwater system for discharge into Lake Eola. Exfiltration into the surrounding soil would allow the system to drain between storm events. The volume of the tank could then be sized to achieve the desired pollutant removal efficiency.

A typical cross section of the percolation design is shown in Figure 3. The aluminum pipe is surrounded on the sides and ends by 30.5 centimeters of gravel (DOT #11 or equivalent) which increases the effective percolation volume. This gravel was characterized as "slag" rock. A filter fabric with a coefficient of permeability = 3.2 x 10^{-2} cm/sec and filtration rate = 107 liters m^2/min is also wrapped around the gravel on all sides and ends and sealed at the seams with roofing tar to prevent soil from washing into the pipe and possibly causing structural or stability problems for the street above. The excavation hole is then filled with clean building sand and the gutter and roadway replaced.

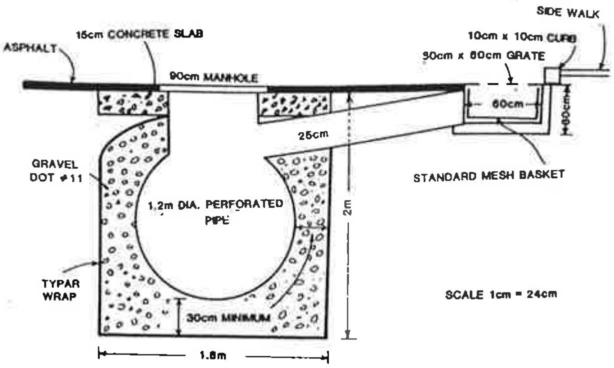


Figure 3.—Typical section of underground percolation system.

Table 5. — Treatment levels and design equations.

Treatment volume (centimeters)	Design equations
0.65	$V = 0.016\ (A)^{1.28}$
1.30	$V = 0.046\ (A)^{1.18}$
1.95	$V = 0.09\ (A)^{1.11}$
2.60	$V = 0.14\ (A)^{1.07}$
3.25	$V = 0.20\ (A)^{1.04}$

where: V = volume of treatment for 100% impervious area (acre-feet)
A = watershed area (acres)

The required volume of the percolation system was calculated from equations developed by Wanielista (1979) through computer simulation of rainfall/runoff/infiltration on watersheds up to 22 hectares. These equations for various diversion volumes and soil types are listed in Table 5.

A pilot structure using underground percolation (exfiltration) was constructed in the downtown Orlando area and was designed to contain the first 1.3 centimeters of stormwater runoff from a 0.4 hectare parking lot and street in an area within sandy soils, classified by the Soil Conservation Service as hydrologic Type A. The aluminum pipe was 130 centimeters in diameter and 12.2 meters in length and was assumed to operate at a minimum exfiltration rate of 2.5 cm/hour. Construction was performed by the city of Orlando at a cost, including labor and materials, of almost $10,000.

Observation of storm events after construction indicated that the actual exfiltration rate was considerably higher than 2.5 cm/hour and that a rainfall excess of approximately 2.8 centimeters over a 3-hour period was required to fill the percolation tank before excess runoff was routed into the existing curb and gutter system. A chemical analysis for this rainfall event comparing stormwater runoff entering the percolation tank and stormwater runoff that flowed over the inlet after the tank had filled is listed in Table 6. Significant reductions were achieved in concentrations of alkalinity, TOC, BOD, NO_3–N, TKN, orthophosphorus, total phosphorus, and suspended solids.

The success of this pilot installation led to the conclusion that in the areas within the Lake Eola watershed where the groundwater elevation permitted percolation, this was the preferred method of pollution control. However, analysis of the watershed indicated at least 36 contributing parking areas would require diversion and treatment of stormwater runoff. At an estimated cost of $10,000 per unit, the treatment cost would be approximately $360,000 and would require over a year of construction for just parking areas, leaving large portions of streets and driveways untreated.

Further refinement and evolution of treatment techniques led to the conclusion that the optimum solution would be

Table 6. — Average chemical analysis of stormwater runoff entering the underground percolation tank compared with the overflow.

Parameter	Stormwater entering the percolation tank	Stormwater overflow	Percent change
pH	8.30	7.63	− 8.1
Turbidity (JTU)	28.0	12.0	−57.2
Alkalinity (mg/l)	96.0	28.7	−70.1
TOC (mg/l)	218.0	14.2	−93.5
NO_3–N (mg/l)	8.9	0.43	−95.2
TKN (mg/l)	5.37	0.41	−92.4
Dissolved PO_4–P (mg/l)	0.530	0.020	−96.2
Total P (mg/l)	0.650	0.158	−75.7
SS (mg/l)	27.0	4.2	−84.4
VSS(mg/l)	26.0	2.9	−88.9
BOD (mg/l)	18.3	1.0	−94.5

to intercept, wherever possible, the main storm sewer line before it enters the lake, allowing the stormwater from all contributing parking lots, streets, and driveways to be treated. Nine key points of interception were defined in areas where percolation was about 25 cm/hour, and exfiltration systems ranging in length from 12 meters to 55 meters with diameters of 91.5 to 130 centimeters were designed at a total projected capital cost of $225,000. A cross section of a typical installation is shown in Figure 4. These systems will treat approximately the first 1.3 centimeters of stormwater runoff from almost 40 hectares or 26 impervious hectares of the Lake Eola watershed. If an average annual pollutant removal percentage of 90 percent is assumed, the capital cost of treatment becomes $94/hectare-annual-percent removal which is competitive with current capital costs of diversion/percolation systems. An economic comparison of various stormwater management alternatives including underground percolation is listed in Table 7.

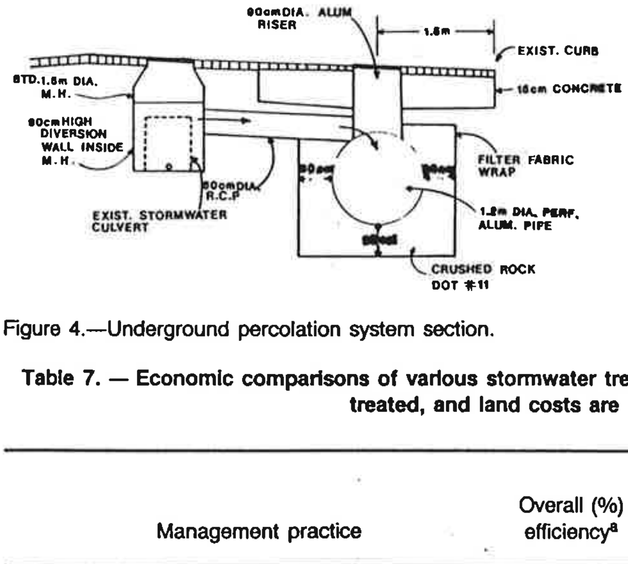


Figure 4.—Underground percolation system section.

Of interest in Table 7 is the exclusion of land costs. When land costs are added to each management practice, except filtration which can be constructed under the right-of-way and would not require land purchases, exfiltration may be more cost effective. As an example of land cost, a $250,000/hectare land cost would add approximately $20-25/hectare-percent removal to the prior estimates. In addition, if sedimentation were used, only 50 percent maximum efficiency would be achieved.

INACTIVATION OF PHOSPHORUS RELEASE FROM BOTTOM SEDIMENTS

Treatment will be required in lakes experiencing significant internal loading of phosphorus. Nutrient inactivation through chemical precipitants such as aluminum, iron, or calcium has been reported by many researchers, and several other treatments, including fly ash, for nutrient inactivation have been reported in the literature (Funk and Gibbons, 1979). However, these treatment processes often involve a substantial investment in chemicals, especially if the area to be treated is large. Using waste products (such as water treatment sludges) that contain a large amount of chemical precipitants to treat natural systems such as lakes, reten-

Table 7. — Economic comparisons of various stormwater treatment alternatives. (Data is listed in terms of impervious areas treated, and land costs are not included; Wanielista, 1979.)

Management practice	Overall (%) efficiency[a]	ORM $/ha/month	Average capital cost ($/ha/% removal)
Surface pond diversion/ percolation[b]	99	39.50	61.80
Percolation pond[c]	99+	86.50	89.70
Swales and percolation[d]	92	74.00	70.20
Residential swales[d]	80	49.50	64.40
Sedimentation[e]	50	71.50	47.40
Underground exfiltration[f]	80	5.00	74.10
Underground exfiltration[f]	90	5.00	93.90
Underground exfiltration[f]	95	5.00	118.60

[a] Yearly average of BOD_5, N, P, and SS not discharged to surface waters
[b] Designed for 2.5 cm of runnoff diversion
[c] Designed for 10 cm of runoff diversion
[d] 80% of the rainwater percolates
[e] Designed for 1.65 cm of runoff water
[f] Designed for Type A Soils, 25 cm/hour percolation rate

tion or detention ponds, and percolation systems could become a very attractive alternative. The possibility of using these waste products to inactivate anaerobic phosphorus release in Lake Eola was investigated in a series of *in situ* experiments.

In situ experiments designed to simulate anaerobic conditions were conducted using isolation chambers constructed from heavy duty 200-liter polyethylene containers as shown in Figure 5. All tanks were painted on the outside with a semigloss black alky-enamel to prevent light penetration and subsequent photosynthetic activity. Chambers were inverted on the lake bottom, isolating 0.25 square meters of surface area. Chemicals were added through a 1.9 cm diameter tygon tube that extended from the top of each tank to the water surface in the lake. The tubing was connected on the top of the tank to an inverted 28-cm diameter polyethylene funnel, as shown in Figure 5, to insure even distribution of the chemical inactivants over the sediment bottom.

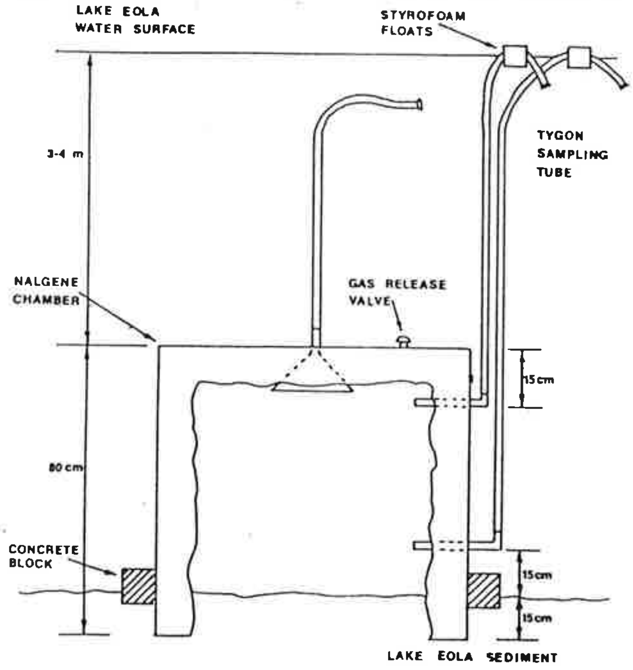


Figure 5.—Typical isolation chamber.

Two different water treatment plant sludges were investigated in Lake Eola for possible inactivation of bottom sediments. A calcium carbonate-based water treatment plant sludge was obtained from the Clyde Doyle water treatment plant in Cocoa, and an alum-based water treatment plant sludge was obtained from a treatment plant in Tampa, Florida. The moisture content and percent loss on ignition averaged 0.4 and 2.9 percent for the Cocoa sludge. Similarly, Tampa sludge exhibited 89 percent moisture content and 45.8 percent loss on ignition. The calcium sludge showed very little moisture content since it was air-dried in the laboratory after collection.

Chemical analysis of the water treatment sludges used as chemical inactivants is presented in Table 8. The data shown in this table represent an average of five samples tested.

Experimental concentrations of inactivants and corresponding isolation chamber designations are listed in Table 9. Dosages were selected to provide a fairly uniform floc. Water samples were collected in each tank approximately 24 to 48 hours after addition of the inactivant after which they were then collected at approximately 1-week intervals for 1 month with samples collected at 2 to 3-week intervals thereafter.

Table 8. — Chemical analysis of water treatment plant sludges.

Element	Average concentration μg/g oven dry weight	
	Cocoa plant	Tampa plant
Cd	1	1
Zn	6	56
Cu	9	44
Fe	256	8,770
Pb	226	70
Ni	14	10
Cr	29	254
Al	379	206,700
Mg	11,400	3,140
Ca	207,200	10,400
P	233	351
Mn	36	193
Ba	77	31

Table 9. — Experimental concentrations of chemical inactivants used in Lake Eola.

Chemical inactivant	Inactivant dosage (wet weight)	
	(g)	(g/m^2)
$CaCO_3$ sludge	350	1400
Alum sludge	2000	8000
None (control)	None	—

The release of phosphorus under anaerobic conditions using various chemical inactivants is shown in Figure 6. The results obtained in these experiments indicated that alum sludge was able to inhibit the release of phosphorus while calcium carbonate sludge did not when compared with a control tank that contained no chemical inactivants. Alum sludge was found to reduce anaerobic phosphorus release from the bottom sediments of Lake Eola into the overlying water. The dosage used in these experiments, however, was 200 grams of wet alum sludge which is equivalent to 880 grams of dry sludge per square meter since this sludge contained 80 percent moisture. This dosage was admittedly excessive, but was used to illustrate the usefulness of alum sludge. The data do not suggest the release of heavy metals from water treatment sludges to the overlying water column. Jellerson (1981) found no significant difference between benthic populations in alum sludge-treated tanks and control tanks.

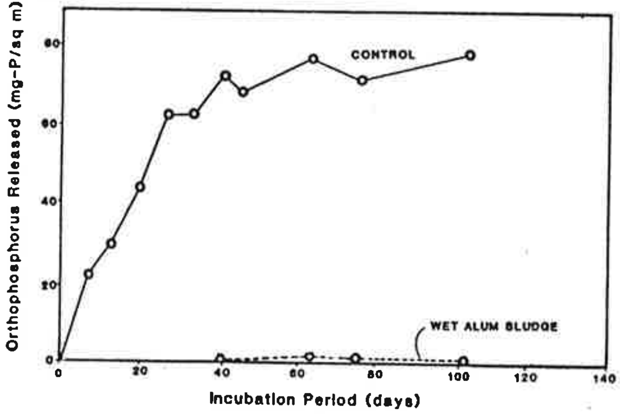


Figure 6.—Orthophosphorus released from treated Lake Eola bottom sediments with incubation time under anaerobic environment.

To determine an optimum dose required to inhibit anaerobic sediment release of phosphorus, another series of experiments was designed using various doses of alum sludge inside isolation chambers. Six isolation chambers were dosed with various concentrations of wet sludges as shown in Table 10.

Table 10. — Experimental concentrations of alum sludge used in optimization studies.

Chamber designation	Inactivant dosage (wet weight)	
	(g)	(g/m²)
Alum sludge #1	27.5	110
Alum sludge #2	55	220
Alum sludge #3	110	440
Alum sludge #4	220	880
Alum sludge #5	440	1760
None	None	—

This experiment was run for 62 days and changes noted in water quality parameters inside the anaerobic isolation chambers with various dosages of alum sludge. The data showed the general trends observed in the previous experiments. pH values and turbidity measurements generally decreased, while specific conductance and ammonia nitrogen increased with incubation time under anoxic environments. Phosphorus concentrations increased gradually in the control chamber and declined in isolation chambers treated with alum sludge. It was apparent that when used in large concentrations alum sludge retained the phosphorus released from the bottom sediments and could also remove phosphorus associated with the overlying water.

Changes in optimum orthophosphorus released from bottom sediments treated with various concentrations of alum sludge under an anaerobic environment for 2 months are presented in Figure 7. The orthophosphorus released was calculated by multiplying the difference between the initial phosphorus concentration in the water column beneath the isolation chamber and the maximum concentration reached during the study period with the water volume of the isolated column, and dividing by the bottom sediment area. It was interesting to see that the smooth curve shown in Figure 7 intercepted the zero optimum orthophosphorus released in mg-P/sq m at alum sludge dosages between 110 and 220 grams which were equivalent to 2.0 to 4.0 metric tons of wet sludge per acre of bottom sediments. Above these dosages, not only was the release of orthophosphorus from bottom sediments inhibited, but the orthophosphorus content in the overlying water column was also reduced.

APPLICATION OF ALUM SLUDGE TO LAKE EOLA

In view of the impressive phosphorus adsorption and retention capability of alum sludge it was decided, after much discussion, to employ this technique to inactivate anaerobic sediment phosphorus release in Lake Eola. It was estimated that approximately 8 hectares of Lake Eola would be subject to anaerobic conditions during the year and would require treatment. Based on the optimization experiments, a sludge dose of approximately 7 metric tons per hectare of a wet sludge with 89 percent moisture, was selected since this dose was shown to reduce phosphorus release in isolation chambers to virtually zero.

To supply a sufficient amount of energy to return the sludge into solution so that it could be spread easily, it was decided that a side-entering large impeller system operated at several thousand r.p.m. would be necessary. A side-entering belt-driven agitator with three impellers was ordered from Process Equipment Corp., of Belding, Michigan. This impeller was coupled with a 3.5-horsepower, 240-volt, 3-phase electric motor with a 1:1.5 reducer that produced an agitator speed of approximately 2,500 r.p.m. A sturdy support bench was constructed to accommodate the 550 liter rewatering tank and to suppress the expected vibrations. The bench motor mounts were designed to facilitate the anticipated daily removals for security reasons. A schematic of the land-based sludge rewatering system is given in Figure 8.

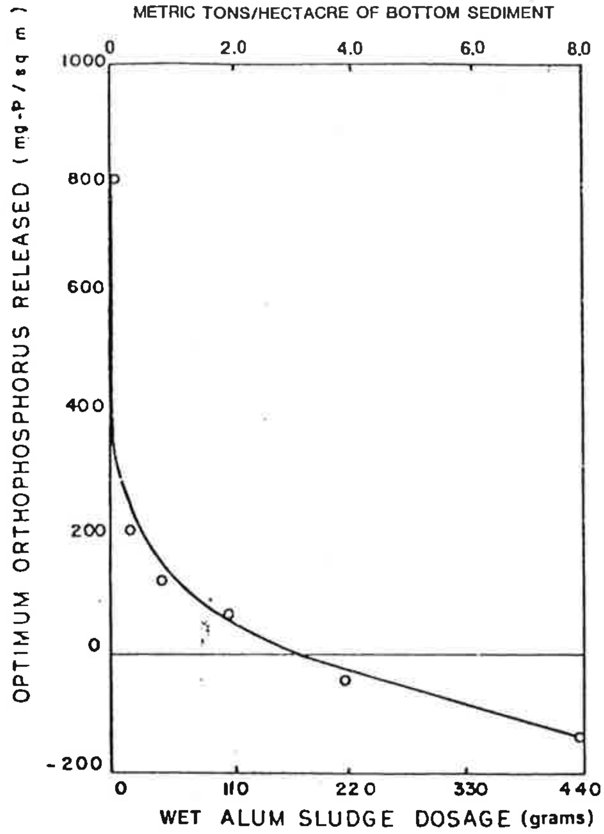


Figure 7.—Effect of alum sludge on release of orthophosphorus from Lake Eola sediments under anaerobic conditions.

The sludge injection system proved to be the most difficult to design. The system was designed to be as mechanically simple as possible to minimize the probability of field failures. Another 550 liter container (holding tank) was fastened on a flat deck, 5.8 meter utility boat powered by a 90-horsepower outboard. The holding tank, mounted on a wooden platform, would contain the sludge slurry during spreading operations and was designed to evenly distribute its weight when full (approximately 550 kilograms). A high capacity sludge pump powered by a 1,200-watt gasoline generator on board the boat was used to pump the slurry. The exit pipe coupled to this pump extended to the front of the boat and connected to a flexible joint (automatic radiator hose). A 5 centimeter PVC inverted "T" bar was attached to the joint. After drilling 0.6 cm holes into the inverted T, it was used as a spreading mechanism (Fig. 9).

An average 180 kilograms of alum sludge, based on a wet weight basis, were placed into the rewatering tank for each mixture. The team loaded 10 buckets of sludge, each weighing 18 kilograms, over a 15-minute period. This timed addition allowed the impeller to break down large clumps of sludge without excessively straining the motor. The sludge mixture was agitated for about 20 minutes. The consistency of the rewatered sludge, when correctly mixed, was com-

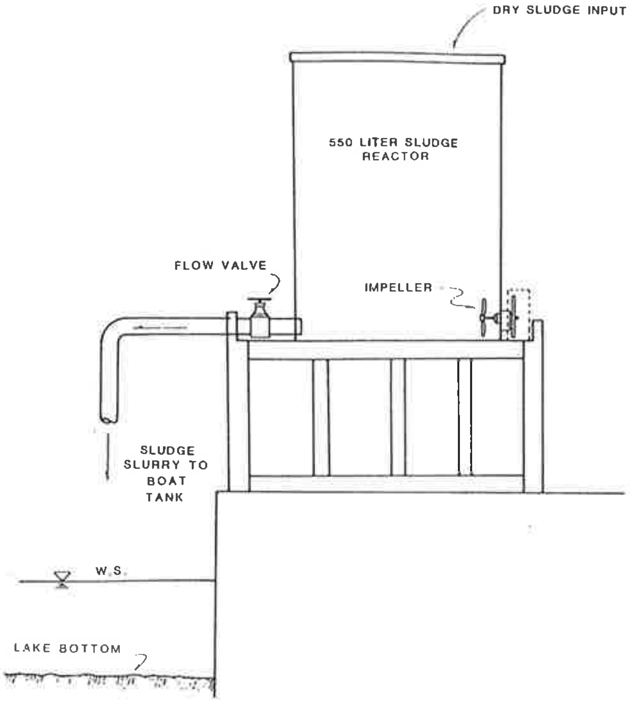


Figure 8.—Schematic diagram of land-based sludge rewatering system.

parable to that of cooking oil. Barring mechanical failures, the crew could spread approximately 12 loads of sludge per day. At this rate, which corresponds to 2.2 metric tons of sludge per day, it required approximately 25 days to cover the 8 hectares of Lake Eola that were treated.

FILTRATION OF STORMWATER THROUGH ALUM SLUDGE

Of the total 65 hectares in the Lake Eola watershed, approximately 25 hectares are located in low areas near the lake in which the water table is too high to allow for efficient percolation by underground exfiltration. Since treatment of stormwater runoff generated in these areas was thought to be an essential portion of the overall restoration process, investigations were conducted to develop treatment techniques for these areas.

In view of the impressive phosphorus adsorption characteristics of alum sludge when used as a sediment inactivant the possibility of using finely ground dried alum sludge as a filter media was investigated. Initial laboratory column studies were conducted in which various mixtures of alum sludge along with sand and gravel were tested for filtration rates and pollutant removal efficiencies. The objective of these investigations was to optimize filtration rates without sacrificing efficiency.

Early experiments indicated that crushed alum sludge itself could not be used as a filtration media without mixing with sand or gravel. Once the sludge became wet, it tended to form into a dense cake, especially if compacted, and filtration would stop. After much investigation, the optimum solution seemed to be a 50-50 mixture of sludge and coarse building or silica sand. Filtration rates ranging between 20 and 200 centimeters per hour were obtained depending upon compaction of the media, sludge moisture content at time of crushing, and particle size. It was also determined that the best results were achieved when the alum sludge was crushed into particles approximately 1 millimeter in diameter and mixed with sand just before it completely dried and when compaction of the media was held to a minimum.

Laboratory column studies were conducted to investigate the adsorption characteristics of this media for phosphorus and heavy metals in stormwater runoff. The results of this investigation are listed in Table 11. Although it was not possible to determine adsorption capacities for each of the heavy metals tested, it was determined that the maximum capacity for phosphorus was approximately 140 gP/m^3 of sludge-sand mixture.

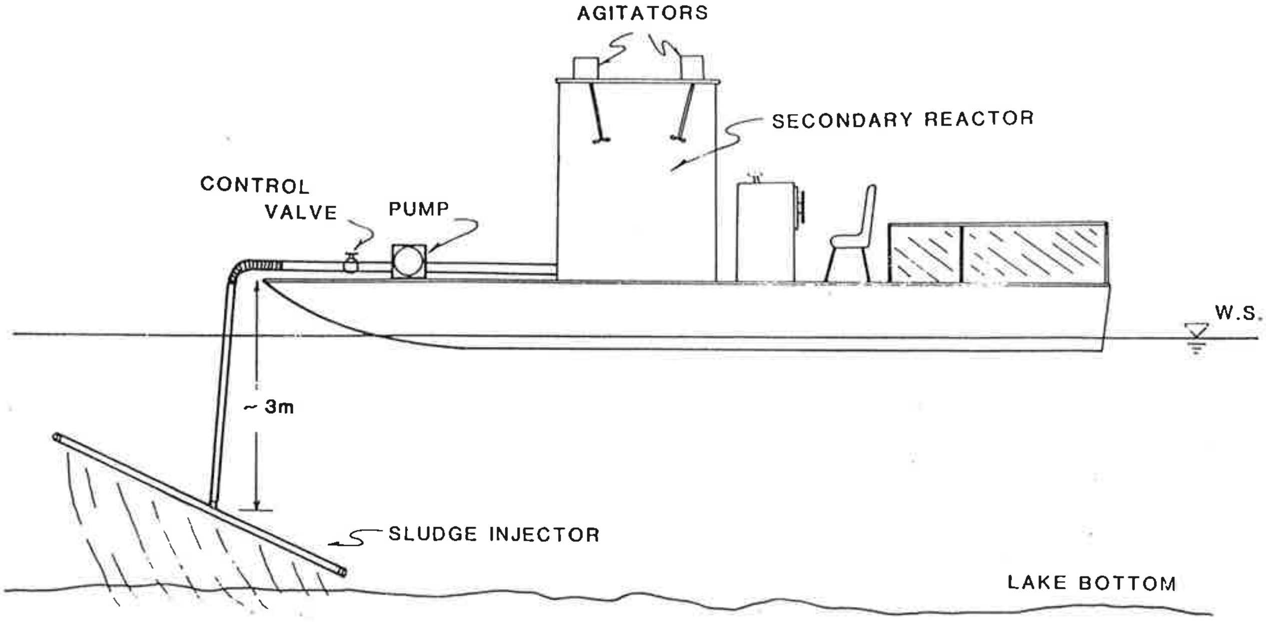


Figure 9.—Schematic diagram of alum sludge spreading operation.

Table 11. — Removal percentages of phosphorus and heavy metals in stormwater runoff filtered through 20 cm of a 50-50 mixture of alum sludge and sand (Filtration rate = 25 cm/hour)

Parameter	Average influent (mg/liter)	Average effluent (µg/liter)	Percent removal (%)
Orthophosphorus	791	90	81
Total P	993	117	88
Total Cadmium	258	5	98
Total Zinc	695	15	98
Total Copper	596	47	92
Total Iron	708	28	96
Total Lead	880	88	90
Total Nickel	323	39	88
Total Chromium	83	15	82

In view of the laboratory results obtained, it was decided that this media would be used in an in-line filter on two large storm sewer lines before discharge into Lake Eola. One of the storm sewers was already equipped with an underground concrete settling basin which was modified to act as a downflow filter with underdrains. Stormwater runoff is collected in the basin, filtered through the sand and sludge mixture, collected in the underdrains, and then discharged into the lake. A diagram of this structure is shown in Figure 10.

The other alum sludge filtration system was constructed above ground in a 1.5 meter deep excavation approximately 20 meters in diameter. This unit was also designed to act as a downflow filter with underdrains leading to the lake. The sludge-sand mixture was covered with decorative rock, and the sides of the excavation were sloped and landscaped to resemble a Japanese garden. During a rain event, stormwater first enters an entrance structure which diverts the water onto the top of the rock layer, flooding the excavated basin. The stormwater then percolates through the rocks and media and into the underdrains. A cross-section of this unit is shown in Figure 11. Chemical analysis of the influent and effluent from an actual storm event is listed in Table 12.

SUMMARY AND CONCLUSIONS

During this project, periodic water quality analyses were conducted in Lake Eola to determine the effects of stormwater runoff on water quality and to establish pre-restoration background water quality. The feasibility of using water treatment sludges to inactivate anaerobic phosphorus release from bottom sediments and infiltration of stormwater was studied. From the information obtained in this research, the following conclusions were reached:

1. Stormwater runoff was determined to be the primary source of pollution in Lake Eola. Continual stormwater inputs have degraded water quality as typified by high algal production, a stratified hypolimnion, and periodic fish and duck kills. Bottom sediments have become covered with a layer of loose flocculant material, and anoxic conditions exist in areas more than 4 meters deep during the spring and summer. As a result, a restoration project was begun to restore Lake Eola.

Table 12. — Removal percentages of selected parameters in stormwater runoff passing through the garden alum sludge filter.

Parameter	Average influent	Average effluent	Percent removed (%)
pH	6.20	6.10	1.6
Turbidity (JTU)	3.0	1.5	50.0
Spec. cond. (µmhos)	208	200	3.8
Alkalinity (mg/liter)	95.0	99.0	4.2*
Organic carbon (mg/l)	2.7	1.1	59.3*
NH_3–N (µg/l)	87	129	48.3*
NO_2–N (µg/l)	3.3	3.8	15.2*
NO_3–N (µg/l)	204	212	3.9*
Organic N (µg/l)	563	184	67.3*
Diss. orthophosphorus (µg/l)	113	12	89.4
Total P (µg/l)	382	68	82.2
S.S. (mg/l)	128	28.1	78.0
V.S.S. (mg/l)	61.0	14.4	76.4

* Denotes increase

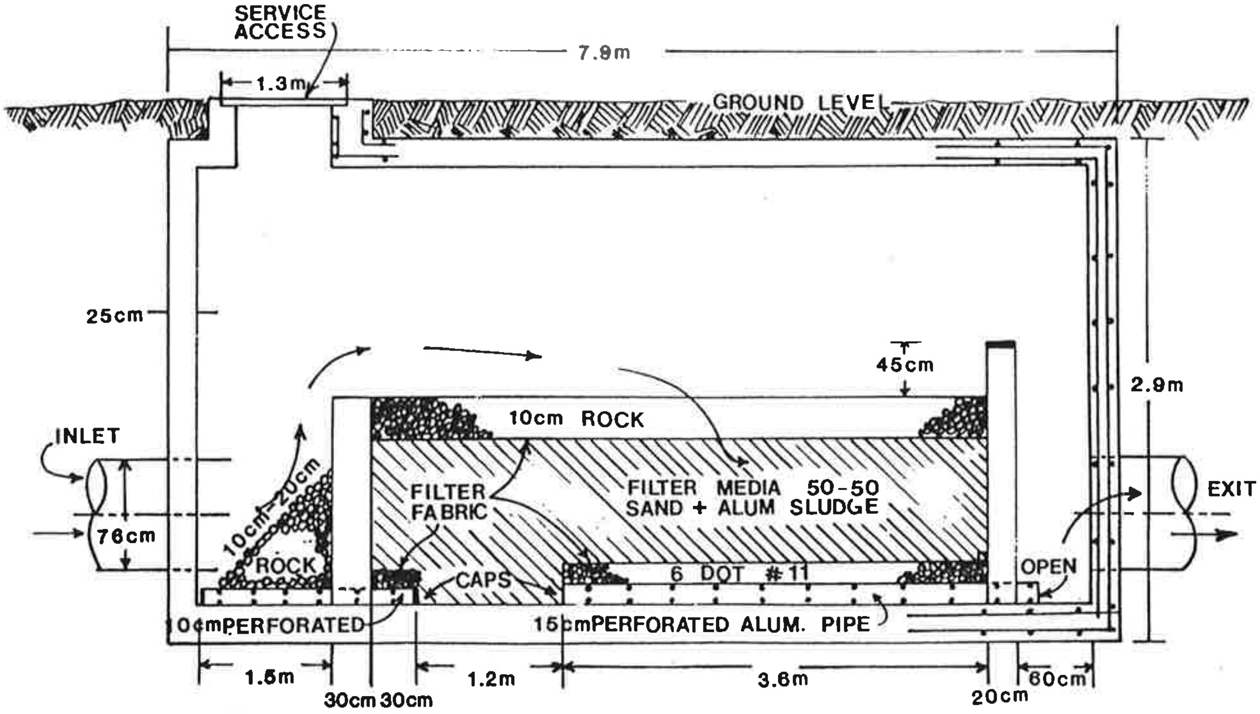


Figure 10.—Underground alum sludge filtration system section.

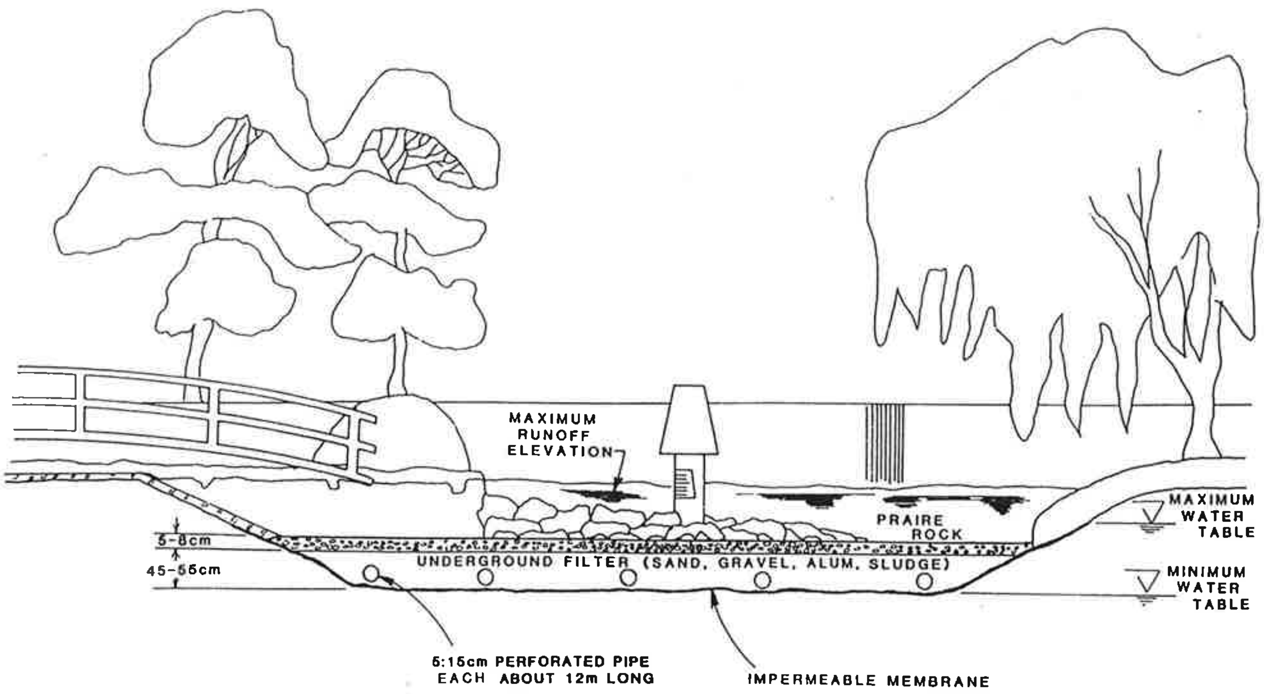


Figure 11.—Garden walk filter - section.

2. Analysis of the contributing watershed indicated that a first-flush effect was present with approximately 90 percent of the stormwater pollutant mass contained in the first 1.3 centimeters of rainfall excess. Since an area was not available within the highly urbanized watershed for conventional stormwater management practices, an underground exfiltration system was developed. Stormwater practices were constructed and lake modifications were made. A preliminary estimate of the efficiency of pollutant mass removal was determined for this system.

3. Stormwater management by diversion to underground exfiltration systems is an alternative to traditional surface diversion/retention structures. Pollutant removal appears to be possible in areas where a first-flush effect exists by selecting the proper exfiltration volumes. The most cost-effective method of treatment by underground exfiltration was to intercept the storm sewer line directly before it discharged in to the lake.

4. Alum sludge was shown to be effective in the inactivation of anaerobic release of phosphorus from bottom sediments. The orthophosphorus and total phosphorus released from bottom sediments to the contained lake water column inside the isolation chambers treated with various dosages of alum sludge decreased with increasing sludge dosage. In some cases, the sludge inhibited the release of phosphorus from the bottom sediments and also reduced the phosphorus content in the overlying water column. The control isolation chambers showed a gradual increase in orthophosphorus concentrations reaching maximum values within 2 to 3 months of incubation time. The maximum orthophosphorus released was 136 mg P/m^2 for the 3-month period or 1.5 mg P/m^2/day. Generally, all phosphorus released appeared to be in the orthophosphorus form. Based on these findings, alum sludge at a dose of 7 metric tons/hectare was applied to Lake Eola sediments.

5. Alum sludge was found to be effective as a filtration media for stormwater runoff. Removal percentages between 80 and 99 percent were obtained in laboratory column studies for various heavy metals and phosphorus. Two inline stormwater filters were constructed and removal efficiencies monitored.

6. Monitoring of lake water quality will continue to determine the effects of the various pollution removal systems.

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