HESS LAKE
WHEELER DRAIN PHOSPHORUS REMOVAL SYSTEM
FEASIBILITY EVALUATION REPORT

Prepared For:

The Hess Lake Board

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1. INTRODUCTION AND BACKGROUND

In October of 1988, the Hess Lake Board retained Progressive to conduct an evaluation of a phosphorus removal system via soil filtration for the Wheeler Drain, a major tributary of Hess Lake in Newaygo County. The primary purpose of this report is to discuss the technical feasibility and refined cost estimates for the proposed system.

The concept of the phosphorus removal system is described in detail in the Hess Lake - EPA Clean Lakes Program grant application narrative statement (see Appendix A). The preliminary cost estimate presented in the grant application for the construction of the system was $200,000, and pursuant to Clean Lakes Program regulations, 50 percent of the cost of constructing the phosphorus removal system could be secured through a federal grant.

Upon the initiation of this study, a thorough review of the grant application and support documents was conducted to facilitate the feasibility evaluation. Major conclusions and recommendations cited in the grant application narrative are summarized as follows:

- The water quality of Hess Lake has shown some improvement in recent years due to a program consisting of aquatic plant harvesting, the limited use of herbicides, the construction of a sediment removal basin on the Wheeler Drain and the implementation of upland best management practices.
- Despite recent improvements, the condition of Hess Lake remains marginal. Nuisance submersed macrophyte growth covers much of the lake bottom, and blue-green algae blooms are common during the summer months.
- Deteriorated water quality conditions are related, in part, to excessive allochthonous (i.e., external) nutrient loading from the watershed.

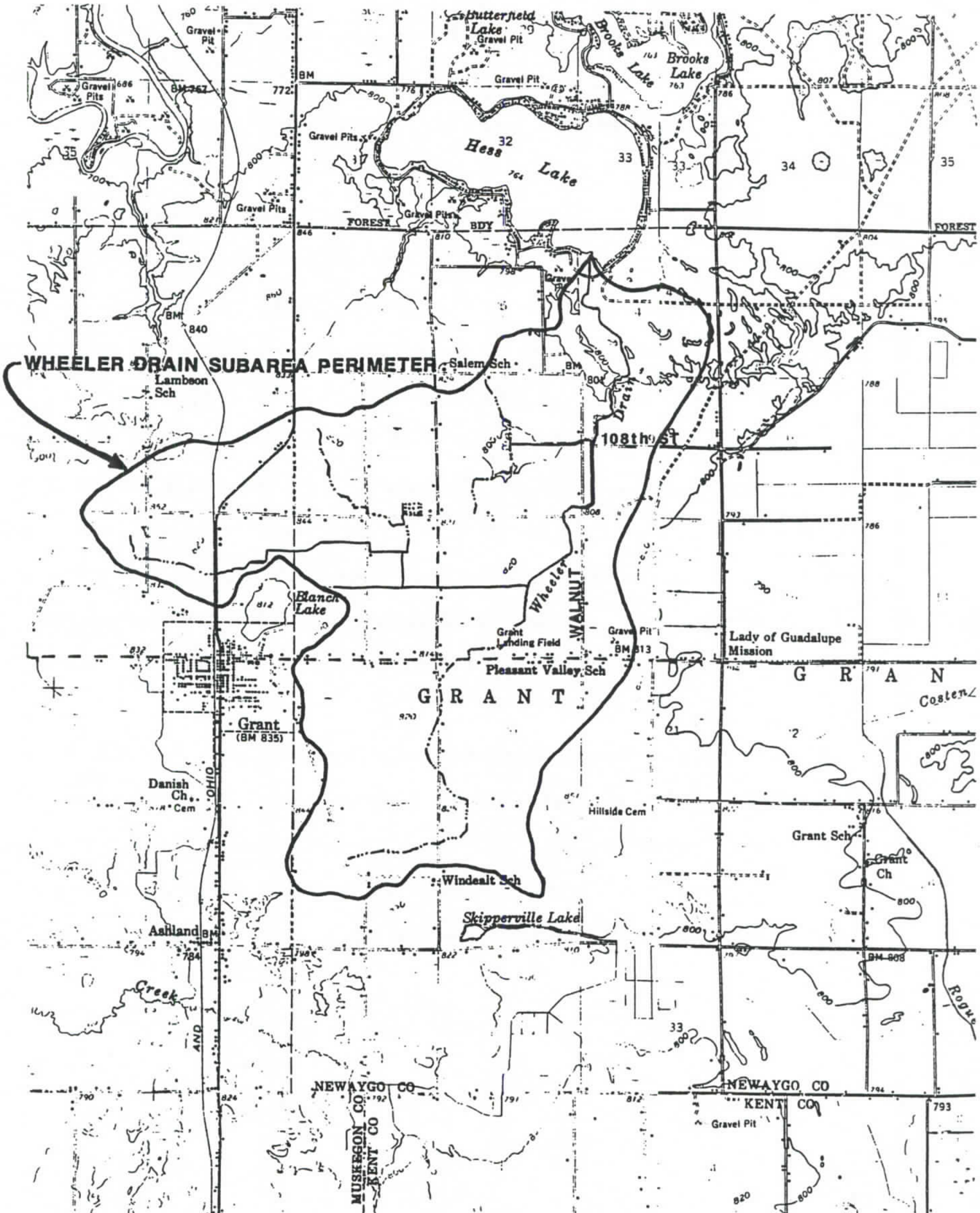
- The major source of phosphorus loading to Hess Lake is the Wheeler Drain which contributes approximately 55 percent of the total annual phosphorus load.
- Empirical sampling data indicates that the majority of the phosphorus contributed by the Wheeler Drain is contained in the "first flush" of a storm event. Further, physical settling of course soil particles in laboratory experiments did not significantly reduce ambient supernatant phosphorus levels. Thus, it was concluded that most of the phosphorus in Wheeler Drain is either in a soluble form or adhered to fine, colloidal soil particles.

Based on these findings, it was concluded that sufficient removal of phosphorus transported to Hess Lake by the Wheeler Drain could not be achieved via settling of course soil particles alone. The phosphorus removal system proposed for construction would be designed to retain the first flush water of high nutrient content and force it through a soil percolation system. Phosphorus removal would then be achieved by small particle filtration and soil adsorption. In the grant application, it was noted that the topography of the upland portion of the Wheeler Drain watershed sub-basin was relatively flat. The headwaters of the drain were predominately runoff-fed and carried mostly fine particulate matter following storm events. By contrast, the downstream (northern) portion of the drainage sub-basin had a steeper grade, was less impacted by immediate runoff, had a significant base flow and carried a substantial course particle load during periods of high flows.

In light of these considerations, the feasibility evaluation of the phosphorus removal system conducted during the course of this study focused on locating the system in an area that would permit capture and treatment of the nutrient-enriched upland drainage. Since the upland drainage contains fine particulate matter, it was apparent that pre-settling of the fine particles would be necessary prior to filtration of runoff to prevent clogging of the sand filter bed. Therefore, a retention basin was incorporated into the design of the phosphorus filtration system.

Subsequent to this determination, recently issued U.S.G.S. topographic maps (scale 1:24,000), U.S.D.A. soils maps and aerial photographs (DNR 1987) of the study area were acquired and field investigations were undertaken to determine optimum site locations for a phosphorus removal system. A 40-acre site located at the intersection of 108th Street and Walnut Avenue appeared suitable in that it was easily accessible and would allow capture of all of the upland drainage (see Figure 1). In addition, the site was in single ownership, was unforested and contained ideal soils which were highly permeable with a high phosphorous adsorption capacity. Based on these findings, a topographic survey and soil borings of the site were conducted to evaluate subsurface conditions. The results of these field investigations are graphically depicted in the folded insert.

Concurrently, detailed topographic and engineering analyses of the site were conducted to evaluate the feasibility of a gravity-fed phosphorus removal system consisting of a retention basin and filtration bed. Based on this evaluation, several alternatives were advanced for the design configuration and site location of a phosphorus removal system. These alternatives are discussed herein.

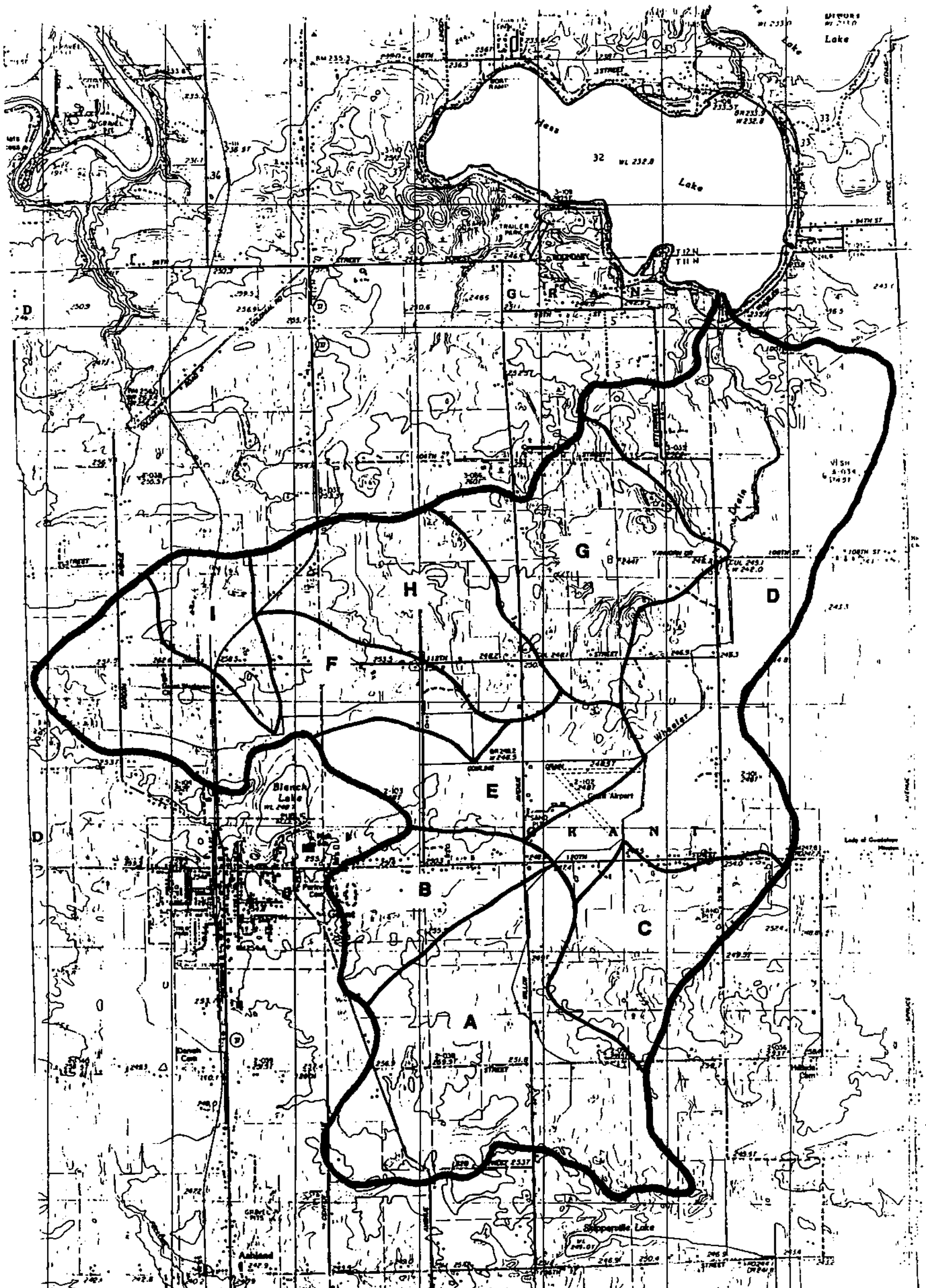


PROJECT LOCATION MAP

FIGURE 1

2. RETENTION BASIN DESIGN

As stated previously, it was necessary to include a retention basin in the design of the phosphorus removal system in order to settle out suspended particles from the runoff water which would otherwise clog the phosphorus filtration system and quickly render it ineffective. Additionally, retaining the runoff allows for a more controlled dispersion of water through the sand filter. In order to retain water and settle particles from the first flush of a rainstorm, the volume of water contained in the first flush in the Wheeler Drain watershed had to be determined. Since the accuracy of an empirical determination is directly related to the frequency and duration of sampling, a theoretical estimate of runoff volume is more appropriate than a limited stream flow monitoring program. In this analysis, the theoretical model utilized to estimate runoff volume was the Soil Conservation Service (SCS) method (McCuen 1982). The underlying premises of the model are these: During a storm event, precipitation may infiltrate the soil or run off along the surface depending upon variables such as slope, soil characteristics, land use and rainfall intensity. Further, precipitation that falls upon an area of the watershed that is in close proximity to the retention basin will be "captured" before runoff that must traverse the entire length of the watershed. This concept lends itself to two descriptive terms: travel time and time of concentration. The former refers to the time required for the first drop of water leaving a watershed drainage sub-basin to reach the retention basin site, as opposed to the latter term which is the time required for runoff from the most remote point in a sub-basin to reach the sub-basin's confluence with the major tributary. In the interim, all runoff generated will have accumulated in the retention basin. The SCS model utilizes the variables which affect the rate of runoff -- land use, farming practice, hydrologic soil condition, etc. -- to estimate total runoff volume for a given size storm event and a calculated time of concentration. However, it is not necessary to retain the entire runoff volume for the watershed, since in this case, treatment of the first flush only is desired. Hence, the concept of travel time becomes important. If it is necessary to account for the first flush runoff from all parts of the watershed (even the most remote), then the longest travel time out of all those calculated for each sub-basin will be used as the minimum time required to contain all first flush volume. Note that this is different from using the greatest time of concentration (which would yield the total runoff volume) since travel time accounts only for the first drop of water leaving a sub-basin area; i.e., the first flush. To improve the accuracy of these estimates, the Wheeler Drain sub-basin was divided into smaller sub-basins for each stream or drain that was tributary to it (see Figure 2). Runoff volume was calculated for each of the smaller sub-basins, and a first flush volume was determined based on the longest travel time of the sub-basins, that of Sub-basin F. Therefore, as shown in Table 1, a period of 10 to 12 hours is required to retain the first flush volume from all sub-basins. The volume of runoff for 10 to 12 hours of retention is between 8 and 13.5 million gallons, respectively (see Table 1). Thus, it is estimated that a retention basin sized to contain 8,000,000 gallons of water would be sufficient to retain the first flush of a storm event in the Wheeler Drain. If the retention basin was excavated to a depth of three feet, for example, an area of approximately 8.5 acres would be required to store this water.



WHEELER DRAIN SUB-BASINS

FIGURE 2

TABLE 1
WHEELER DRAIN
FIRST FLUSH RUNOFF VOLUME CALCULATIONS

T = 10 hours

Sub-Basin	Tt Travel Time (hr)	tc Time of Concentration (hr)	Tp Time to Peak (hr)	(t-Tt)/Tp Design Time (hr)	Qa/Q* Mass Ratio	Q** Total Runoff Volume (gallons)	Qa*** Volume Time t (gallons)
A	8.59	11.52	7.68	0.18	0.006	9,330,058	55,980
B	5.55	6.00	4.00	1.11	0.450	2,797,267	1,258,770
C	4.45	13.00	8.67	0.64	0.163	4,372,312	712,687
D	2.60	9.50	6.33	1.17	0.522	3,204,376	1,672,684
E	6.71	8.13	5.42	0.61	0.107	3,892,461	416,493
F	10.17	12.37	8.25	-0.02	0.000	7,024,593	0
G	1.96	7.38	4.92	1.63	0.751	5,137,251	3,858,076
H	7.18	13.55	9.03	0.31	0.012	7,333,381	88,001
I	8.18	4.40	2.93	0.62	0.107	1,451,330	155,292
TOTAL							8,217,983

3. PHOSPHORUS ADSORPTION VIA SOIL FILTRATION

In concept, phosphorus adsorption via soil filtration is a relatively simple process, and the techniques for applying water to the soil are not complicated. The subtleties in the design of a filtration system include the size of the application area, the rate at which water will be applied, and the cost associated with any given alternative. The basic design considerations for a phosphorus filtration system on the Wheeler Drain are discussed as follows:

The first flush runoff from a one-year storm event can be applied to the soil by overland flow, an above-ground irrigation system, or by subsurface land application. Overland flow involves simply discharging water to a contained area. Above-ground irrigation is the system commonly used by farmers in which water is pumped to spray heads and thereby distributed evenly over a given land area. Subsurface application has been used to treat wastewater effluent on a municipal scale for many years. In this type of system, water is pumped into small pipes which are laid in gravel trenches about 18 inches below the surface. An alternative to the use of trenches is a filter-wrapped PVC pipe which is placed about 12 inches below the surface. Either of these methods can be utilized to enhance the migration of water into the ground. Once in the soil, the water percolates downward; and, consequently, phosphorus adheres to the soil. In the case of Rubicon sand, which is present throughout the Wheeler Drain watershed, the degree to which phosphorus adheres to the soil is quite high; the phosphorus adsorption capacity is approximately 3,700 pounds per acre for the upper five foot strata of soil (Schneider and Erickson 1972). Note, however, that this is a finite capacity. Upon reaching the capacity, soil will no longer continue to filter out phosphorous. Given this phosphorus adsorption capacity and the phosphorus loading rate, a desired life span for the system can be incorporated into its design. Previous studies of Wheeler Drain estimate its

TABLE 1 (continued)
WHEELER DRAIN
FIRST FLUSH RUNOFF VOLUME CALCULATIONS

T = 12 hours

Sub-Basin	Tt Travel Time (hr)	tc Time of Concentration (hr)	Tp Time to Peak (hr)	(t-Tt)/Tp Design Time (hr)	Qa/Q* Mass Ratio	Q** Total Runoff Volume (gallons)	Qa*** Volume Time t (gallons)
A	8.59	11.52	7.68	0.44	0.065	9,330,058	606,454
B	5.35	6.00	4.00	1.61	0.751	2,797,267	2,100,748
C	4.45	13.00	8.67	0.87	0.300	4,372,312	1,311,694
D	2.60	9.50	6.33	1.48	0.700	3,204,376	2,243,063
E	6.71	8.13	5.42	0.98	0.375	3,892,461	1,459,673
F	10.17	12.37	8.25	0.22	0.006	7,024,593	42,148
G	1.96	7.38	4.92	2.04	0.871	5,137,251	4,474,546
H	7.18	13.55	9.03	0.53	0.065	7,333,381	476,670
I	8.18	4.40	2.93	1.30	0.589	1,451,330	854,833
TOTAL							13,569,827

* Mass curve ratio values are obtained from the dimensionless unit hydrograph - mass curve table (see Appendix B), given the calculated design time.

** Total runoff volume calculations from SCS method analysis.

*** Total runoff multiplied by mass ratio.

annual phosphorus loading rate to be 2,000 pounds per year of which 1,000 pounds was targeted for removal. If, for example, a 50-year life span for the system was desired, the quantity of soil that would be required to achieve the 50-year life span assuming five feet of underlying filtration soil would be:

$$1{,}000 \text{ lbs. P/yr.} \times 50 \text{ yr.} = 50{,}000 \text{ lbs. P}$$

$$\frac{50{,}000 \text{ lbs. P}}{3{,}700 \text{ lbs. P/acres}} = 13.5 \text{ acres}$$

Thus, 13.5 acres would be required to achieve a 50-year life span.

In addition to its high capacity for phosphorus removal, Rubicon sand also has a very high rate of permeability, approximately 40 inches per hour. To again use the example of a 10-acre application area, a 40-inch per hour permeability rate could percolate the 8,000,000 gallons of first flush stormwater in approximately 44 minutes. Given these soil conditions, almost any frequency of storm events could be accommodated. The limitation to this permeability rate, however, is the groundwater. Groundwater moves much more slowly through the soil (approximately 6 inches per day) and inhibits the rapid downward movement of percolating water. If water is applied in large volumes, or at a rapid rate, or over a small area, a rise in the static elevation of the groundwater will occur. This phenomenon is known as groundwater mounding. It is possible for mounding to continue to a point where water begins to run off the ground's surface. In this case, no phosphorus removal would be achieved. Additionally, the saturated condition of the soil during mounding causes the soil to become anaerobic. When this occurs, the soil ceases to physio-chemically react with percolating water and, again, no phosphorus removal is achieved. Thus, water must be applied at a rate which will prevent mounding or limit it to an acceptable level.

The permissible loading rate for Rubicon sand is approximately one gallon per square foot per day (estimated from Hantush 1967 methodologies). The units of this loading rate denote the variability which can be utilized in design: the size of the filter bed or the time over which the bed is dosed could be varied to maintain this acceptable loading rate. If the 8 million gallons of first flush stormwater were to be filtered on a seven-day basis, 26 acres of land area would be required to prevent the potential for excessive mounding. If the first flush were to be filtered on a daily basis, 182 acres would be required. The application rate could be fixed to accommodate either a constraint in available land area or the estimated time between storm events.

The permissible loading rate could be exceeded, however, if an underdrain system were installed. Theoretically, with underdraining, the first flush water could be applied at a rate equivalent to the permeability rate of the Rubicon sand; the entire 8,000,000 gallons could be drained in 44 minutes. At that rate, the system could handle storms at almost any frequency. As may be expected, limitations do exist, and these include cost and contact time. The underdrain pipes increase in cost as the application area increases. But perhaps more importantly, the contact time of the water with soil must be sufficient to allow for the adsorption of phosphorus to soil particles.

Thus, a phosphorus removal system is designed given the constraints of such factors as available land area, frequency of storm events, desired life span, groundwater mounding potential, required contact time, and cost.

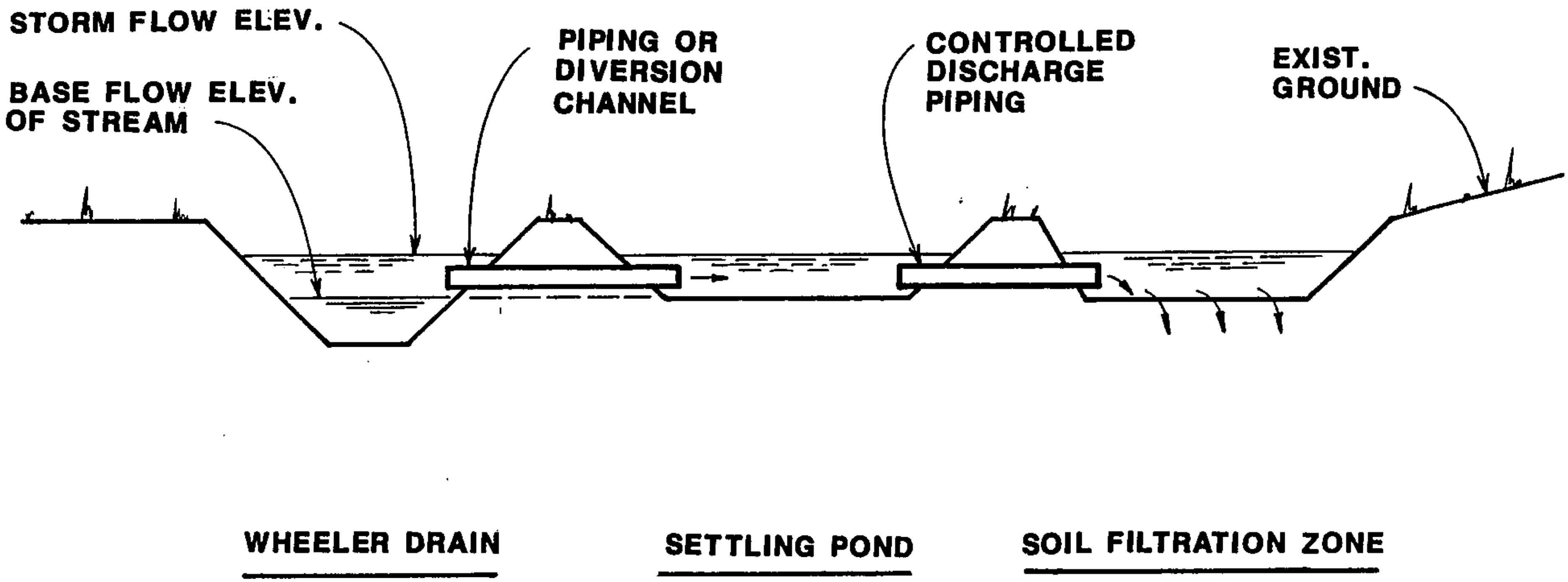
4. PHOSPHORUS REMOVAL SYSTEM DESIGN ALTERNATIVES

Alternatives exist for the design of the two components of the phosphorus removal system; i.e., the retention basin and the filtration system. However, while these alternatives are technically feasible, site constraints within the Wheeler Drain sub-basin would require a substantially greater monetary commitment for construction than is now budgeted. Design considerations and cost estimates of phosphorus removal system alternatives are discussed as follows.

The concept of the phosphorus removal system as described in the Hess Lake EPA grant application narrative statement was one that would not require pumping (i.e., a gravity-fed system) and would be self-maintaining. The basic design contemplated for the system included construction of a weir-type structure that would allow passage of base-flow during dry conditions and retention of first flush storm events (see Figure 3). An overflow structure would allow short-circuiting of high-flow volume that would otherwise scour the retention basin. The retention basin would gravity-drain to the filtration bed, and the drainage rate of the retention basin would be determined by the size of the outlet piping. The storage depth of the retention basin would be determined by the height of the weir. The height of the weir, in turn, would determine the extent of the upstream area that would be inundated. Relatively flat portions of the Wheeler Drain would be inundated over a larger area than would steep sections. Given this generalized scheme for the design of the overall system, several design alternatives were evaluated during the course of this study.

A. Alternative 1

The 40-acre site at the northeast corner of 108th Street and Walnut Avenue is located in the northern extreme of the relatively flat portion of the Wheeler Drain sub-basin. Thus, the height of the weir and, therefore, impoundment of upstream waters must be limited in order to avoid flooding of upstream farming



CROSS SECTION

CONCEPTUAL SOIL FILTRATION SYSTEM DESIGN

FIGURE 3

operations. Inspection of road culverts at the 108th Street site revealed a natural rise in the stream elevation of 18 to 24 inches during storm events. Because of this shallow storage depth, approximately 13 to 17 acres of land would be required to store 8,000,000 gallons of first flush runoff. The banks of the channel at the 108th Street site are approximately six feet in height; thus, a six-foot excavation would be required to reach the desired depth. Earth moving would involve approximately 125,000 cubic yards of soil. Assuming the excavated soils could be stored on-site, the cost of constructing a retention basin at the 108th Street site would be $220,000. If excavated soils had to be transported to an off-site location, the construction cost would be considerably higher.

Due to the configuration of the 40-acre site (i.e., stream location, slopes, stream channel height, location of wooded areas, etc.) only ten acres of land may be allocated for the sand filtration system. However, it is cost-effective to utilize small land areas since certain costs increase as land area increases. The least expensive method of application is by spray irrigation. Such a system would consist of 90 agricultural sprinkler heads, duplex 50 horsepower pumps, piping and valves; and equipment costs would be approximately $75,000. Because the 8,000,000 gallons would need to be applied over a relatively small area and a seven-day turnover time would be appropriate for anticipating storm frequency, an underdrain system would be required to control mounding of groundwater under the soil filtration bed. The cost of an underdrain piping network would be approximately $40,000. Land purchase costs are estimated at $40,000. Associated engineering, administration and contingency expenses would be $55,000. Therefore, the total cost to construct a soil filtration system at the 108th Street-Walnut Avenue site would be approximately $430,000.

Since the construction costs for the 108th Street site far exceeded the amount budgeted, field surveys were conducted to locate a downstream land parcel which contained sufficient fall in elevation across the site to provide storage depth, and which did not have high stream banks requiring excessive excavation. No such location was found to exist. The stream banks increase in height as the drain descends to Hess Lake. Also, much of the fall in elevation between 112th Street and Hess lake (as noted in the EPA grant application narrative), which could be utilized for storage depth, actually occurs between the existing retention basin and Hess Lake. In addition, properties downstream of the 108th Street site adjacent to the drain are, for the most part, ten acres or less in area. Thus, it would likely be necessary to acquire multiple properties or easements in order to accommodate construction of the entire phosphorus removal system. Access in the area downstream of 108th Street would also be difficult since few roads presently exist in that area. Based on these findings and observations, it was concluded that no suitable area exists for location of a phosphorus filtration system between 108th Street and the existing retention basin.

B. Alternative 2

An alternative to the use of a centralized retention basin and filtration bed to filter the entire first flush volume would be the use of several smaller, decentralized basins to filter the first flush runoff from individual sub-basins of the Wheeler Drain. Monitoring of upstream locations could be used to prioritize sub-basins as to their contribution to the overall nutrient load. However, as with the 108th Street location, the drainage area further upstream is also flat, which does not allow for sufficient storage depth of the first flush volumes. In addition, U.S.G.S. soils data indicates land areas adjacent to the drains contain muck soils which would be inappropriate for phosphorus filtration. Therefore, a decentralized approach to phosphorus removal was rejected as infeasible.

C. Alternative 3

The third alternative design of the phosphorus removal system involves utilizing the existing detention basin for storage followed by spray irrigation over the filtration area. The existing basin would need to be modified to store the 8,000,000 gallons of first flush runoff. Modification would include enlarging the basin from its present 2.3 acres to 6.4 acres and increasing the height of the weir by four feet. Though maintenance would be difficult in a basin of this size, the modifications are feasible on the existing parcel of county land. The natural hill slopes at the periphery could be utilized as the outer berm of the basin, but would exclude the possibility of gravity draining to the filtration bed because of the excessive excavation that would be required. Therefore, pumping from the retention basin with spray irrigation would be necessary. Unfortunately, there is no cleared land, such as croplands, in close proximity to the existing retention basin that could be utilized for spray irrigation. Therefore, estimates must include costs to clear and regrade existing land.

The cost for modification and construction of a dam structure is approximately $80,000, including the structure, related sitework, control gates, and handrail. Clearing and excavation costs for the existing detention basin are approximately $45,000. Pumping costs to the filtration bed are estimated to be $75,000, assuming suitable land is available in close proximity to the existing detention basin. Costs for acquisition, clearing, and regrading of land for the filtration bed are estimated to be $20,000. Engineering, administration and contingency costs would be approximately $30,000. Therefore, total project costs for modification of the existing detention basin site would be approximately $250,000.

Considering the cost and the unavailability of suitable land for irrigation in close proximity to the existing detention basin, this alternative was determined to be impractical.

5. RECOMMENDATIONS AND CONCLUSIONS

It is apparent from the data collected and presented herein that a phosphorus removal system for the Wheeler Drain cannot be constructed within the preliminary budget estimate. In concept, conditions in the Wheeler Drain watershed subarea (i.e., soils and topography) appeared ideal to permit construction of the system. However, field investigations and feasibility evaluations of phosphorus removal system alternatives conducted during the course of study indicated localized conditions were such that construction costs would far exceed preliminary estimates. Based on these findings, it is unlikely that a phosphorus removal system for the Wheeler Drain would provide a cost-effective means of reducing phosphorus loading to Hess Lake.

It should be noted, however, that given the phosphorus loading potential of the Wheeler Drain, attempts should be made to mitigate and control phosphorus loadings from this source. Upland erosion controls such as rip-rap banks and soil stabilization improvements implemented during the mid-1980's should be maintained as should the existing detention basin. The efficiency of sediment removal within the existing basin could be enhanced if a baffle or flow dissipater device was constructed at the upstream end of the basin. If properly located and sized, a baffle system would prevent channelization of water passing through the basin and would allow additional detention time, thus increasing settling efficiency.

In order to ensure timely maintenance of existing controls, field inspections of the Wheeler Drain should be conducted on an annual basis to identify potential and actual problem areas and to evaluate possible remedial actions. The Hess Lake Board may wish to consider including annual inspection and maintenance of the Wheeler Drain as a budgeted item in the ongoing lake improvement program.

A P P E N D I X A