15-001

CHARACTERISTICS AND MANAGEMENT OF STORM WATER RUNOFF IN A PLANNED COMMUNITY

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SYNOPSIS

A management strategy for the utilization of water resources within a planned community is being developed. The plan will include the use of storm water runoff, groundwater and treated waste water in a manner compatible with the natural environment and existing natural drainage. The purpose of the plan is to maximize the beneficial use of water resources within the community and prevent flood damage to downstream communities due to development within the new community.

While the plan considers numerous water resources and their uses, emphasis is on the reuse of urban runoff and treated waste water for recreational, aesthetic and irrigation purposes.

The site is The Woodlands, Texas, approximately 35 miles north of Houston, and is located in a heavily forested area. The Woodlands encompasses approximately 18,000 acres and will be developed over a period extending through 1992 for a population of 150,000. Concern for design with nature was a major

criteria in the development of the general plan which depended on a unique ecological inventory for basic design data.

INTRODUCTION

The Woodlands is a planned community being constructed in southeast Texas, 35 miles north of downtown Houston (Figure 1). In contrast to a residential subdivision, The Woodlands will contain all services of a modern city, including facilities for social, recreational, educational, commercial, institutional, business and industrial pursuits. The community concept is committed to high standards for environmental and lifestyle quality. The phased, long range development places priority on ecological preservation and balance, as well as social and habitational quality. This objective is to be accomplished through a comprehensive environmental preservation and management program, including planning and design controls. The water resource system in The Woodlands, including its drainage system, is a good example of such planning and is the subject of this paper.

WATER RESOURCE SYSTEM OF THE WOODLANDS

An approximate water balance for The Woodlands is presented schematically in Figure 2. Approximately 45 inches of rain falls annually over the 17,776 acres of heavy forest.

The maintenance of a satisfactory groundwater reservoir above the perched water table is critical for the continued growth of vegetation. Any drainage system for The Woodlands must consider the detrimental consequences of disrupting the movement of water within this shallow aquifer. Deeper aquifers

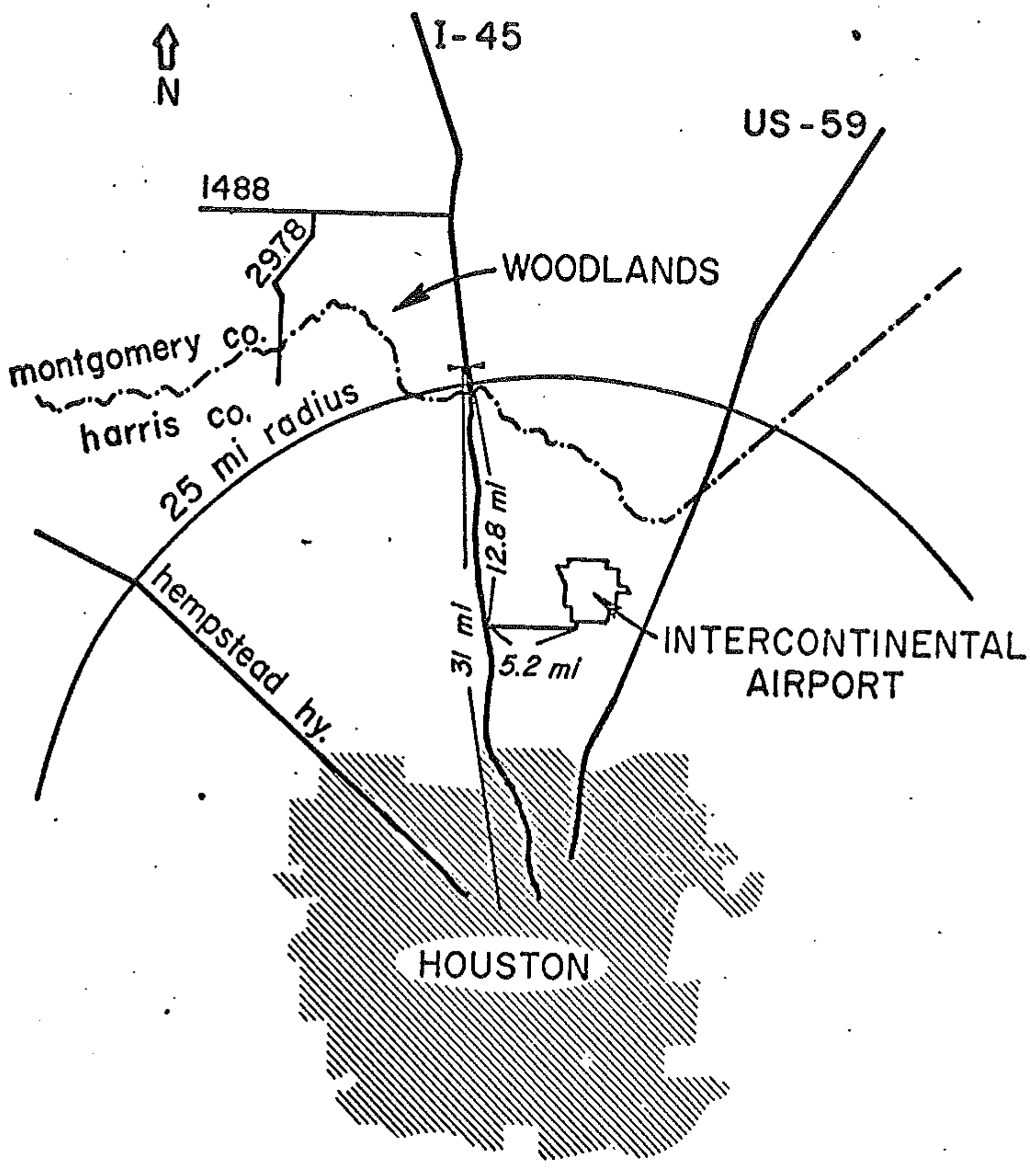

Figure 1. Location of The Woodlands within the Houston Metropolitan Area.

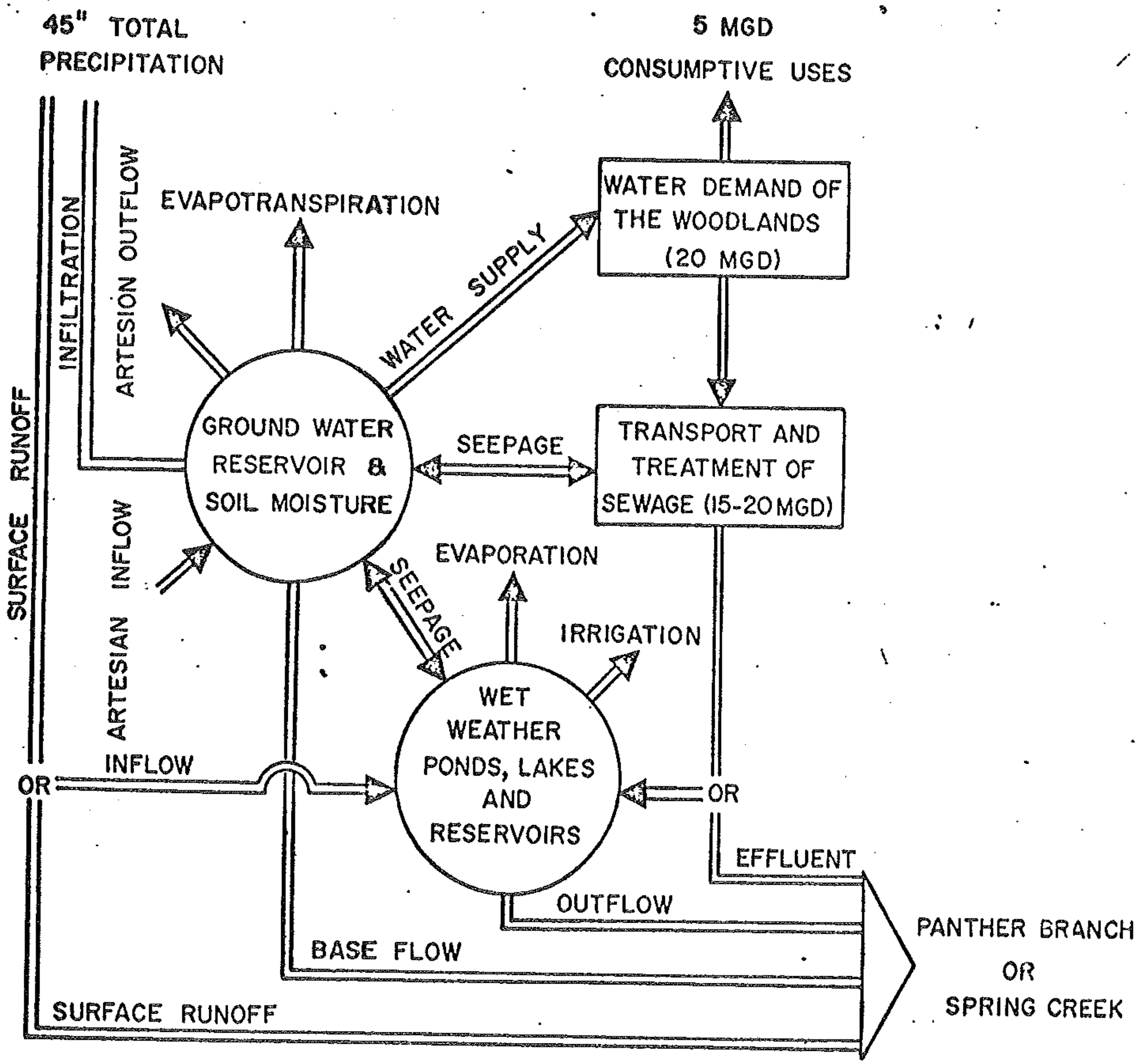

Figure 2. Approximate Water Balance for The Woodlands.

(1800 feet) are used for community water supply.

A series of wet weather ponds and variable volume lakes will serve as recreational centers, wildlife preserves and, more importantly, storage of storm water runoff. This system of water bodies also contributes to the maintenance of an adequate perched water table for plant life. Lake water will be lost primarily through surface evaporation and irrigation. Inflow to the lake system will result primarily from storm water runoff and reclaimed waste water from 2 or 3 sewage treatment plants. The projected volume of waste water is 20 MGD. If necessary, the sewage effluents can be discharged directly into Panther Branch.

URBAN STORM WATER RUNOFF

The effects of urbanization on the hydrologic characteristics of a previously undeveloped watershed are becoming known through continuing data collection programs.

Peak flow rates in undeveloped watersheds dramatically change under the effects of urbanization (1-9). These changes are a direct result of urbanization characteristics. The construction of impervious surfaces, such as parking lots, roof tops, storm sewers, etc., increases the total water runoff while decreasing the time of its concentration, often resulting in downstream flooding and property damage.

Pollution problems occur with urban storm water runoff systems. Increased pollutant loads, intrinsic to the urban and industrial environment, degrade storm water runoff quality. Urbanization also affects the hydrological characteristics of runoff systems, compounding the storm water pollution problem.

Because of an increase in runoff flow rates and velocity, urban storm water systems are capable of transporting more contaminants since impermeable surfaces not only increase flow rates but prevent natural purification of rain water by infiltration.

Recent investigations recognize the significance and magnitude of pollution problems from urban storm water runoff (10-14). In terms of specific pollutants, the sediment yield problem is the most dramatic. Due primarily to urban construction, urban sediment loads are as much as 75 times greater than loads in agricultural regions (15-19). Other runoff pollutant levels are also higher in the urban regions, including dissolved solids (20), coliforms (21,22), suspended solids (23,24), BOD and COD (24), polychlorinated biphenyls, heavy metals, pesticides, and fertilizers (25-29).

WOODLANDS DRAINAGE CONCEPT

The basic drainage system planned for The Woodlands has been designed on the basis of what has been termed the "natural drainage" concept. This concept consists of the following principles: (a) the existing drainage system in its unimproved state is utilized to the fullest extent possible; (b) where drainage channels need to be constructed, wide, shallow swales lined with existing native vegetation are used instead of cutting narrow, deep ditches; (c) drainage pipes and other flood control structures are used only where the natural system is inadequate to handle increased urban runoff, such as in high-density urban activity centers; (d) recharge berms are used where practical to minimize increases in runoff volume and peak flow rates due to development. The "natural drainage" concept as outlined by these four principles seeks to minimize changes in the runoff regime due to urbanization by providing increased infiltration and storage capacity and higher resistance to flow within the channels.

The natural drainage for The Woodlands community is shown in Figure 3. Approximately 80 percent of the development is drained by Panther Branch, a tributary of Spring Creek. The remaining portion of the development drains directly into Spring Creek, which has a total drainage area of 750 square miles (30). Because Panther Branch and its major tributary, Bear Branch, represent the major existing drainage for the development site, the hydrologic, morphologic and transport characteristics of this stream are of extreme importance.

Both Bear Branch and Panther Branch meander extensively along well defined low-flow channels respectively 9.0 and 14.6 miles in length. Alluvial sediments, small riffles, and slow moving pools are commonplace within Panther Branch and Bear Branch. The width of the low-flow channel is highly variable but is normally between 5-20 feet. When the capacity of the defined channel is exceeded, storm runoff discharges into a very broad, flat floodplain, presently covered with heavy brush. Flood runoff is characterized by low velocities and shallow depth because (a) a large land area is inundated, (b) flow resistance is high and (c) hydraulic slope is low. Excluding those areas presently under construction, essentially no evidence of any serious erosion can be found anywhere in Panther Branch watershed.

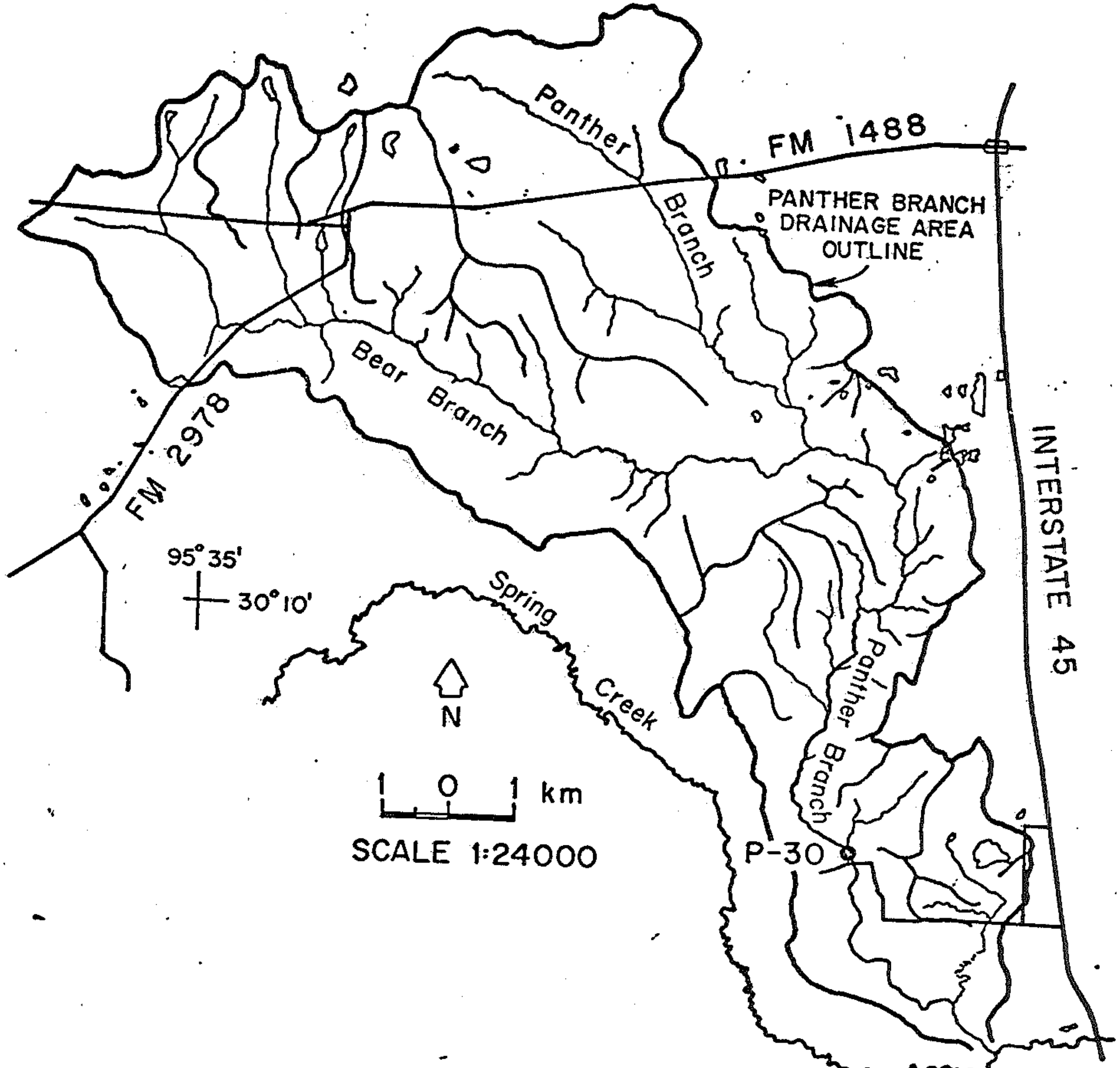

Figure 3. The Woodlands Natural Drainage Network with Location of [illegible]eamflow Monitoring Site at Sawdust Road (P-30).

The impact of low channel and land slopes within The Woodlands is reflected in an extremely low surface water runoff coefficient. Considering the average rainfall of 45 inches, it is estimated that only 10-15% of the rainfall will run off, the majority either evaporates, transpires, infiltrates into the ground or is stored in perennial ponds, wet weather ponds and lakes.

The Woodlands Development Corporation has specified that the basic drainage system for their new community will utilize "natural drainage" concepts (31).

The normal procedure for disposing of storm water runoff within the Houston Metropolitan Area is to enlarge the natural drainage by deepening and widening existing stream channels and providing supplementary lateral drains. In the City of Houston, this approach generally results in storm water sewers for the lateral drainage and deep, wide, concrete-lined ditches for the major drainage. This solution to storm water disposal, although widely used and approved by the City of Houston, was incompatible with one of the major criteria used in developing The Woodlands---preserving and enhancing the natural environment. The "natural drainage" concepts adopted by the WDC are envisioned as a method of providing adequate drainage and yet minimizing the disruption of natural processes. The primary objectives of the drainage approach are to impede the movement of surface runoff and to recharge storm water runoff into the ground where feasible. Impediment and storage is provided by modifying the existing drainageways, where necessary, with wide, shallow swales, check dams, storage lakes and wet weather ponds. In comparison with the normal approach, the benefits of the "natural drainage" approach in managing storm water runoff are as follows: (a) maximizes recharge; (b) minimizes runoff; (c) minimizes erosion and siltation problems; (d) minimizes vegetation removal and (e) minimizes the cost of the drainage system. The "natural drainage" concept is essentially a recharge and containment approach to managing storm water runoff. The system is designed to achieve the following goals: (a) reduce legal entanglements resulting from excessive runoff leaving the property; (b) minimize clearing and grading costs for swale and storm sewer trenching. An impartial evaluation of the effectiveness, applicability, and economics of the "natural drainage" approach of managing storm water runoff is the task at hand.

CHARACTERISTICS OF STORM WATER RUNOFF

The biological, chemical, hydrological and physical characteristics of storm water runoff was evaluated for five distinct storm events to date. Two of these storms were monitored on Panther Branch at Sawdust Road gauging station.

Water quality parameters monitored are as follows: orthophosphate, total phosphorus, ammonia, nitrite, nitrate, Kjeldahl nitrogen, suspended solids, turbidity, total organic carbon, total chemical oxygen demand, soluble chemical oxygen demand, pH, dissolved oxygen, temperature, specific conductance, biochemical oxygen demand, total bacteria, total coliform bacteria, fecal coliform bacteria, fecal streptococcus bacteria, *Salmonella-Shigella* sp., *Pseudomonas* sp., *Staphylococcus* sp. and chlorinated hydrocarbons. In addition, bioassays are performed to determine the limiting algal growth nutrient in storm water runoff. The preliminary results of bioassay experiments and pollutographs from the April 22-23, 1974 storm event on Panther Branch are described in the following paragraphs to clearly indicate the scope of the storm sampling program. The data was obtained from the single sampling site at Sawdust Road (P-30), (see Figure 3).

Precipitation associated with a thunderstorm began at about 2 p.m. on April 22. Two periods of intense rainfall were recorded between 2-3 p.m. and 6:45 - 7:15 p.m. Precipitation throughout the watershed ceased shortly after 7:30 p.m. (Figure 4). Rainfall was not evenly distributed throughout the river basin. The range in recorded total precipitation from three gauges were 0.25 - 0.78 inches. The average amount of rainfall over the entire watershed was calculated as 0.45 inches. The effective rainfall intensity for the storm was calculated as 0.54 inches/hour. Antecedent soil conditions were extremely dry with only 0.2 inches of rain recorded in the 7-day period prior to April 22.

The rate of surface runoff in Panther Branch was observed continuously at the U.S.G.S. gauging station at Sawdust Road. The resulting hydrograph and mass curves are shown in Figure 4. Streamflow increased from a base-flow rate of 0.02 cfs to a temporary plateau of 0.06 cfs. The discharge then increased

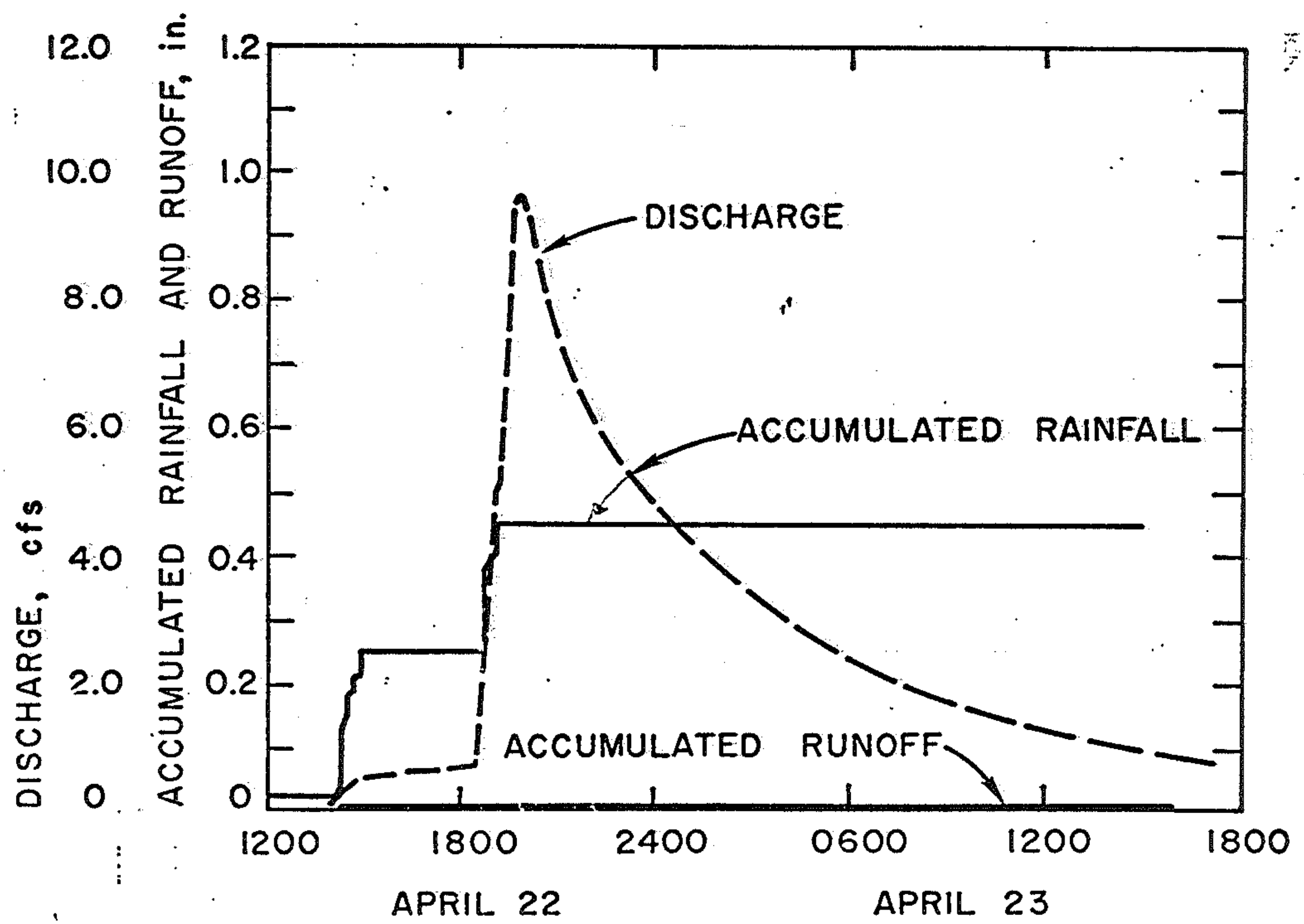

Figure 4. Mass Curves of the Storm Event of April 22-23, 1974.

to a peak flow rate of 9.7 cfs in response to the second period of intense rainfall. The stream subsided to pre-storm conditions about 36 hours after the peak discharge. The volume of runoff for this storm event was extremely low in comparison to the observed precipitation. Only about 0.7% of the total rainfall was measured as runoff at the gauging station. This low runoff coefficient is attributed to low land slopes within the watershed and dry antecedent soil conditions. As such, the majority of the runoff from this storm event originated in the immediate vicinity of the gauging station. This area was under heavy construction activity at this time.

A total of 53 water samples were collected by hand throughout the period of runoff and analyzed for specific bacterial, physical and chemical tests. The temporal distribution of several of these parameters is described in the following paragraphs.

The pollutograph for suspended solids and turbidity is shown in Figure 5. The corresponding hydrograph is also presented for comparative purposes. The concentration of suspended solids rose from a base-flow value of 30 mg/l up to a maximum concentration of 1600 mg/l at 11 p.m. (April 22). Thereafter, the concentration of suspended materials gradually decreased and was about 300 mg/l when sampling was discontinued. The total load of suspended solids passing the gauging station during the period of runoff was 7.1 tons. The high concentration and load of suspended materials recorded in the storm runoff is a direct consequence of unstabilized soils in the immediate vicinity of the sampling site.

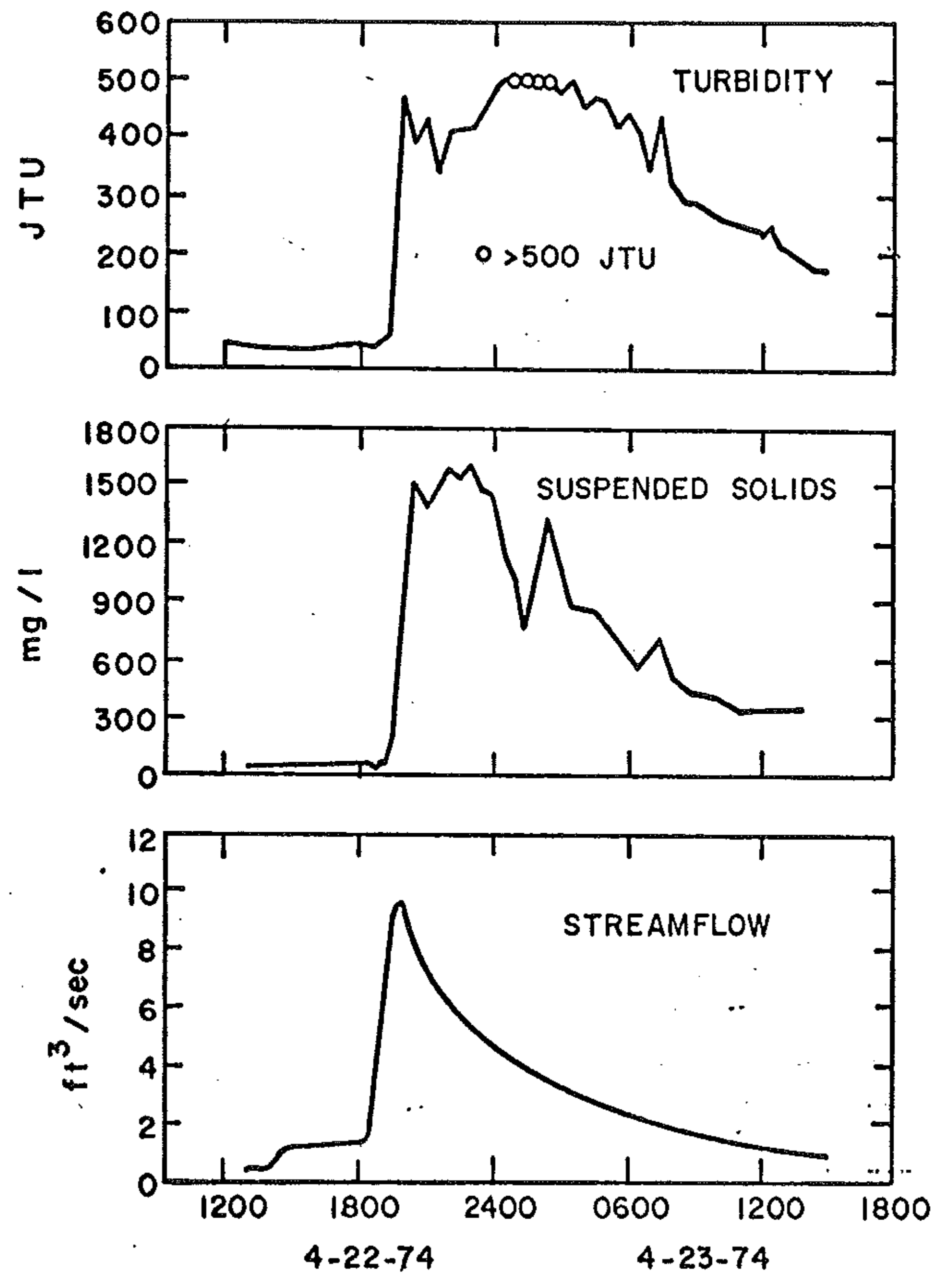

Figure 5. Temporal Distribution of Streamflow, Suspended Solids, and Turbidity for Storm Event of April 22-23, 1974.

The temporal distribution of soluble organic carbon (SOC), total COD, soluble COD and streamflow during the period of runoff is shown in Figure 6. Soluble COD and SOC fluctuate throughout the period of sampling and no definitive flush of these two parameters is evident. However, a definite increase in the concentration of total COD was recorded. Total COD values increased from a base-line concentration of 50-60 mg/l up to a peak value of 150 mg/l between 10-11 p.m. (April 22). The increase in total COD during storm runoff is associated with organics adsorbed onto particulate matter.

The pollutographs for nitrogen and phosphorus species are shown in Figures 7 and 8. The concentrations of ortho-phosphate and nitrite were extremely low (0.1 mg/l) and did not vary significantly during the period of runoff. Ammonia concentrations were slightly higher (0.25-0.50 mg/l) and more erratic than those measured for nitrite and ortho-phosphate. No definite flush of ammonia occurred. In contrast, total phosphorus, nitrate and Kjeldahl nitrogen all exhibited increased concentrations during the runoff event. For example, the concentration of total phosphorus increased from a base-line value of 0.05 mg/l to a peak of 1.14 mg/l at 10:30 p.m. (April 22).

Pollutographs were also developed for the following bacterial parameters: total bacteria, total coliform, fecal coliform, fecal streptococcus, probable Salmonella-Shigella sp., and Pseudomonas sp. Pseudomonas sp. exhibited no definite increase in concentration during the runoff whereas the other

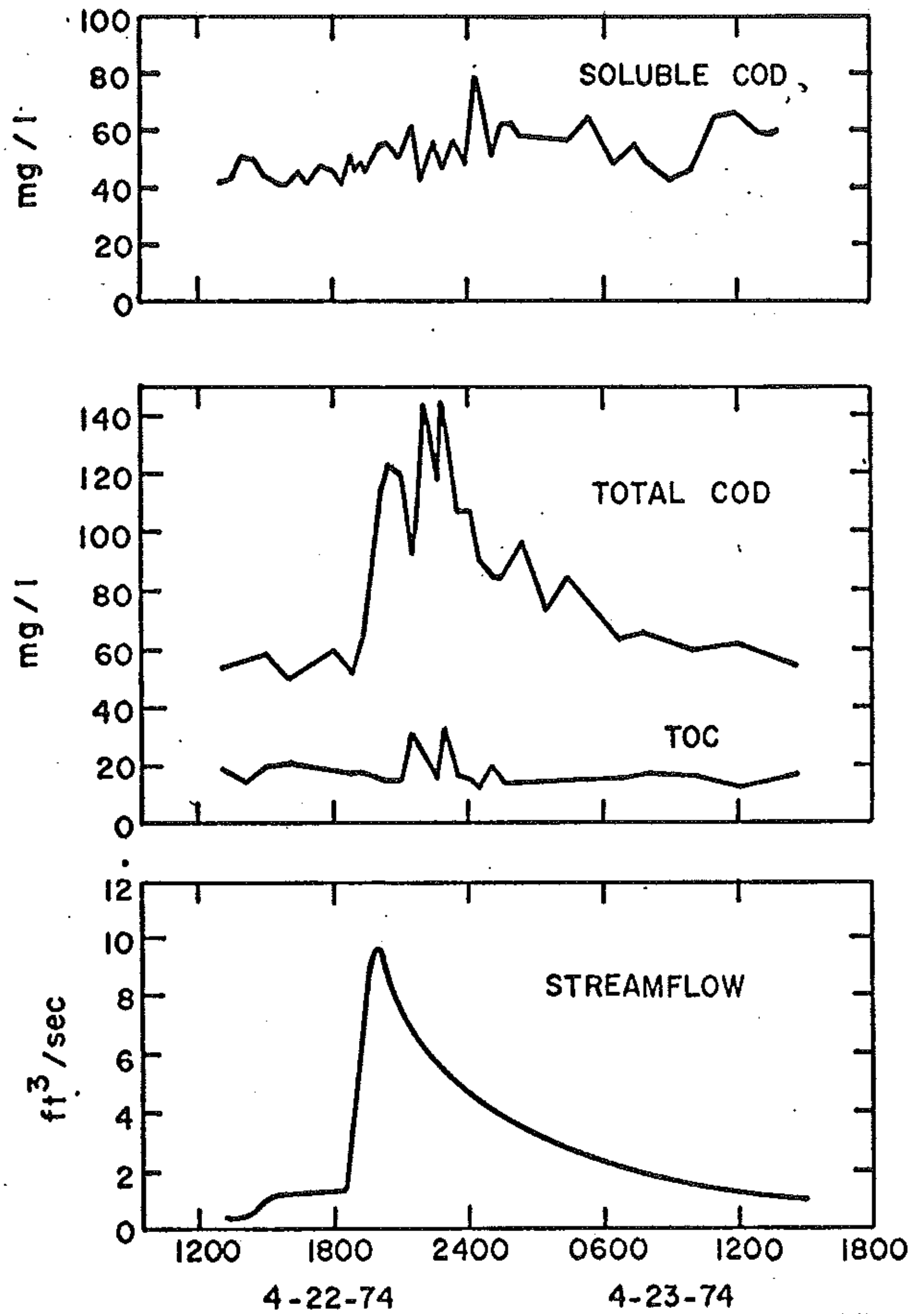

Figure 6. Temporal Distribution of Streamflow, Total Organic Carbon (TOC), Soluble COD, and Total COD for Storm Event of April 22-23, 1974.

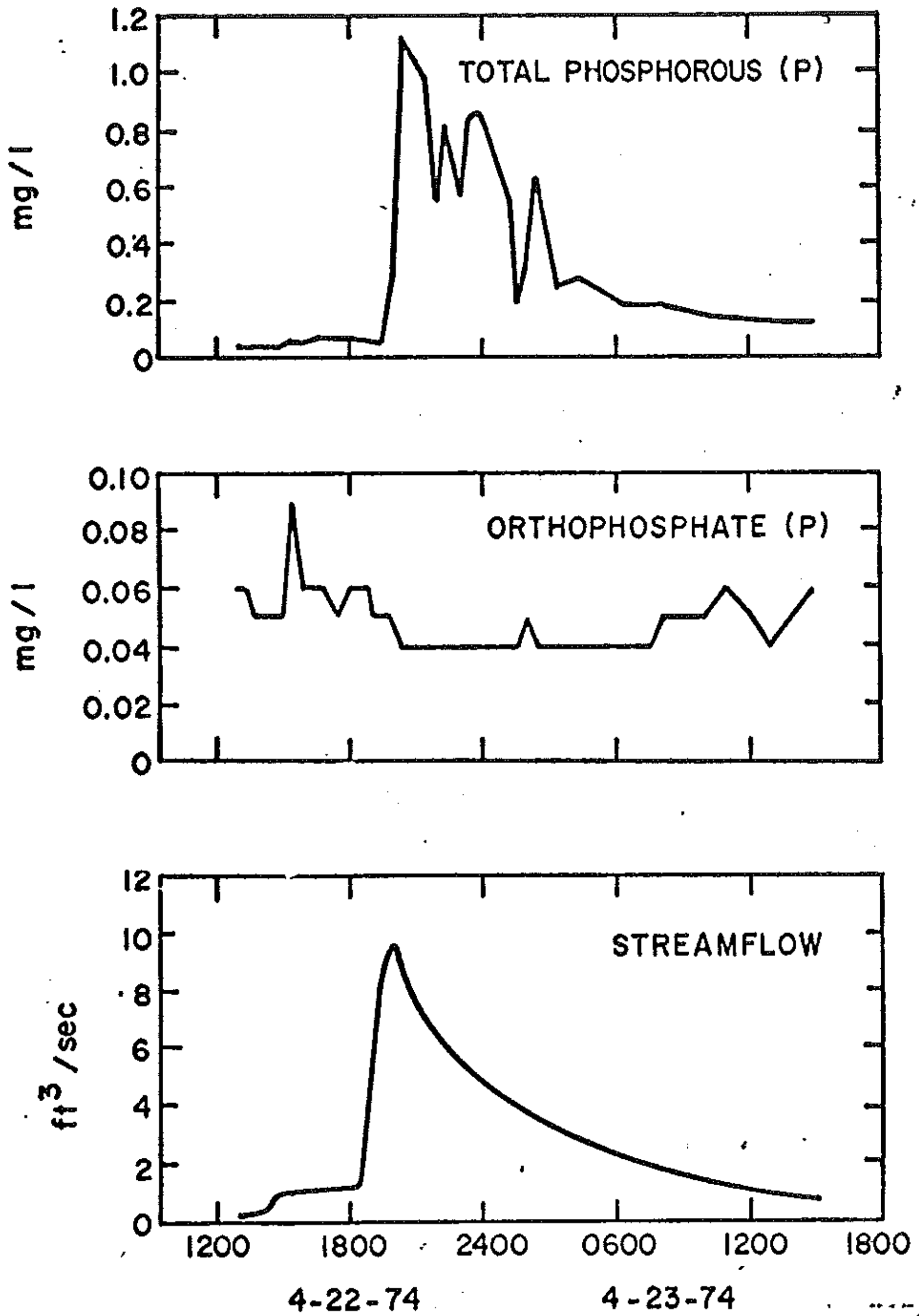

Figure 7. Temporal Distribution of Streamflow, Orthophosphate and Total Phosphorus for Storm Event 4-22 to 4-23, 1974.

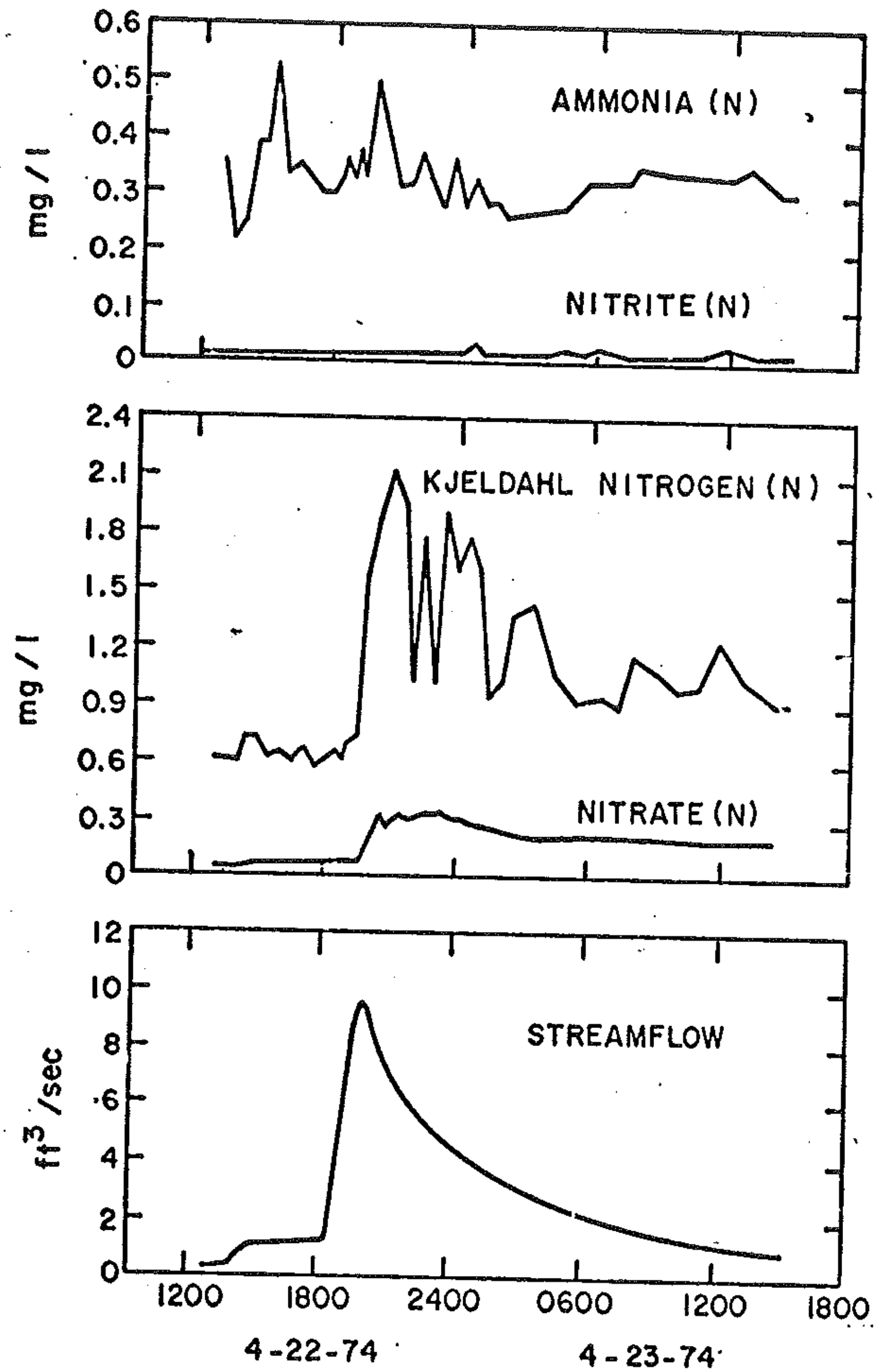

Figure 8. Temporal Distribution of Streamflow, Nitrate, Kjeldahl Nitrogen, Nitrite and Ammonia for Storm Event of 4-22 to 4-23, 1974.

five parameters exhibited definite increases during runoff.

Laboratory experiments were conducted with pure algal cultures to ascertain the limiting nutrient for the temporally collected storm water. Preliminary data on storm water collected from The Woodlands and Hunting Bayou indicates nitrogen to be the limiting algal growth nutrient.

Effective January 1, 1974, the storm sampling program was expanded within The Woodlands to include four sampling sites per storm event. Approximately one storm event will be monitored per month. If feasible, all four sampling sites will be monitored during each storm event. A fifth storm sampling site will be added to the program as soon as the first phase of construction in the residential areas is complete.

CONCLUSIONS

An integrated monitoring network has been established on the site of a planned community to monitor quantity and quality of the water resources. Initial data will provide base lines for comparison as the community develops. Woodlands, Texas, provides a unique opportunity because of its proposed "natural drainage" design and emphasis on design with nature.

Over fifteen water quality parameters for storm water runoff from developed and undeveloped watersheds have been monitored. The data provides management alternatives for the water resources system, including the beneficial use of waste water and storm water runoff for recreation and aesthetic purposes.

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