FORESTED WETLANDS FOR WATER RESOURCE MANAGEMENT IN SOUTHERN ILLINOIS

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ABSTRACT

FORESTED WETLANDS FOR WATER RESOURCE MANAGEMENT IN SOUTHERN ILLINOIS

A 30 ha cypress - tupelo (Taxodium distichum - Nyssa aquatica) floodplain swamp in Southern Illinois was studied for its hydrologic, biogeochemical and ecological characteristics. The hydrology, water chemistry, sediment dynamics and ecosystem productivity were described for the swamp and interactions with the adjacent Cache River were emphasized. A representative flood in the spring spilled water and sediments from the river to the swamp, temporarily reversing the normal flow of water from the swamp to the river. The annual hydrology budget for the swamp showed inflows of 74.4 cm throughfall, 63.9 cm runoff, and 21.9 cm groundwater; the outflows were 72.8 cm evapotranspiration, 54.9 cm surface outflow, and 21.0 cm groundwater, the latter two draining to the river. Loading rates for several chemical parameters were calculated from the swamp to the river and water chemistry of the swamp and river was contrasted. Primary productivity measurements showed high rates when the floating duckweed was included; cypress productivity was shown historically to be related to amount of flooding. A phosphorus budget was determined for the swamp and this indicated that the flooding river contributed over 10 times the phosphorus to the swamp as was discharged the rest of the year.

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KEYWORDS: wetlands / cypress swamp / phosphorus cycle / Taxodium / hydrology budget / sedimentation rates / flooding river / floodplain / water quality / swamps / primary productivity / ecosystem / Southern Illinois / non-point source loading / duckweed / nutrients

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EXECUTIVE SUMMARY

Forested wetlands are often found in close proximity to rivers, especially in the Southeastern Coastal Plain and in the Lower Mississippi River Basin as far north as Illinois and Indiana. The Cache River in Southern Illinois was found to have 4770 ha of forested wetlands in its 1912 km^2 drainage basin. The goal of this study was to describe the hydrologic, biogeochemical and ecological characteristics of a forested swamp in Southern Illinois, with particular attention paid to the interactions of the swamp with its adjacent river. It was also a goal of this study to demonstrate if these swamps are performing natural services that would otherwise cost man fossil fuel energy to achieve.

This study was conducted at Heron Pond, a 30 ha cypress - tupelo (*Taxodium distichum* - *Nyssa aquatica*) floodplain swamp adjacent to the Cache River. Heron Pond is separated from the river by a natural levee and is normally 2 - 3 meters above the river elevation. A seasonal flood in late March of the study period passed 16×10^6 m^3 of highly sedimented flood water over the swamp. An annual hydrology budget for Heron Pond showed that the inflows were 74.4 cm throughfall, 63.9 cm runoff, and 21.9 cm groundwater while the outflows were 72.8 cm evapotranspiration, 54.9 cm surface outflow, and 21.0 cm groundwater; the latter two draining primarily into the river. In March, inflows were 3.6 times greater than outflows while in June, outflows were 1.9 times greater than inflows. Evapotranspiration experiments in June showed that approximately 57 percent was

due to duckweed (Azolla mexicana and Spriodela polyrhiza). An open surface without tree shading was shown to evaporate 14 percent more. Analysis of the flood data showed that the floodplain swamps aided in floodwater storage and a reduction in peak discharge.

Water chemistry data indicates that the swamp has no apparent nutrient deficiency although its acidic and reduced conditions may reduce availability. The following loadings to the river from the swamp in gm/m^2-yr were calculated: P-0.183; N-1.03; total solids - 282; SO_4-S - 5.1; K^+ - 2.33; Mg^{++} - 1.88; Na^+ - 2.06; Ca^{++} - 4.74. Export levels were similar to or lower than those from undisturbed forests for several parameters and were far less than disturbed ecosystems. Water concentrations were lower in the swamp discharge than in the river itself for: alkalinity, hardness, conductivity, total dissolved solids, $SO_4^=$, NO_3^-, NO_2^-, K^+, Mg^{++}, Na^+, and Ca^{++}. Discharges from the swamp were higher than the river in COD, NH_3^-, and TKN. Although phosphorus values were similar, the river contained considerably more insoluble phosphorus during the flood season.

Sedimentation traps, litter traps, and tree growth analysis showed the ecosystem net primary productivity to be 1963 gm/m^2-yr, 56% of which is associated with the duckweed. Tree productivity is considerably less than that found in a Louisiana cypress - tupelo swamp; the primary reason is probably the increased water levels in Heron Pond created by a beaver dam 10 years ago. The flood was estimated to have contributed 447 gm/m^2 of sediment to the swamp, or 8.4% of the total measured during the year. Tree ring analysis showed a significant relationship between cypress tree growth and flooding of the swamp, suggesting that the highly nutritive sediments increase swamp productivity.

A phosphorus budget was constructed with the above data and with phosphorus analysis of water and ecological materials. Based on a square meter of swamp surface, 729 g-P/m^2-yr discharges past the swamp in the river. Of that, approximately 80 g-P/m^2-yr passed over the swamp during the flood and 3.6 g-P/m^2-yr of that was sedimented out. Approximately 0.87 g-P/m^2-yr is taken up by the trees while about 3.3 g-P/m^2-yr is cycled due to all understory productivity in the swamp, primarily from the floating duckweed. Rainfall, runoff and groundwater contributed approximately 0.25 g-P/m^2-yr while 0.34 g-P/m^2-yr discharged from the swamp during the non-flooding times. Thus, the swamp took in 11.3 times the amount of phosphorus it discharged during the study period.

Preliminary calculations showed that it would cost the equivalent of $18,500/year in dollar terms or 415 barrels of oil equivalent/year in energy terms to perform through technological alternatives the phosphorus removal and flood control performed by the swamp during the study year.

INTRODUCTION

by

William J. Mitsch

Wetlands have come under increased study in recent years. This renewed interest is due to two major factors. First, a significant number of natural wetlands throughout the nation have been drained due to increased land requirements, especially for agricultural fields and urban centers. It was estimated in 1968 that only 55 percent of the original 51 million hectares (127 million acres) of wetlands in the United States remained and that this was disappearing at a rate of one percent per year (Niering, 1968). A second factor involves the importance of these areas to man. Benefits include wildlife conservation (Shaw and Fredine, 1956), water management (Dachnowski - Stokes, 1935; Goodwin and Niering, 1974; Odum _et_ _al_., 1974), sediment removal (Wharton, 1970), wastewater recycling (Odum _et_ _al_., 1974, 1975, 1976, 1977; Brown _et_ _al_., 1974; Grant and Patrick, 1970; Kadlec _et_ _al_., 1974; Mitsch, 1975) and background nutrient control (Kitchens _et_ _al_., 1974).

Southern Illinois Wetlands

The southern-most counties of Illinois have a few scattered remnants of forested wetlands that were estimated to originally cover 100,000 hectares (Anderson and White, 1970). This area is in the northern extreme of the bottomland forests of the Southeastern Coastal Plain and the lower Mississippi basin. Bald cypress (*Taxodium distichum*) and water tupelo (*Nyssa aquatica*) dominate those swamps which have standing water most of the year. The riverine swamps are usually hydrologically connected to nearby streams and rivers for at least part of the year.

The Cache River watershed (Fig. 1) covers 1912 square kilometers of southern Illinois in Union, Johnson, Alexander, Pulaski, Massac, and Pope counties. Analyses of aerial photographs and topographic maps of the watershed showed 4770 ha of forested wetlands within the drainage basin. While this is one of the main wetland areas in southern Illinois, it comes considerably short of the 100,000 ha estimate given above; many of the former wetlands in this watershed have been drained for use as agricultural land after logging.

The Cache River originates in the Shawneetown Ridge, an east-west escarpment of the Pennsylvanian period (Voigt and Mohlenbrock, 1964). Much of the Cache River itself flows in an abandoned channel of the Ohio River. The Post Creek cutoff, constructed in the 1910's, creates a short-circuit for the Cache River to the Ohio River (see Fig. 1), dividing the Cache Basin into essentially two drainage areas. As the Cache River reaches the lower half of its course out of the Shawnee Hills, the land suddenly flattens and drainage conditions change to slow flowing and meandering channels and numerous wetlands characteristic of the Coastal Plain. The lower Cache valley, in fact, is inundated by the Ohio River itself on an average interval of 100 years (Gooding, 1971). It is in this environment that this study was conducted.

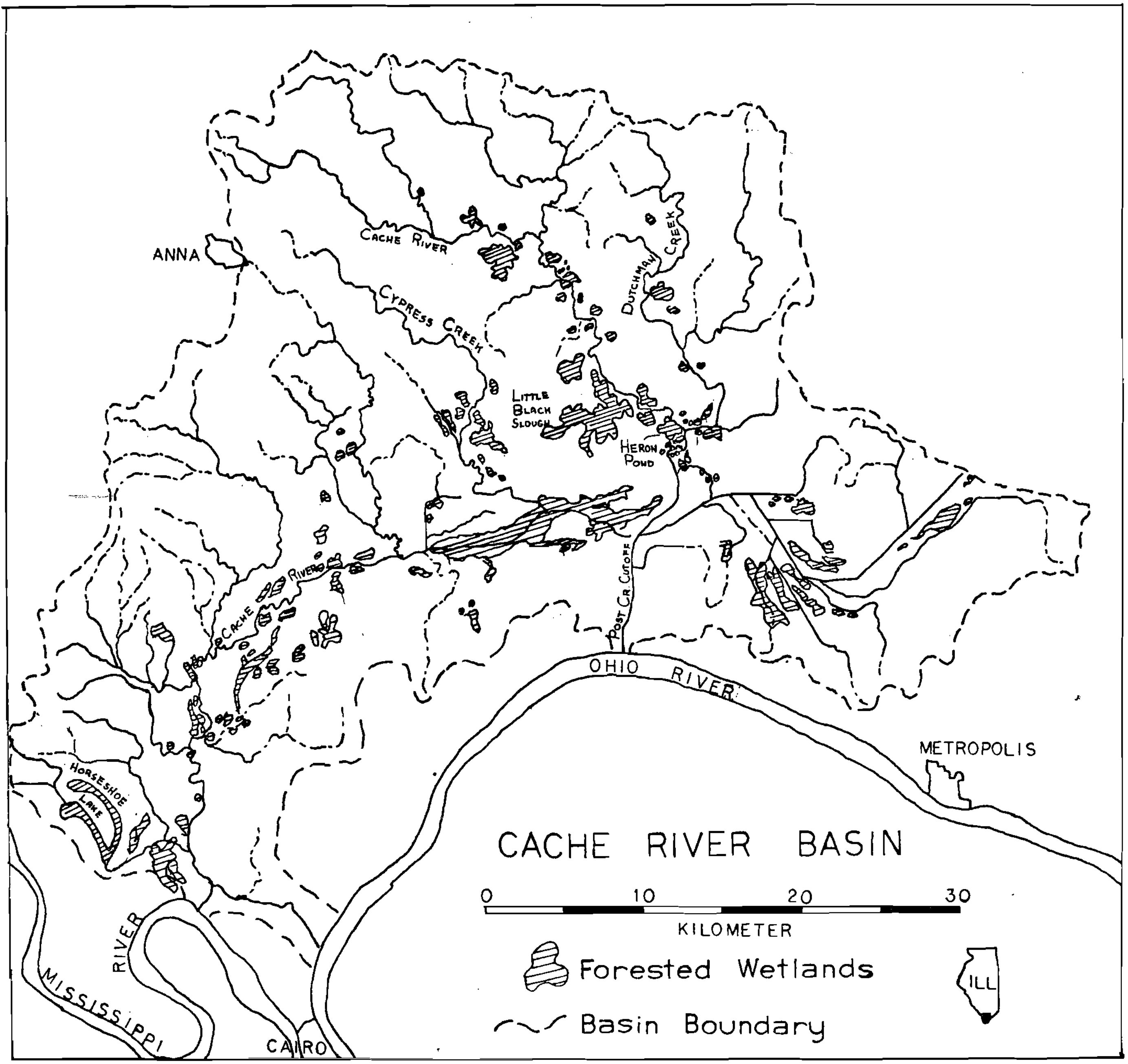


Figure 1. Forested wetlands in the Cache River basin

Heron Pond

Heron Pond, a 30 ha cypress - tupelo swamp in Johnson County and adjacent to the Cache River near Vienna, was used as the study site in this research. Fig. 2 shows the swamp and river location along with sampling locations discussed throughout this report. Heron Pond, so named because of its former function as a rookery for the Great Blue Heron, is presently a nature preserve maintained by the Illinois Department of Conservation. It is part of a much larger parcel of swamp land called the Little Black Slough, one of the largest tracts of wetlands ever purchased for conservation measures (Wharton, 1977). The site was chosen for study because of the relative seclusion and protection offered by the state preserve, because of the unique drainage conditions which facilitate outflow measurements, and because previous research had been conducted in this swamp. Anderson and White (1970) conducted a floristic study of the swamp; these investigators suggested a recent high mortality of tupelo around the swamp's edge to be due to higher water levels caused by beavers. It has been estimated that the beavers entered the area in 1967 (Max Hutchison, personal communication). Some of the swamp had been logged in the past.

Research Design

This study was designed to be an ecosystem level look at the cypress-tupelo swamps of southern Illinois and to describe the importance of these swamps in local biogeochemical and hydrological cycles. Furthermore, quantification of potential benefits of forested wetlands to man in water resource management was a primary objection of the research. These benefits may include flood control, drought control, enhancement of water quality, and sediment retention.

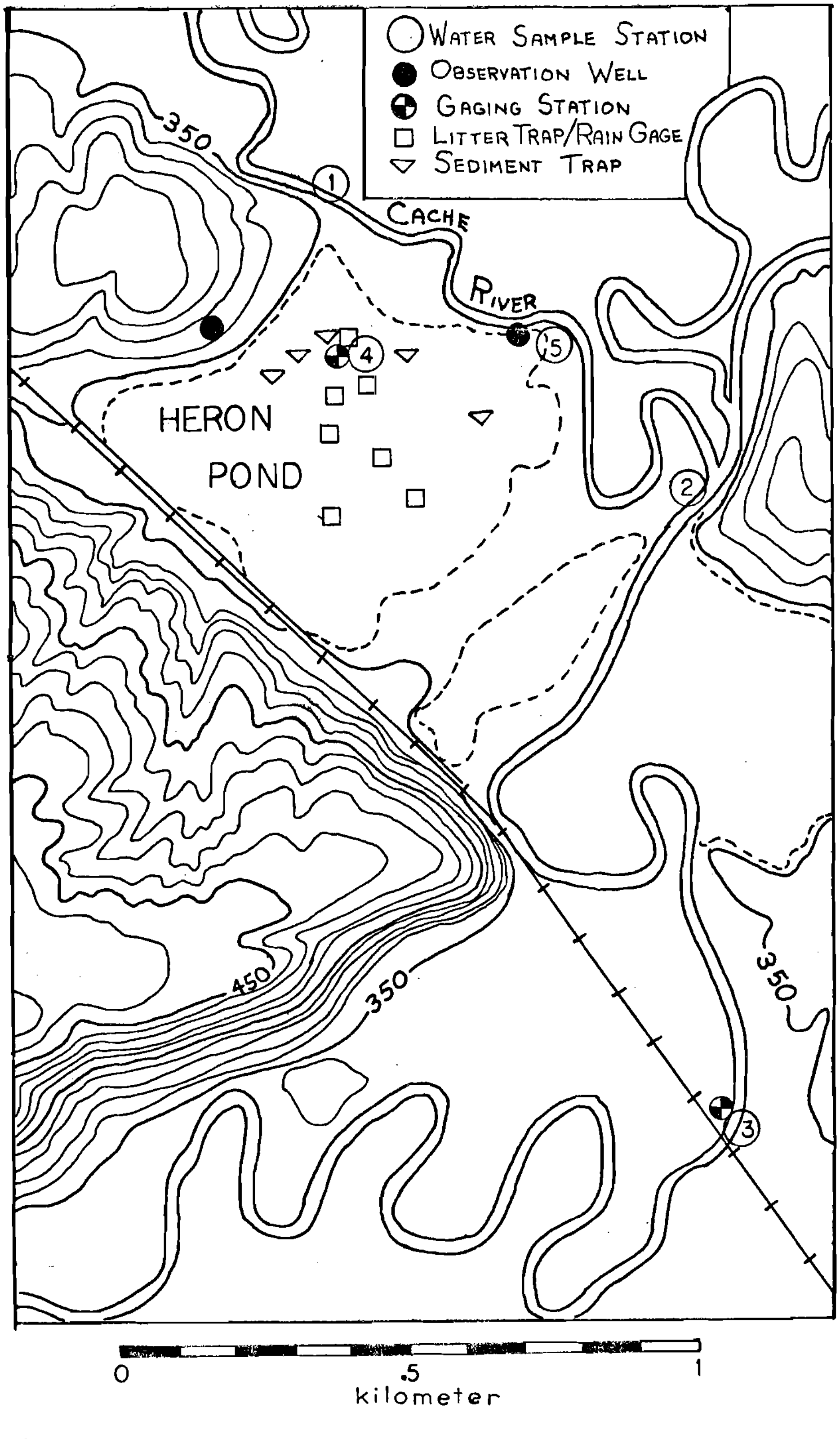


Figure 2. Location of sampling stations in Heron Pond

These objectives were pursued with one year of field and laboratory measurements of Heron Pond as a part of the Cache River floodplain; hydrologic, geochemical and ecological connections between the swamp and the river were described.

Fig. 3 shows the typical relationship of a floodplain swamp and river in the Coastal Plain area of southern Illinois. Southern Illinois is often described as having significant water shortage problems despite adequate annual precipitation (Illinois State Water Survey, 1975). This is due to a pronounced low flow period in the streams in late summer coupled with a minimal groundwater storage. During the flood season, however, water is more abundant than necessary.

It has been shown that increased flooding of the Mississippi River can be explained by the increased use of channels and levee systems replacing the meandering river with its floodplain (Belt, 1975). This study investigated the value of forested wetlands as natural reservoirs with significant floodwater storage in the wet season and slow water recharge in the dry season. The study was aided by a representative annual flood which occurred on March 29, 1977 which contributed data on our knowledge of swamp - river interactions.

Biogeochemical studies were designed around water, sediment, and vegetation analyses and measures of ecosystem structure and function. While output levels and swamp - river comparisons were determined for several chemical parameters, a complete biogeochemical cycle was determined only for phosphorus. A system diagram showing the major energy storages and flows is given in Fig. 4. A model of the phosphorus cycle in the swamp is shown

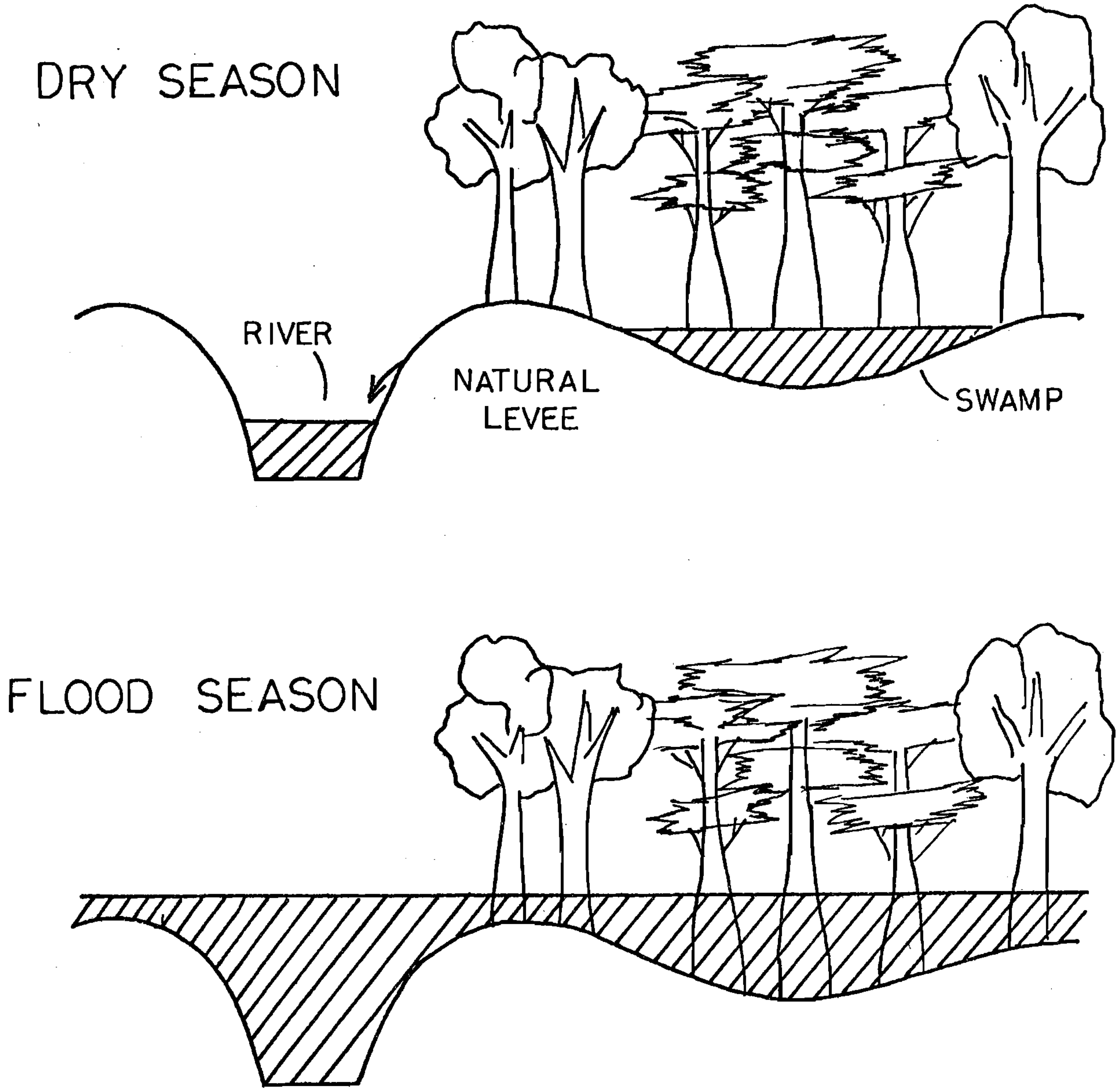


Figure 3. General relationship between Heron Pond and Cache River during dry and flood seasons.

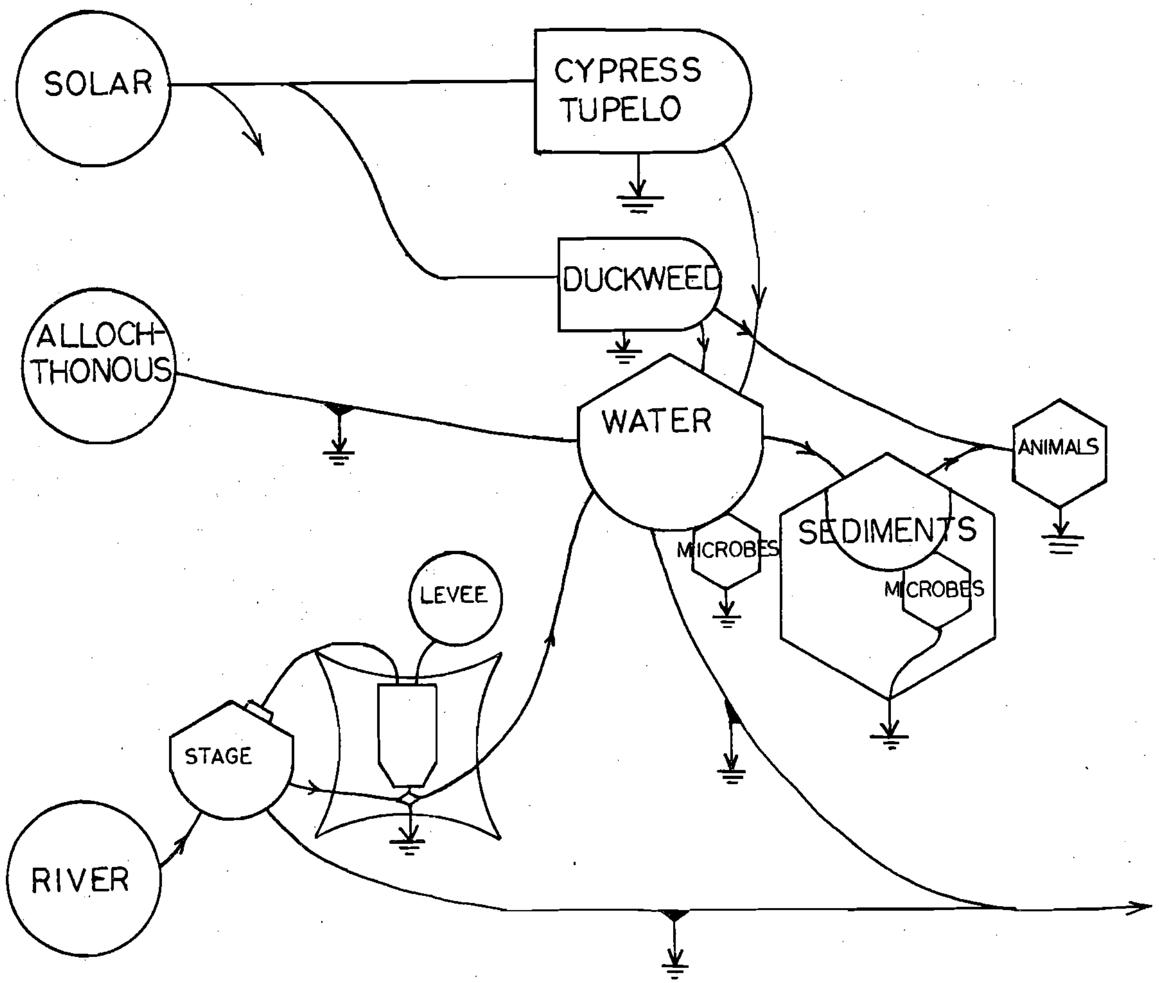


Figure 4. Systems diagram of energy flow in Heron Pond

in Fig. 5. Models such as these were used to design the sampling program. While the models are similar in appearance, Fig. 4 shows that energy makes a one way trip through the system while phosphorus (Fig. 5) is cycled again and again from biotic to abiotic compartments. It is this system view which dominates this study and allows for a study of the parts to be brought together as a culmination of the research.

Figures 6 through 10 show photographs of the Heron Pond study area and some of the research sites. The research results are presented for convenience in this report as individually authored papers under the following phases:

Phase I	Hydrology
Phase II	Water Chemistry
Phase III	Ecosystem Studies
Phase IV	Systems Analysis

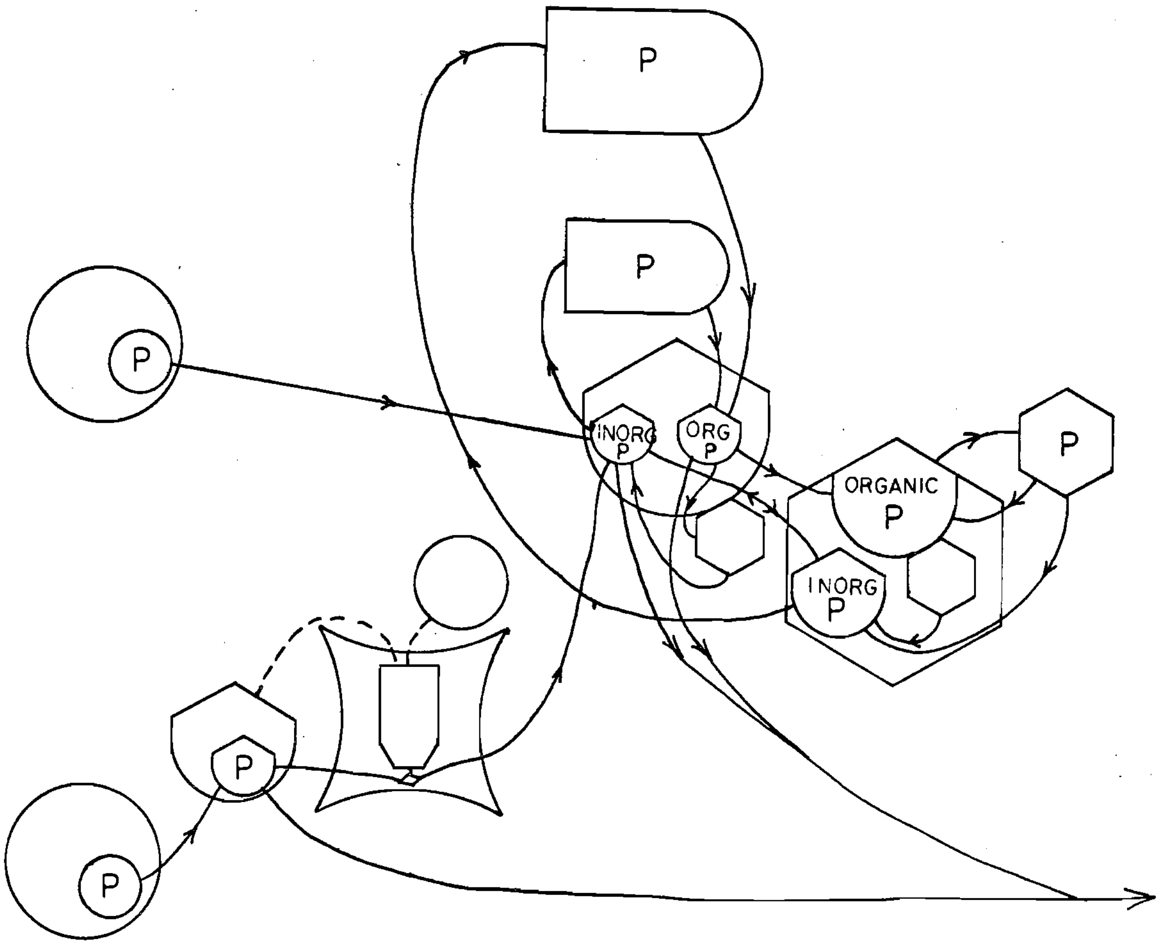


Figure 5. Systems diagram of phosphorus flow in Heron Pond symbols similar to Figure 4.

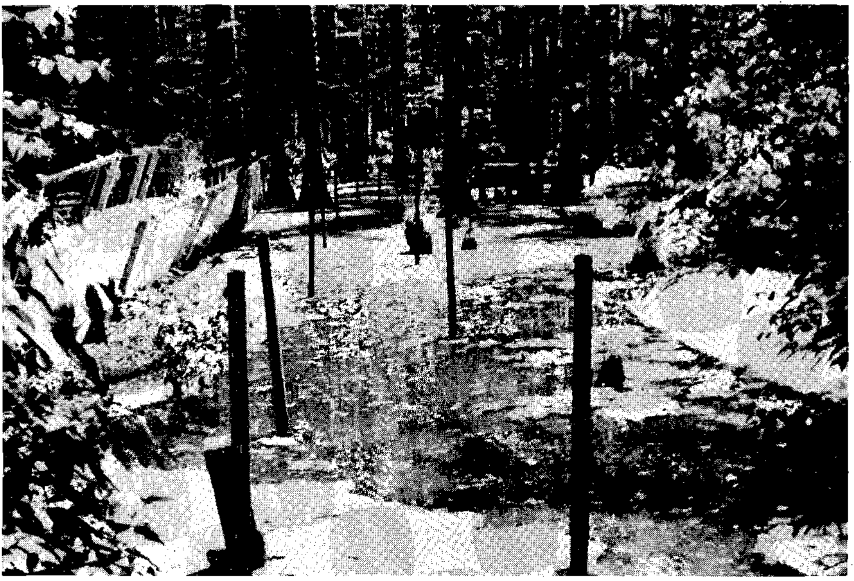
Figure 6. General view of Heron Pond

A. October 1976 with foliage in full bloom

B. January 1977 with pond frozen

Figure 7. Seasonal changes seen in Heron Pond during study period.

C. April 1, 1977 during flood



D. June 1977 showing aftermath of flood

Figure 7 (continued)

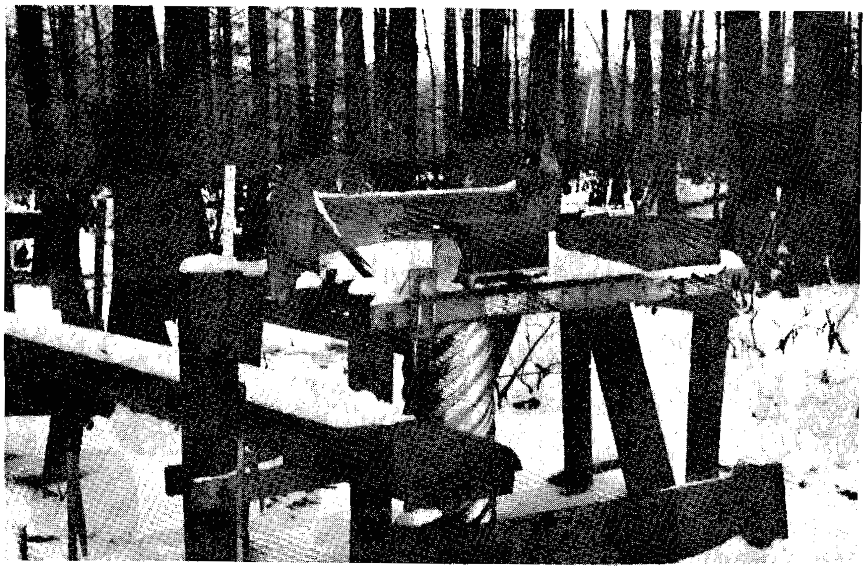


Figure 8. Water level recorder platform in Heron Pond

Figure 9. Outflow weir at Heron Pond

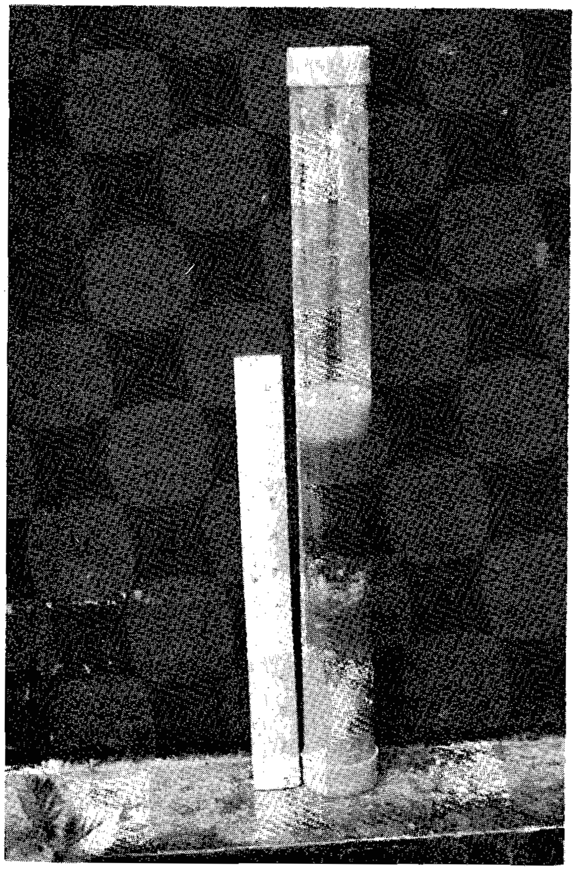


Figure 10. Sediment core taken from Heron Pond

PHASE 1 - HYDROLOGY

Heron Pond Annual Water Budget

By

John Wiemhoff

INTRODUCTION

This project investigated the hydrology of Heron Pond, a cypress - tupelo swamp bordering the Cache River in Southern Illinois, in an attempt to quantify its water management contribution. From the data generated in this study, it will be possible to extropolate to the entire wetland area of Southern Illinois to approximate the value of all southern Illinois wetlands in providing less extreme annual flood - drought cycles.

The Cache River is the outlet for the drainage from 720 square miles of territory in Union, Johnson, Alexander, Pulaski, Massac, and Pope counties. Although many attempts have been made to drain all lands (prior to conservation of these wetlands), portions of the floodplain are periodically or continually flooded (Pickels and Leonard, 1921).

Heron Pond is 5 miles south of Vienna in Johnson County. The site includes Heron Pond Nature Preserve, now owned and maintained in its natural state by the Illinois Department of

Conservation. In a botanical study of Heron Pond, Anderson and White (1970) observed this remnant of once numerous old growth cypress swamps. The swamp, about 90 acres in size, receives flood water, often at least once a year from the Cache River. The soil underlying Heron Pond is mapped as Piopolis clay, a poorly drained acid, fine textured soil, a silty clay loam. The average January temperature at New Burnside, 20 miles to the northeast is 34.6^{o}F and the average July temperature is 78.6^{o}F. The average rainfall is 45.1 inches and the length of the growing season is about 187 days. At the time of sampling in 1968 by Anderson and White, the water depth in the pond varied from 2 to 4 feet and local residents indicated that the swamp never dries up.

As land use pressures mount, both for urban and agricultural use, the common practice of systematically draining forested wetlands must be curtailed until the benefits of these wetlands to the local water resources can be determined. These areas have been drained and the adjacent rivers channelized, yielding extensive agricultural lands (Wall, 1905). Forested wetlands may have significant value in providing "reservoir capacity" during floods, and providing slow water recharge in low flow season.

In southern parts of Illinois sufficient groundwater is not always available (Gunning, 1963), and the Mississippi, Wabash, and Ohio Rivers are heavily utilized as sources of surface water. It is a misconception by many that the southern most 17 counties of Illinois are water deficient (Illinois State Water

Survey, 1957). The region is bordered on three sides by the Mississippi, Ohio, and Wabash Rivers, and the highest mean rainfall within the state occurs there. This paradox is explained by the fact that streamflow is highly variable in southern Illinois. This is due to limited groundwater contribution and high percentage of thunderstorm type rainfall. During the wet season, water is more abundant than necessary, and with the elimination of swamp storage and construction of channels and levee systems, large rivers as the Mississippi experience increased flooding.

With this in mind, it was the goal of this portion of the study to determine the usefulness of forested wetlands to the hydrologic scheme by determining the water budget of a typical river cypress swamp, Heron Pond.

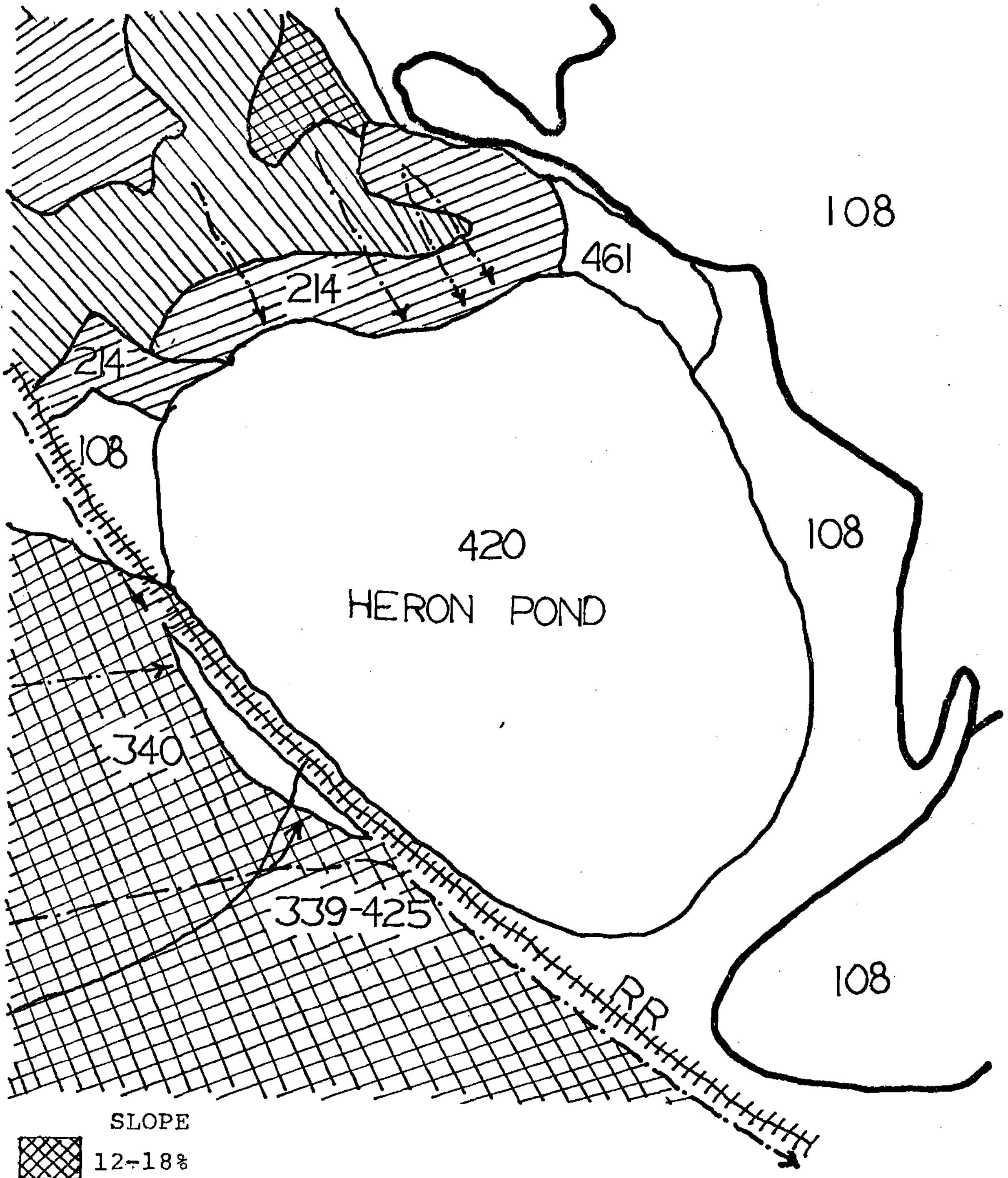
Soils

The old Ohio River valley or alluvial plain along the south line of Johnson county is characterized by alluvial terraces and recent floodplains of the Cache River and Bay Creek, (U.S.D.A., 1964). Except for terrace ridges, this area has been wet and very poorly drained until dredging, channel straightening, and construction of the Post Creek cut-off which runs south from the eastern end of the old Ohio River valley, across Pulaski county for about 5 miles to the Ohio River, short circuiting some of the normal flow of the Cache River away from the Mississippi River. Today, as is seen by such areas as Little Black Slough and Heron Pond, some of the floodplains are poorly drained, with cypress and tupelo swamps still present.

The Karnak - Dupo Association soil, which includes Heron Pond, occurs mainly in the southwestern part of Johnson county in the lowlands along the Cache River, occupying less than 30% of the total area of the county. These soils are nearly level, poorly to imperfectly drained soils of the lower Cache River floodplain (Fig.11). These soils are derived largely from sediments left by the Ohio River when it flowed through this valley. Piopolis clay, the soil over which Heron Pond lies, is an acid silty clay loam to a depth of 40 inches or more. Piopolis silty clay loam (Fig.12, #420) is poorly drained with very impermeable characteristics (Table 1).

Bonnie silt loam (Fig.13) making up the natural levee between Heron Pond and the Cache River, is a gray, poorly to very poorly drained soil type found in low lying bottomland areas that have had poor natural drainage. It is in this natural levee that well #1 was installed to determine groundwater flow from Heron Pond to the Cache River.

Hosmer silt loam (Fig. 14), with a slope of 7 - 12%, is adjacent northwesterly to the swamp, and is the site of well #2, used to determine flow into the swamp from adjacent higher land elevations. Hosmer silt loam is a light colored, moderately well drained upland soil type developed under forest. The parent material is usually more than 80 inches of loess. Hosmer occurs in western and southwestern Johnson county, associated in this case with Zanesville soil. The upper part of the Hosmer profile has good moisture - storage capacity and is permeable to water and plant roots. However, the slightly to moderately well developed fragipan in the lower



SLOPE

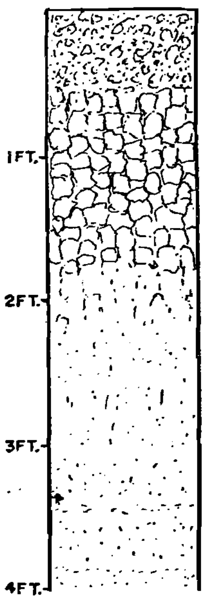
▩ 12-18%
▨ 7-12%
▧ 4-7%
☐ 0-1.5%

Soil Types

420	Piopolis Silty Clay Loam
108	Bonnie Silt Loam
214	Hosmer Silt Loam
461	Weinbach Silt Loam
340	Zanesville Silt Loam
339-425	Wallston - Muskingum Complex

Figure 11. Soil Types Bordering Heron Pond

Piopolis silty clay loam (420A), representative profile



A$_1$ (0-6″)	Grayish-brown (10YR 5/2), with some mottles and streaks of red (2.5YR 4/6), firm silty clay loam with granular to fine subangular blocky structure. pH 5.2.
BC (6-20″)	Gray (10YR 5/1), with some mottles of dark brown (7.5YR 4/4) and dark grayish-brown (10YR 4/2), firm silty clay loam with weak to moderate, coarse blocky structure. pH 5.1.
C (20″+)	Gray (10YR 5/1), mottled with yellowish-red (5YR 4/6) and light gray (10YR 7/1), firm silty clay loam with little if any structure. pH 5.3

Figure 12. Piopolis Silty Clay Loam Profile (U.S.D.A., 1964)

Table 1

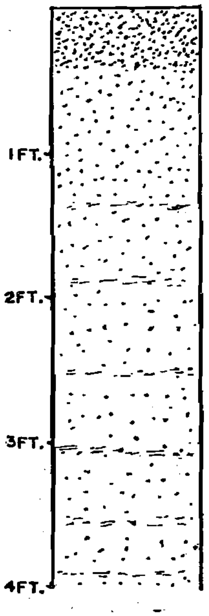
Properties of the Soils Bordering Heron Pond*

			Hydrological		Characteristics	
Soil type and Number	Depth to Seasonal High Water, m	Depth to Bedrock, m	Depth from Surface, cm	Shrink-Swell Potential	Available water cm of depth	Range Permeability cm/day
Piopolis Silt Clay Loam(420A)	0-1	>3	0-107	High	0.53	3.0-12.2
			107-152	High	0.51	0.0-3.0
Bonnie Silt Loam(108A)	0-1	3*	0-51	Moderate to Low	0.76	12.2-48.8
		1**	52-89	Moderate to Low	0.76	3.0-12.2
			90-152	Moderate to Low	0.76	12.2-48.8
Hosmer Silt Loam(214D)	>3	2-4*	0-30	Moderate to High	0.61	48.8-152.4
		1**	31-76	Moderate to High	0.69	12.2-48.8
			77-152	Moderate to High	0.71	3.0-12.2
			>152	Moderate		12.2-48.8
Weinbach Silt Loam(461A)	1.5-3.0	>3	0-30	Moderate to Low	0.66	12.2-48.8
			31-91	Moderate to High	0.66	3.0-12.2
			92-152	Moderate to High	0.56	12.2-152.4
Zanesville Silt Loam(340E)	0.5-1.0	0.5-1.0	0-30	Moderate to Low	0.61	48.8-152.4
			31-91	Moderate to High	0.69	12.2-48.8
Wellston-Muskingum Complex(339-425E)	0.2-0.5	0.2-0.5	0-30	Low		48.8-152.4

* Modified from <u>Soil Survey: Johnson County</u>, Illinois, University of Illinois (U.S.D.A., 1964)

** Average

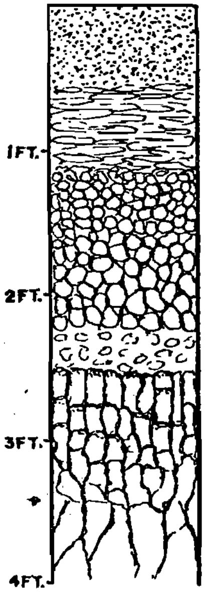
Bonnie silt loam (108A), representative profile



A_1 (0-4″)	Dark grayish-brown (10YR 4/2) to grayish-brown (10YR 5/2) friable silt loam with weak crumb to platy structure. pH 4.7.
C (4-15″)	Light brownish-gray (10YR 6/2) to light gray (10YR 7/2) friable silt loam with numerous very dark grayish-brown (10YR 3/2) iron stains and concretions. Nearly structureless. pH 4.7.
C (15″+)	Mixed light brownish-gray (10YR 6/2) and white (10YR 8/1) friable silt loam with numerous iron concretions. Massive, breaking out in large irregular clods when dry. pH 4.5.

Figure 13. Bonnie Silt Loam Profile (U.S.D.A., 1964)

Hosmer silt loam, 1.5- to 4-percent slopes (214B or WB), representative profile



A_p (0-6")	Dark grayish-brown (10YR 4/2) friable silt loam with weak crumb structure. pH 5.0.
A_2 (6-14")	Brownish-yellow to yellowish-brown (10YR 6/6-5/4) friable silt loam with platy structure. pH 4.7.
B_1 (14-18")	Yellowish-brown (10YR 5/4) firm, heavy silt loam to silty clay loam with granular to fine subangular blocky structure. pH 4.7.
B_2 (18-28")	Yellowish-brown (10YR 5/4) to brown (7.5YR 5/4) firm silty clay loam to heavy silt loam with subangular blocky structure. Few dark brown (7.5YR 4/4) clay coatings present. pH 4.8.
A_2' (28-31")	Yellowish-brown (10YR 5/4) to brown (7.5YR 5/4) firm silty clay loam with subangular blocky structural aggregates which are coated with light gray (10YR 7/2). Some dark brown (7.5YR 4/4) clay coatings present. pH 4.7.
B_2' (31-39")	Brown (7.5YR 5/4) to yellowish-brown (10YR 5/4), mottled with gray (10YR 6/1) and yellowish-brown (10YR 5/8), very firm silty clay loam with coarse prismatic breaking to coarse blocky structure. Thick dark brown (7.5YR 4/4) clay coatings present. pH 4.8.
B_3' (39-48"+)	Similar to B_2' but having weaker, much coarser blocky structure and fewer clay coatings, and approaching silt loam in texture, especially in the lower part. Large polygonal blocks bounded by gray streaks of clay and silt are present. pH 4.9.

Figure 14. Hosmer Silt Loam (U.S.D.A., 1964)

part of the profile allows root penetration only in the gray streaks. Since few roots penetrate the fragipan, little moisture is obtained in this zone. Hosmer is the most extensive soil type in Johnson county, occupying more than 30% of the county.

Weinback silt loam is very level as is Bonnie silt loam and is also found on a short stretch between Heron Pond and the Cache. It is an imperfectly drained forest soil type developed on the Ohio River terraces which border what is now the Cache River and Bay Creek flood plains in southern Johnson county. After the Ohio abandoned its channel, Cache River and Bay Creek occupied the valley. But the terrace sediments are largely those left by the Ohio. This area of Weinback is one of the short circuits the Cache River makes out of its channel while flowing through Heron Pond during floods.

Zanesville silt loam is 12 - 18% in slope in this study area and borders the southwest part of Heron Pond. The surface of the overall area exhibits 3 large seasonal runoff ravines. This soil is well drained, light in color, developed under forest from about 40 inches of loess over sand stone residium or sand stone bedrock. There is fragipan development in the lower part of the profile of Zanesville, but it is not as strongly expressed nor as thick as the fragipan of Hosmer.

Wellston - Muskingum complex occupy steep slopes to the south of Heron Pond. These soils are well drained to excessively drained. Because sand stone occurs at shallow depths, they are somewhat poor for tree growth. Also, stones are frequent. Wellston may have as much as 20 inches of loess parent material in its profile.

The soils of major concern in this study were 1) Piopolis Silt Clay Loam, over which Heron Pond sits and which, with its clay lens just beneath the upper sediments, was assumed to be impermeable (Table 1), and 2) Bonnie Silt Loam, in which the groundwater loss from Heron Pond to the Cache River, was determined with permeability constants using Darcy's law.

METHODS

To determine the various flows and storages in the swamp hydrologic system, a water budget was computed on a daily basis. A summary diagram of the gaging devices used is given in Fig.15. A water budget is a quantitative statement of the balance between the total water gains and losses of the swamp for a given period of time. The budget considers all water entering, leaving, or stored within the swamp. The following equation describes the relationship between the significant water budget components:

$$\frac{dS}{dt} = TF + RO + G_{in} - ET - WEIR$$

Where

TF = Throughfall

RO = Runoff

*G_{in} = Net Groundwater input

ET = Evapotranspiration

WEIR = Stream flow out through channels

* Net Groundwater input can be separated into groundwater flowing in and groundwater flowing out.

The daily change in level of Heron Pond will be reflected by the daily flows into or out of the swamp by these various pathways. Since the most difficult component to measure in this equation is the net groundwater flow, the equation is rearranged to solve with that component being the only unknown:

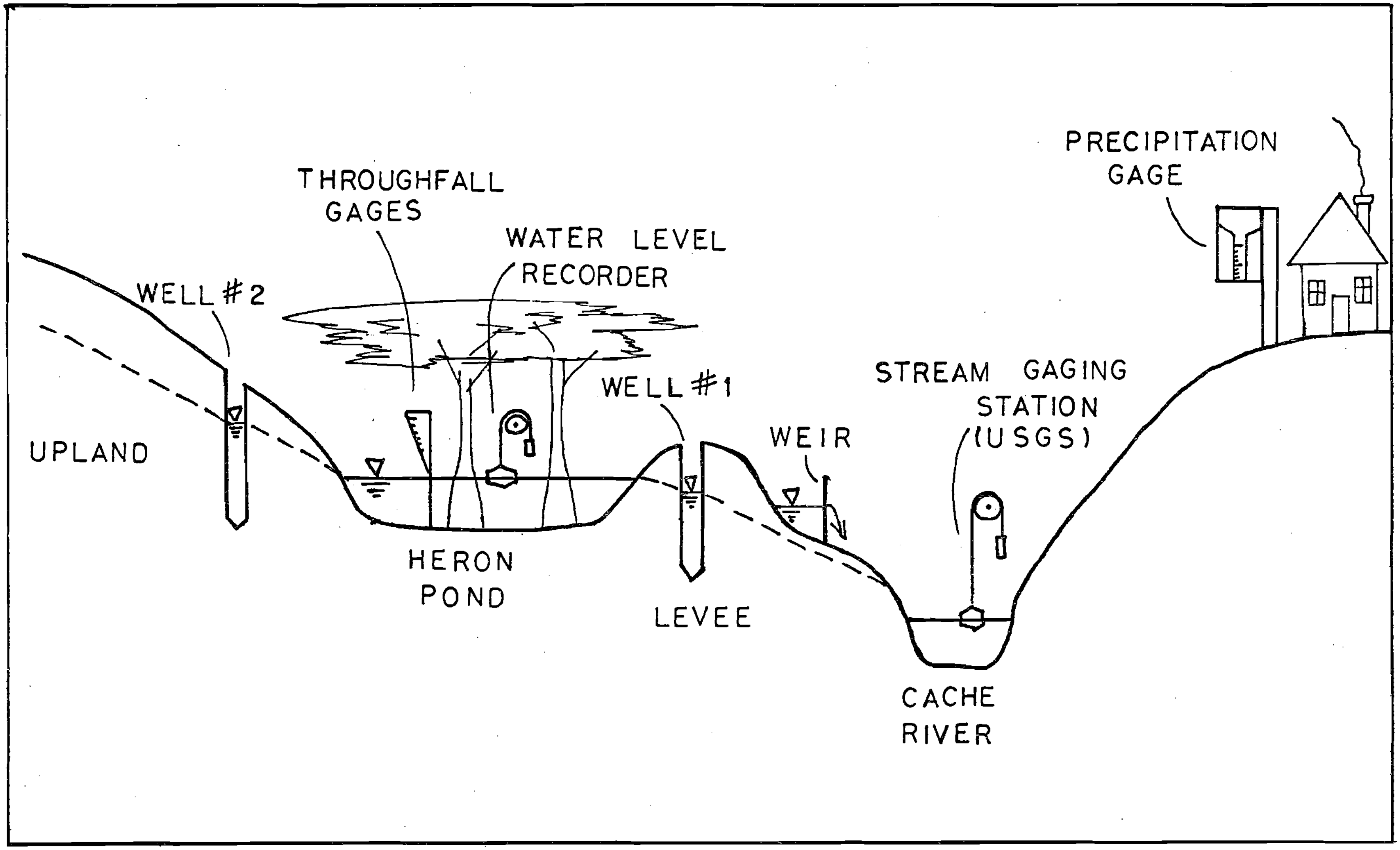


Figure 15. Hydrologic Measuring Devices Used For Hydrologic Budget at Heron Pond

$$G_{in} = \frac{dS}{dt} - TF + ET + WEIR - RO$$

Since the study area was not accessable on a daily basis, the only component that was measureable on a continuous basis was the water level. This component was graphed on a continuous basis by a Stevens Type F water level recorder (Fig.16). All other components were approximated by deriving correlations between them and parameters that are measured on a daily basis within the general study area. By interpolating on a daily basis from these correlations, the approximate component values are derived.

The daily budget was calculated by a computer program which did the following:

(1) Each subsequent daily water level as recorded at 8:00 am was entered, and then substracted the previous days water level to yield the daily change, in cm.

(2) Flows of throughfall, evapotranspiration, weirflow (surface outflow) and runoff were calculated on a daily basis by equations to yield their regression contributions to water level changes, also in cm.

(3) The residual calculated in the equation is the net groundwater input into the swamp.

For the water budget program to function in this manner, an assumption had to be made that changes in water level had no effect on the surface area of swamp, i.e. the sides of the swamp were vertical. This was shown to be a valid assumption.

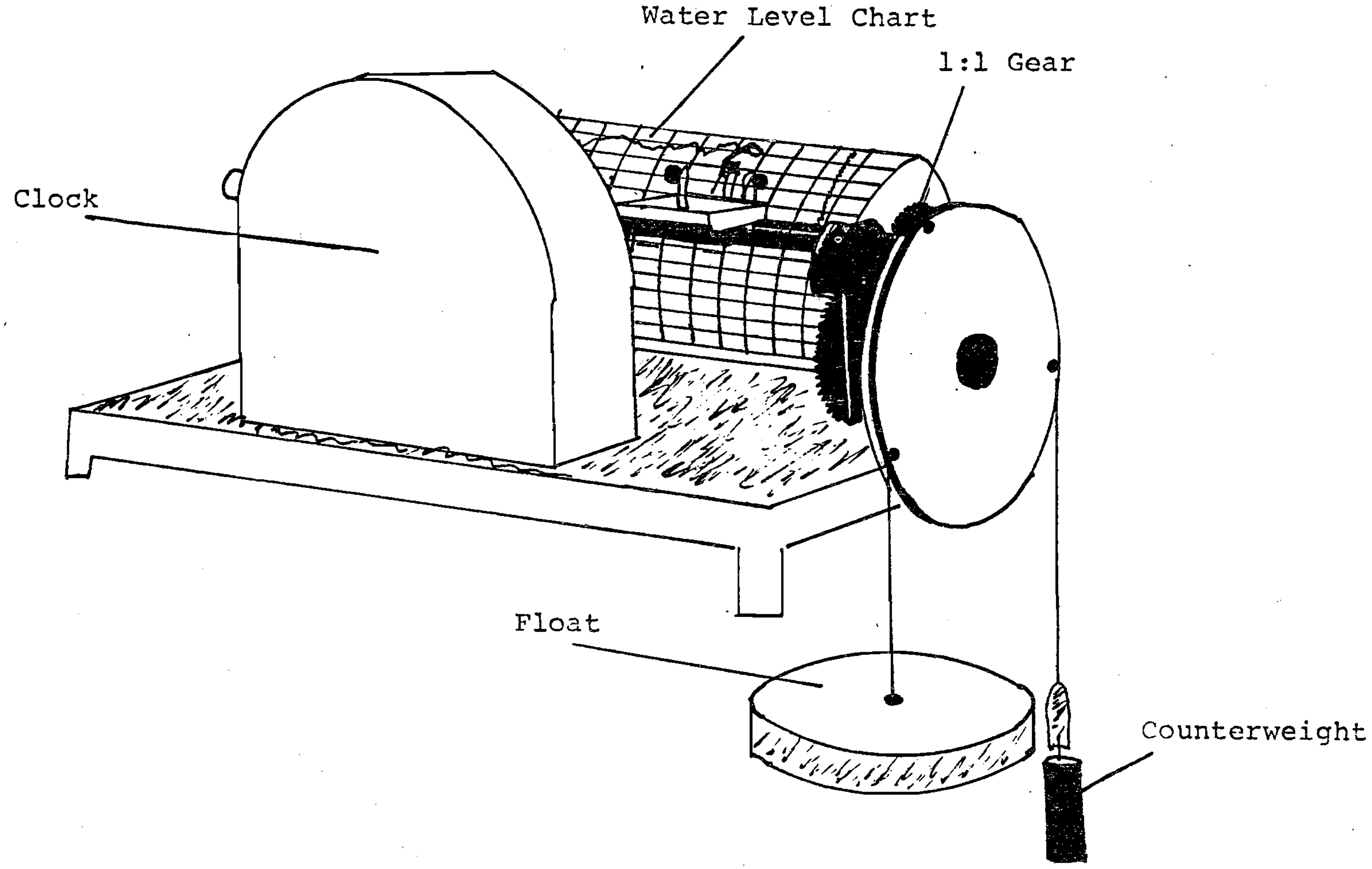


Figure 16. Stevens Water Level Recorder

Precipitation and Throughfall

Rainfall can be separated into several components after it falls into the swamp area. Water that is intercepted and eventually evaporated from the cypress canopy is called interception. Rainfall is almost entirely intercepted when the rain initially starts falling. This applies especially to the months when the cypress canopy contains needles. As more rain falls, the canopy becomes saturated and as much water drips from it as is falling on it, and as branches and stems become saturated, the swamp water level increases as fast as the rain falls. At this point throughfall, the water not intercepted but falling straight through the canopy, and stemflow, the water dripping down the branches and trunks, are significant. Since previous studies of cypress swamps hydrology have determined that at its very maximum stemflow is 3% of throughfall (Heimburg, 1976), it has been left out of the calculations. It would appear as a part of the runoff discussed below.

To develop a calibration curve to determine daily throughfall values, nine rain gauges were set out throughout the swamp (Fig. 2) and were collected either every month or every 2 months. To prevent evaporation of water in the rain gauges, a small amount of mineral oil was added. Also, during winter months, 0.5 inch of ethelene glycol was added to all rain gauges when reset, and 0.5 subtracted from the throughfall readings when collected. This precaution was taken after several rain gauges were found cracked from ice expansion in December, and their readings had to be discarded. They were averaged to determine a total throughfall. Total precipitation was measured on a daily basis in an open area within 1 km of the swamp and were summed to correspond to the same time period as the swamp rain gauges. Total rain was then plotted vs. throughfall for various segments of the year, and a regression equation was developed. Throughfall within the canopy could then be calculated for any precipitation event.

Runoff

Runoff is the surface flow that enters the swamp from the adjacent land areas. Two types of runoff occur. Sheetflow occurs where waters flow slowly down gentle slopes, while and in steeper areas water collects into small ravines and flows into the swamp. These steeper slopes predominate on the south and southwest borders of the swamp (Fig.11). To determine runoff for a particular storm, the total swamp level increase was read from the water level record, even if it continued for a day or two after the storm stopped. From this value throughfall is subtracted, the balance considered to be runoff.

Seasonal differences can be observed when plotting total rain vs. runoff. For the month of March, snowmelt, heavy rains and saturated soils resulted in large runoffs. March is a time in which much snowmelt is seen and frontal rain storms, light in intensity but long in duration are also experienced. Summer months experience convective rainstorms more often which are heavy in intensity and short in duration. For these reasons separate regression curves were developed for different seasons for runoff.

Evapotranspiration

Evapotranspiration is the combined effect of vegetation transpiring water and evaporation of surface and groundwater. Evapotranspiration is very seasonal being highest in June and July and tapering off to zero in the winter months. Evapotranspiration also experiences diurnal fluctuations, occuring primarily during daylight when transpiration dominates. Evapotranspiration amount is dependent upon temperature, solar intensity, wind, humidity, and whether or not trees have leaves. In winter months all climatogical factors are small and the deciduous trees have no leaves. Some small amounts of sublimation will occur in winter, but is assumed negligible. Evapotranspiration is exerted on Heron Pond by cypress and tupelo trees and duckweed in the swamp, and exerted on the surrounding groundwater by the surrounding forest.

To determine daily evapotranspiration within the swamp, correlations were drawn between corrected pan evaporation, as measured by a nearby meteorological station, and evapotranspiration as determined from the water level record within the swamp. Daily pan evaporation values were obtained from Dixon Springs Agricultural Station. The pan evaporation was multiplied by a pan coefficient of 0.7 to compensate for the over-estimation of actual evaporation due to the location and type of pan used. Evapotranspiration within the swamp was measured by the diurnal fluctuation method described by White (1932) and Todd (1959). Periods were chosen that did not reflect interference by rainfall in the decay rate of the waters level. Average nighttime level slope was determined for a period which reflect the amount of water being lost by only groundwater and streamflow losses. This slope was extrapolated down for a certain period and the difference between this level and the actual lower level was due to evapotranspiration over that time period. Both the values of corrected pan evaporation and evapotranspiration were put on a daily basis, then graphed, and a correlation equation determined. Therefore, by obtaining daily corrected pan evaporation data from the weather station, evapotranspiration within the swamp could be approximated.

Surface Outflow

Surface outflow (Weir flow) is the streamflow from the swamp through a channel into the Cache River as measured by a compound weir (Fig. 9). Four outlets actually empty into the Cache River, but the outflow with a weir was significantly higher than the others. As the water level of the swamp increased, discharge through these outlets increased. A log relationship was determined between the surface outflow and and the swamp stage knowing the water level of the swamp. The amount of stream flow from the swamp to the river could then be calculated knowing the swamp stage.

Groundwater

From the water budget equation, net groundwater is determined as the residual. In an attempt to separate groundwater flow in and groundwater flow out of the swamp, two shallow wells were installed (Fig. 2). Well #1 was installed in the natural levee between Heron Pond and the Cache River in an attempt to determine the groundwater flow out of the swamp into the river. Well #2 was installed on the slope of the western adjacent land in an attempt to determine flows into the swamp from higher land elevations.

Darcy's law was used to calculate the flow out from the swamp to the river, using the swamp stage and the Well #1 measurements for the head drop. The flow into the swamp, in these periods, in which that is the case, could not be done quite as easily since while Well #2 could give a good average flow for the land area northwest of the swamp, it could not account for the water table with differing slopes to the west and southwest of the swamp. For this reason, the total inflow of groundwater into the swamp was determined by taking the net flow determined by the residual amount in the computer program calculation, and adding the amount which was determined by Darcy's law from Well #1.

RESULTS AND DISCUSSION

Hydrologic Components

Precipitation and Throughfall - Table 2 indicates: 1) the amount of throughfall recorded at different points throughout the swamp by farm rain gauges, 2) the mean of these throughfall readings representing mean throughfall for the period of time, 3) total rain as the sum of daily rainfall values recorded by a standard precipitation gauge (Table 3), just outside the swamp in an open field and 4) total rainfall for the entire period recorded just outside the swamp in the same open field by a farm rain gauge similar to those used in the swamp. Due to flooding of the swamp and subsequent flooding of the rain gauges within the swamp, throughfall readings could not be recorded for March, April and May.

The total precipitation recorded outside the swamp is compared to throughfall recorded within the swamp in Fig. 17. This was done to approximate the daily throughfall as a function of the daily total rain. The regression equation is solved by the least squares method. The equation describing this relationship ($r = 0.987$) is:

$$TF = 0.6975\,(TR) + 0.0009$$

where,

TF = Throughfall, cm

TR = Total Rainfall, cm

Thus 70% of rainfall was entering the swamp as throughfall. No seasonal change in this value was seen.

Table 2

Precipitation and Throughfall for Heron Pond Study

Period	Heron Pond Throughfall, cm										Total Precipitation, cm	
	1	2	3	4	5	6	7	8	9	Average	Std. Precipitation Gauge	Farm Gauge
10/1-12/4	9.39	8.76	8.38	9.90	10.16	10.41	10.41	9.06	8.38	9.43	11.78	10.41
12/5-1/8	-	-	-	-	-	1.67	1.80	1.37	1.80	1.66	2.89	1.67
1/9-3/5	8.05	8.00	-	8.30	-	-	-	8.25	9.27	8.37	12.88	10.52
6/4-6/24	3.18	3.15	-	3.56	-	3.10	3.30	2.97	3.23	3.21	4.50	4.32
6/25-7/30	11.94	12.70	8.64	13.59	14.35	13.59	13.59	11.56	13.34	12.59	18.49	-
7/31-9/18*											23.50	

* farm rain gauges overflowed

Table 3

Precipitation Record (cm) For Heron Pond Study Period

Location: Max Hutchison's farm approximately 0.8 km east of Heron Pond

Time of Observation: 0700

	1976			1977		
Day	Oct.	Nov.	Dec.	Jan.	Feb.	March
1						0.08
2						
3				0.30*		0.51
4						4.72
5	1.45			0.13	0.03	tr.
6			0.09			
7			0.81	0.58**		
8			0.01			
9	0.18			-		
10				0.36**		
11			0.86			tr.
12			0.08		0.71	2.64
13					0.13	
14				1.19		
15				0.10		
16				0.10		
17						
18				0.03*		1.07
19				0.05*		
20	1.09			0.20*	0.02	0.13
21						
22						
23	0.30					
24	4.24			0.38*	3.17	
25			0.01			
26		1.22	0.01			
27		0.89			1.09	0.66
28		0.08				12.09
29			tr.*			0.41
30	1.98					
31	0.36					
TOTALS	9.60	2.19	1.87	3.42	5.15	22.31

* precipitation as snow

** precipitation as snow; probably underestimated

Table 3 (Cont.)

Precipitation Record (cm) For Heron Pond Study Period

Location: Max Hutchison's farm approximately 0.8 km east of Heron Pond

Time of Observation: 0700

	1977					
Day	April	May	June	July	Aug.	Sept.
1				2.57	0.05	
2	0.84					
3	0.03					
4	0.30	1.45				
5	0.38	2.21				
6						
7		0.56				
8						
9						
10					3.27***	1.57
11				0.84		
12				0.36	0.71	
13			0.15		4.39	
14					0.94	3.43
15					tr.	1.35
16			tr.			
17			0.81		2.08	
18					0.18	2.18
19						
20	0.86					
21	0.48		0.15	0.30		
22	3.56	0.18	0.05			
23		0.36		0.10		
24	0.05	0.43	2.33		0.10	
25			0.96	4.67		
26		0.25	0.48			
27			1.68			
28	0.08		1.02			
29	3.25		1.55	0.53	3.20	
30					0.03	
31		0.38				
TOTALS	9.83	5.82	9.18	9.37	14.95	

* precipitation as snow

** precipitation as snow; probably underestimated

*** total since August 8

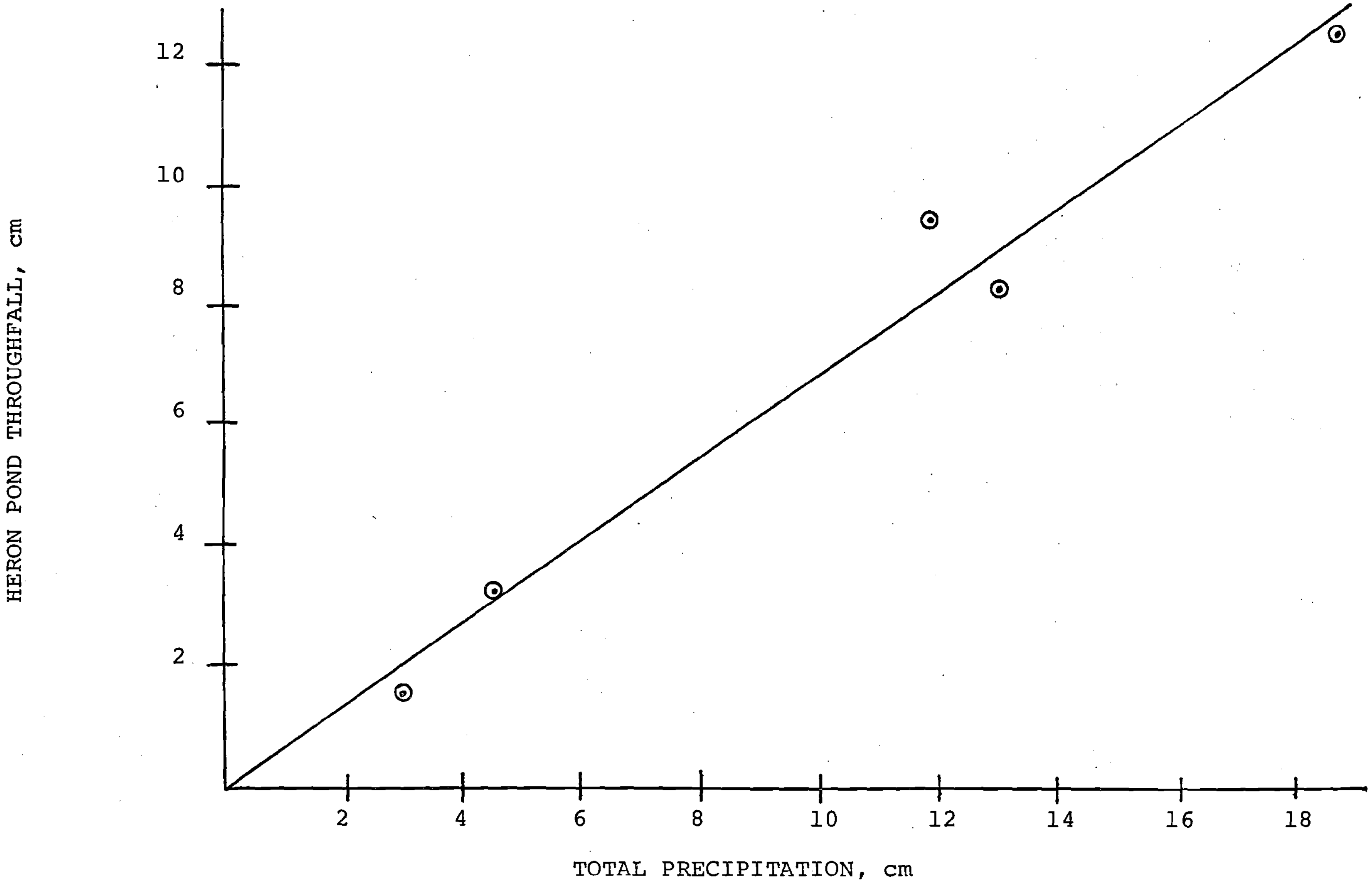


Figure 17. Relationship between throughfall in Heron Pond and total precipitation in open field outside Heron Pond.

Runoff - Runoff was determined after precipitation events by measuring the total water level increase in Heron Pond and then subtracting out the amount which is throughfall as calculated by the regression equation. The runoff value is a function of the season as can be seen by comparing total precipitation to runoff (Table 4, Fig.18). March includes very large amounts of runoff, partically due to snow melt (which is actually delayed runoff, from the winter months), and due to saturated top soil during long duration storms. October and July are less steep in runoff equation slope. Also February exhibits a large increase which is registered as runoff which is in reality thawing of the ice in the swamp.

For the period of April the water level record had to be reconstructed by an exponential decay method due to a malfunctioning water level recorder. The equation describing July runoff was used rather than that from March since it is assumed that by April snow melt is complete. Also, the total throughfall amounts for April and July are similar. Using this equation to determine and add the daily runoff to the April calculations, brought the ending of April's exponential decay determined water level in line with actual levels recorded at the start of May.

The equations for runoff for the three seasons were:

$$RO = 0.531\ (TP) - 0.525 \text{ for October}$$

$$RO = 2.336\ (TP) - 2.094 \text{ for March}$$

$$RO = 0.371\ (TP) + 0.170 \text{ for July,}$$

where,

RO = runoff

TP = total precipitation.

Table 4

Total Precipitation and Runoff in Heron Pond Study

Dates	Total Precipitation, cm	Runoff, cm	Equation Describing Correlation for period
10/5	1.45	0.20	
10/19	1.09	0.03	
10/23	4.55	1.86	RO=0.531(Total Precip) -0.525, r=.996
10/30	2.34	0.80	
2/26	1.03	0.41	
3/3	5.23	10.41	
3/12	2.64	3.31	RO=2.336(Total Precip) -2.094, r=.994
3/18	1.07	0.78	
7/1	2.54	1.28	
7/11	1.19	0.51	RO=0.371(Total Precip) +0.170, r=.975
7/25	4.67	1.84	

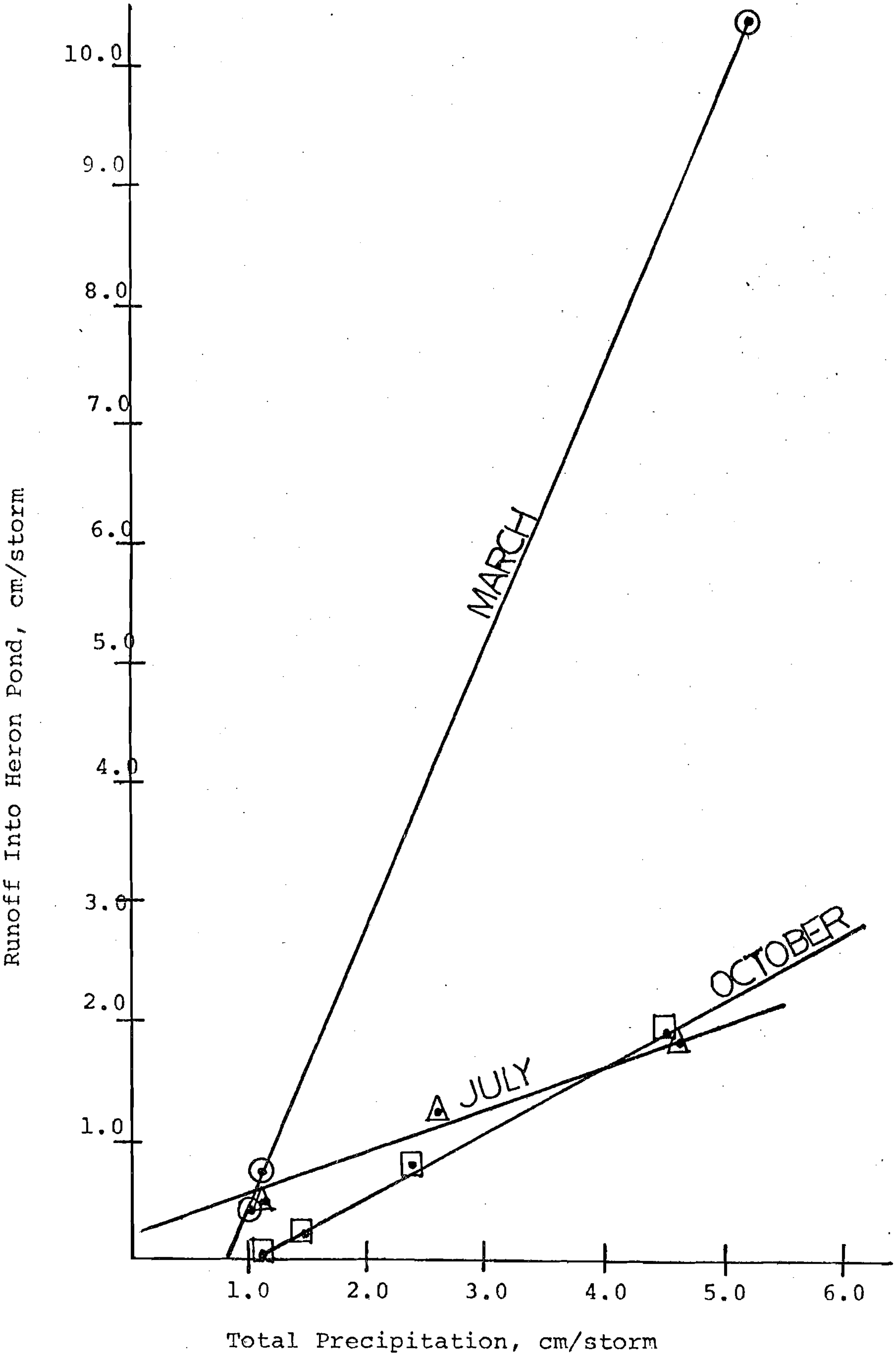


Figure 18. Relationships between runoff and precipitation in Heron Pond

Evapotranspiration - Corrected pan evaporation, as recorded at Dixon Springs Agricultural Station, approximately 25 km northeast of Heron Pond, is compared to the actual evapotranspiration, as measured from the water level records in Table 5. A regression equation was then developed to approximate evapotranspiration knowing daily pan evaporation (Fig. 19). The equation (r = 0.999) describing the relationship is:

$$ET = 0.8991\ (EVAP) + 0.0236$$

where,

ET = daily evapotranspiration, cm/day,
EVAP = corrected pan evaporation, cm/day.

An experiment was run the first four days of June, a time when evapotranspiration is significant, to determine the quantity of evapotranspiration attributable to duckweed. Two tubs were placed within the swamp resting low in the water, both filled with the same quantity of water, one tub with the surface covered with duckweed, the other with its surface clear (Fig. 20). Water temperatures within the two tubs were kept equal since the tubs had most of their surface area exposed to the swamp water, which kept the tub water at approximately the same temperature as the swamps. After 4 days the tub with a clear surface had dropped 0.59 cm, whereas the tub with duckweed had dropped 0.71 cm. The total drop in swamp level, after subtracting off the amount of level drop due to surface outflow and groundwater, was 1.64 (Table 6). Therefore out of the total amount of evapotranspiration taking place within Heron Pond, cypress - tupelo trees account for 57%, and duckweed accounts for a significant 43%.

Table 5

Corrected Pan Evaporation and Evapotranspiration for Heron Pond Study

Period	Corrected Pan Evaporation, cm/day	Measured Evapotranspiration, cm/day
Oct. 10-14	.260	.256
June 5-11	.505	.322
July 3-9	.465	.440
July 12-19	.373	.362
Aug 1-7	.429	.305
Aug 19-22	.391	.267
Sept 1-7	.290	.226

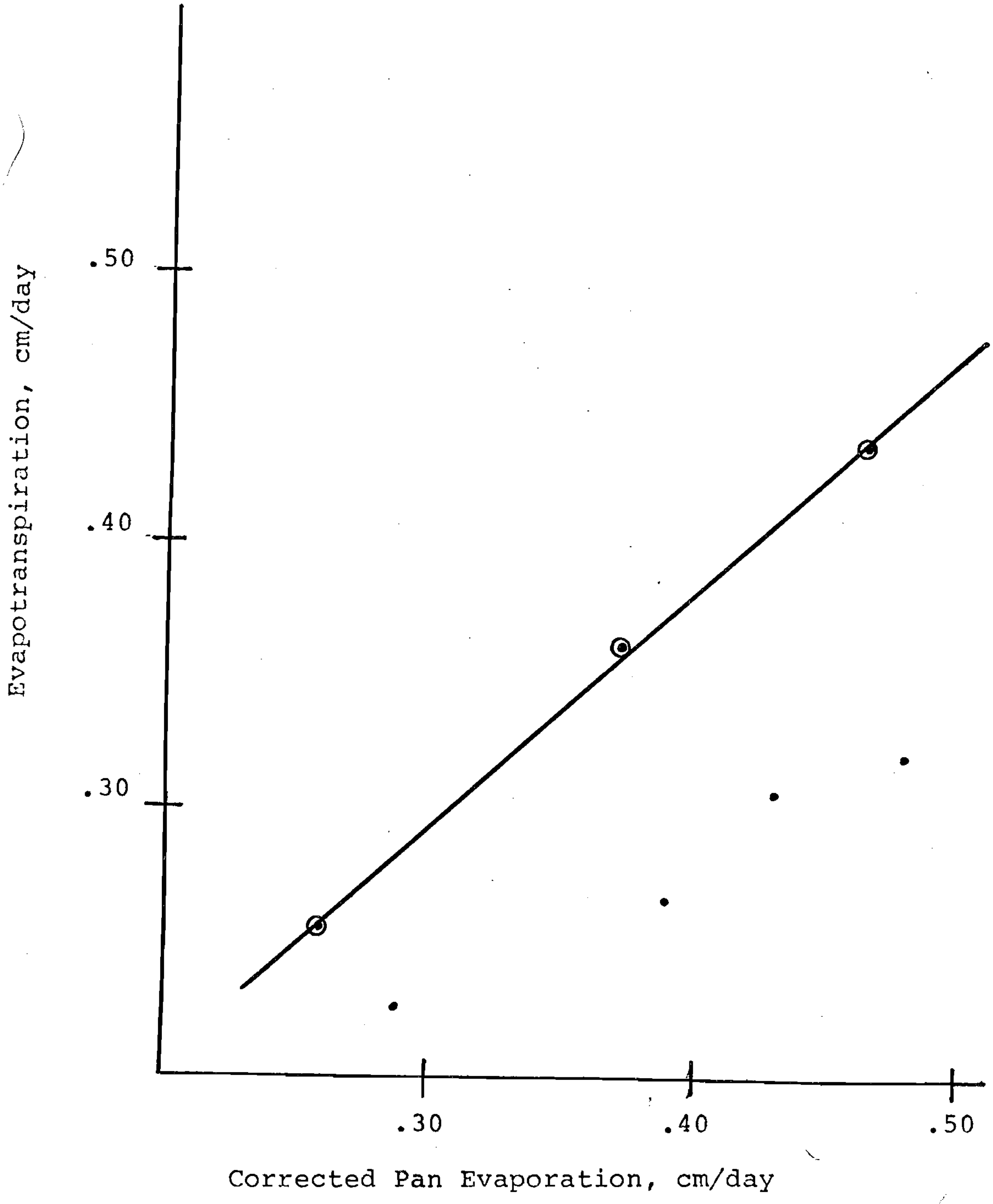


Figure 19. Relationship Between Evapotranspiration in Heron Pond and Corrected Pan Evaporation at Dixon Springs Agricultural Center.

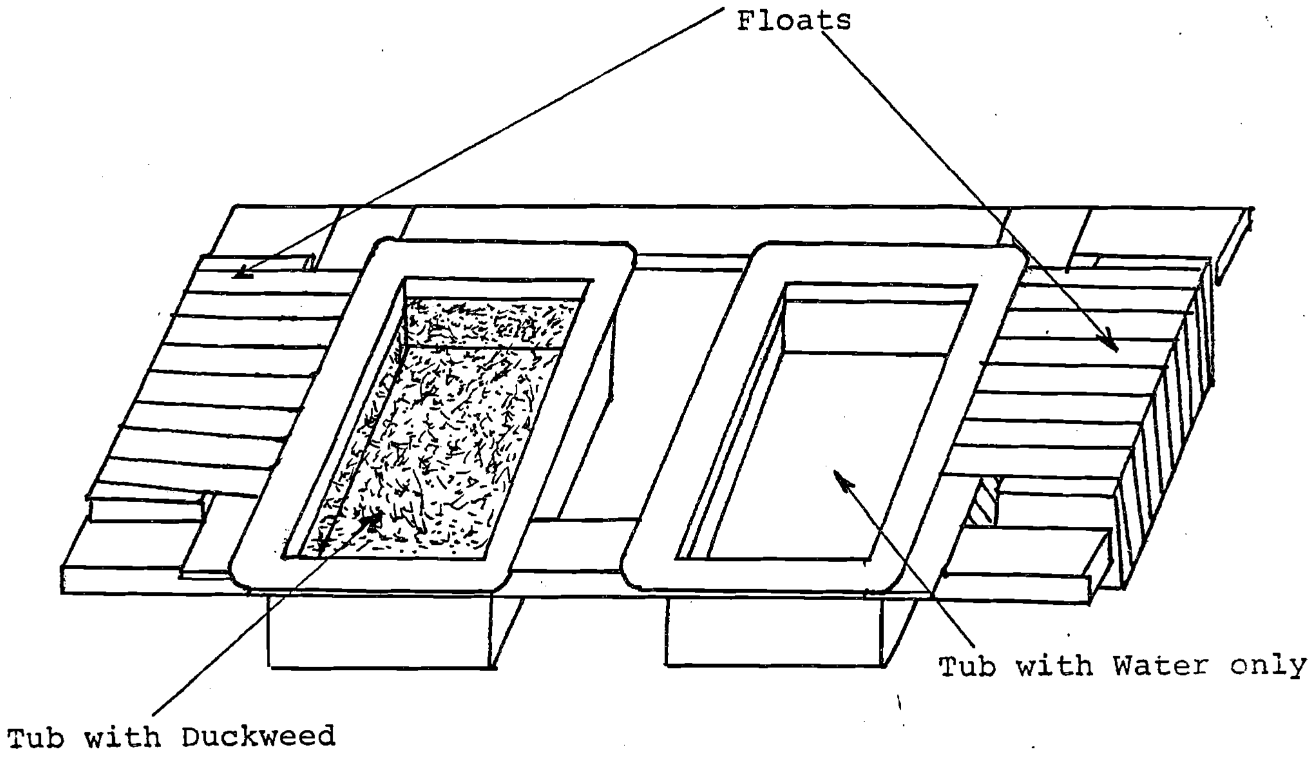


Figure 20 . Equipment constructed for Evapotranspiration experiment.

Table 6

Evapotranspiration Experiment

June 1-4, 1977

Evapotranspiration, cm				
Swamp	Clearing		Under Canopy	
	Duckweed	Free Surface	Duckweed	Free Surface
1.64	1.42	1.87	0.71	0.59

Total ET	1.64	(100%)
Duckweed ET	0.71	(43%)
Cypress ET	0.93	(57%)

Surface Outflow - The amount of surface outflow was measured during various swamp stage levels at different times of the year, as seen in Table 7. The flow through the main channel was measured with a calibrated V-notch weir, in which the relationship between the head and the flow of water through the weir is expressed by the following equation:

$$Q = 2.49 H^{2.48}$$

where,

Q = flow, cfs

H = head, in feet

To this flow was added the flows of the smaller streams, which were usually an order of magnitude less than the main outflow channel.

During periods in which readings were taken when the swamp was frozen (Dec., Jan.), flow was considered to be retarded in comparison to thawed readings. Due to the variability in readings which was probably due to different thickness of ice cover, these readings were not considered.

To determine at what swamp water level no surface outflow occurs, lower swamp level readings were compared to their corresponding surface outflow values (Fig. 21). The curve created by the data points was extrapolated downward until it itercepted the zero readings of surface outflow, yielding a swamp stage of 26.00 cm as the point at which no surface flow occurs.

A linear relationships can be seen in four of the seven data points when surface outflow is plotted vs swamp stage (Fig. 22). Since it was very hard to seal all leakage around the weir,

Table 7

Heron Pond Water Level and Surface Outflow

Date	Heron Pond Water Level, cm	Surface Outflow, cm/day
8/13	50.902	.024
10/3	30.442	.004
12/5	38.100*	.003
1/8	38.710*	.007
3/5	60.503	.362
6/2	56.693	.033
6/4	54.712	.045
6/25	46.543	.083
7/30	42.367	.045
9/17	46.767	.013

* Heron Pond frozen over.

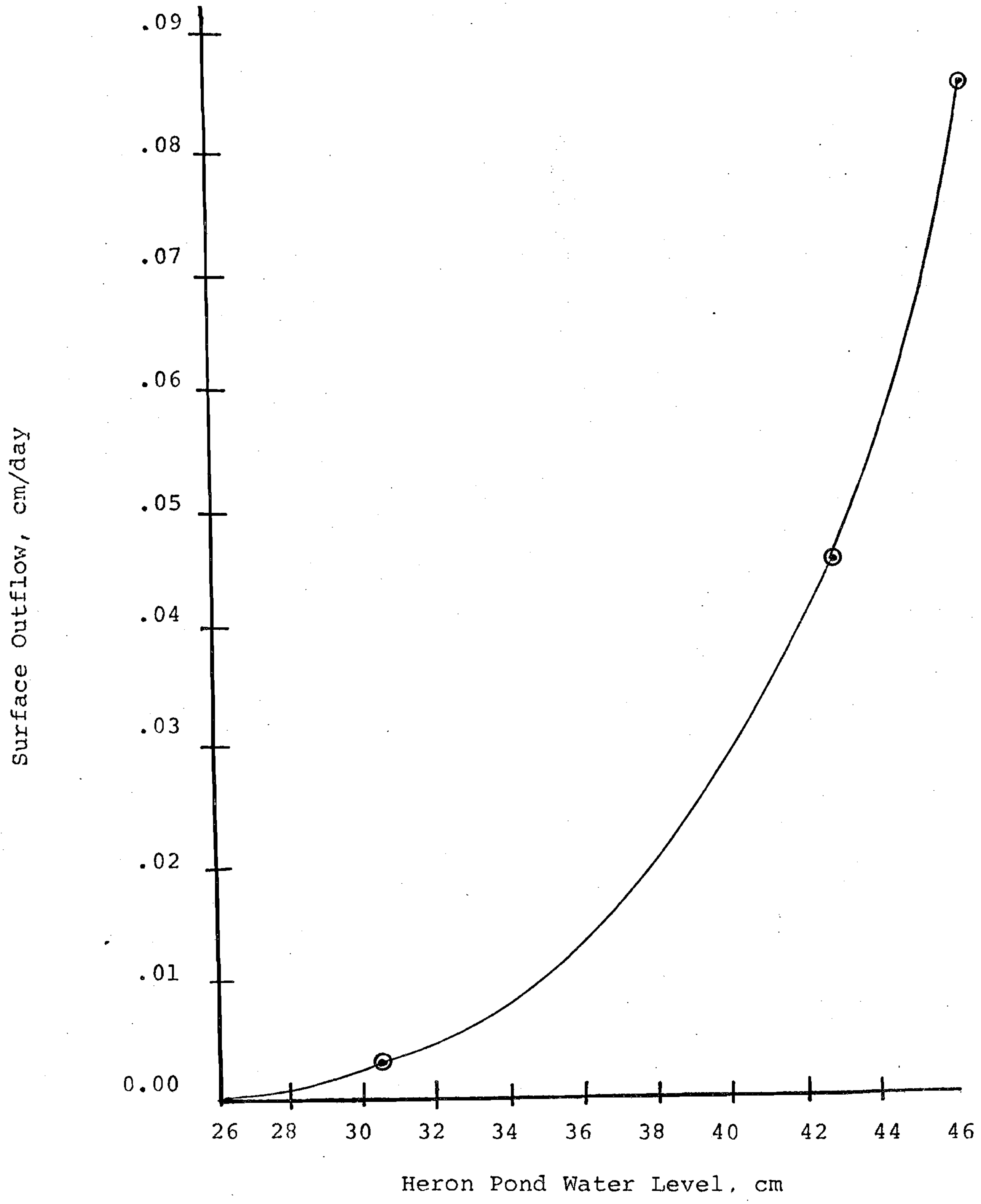


Figure 21. Relationship Between Surface Outflow at Weir and Heron Pond Water Level Used to Determine Zero Flow Conditions.

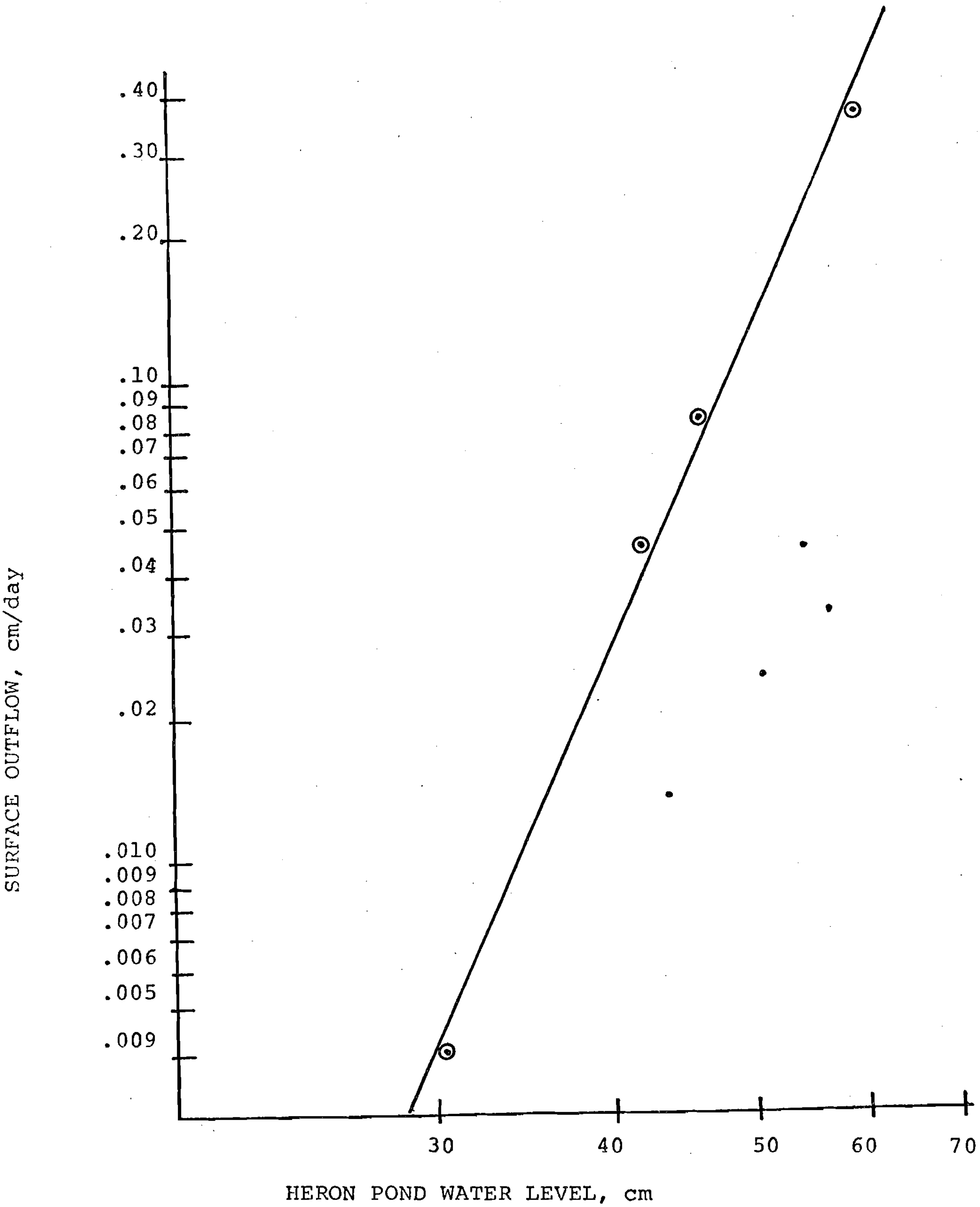


Figure 22. Relationship between surface outflow at weir and water level of Heron Pond. This relationship was used in water budget.

some points were assumed to be under-estimations of the total flow, and were neglected. From the four remaining data points, the following equation was developed:

$$\text{WEIR} = 1.461 \times 10^{-4} (L-26.00)^{2.138}$$

where,

WEIR = Daily swamp level decrease from surface outflow, cm/day,

L = Swamp water level, cm.

Therefore, by knowing the water level, daily stream flows can be approximated. The correlation coefficient for the data is 0.994. This relationship proved to be useful in extrapolating to high flows (as described by Linsley _et_ _al_., 1975).

Groundwater - Net groundwater, as calculated in the daily program, can be broken down into the amount of water entering and the amount of water leaving the swamp by groundwater flow, for a given amount of time, in this case on a monthly basis.

Groundwater leaving the swamp via flow through the natural levee and into the Cache River is calculated by Darcy's law to determine the velocity, then by multiplying the velocity by the area the water is flowing through, the volume of water leaving the swamp is known. By dividing this volume by the area of the swamp, the water level drop in the swamp is determined.

Darcy's law states that the velocity is determined by multiplying the permeability of the soil by the slope of the water table (Fig. 23),

$$V = KS$$

where,

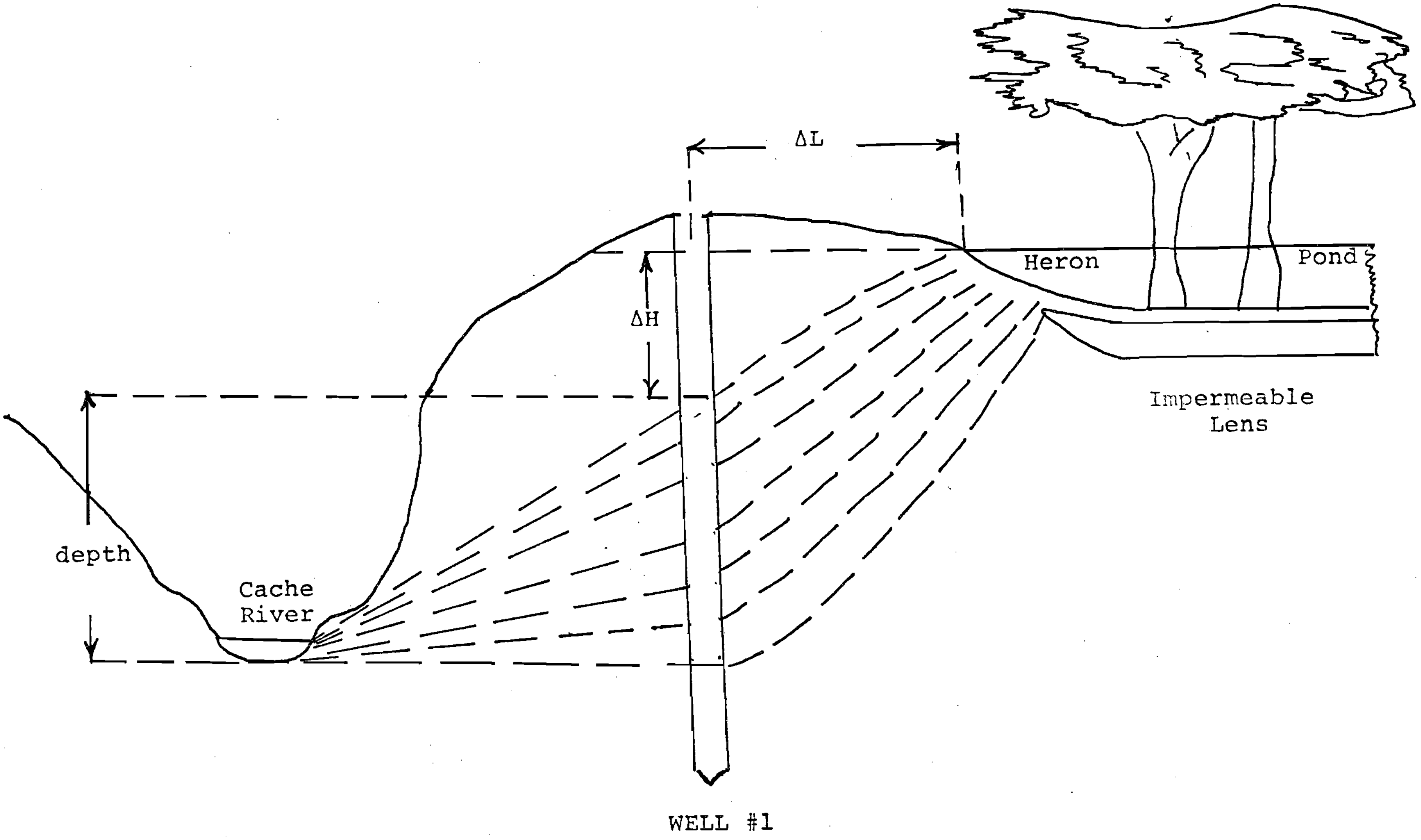


Figure 23. Diagram of Calculation Used to Determine Groundwater Flow From Heron Pond to the Cache River

V = Velocity, cm/day

K = permeability, cm/day

S = Slope of water table from edge of swamp to the well, and is represented by $\frac{\Delta H}{\Delta L}$.

To determine the monthly mean ΔH, the head difference between the swamp water level and the water level in the well, the mean values of the entire month were determined by interpolating the daily well levels between well level data points (Fig. 24), and determining the average for the month (Table 8).

To determine the mean monthly ΔL swamp level was compared with the distance the swamp edge was to the well (Table 9) with the semilog relationship

$$\Delta L = 10\ (W.L.)\ -.0044) + 3.566$$

where,

$W.L.$ = Swamp water level

ΔL = Distance.

By multiplying the soil permeability of Well #1 by each respective mean monthly slope, the mean monthly velocity is realized. To determine the area this velocity is moving through, the length of the natural levee separating the swamp and river was measured and was expressed as a constant 1.8 km. The mean monthly depth of soil the water was flowing through was determined to be the difference in mean monthly well level and the level of the Cache River bed (Fig. 23). By multiplying this difference of monthly means by the length of the levee, the area is determined, and by multiplying the monthly velocity by this area yields the water volume lost. The loss in swamp level due to this volume can be

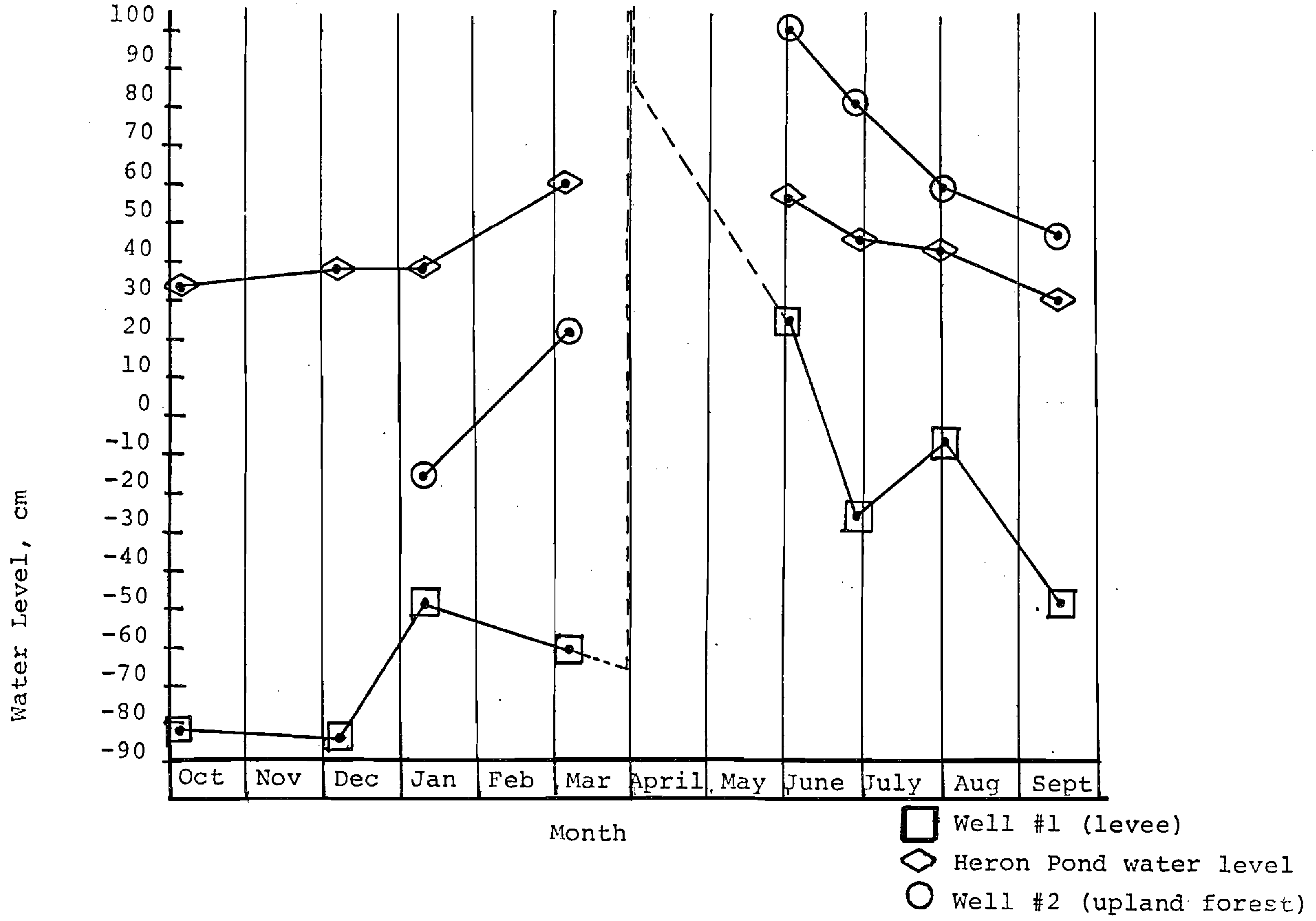


Figure 24. Well water levels around Heron Pond compared with swamp water levels.

Table 8

Relative Mean Monthly Water Levels in Well #1, cm

					Month						
Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.
-81.90	-83.00	-72.8	-51.8	-57.0	-63.3	71.9	40.7	-5.1	-15.5	-21.6	-57.2

Table 9

Heron Pond Water Level and Distance to Well # 1

Date	Well level, cm	Distance from well to edge of swamp, cm
10/3	34.199	2600
3/5	60.656	2000
6/1	57.000	2050
7/30	42.367	2400
9/17	46.767	2300

Table 10

Groundwater Loss Through The Natural Levee At Well #1 From Heron Pond To The Cache River As Calculated Using Darcy's Law

	Darcy's Law Calculations					Area Calculations			Heron Pond Water Loss	
Month	ΔH, cm	ΔL, cm	S(slope)	K(permeability), cm/mo.	Velocity, cm/mo.	Length, m	Depth, cm	Area, cm^2	Volume, cm^3	Water Level Drop, cm
Oct.	115.970	2606	.044	1512	66.528	1800	230.520	4.149x10^7	2.760x10^9	0.926
Nov.	120.340	2522	.048	1463	70.224	1800	229.420	4.130x10^7	2.90 x10^9	0.956
Dec.	112.050	2473	.045	1512	68.040	1800	239.620	4.313x10^7	2.935x10^9	0.980
Jan.	90.720	2482	.037	1512	55.944	1800	260.620	4.691x10^7	2.624x10^9	0.860
Feb.	100.210	2376	.042	1366	57.372	1800	255.420	4.598x10^7	2.638x10^9	0.878
Mar.	124.470	1980	.063	1512	95.256	1800	249.120	4.484x10^7	4.271x10^9	1.414
April	148.840	1688	.088	1463	128.744	1800	384.320	6.918x10^7	8.906x10^9	2.960
May	103.660	1945	.053	1512	80.136	1800	353.120	6.356x10^7	5.094x10^9	1.698
June	54.570	2231	.024	1463	35.112	1800	307.280	5.531x10^7	1.942x10^9	0.657
July	60.070	2344	.026	1512	39.312	1800	296.920	4.859x10^7	1.910x10^9	0.686
Aug.	64.720	2378	.027	1512	40.824	1800	290.850	5.235x10^7	2.137x10^9	0.715
Sept.	101.030	2361	.043	1512	65.016	1800	255.220	4.594x10^7	2.987x10^9	0.986

calculated by dividing the volume by 301,440 m^2, the area of the swamp (Table 10).

Knowing the net amount of groundwater flowing into the swamp as a residual of the water budget calculations, and now having determined the flow out of the swamp to the Cache River, it is possible to calculate the flow into or out of the swamp from other adjacent area (Table 11). It is therefore possible to estimate total inflow and outflow of groundwater to and from Heron Pond.

WATER BUDGET

By the summation of daily water budget component values, it is possible to see how much water is gained or lost by the swamp on a monthly or yearly basis (Table 12). Throughfall is seen to have the most significant effect on the hydrologic cycle of the swamp in contributing more than 74 cm to the water level, however almost that much is lost from evapotranspiration over the same years time, even though evapotranspiration occurs more seasonally. So the two components moreless counteract each other. The amounts of yearly runoff and surface outflow are also an output and input with relatively the same yearly values. Groundwater input and groundwater output are almost balanced making the net groundwater gain for the year less than one cm. The magnitude of importance of each hydrologic component over the annual cycle can be seen (Fig. 25). Of the total inputs of the year, 46% was throughfall, 40% was runoff, and 14% groundwater. Total yearly outputs were 49% evapotranspiration, 37% surface outflow, and 14% groundwater.

Table 11

Groundwater Inflows And Outflows Of Heron Pond

Month	Net Groundwater Loss or Gain To Heron Pond (Residual of Program), cm	Groundwater Loss to Cache River, cm	Groundwater Loss or Gain From Other Areas, cm	Total Groundwater Into Heron Pond, cm	Total Groundwater Out Of Heron Pond, cm
Oct.	1.825	-0.926	2.751	2.751	0.926
Nov.	0.263	-0.956	1.219	1.219	0.956
Dec.	-0.600	-0.980	0.380	0.380	0.980
Jan.	-2.663	-0.860	-1.803	0	2.663
Feb.	-1.849	-0.878	-0.981	0	1.849
Mar.	7.647	-1.414	9.061	9.061	1.444
April	1.883	-2.960	4.843	4.843	2.960
May	0.814	-1.698	2.512	2.512	1.698
June	-2.517	-0.657	-1.860	0	2.517
July	-2.888	-0.686	-2.202	0	2.888
Aug.	-1.124	-0.715	-0.409	0	1.124
Sept.	0.191	-0.986	1.177	1.777	0.986
TOTAL				21.943	20.961

Table 12

Inflow and Outflow Components of Heron Pond's Hydrologic Budget

		Inflows			Outflows		
Months	Water level, cm	Throughfall, cm	Runoff, cm	Groundwater, cm	Evapo-transpiration cm	Surface Outflow cm	Groundwater cm
Oct	34.070	6.666	2.486	2.751	6.075	0.413	0.926
Nov	37.340	1.525	1.218	1.219	2.244	0.794	0.956
Dec	39.255	1.319	1.120	0.380	0	1.138	0.980
Jan	38.917	3.467	0	0	0	1.081	2.663
Feb	43.205	3.602	6.828	0	0	1.850	1.849
Mar	61.170	15.668	32.267	9.061	5.735	8.603	1.414
April	76.938	6.868	3.952	4.843	7.099	18.816	2.960
May	62.957	4.066	0.520	2.512	9.684	11.812	1.698
June	49.928	6.423	2.600	0	11.083	3.834	2.517
July	44.566	6.528	4.105	0	11.785	2.403	2.888
Aug	43.147	10.409	5.831	0	10.771	2.055	1.124
Sept	43.827	7.821	2.944	1.177	8.412	2.105	0.986
Mean	47.817						
Total		74.362	63.876	21.943	72.828	54.904	20.961

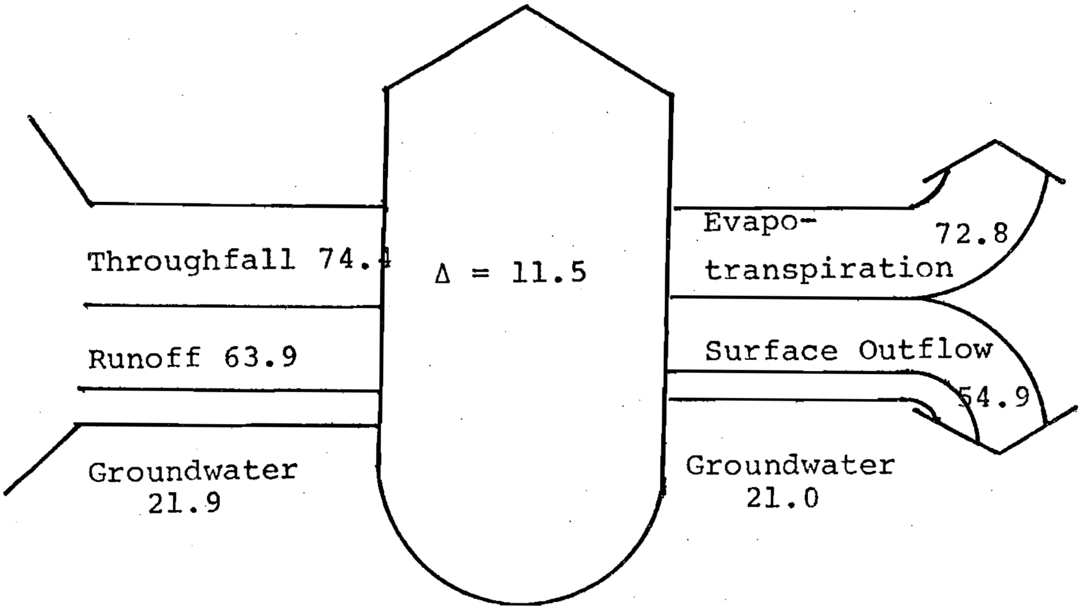


Figure 25. Heron Pond Annual Water Budget (Values in cm/yr).

Since different components show seasonal fluctuations at different times of the year, high inputs will usually be counter-balanced after a short lag time by high outputs. Examples of this are when heavy rains occur and throughfall and runoff increase the water level significantly, two drains of the hydrologic system, surface outflow and groundwater outflow become more significant since they are a function of the water level. Similarly, when swamp water levels are very low, as in October, groundwater will flow in from surrounding higher water tables. The swamp consequently maintains relatively constant levels throughout the year and has never been known, according to the local residents (Anderson and White, 1968), to dry up.

A seasonal water budget can also be seen (Fig. 26) and is well illustrated by 3 months representing 3 seasons experienced in the swamp. In March, when much rainfall occurs, inflows are 3.6 times greater than outflows. In June, when the rainy season is over leaving the water level high and the solar intensity, temperature, and plant productivity (transpiration) are high, outflows are 1.9 times greater than inflows. By October, the water level has stabilized after the summer and is not affected as highly by climalological factors. During this time inflows are only 1.6 times greater than outflows.

As has been illustrated, it is possible to breakdown all hydrologic components involved in the study area and determine their significance during any specified time period, by using the water budget method, solving for a residual in the equation, then breaking the residual down even further as in groundwater into or out of Heron Pond.

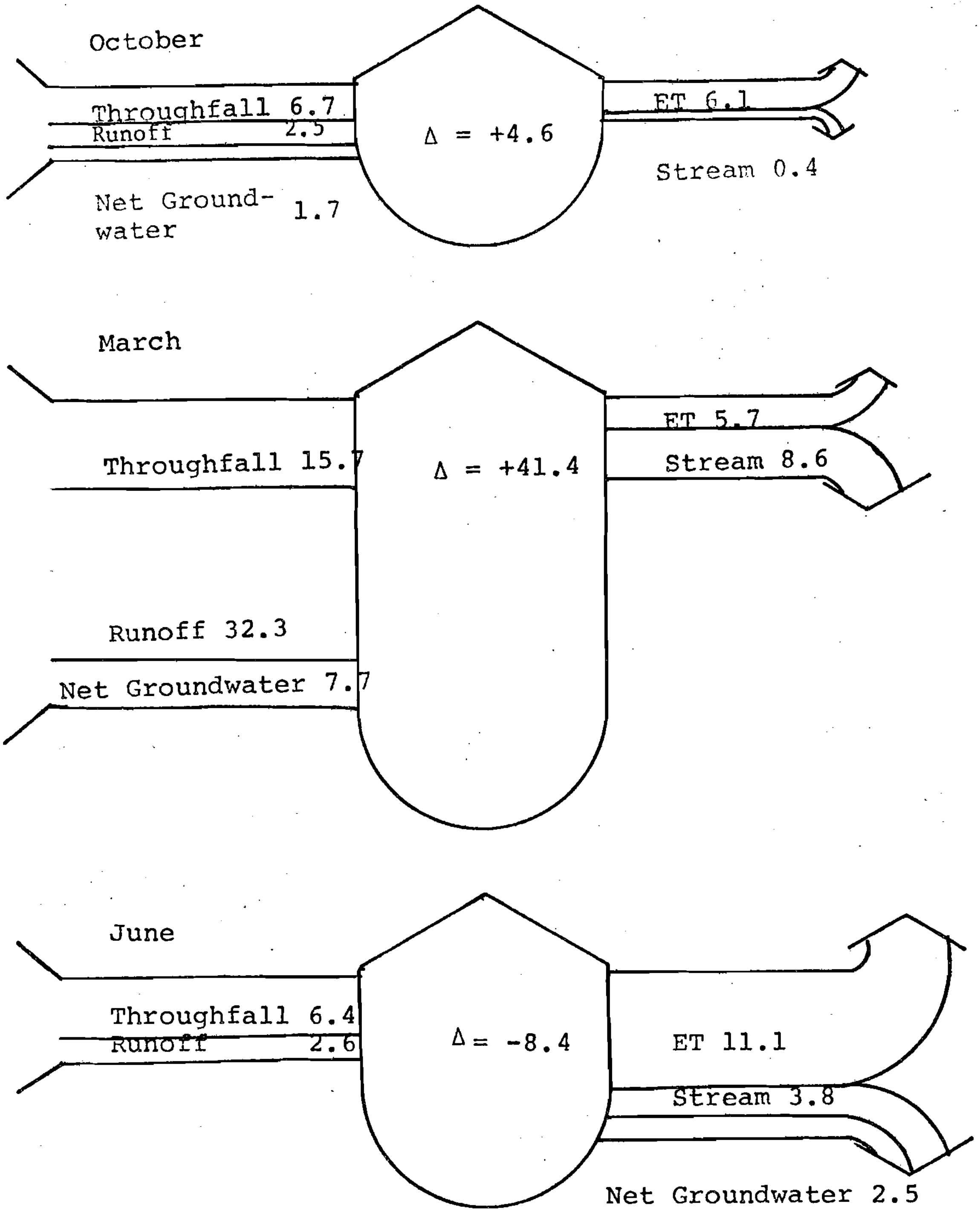


Figure 26. Seasonal Water Budget for Heron Pond
(values in cm/mo)

The Role of Heron Pond and Other Wetlands in Southern Illinois Water Management

By

John Wiemhoff

INTRODUCTION

To insure an abundant supply of water in the future, consideration must be given to natural water conservation entities, rather than destroying them and replacing them with costly man-made structures. Wetlands are potential useful natural ecosystems which can provide natural storage of water to be used as recharge during low flow periods. Ruckelshaus (1973) stated the U.S. EPA's policy to preserve wetland ecosystems: "Wetlands represent an ecosystem of unique and major importance to the citizens of this Nation and, as a result, they require extraordinary protection. The Nation's wetlands, including marshes, swamps, bogs, and other low lying areas, which during some period of the year will be covered in part by natural non-flood waters, are a unique valuable irreplaceable water resource. Comparable destructive forces would be expected to inflict more lasting damage to them than to other ecosystems". Unfortunately wetlands used to be generally thought of only as so much waste-land - an unfortunate occurrance in the land-economists classification of productive land uses. Only when they could be drained or filled to create suitable land for agriculture, industrial, or residential expansion were wetlands of any value. Only as a result of various periods of critical water shortages or over abundances (flooding) has a new awareness of wetlands as a natural tool for water conservation been realized.

With increased settlement and industrialization of previously unsettled areas, there has been a subsequent lowering of groundwater tables. Lowering of water tables was not due to changes in rainfall, but rather to the loss of water from drainage operations and clearing, through surface runoff and increased consumption by industries (Dachnowski - Stokes, 1935). This study investigated the influence of peat deposits in their ability to conserve water, check floods, retard erosion and silting, and maintain a sufficiently high water table. Undrained peat areas in level terrain show very little runoff. Sufficient water is retained to cause a general rise in the water table and a tendency to float layers of peat and their surface vegetation. Peat moss, when saturated, may contain 20 times its weight in water, and, under certain natural field conditions, will swell 14 - 20 feet above the general surface. Peat materials, also being poor conductors of heat, do not freeze to the bottom, thereby keeping up an underground supply of available water nearly through out the entire year. Ackermann (1971) states that the Sangamon River in Illinois has a small channel for a drainage area of about 800 square miles, because 100 years ago, and for thousands of years before that, the upstream drainage area was largely swamp and marsh. This retained a great deal of runoff and released it slowly, so a small channel was all that was required.

Wetlands function as nature's age-old method of flood control by furnishing overflow areas where excess water is temporarily held, and, as stated by Gabrielson (1962), "is fed out later as the downstream channels are able to accomodate the runoff. Marshes, swamps, small lakes and even bog-holes act as flood control devices to the extent that they are collection basins for surface water and feed it out gradually through springs and seeps or through open outlets. This is also the first value usually cited as the justification for building farm ponds or small impoundments in the upper portions of small water sheds." The U.S. Department of Interior (1962) states "it seems obvious that, in many instances, natural wetlands similarly located (as are small flood water detention reservoirs) in headwater areas would aid in retarding flood waters and preventing down-stream floods." Those streams or rivers with extensive swamp lands with natural vegetation are slower to rise and slower to discharge when inundation comes. The natural levee, vegetation and litter act to dam and impede the excess water.

Once water is stored within the swamp, the swamp exhibits some natural water conservation qualities not seen in man-made alternatives, Wharton _et_ _al_., (1976) states for Florida cypress swamps: "They are self maintaining and can add sediment without filling up. Cypress swamps are protected against excessive transpiration in dry periods by the drop of leaves and shading of trunks. Cypress swamps grow and transpire water in wet periods when waters are in excess. Reservoirs are more exposed to water loss. Swamp storages absorb nutrients into trees, instead of becoming eutrophic with problems of floating plants, anaerobic waters and fish kills. The swamp ponds and strands are means for holding waters long enough for recharge to occur into groundwaters with filtering actions of the vegetation and pond sediments.

Wharton (1970) compared the hydrograph of two Georgia rivers, the Yellow and the Alcovy, over a five year period, both streams being sister tributaries of the Ocmulgee. The major difference is that the Alcovy has much more swamp land. Following heavy rains both streams begin to rise at the same time, but the high water peaks of the Alcovy lag 24 hours behind those of the Yellow. Most inundations of the Yellow River are more "flashy" than those of the Alcovy: The Alcovy's curves are smooth and the minor fluctuations seen on the Yellow are missing. Although the Yellow drains a watershed 36% greater than the Alcovy, its low water flows are surprisingly close in volume to those of the Alcovy, suggesting some possible influence of the swamp on base flow.

The effect of swamps on base flow during river low flows is significant. When flooding occurs, both groundwater reserves and wetland surface water are refilled. As river levels go down, groundwater serves as a vast underground reservoir which is the source of the river base flow. Groundwater may be recharged at this point by surface water stored in wetlands. Not only capacity but duration of base flow is important. Riggs (1964) compared a swampy and non-swampy stream. The recession of the base flow from the swampy Haw River in North Carolina was shown to be markedly less than the base flow from the New River, Tennessee, a stream which courses through rolling terrain and has no swamp.

There have been some attempts to determine the economic value of forested wetlands in water management. Unfortunately, the economic value of these particular ecosystems do not show up directly in monetary exchange until we have to replace the service when it is lost. One such study was done on the Alcovy River swamp ecosystem (Wharton, 1970) in which the value to water quantity was estimated at $228,014 annually (Table 13).

Heron Pond Flood Storage

The entire Cache River Basin contains about 47 sq. km. of forested wetlands strung out along the length of its path through Southern Illinois (Fig. 1). About one third, or roughly 16 sq. km. of these swamps are situated along the Cache above the Forman U.S.G.S. gauging station, a point at which flows are recorded every hour. Residents living within proximity of the study area indicated that the Cache River floods into Heron Pond usually once a year. It was anticipated that during this study period a flood would occur, and the susbequent data associated with it could be collected.

The elevations of importance were surveyed at the onset of this study in an attempt to determine what river stage, as measured at the Forman guaging station, would flood Heron Pond. The following data and calculations were accumulated to determine this critical "bankfull discharge" stage:

Table 13

Value to Water Quantity of the Alcovy River Swamp Ecosystem (as from Wharton, 1970)

Value to Water Quantity	Annual value estimate	100 year value estimate
Value of groundwater storage	$201,380	$20,138,000
Loss of groundwater storage	26,634	1,331,700
Total	$228,014	$21,469,700

1)	Cache River level at Forman gauging station (Station 3)	2.05 ft.
2)	Drop in head of Cache River from Station # 5 to Station # 3 (Fig. 2)	8.94 ft.
3)	Vertical difference between Cache River at Station # 5 and "O" on Heron Pond staff guage	8.20 ft.
4)	Bankfull discharge as measured on Heron Pond level recorder	2.86 ft.
	Cache River "Bankfull Discharge Stage" as measured at Forman gauging station.	22.05 ft.

Whenever the level of stage recorded at Forman gauging station rises above 22.05 ft, it can be assumed that Heron Pond, and more than likely the other swamp areas above the gauging station are flooding (Fig. 1). The history of floods occuring in which Heron Pond is flooded is seen in Table 14. The recurrence interval of a flood in which Heron Pond is subsequently flooded is, as read from a frequency curve (Fig. 27), about 2 years. However this frequency curve (Fig. 27) is for annual maxima. Inspection of Table 14 shows that Heron Pond flooded 45 times in 50 years for a partial duration recurrence interval of 1.13 yr. Leopold *et al.*, (1964) found rivers in southern and central Indiana to have bankfull discharge recurrence intervals ranging from 1.07 to 1.9 with an average of 1.30 years.

With the onset of continuous and intense rain beginning on March 27, Heron Pond was flooded on March 29th. The flood peaked at 6:00 am on March 30 with a swamp stage of 227 cm, or more than 1.6 m higher than the water level prior to the rainfall (Fig. 28). The Cache River peak stage at the gauging station was 26.55 ft., with the river discharging 201 m^3/sec. (Fig. 29). The Cache River short-circuited out of its channel, through Heron Pond and surrounding low land areas, recharging groundwater

Table 14

Heron Pond Flooding During Last 50 Years

Date (Most recent first)	Cache River Gauge Forman, Ill., ft.	Cache River Discharge Forman, Ill., m^3/sec	Maximum Heron Pond Stage (Flooding stage = 87.2 cm), cm.
Mar 29, 1977	26.55	201	224**
Mar 30, 1975	24.29	150	155
Nov 29, 1973	22.14	115	90
May 28, 1973	25.19	168	183
April 24, 1973	24.19	143	152
April 17, 1977	23.82	141	141
Jan 31, 1969	26.00	187	208
Mar 11, 1964	27.60*	228	256
Feb 28, 1962	22.60*	122	104
May 9, 1961	26.05*	188	209
Jan 22, 1959	22.20*	116	92
July 20, 1958	24.01*	145	147
May 24, 1957	27.82*	234	263
April 6, 1957	23.82*	141	141
Mar 2, 1952	23.85*	142	142
Jan 16, 1951	22.08*	114	88
April 5, 1950	25.58*	178	195
Feb 14, 1950	25.06*	161	179
Jan 14, 1950	24.43*	153	160
Jan 5, 1950	28.50*	251	284
Jan 26, 1949	25.10*	167	180
April 14, 1948	22.30*	118	95
April 16, 1945	24.29*	151	155
April 3, 1945	23.25*	132	124
Mar 7, 1945	27.20*	217	244
April 12, 1944	23.68*	139	137
Mar 20, 1943	27.38*	222	250
Mar 6, 1939	22.62*	122	105
Jan 16, 1937	28.30*	244	278
June 22, 1935	26.47*	199	222
June 18, 1935	27.38*	134	250
Mar 12, 1935	29.20*	273	305
Nov 24, 1935	24.55*	155	163
May 16, 1933	23.32*	118	126
Jan 1, 1933	26.29*	194	216
Jan 15, 1930	23.22*	131	123
Feb 27, 1929	24.76*	159	170
Jan 26, 1929	28.56*	253	286
Jan 20, 1929	26.11*	190	211
June 29, 1928	24.11*	147	150
June 22, 1928	24.76*	159	170
Dec 15, 1927	25.72*	181	199

Table 14 continued

Heron Pond Flooding During Last 50 years

Date (Most recent first)	Cache River Gauge Forman, Ill., ft.	Cache River Discharge Forman, Ill., m^3/sec	Maximum Heron Pond Stage (Flooding stage = 87.2 cm), cm.
April 16, 1927	24.56*	155	164
Mar 19, 1927	27.71*	230	260
Jan 23, 1927	26.39*	194	219

* Older type guage reading corrected to present guage by using known discharges.

** Flood occurring during study period.

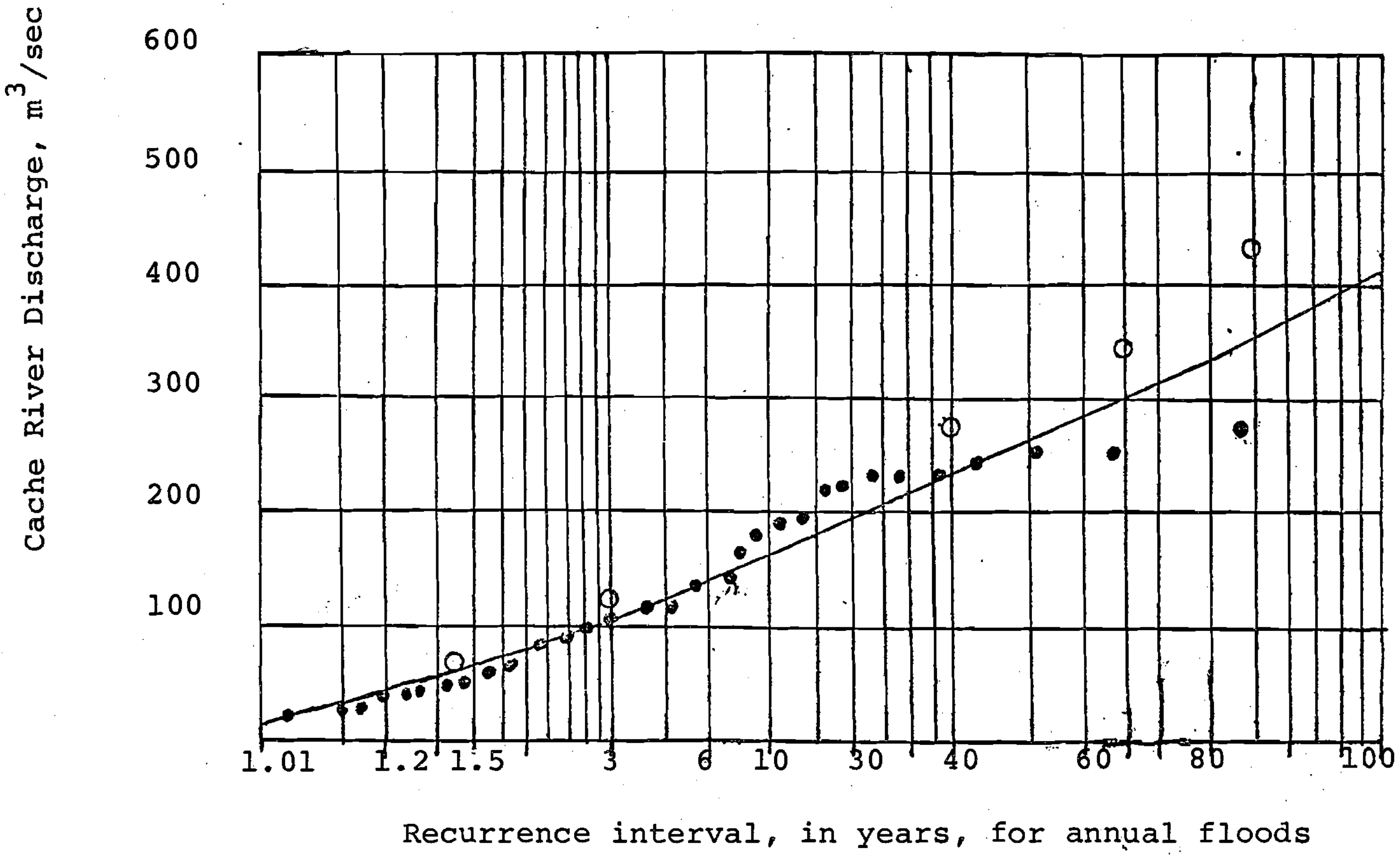


Figure 27. Frequency Curve for annual floods of Cache River (as modified from U.S.G.S., 1972).

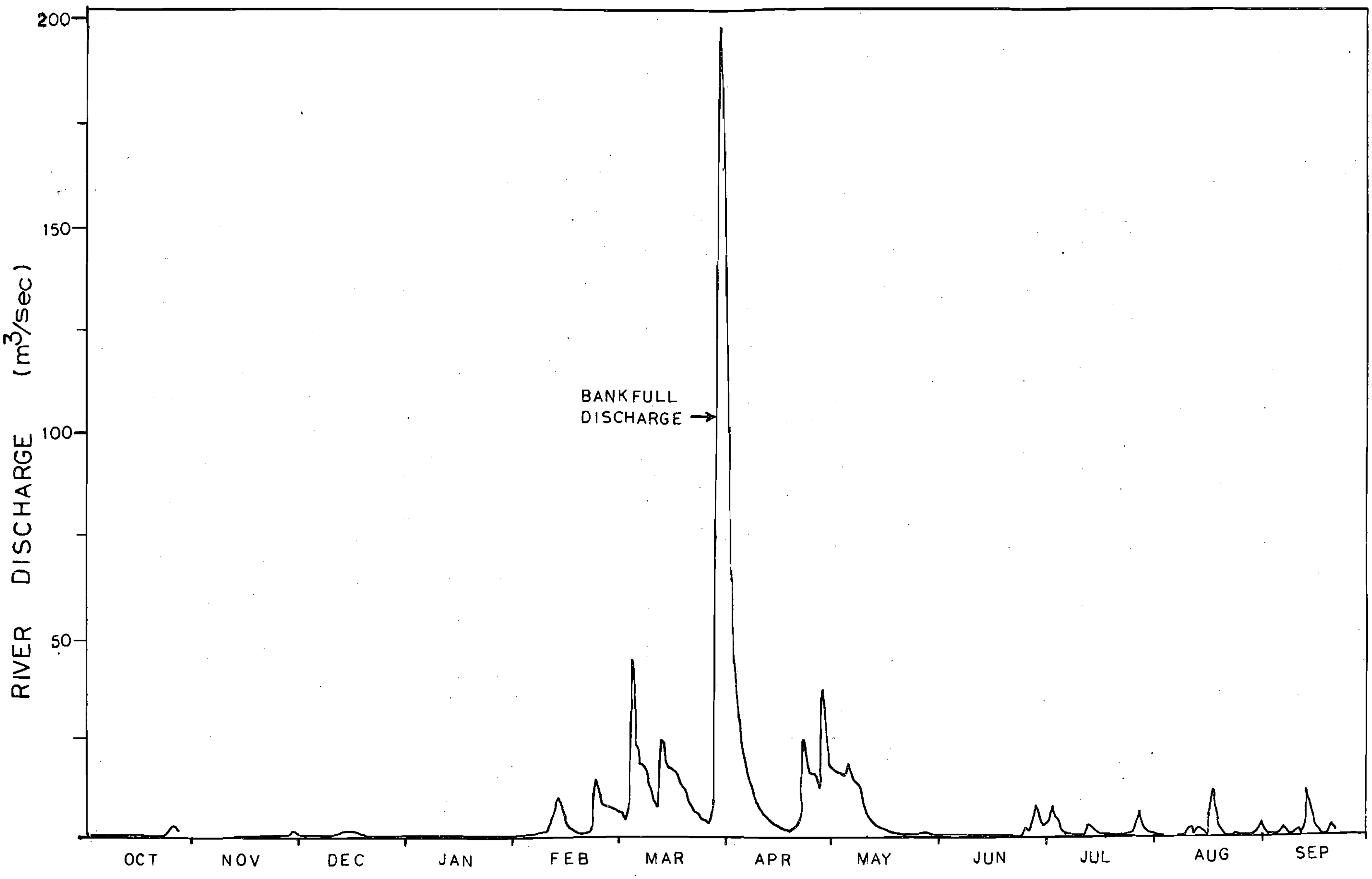


Figure 29. Cache River discharge at Station # 3 during study period.

levels as well as swamp areas such as Heron Pond. Access into the study area during flooding occurred only by boat through flooding lowlands.

From the storm hydrograph for the flood (Fig. 30), the effective rainfall (that portion of rainfall that contributes to runoff) was determined by planimetering the area above base flow and under the hydrograph curve. The area above 114 m^3/sec is the discharge which occurred over and above the "bankfull discharge."

To determine the amount of the storm rainwater that is not runoff, but held back either in soils as infiltration, retained in man-made reservoirs, or held in swamps, effective rainfall must be subtracted from total rainfall (Table 15). It can be seen from this table that the flood that occurred consisted of one rather long storm with light rainfall ending with an intense rainfall of greater than 10 cm in 6 hours. These 2 intensities are seen on the storm hydrograph (Fig. 30). When storms occurs, infiltration into soil occurs fairly rapidly at first, depending upon prior soil moisture conditions. But with intense storms, the soils become saturated very quickly and are impermeable to added rainfall. This explains the very large amount of effective rainfall (65%) of total rainfall during this storm. As can be seen from other storms on March 3 (Fig. 31) and March 11 (Fig. 32), the amount of effective rainfall was 22.8% and 27.5%, respectively, of the total rainfall. In both these smaller storms, flooding of the swamps did not occur.

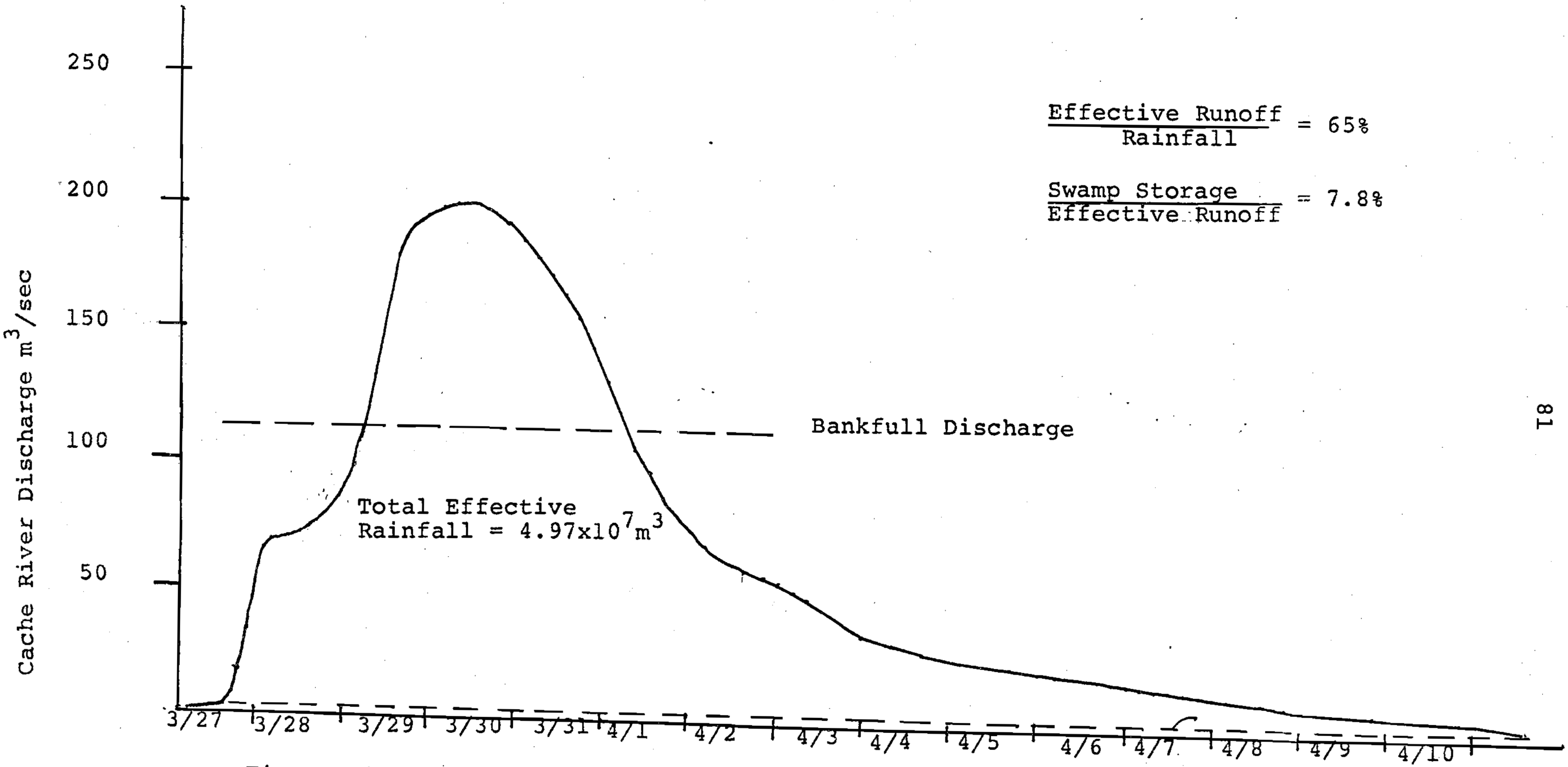


Figure 30. Cache River Storm Hydrograph of March Heron Pond Flood (13.01 cm Rainfall).

Table 15

Analysis of Cache River Hydrographs

Date of Storm Hydrograph	Storm Duration hr.	Rainfall as measured at Dixon Springs, cm.	Effective Rainfall as measured at Forman Gauging Station,* cm.	Storm Water Retained in Swamps or Soils, (Rainfall-Effective Rainfall), cm.	Water Retained in Swamp cm.	Water Retained in Soils, etc. cm.
3/3-3/11	9.5	5.08	1.15	3.93	0	3.93
3/11-3/18	4.0	2.54	0.70	1.84	0	1.84
3/17-4/11	18.0 6.0	2.57 10.44 13.01	7.90	5.11	.40	2.77

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* Cache River Drainage above Forman U.S.G.S Gauging Station = $6.294 \times 10^8 m^2$

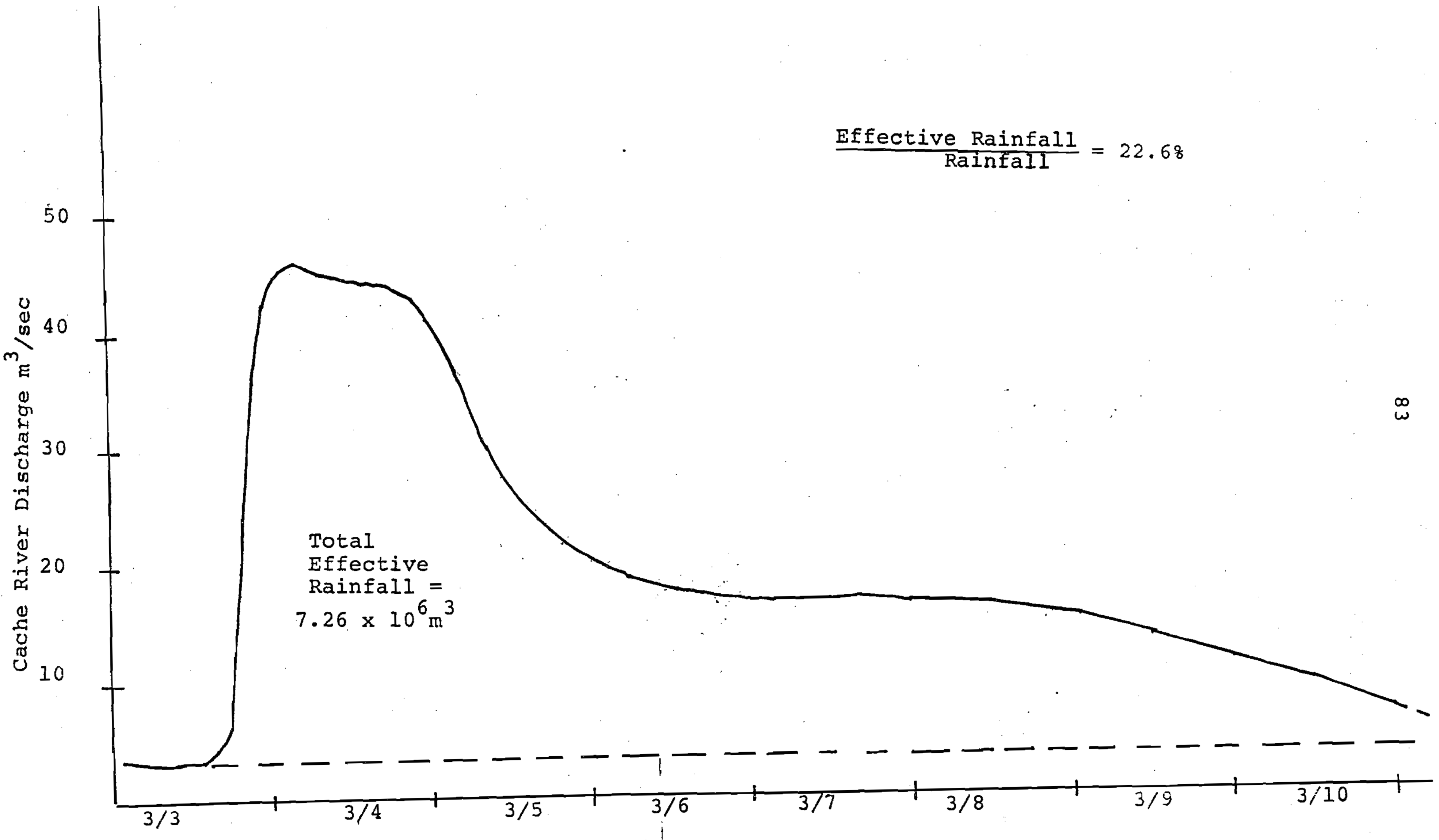

Figure 31. Cache River Storm Hydrograph (5.08 cm Rainfall).

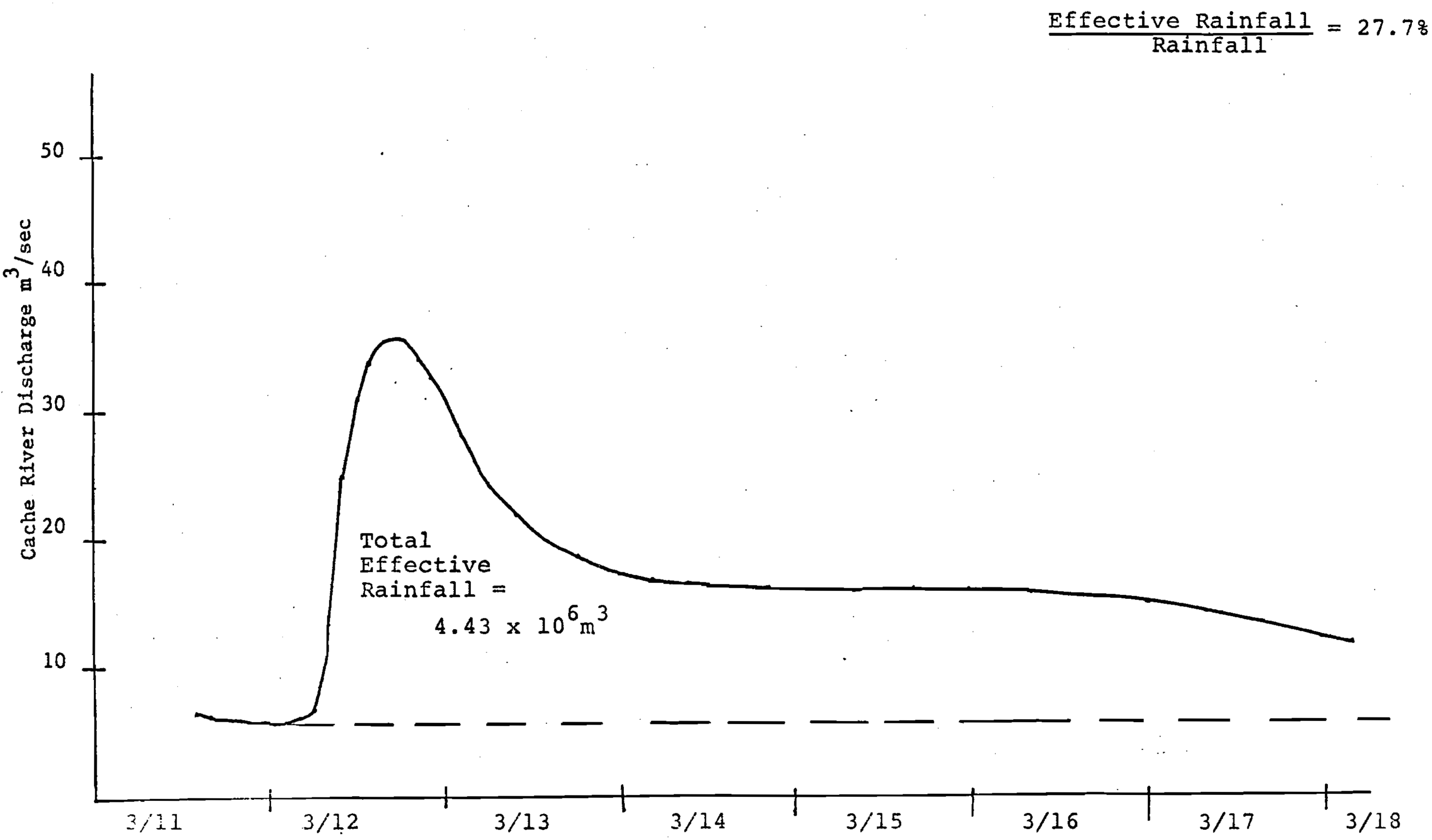

Figure 32. Cache River Storm Hydrograph (2.54 cm Rainfall).

To estimate how much of this flood water is stored by the swamps bordering the Cache River, the amount of flood water stored by Heron Pond can be extrapolated to include all the swamp areas above the gauging station. This storage is to include only storage that is left behind after the flood, not the gross amount of water over the wetland during peak flood stages. The reason for using only the water left behind is that it is the intention of this study to determine the significance of swampy wetlands, not entire floodplains in water conservation. The extrapolation coefficient was determined as follows:

Area of Heron Pond = 301,440 m^2

Area of wetlands above Forman = 1.57×10^7 m^2

$$\frac{1.57 \times 10^7 \ m^2}{301{,}440 \ m^2} = 52.13$$

This is to say that Heron Pond is 1.9% of the total wetlands above Forman, and these wetlands are in turn only one third of the total wetlands in Southern Illinois. The amount of flood water left behind in Heron Pond is 26.58 cm the difference between the water level when the swamp is "full" (87.17 cm) and the level prior to flooding (60.59 cm). By multiplying this 26.58 cm by the area of Heron Pond (301,440 m^2), the volume of 80,131 m^3 is left in Heron Pond after the flood. Extrapolating to the entire wetland area above Forman by multiplying this volume by the extrapolation coefficient suggests that 4.18×10^6 m^3 of flood water was left behind in wetlands after the flood receeded (Fig. 30). This, of course, assumes that other wetlands are similar in structures and had initial water levels the same at the onset of flooding as Heron Pond.

When the Cache River and Heron Pond separate during the recession of the river, the Heron Pond bankfull volume is left behind. The decay rates of the river and the swamps are vastly different (Fig. 33). The river has a decay coefficient of .1386/day and Heron Pond has a decay coefficient of .0117/day. Long after the river has gone down, the swamp still has a high stage and since surface outflow out of the swamp is a function of the level of the swamp, Heron Pond adds much water to the river after river swamp separation of the 1.5 x 10^7 m^3 discharge of the Cache after separation of swamp and river (Fig. 30), 9.7 x 10^5 m^3 of the remaining hydrograph's discharge (prior to resumption of base flow), or 6.4%, is due to swamp recharge after swamp river separation. This was calculated uding Heron Pond surface out-flow during the hydrograph period, separating out its base flow before the flood, and extrapolating to the rest of the swampland above Forman. The 4.18 x 10 m^3 of storm water that is retained in the swamp is 8.4% of the total storm hydrograph (4.97 x 10^7 m^3) as recorded at Forman. The effect of this storage is a smoothing out of the hydrograph. Without flood storage in swamp levels, peak discharges would be higher and recession occur faster than is now occuring.

Recharge

With large amounts of water left behind by flooding, or other imputs into the swamps, this water will either recharge adjacent groundwater storages or flow either by streamflow or by groundwater flow into the Cache River. This flow to the river can be significant and very useful during periods of

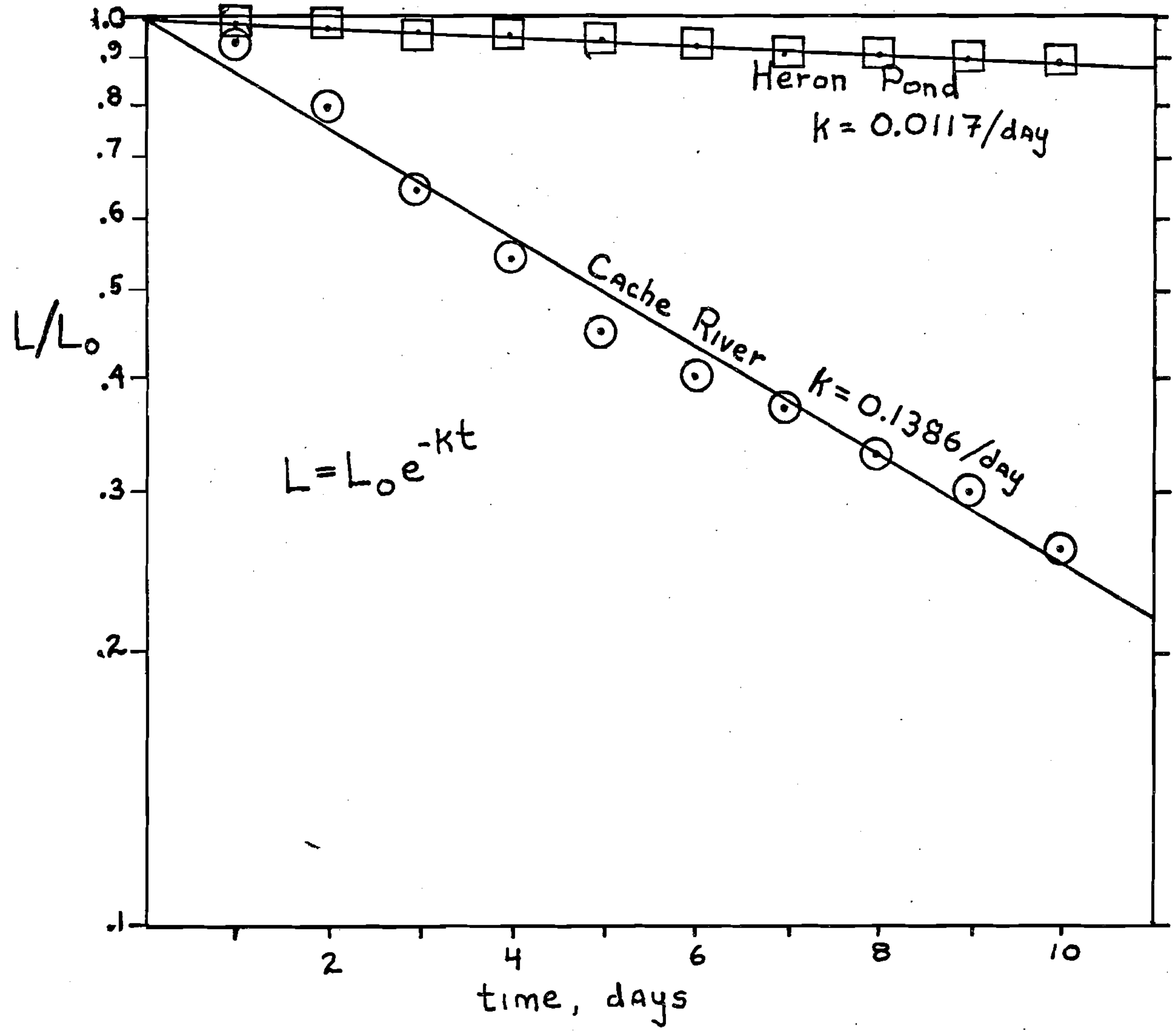

Figure 33. Recessimrate of the Cache River and Heron Pond after separation (following March flood).

low flow in augmenting other groundwater flows to keep the river from drying up.

By determine the mean monthly flows of the Cache River at Forman and determining the total mean monthly flows of all streamflow and groundwater from the wetlands, it is possible to see the potential role of swamp lands to recharge the river during low flows (Table 16). Again, the mean monthly flows had to be extrapolated to the entire area above Forman from Heron Pond data by using the extrapolation coefficient.

The percents must not be taken as exact, since the entire amount of discharge that come from the wetlands will not remain in the channel by the time it reaches the gauging station.

Also, since the swamp was frozen very solid from early December until February, the measurements taken during this period were subject to errors. Two of the main possibilities for error were the float of the water level being frozen up and not reflecting in-coming rainfall or out-going ice melt. The surface outflow also probably did not respond exactly to the logarithmic equation during these frozen periods because of ice blockage. Therefore the precentages may be somewhat inflated; however the relative importance of recharge during the different seasons of the year is worth noting. During periods of little rainfall during the winter (Nov., Dec., Jan.) and summer (June, July, Aug.), recharge by wetlands can be very significant, and during periods of high rainfall in spring (March), rather insignificant.

Table 16

Recharge Potential of Swamps Bordering the Cache River

Month	Monthly Mean Cache River Discharge Forman, Ill. m^3/sec	Monthly Mean Streamflow from swamps upstream from Forman, Ill. (as extrapolated from Heron Pond) m^3/sec	Monthly Mean Groundwater flow from swamps upstream from Forman, Ill. (as extrapolated from Heron Pond) m^3/sec	Monthly Mean Total Contribution from swamps to Cache River upstream from Forman, Ill m^3/sec	% of Cache Discharge at Forman that is from Wetland Recharge
Oct.	0.458	.022	.054	.076	16.7 %
Nov.	0.067	.040	.054	.094	140.3 %
Dec.	0.514	.066	.057	.123	24.0 %
Jan.	0.082	.064	.050	.144	139.6 %
Feb.	2.931	.111	.047	.158	5.4 %
March	12.924	.463	.083	.546	4.2 %
April	8.266	1.121	.168	1.289	15.6 %
May	8.223	.775	.100	.875	10.6 %
June	0.838	.273	.037	.310	37.0 %
July	1.488	.148	.040	.188	12.7 %
Aug.	1.293	.119	.042	.161	12.4 %
Sept.	1.652	.116	.056	.172	10.4 %

CONCLUSIONS

As can be seen, wetlands play on important role in rounding off the peaks and low points of the Cache River discharges. Floods are not as severe as they could be without natural reservoirs, and seasonal low river flows are continually recharged. Storage of the March flood was exhibited with the swamp land retaining 7.8% of the runoff, although no swamp storage was seen on any other storm occurances during the study period. Recharge was seen to be very significant during summer and winter months, when river stages are normally low, being supplied mostly by groundwater.

PHASE 2 - WATER CHEMISTRY

Heron Pond Water Chemistry

by

Carol L. Dorge

INTRODUCTION

Wetlands are among the least and the most productive ecosystems in the world (Rodin and Bazilevich, 1967) and productivity is most closely related to nutrient availability. Likens and Bormann (1972) suggest that the optimum environment for plant growth might be a rooted aquatic medium - carbon dioxide and light are available from above while nutrients in usable form, as soluble ions, can be drawn from the sediments. Nutrient availability is not simply a matter of access, however. Sediment cation exchange capacity, pH (particularly as it affects solubilities) and oxygen levels can be important limiting factors to vegetation, animals and microbes alike. Likewise the biotic part of the ecosystem influences the water chemistry through nutrient leaching, humic acid production, recycling, and metabolism.

The water chemistry of Heron Pond is discussed here in relation to its nutrient value. System dynamics which affect Heron Pond chemistry are considered including groundwater flow, rainfall and relationships with the Cache River, particularly when the river floods the swamp. Nutrients in relation to plant growth are also discussed.

METHODS

Water Samples

Chemical analysis for alkalinity, conductivity, turbidity and phosphorus and all field measurements were made by the researchers in this study. Other analyses were performed by an outside laboratory. All methods are presented in Table 17.

Station 1 was located on the Cache River, upstream of Heron Pond, Stations 2 and 3, were on the river below the swamp. Station 4 was near the main platform in the swamp, 4a was 90 m from the platform and 5 was the swamp outflow (Fig. 2). Water samples were screened for duckweed and fixed with sulfuric acid for phosphorus analysis and nitric acid for cation analysis. Fixed and unfixed samples were transported from the study site to the laboratory on ice.

Throughfall samples were collected in six rain gages at random locations under the swamp canopy. Three additional gages in the swamp which were not under the canopy and another in a clear area, 0.8 km from the swamp, were used for rainfall measurement and analysis. Gages were acid washed before they were set in place. They were covered with screen in order to

Table 17

Methods for Analysis of Physical and Chemical Parameters

Parameter	Method
Dissolved Oxygen	Dissolved oxygen probe
pH	pH probe
Alkalinity	Titration[2]
Hardness	By calculation from Ca and Mg conc.
Turbidity	Turbidimeter
Conductivity	Probe
Ortho-phosphate	Ascorbic Acid Method[1]
Total Soluble Phosphorus	Ascorbic Acid Method[1]
Total Phosphorus	Ascorbic Acid Method[1]
NO_2-N	Diazotization Method (autoanalyzer[2])
NO_3-N	Cadmium reduction method (autoanalyzer)
NH_3-N	Berthelot Reaction Method (autoanalyzer)
TKN	Modified Berthelot Reaction Method (")
$SO_4^=$	Turbidimetric Method[2]
Dissolved Residue	Constant wgt. on drying @ 180 C, filtered[2]
Total Residue	Constant wgt. on drying @ 180 C, unfiltered[2]
COD	Dichromate reflux method[2]
K^+	Atomic emission
Mg^{++}	Atomic absorbtion
Na^+	Atomic emission
Ca^{++}	Atomic absorbtion

[1] Murphy and Riley (1962)

[2] APHA (1976)

limit insect and litterfall contamination, and mineral oil was added to prevent evaporation. A mineral oil blank was run during phosphorus analysis of the rainwater and values were far below the limits of measurement. Other chemical parameters for rainfall samples were measured by the outside laboratory according to the methods used for swamp and river water analyses. No mineral oil blank was run, and samples for only one date, July 29, 1977, were analyzed.

RESULTS AND DISCUSSION

Rain and Throughfall

Rainfall and throughfall were measured to determine input of phosphorus and other minerals to the swamp through atomospheric channels and to determine that part of the input, more accurately described as nutrient cycling within the system, due to leaching from canopy plant tissues. Average concentrations for throughfall and rainfall are given in Table 18. Original data are in appendix A of this section. Eaton *et al.*, (1973) described nutrient input to the system by throughfall, as due to any of the following:

1) Materials contained in the rainfall itself
2) Impacted aerosols on canopy, washed of by incident precipitation, or
3) Nutrients with gaseous phases which have been incorporated in the tissues, removed by incident precipitation.

Rainwater generally has a pH of 5.6 and low buffering capacity due to low alkalinity. Certain atomospheric contaminants, primarily SO_2 and NO_2, easily lower the pH by combining with atomospheric H_2O to form either sulfuric or nitric acid. Heron Pond throughfall has characteristically low alkalinity, 8.3 mg/l, and this value is reflected in the swamp water chemistry which had an average alkalinity value of 33 mg $CaCO_3$/l.

Table 18

Chemical Composition of Rainfall and Throughfall

	THROUGHFALL				RAINFALL				
	Heron Pond	Florida Swamp[1]	Okefenokee Swamp[2]	Hubbard Brook[3]	Heron Pond	Florida Swamp[2]	Okefenokee Swamp[2]	Hubbard Brook[3]	Southern Lake Michigan[4,5]
pH		4.15				4.6		4.14	
Alkalinity	8.3				2.7				
Hardness	6				4				
Conductivity	73	44.5			30	29.0			
Ortho-phosphate	0.046	0.050			0.009	0.020		0.008	
Total P	0.193	0.090	0.048*	0.0026	0.106	0.095	0.017		0.073[4]
NO_3-N	0.5	0.240	0.73		0.40	0.190	0.26	1.47	
NH_3-N	0.38	0.200		0.67	0.38	0.130		0.22	
TKN	1.80			1.21	2.78				0.10[5]
$SO_4^{=}$-S	11.6			5.4	< .01			2.9	
Dissolved Residue	40				29				
Total Residue	60				44				
COD	40.5								
K^+	0.1		0.39	6.37	0.0		0.14	0.07	
Mg^{++}	0.3		0.14	0.45	0.2		0.05	0.04	
Na^+	0.0			0.14	0.0			0.12	
Ca^{++}	2.0		0.48	1.59	1.4		0.17	0.16	

1 - Brezonik et al., (1974); 2 - Schlesinger (1977); 3 - Likens et al., (1977); 4 - Murphy and Doskey (1975); 5 - USEPA (1976). * - total soluble P

All values expressed as mg/l with the exception of pH (pH units) and conductivity (µmho/cm)

Nutrients contained in the rainfall itself, or in dry fallout, increase with proximity to cultivated farms or lawns (Murphy and Doskey, 1975). Flat forested land with ground cover does not significantly input nutrients to the atomosphere; Heron Pond is surrounded by forests, therefore rain nutrient concentrations would be expected to be minimal. Nitrogen increases near areas of saturated, poorly aerated soil. This might explain slightly higher NH_3-N values in Heron Pond rain and throughfall. Phosphorus in rainfall can range in concentration from .005 - 0.120 mg/l (Gorham, as ref. by Brinson, 1977). Concentration has been found to be inversely proportional to rainfall volume for both rainfall and throughfall in a cypress swamp (Schlesinger, 1977).

Throughfall and rainfall inputs to Heron Pond are presented in Table 19. Total phosphorus input to the swamp by throughfall averaged 0.144 gm P/m^2-yr (average concentration 0.193 mg P/l). Brinson, et al. (1977) found a throughfall input of 0.128 gm P/m^2-yr in a North Carolina tupelo swamp. Schlesinger (1977) found 0.075 gm P/m^2-yr to be recycled by leaching while Brinson measured 0.105 gm P/m^2-yr due to canopy leaching. A leachate value for Heron Pond can be computed from throughfall and rainfall input 0.155 gm P/m^2-yr to Heron Pond and is 0.029 gm P/m^2-yr. The Heron Pond rainfall value is greater than that measured by Brinson (0.0499 gm P/m^2-yr) or Schlesinger (0.022 gm P/m^2-yr). In the Murphy and Doskey (1975) study of total atomospheric input of phosphorus to southern Lake Michigan, 0.073 gm P/m^2-yr was the amount deposited annually by rainfall. A comparison of concentration values was presented in Table 18.

Table 19

Nutrient and Chemical Inputs to Heron Pond by Rainfall and Throughfall

	Throughfall, gm/m^2-yr	Rainfall, gm/m^2-yr
Alkalinity	6.2	2.94
Hardness	4.5	4.3
Conductivity	54.3	32.6
Ortho-phosphate	0.034	0.010
Total P	0.144	0.115
NO_3-N	0.56	0.43
NH_3-N	0.28	0.41
TKN	1.34	3.02
$SO_4^=$-S	8.6	<0.01
Dissolved Residue	29.7	31.5
Total Residue	44.6	47.8
COD	30.1	76.3
K^+	0.07	0.00
Mg^{++}	0.22	0.22
Na^+	0.00	0.00
Ca^{++}	1.49	1.52

All values expressed as mg/l with the exception of pH (pH units) and conductivity (μmbo/cm)

Algae was found growing in gages in Heron Pond and in the USEPA collectors during the warmer months. More detailed analysis of Lake Michigan samples also revealed pollen, insect larva and other inputs. These would be assumed to be part of total atomospheric input. While samples containing large insects or otherwise noticeably contaminated were eliminated from data analysis, it is possible that Heron Pond rainfall values are higher than others due to contamination by pollen or small insects. Because "dry fallout" was not measured as a separate component of nutrient input to Heron Pond, for the purpose of calculating nutrient budgets in this study, it is assumed that these values validly represent atomospheric input. It was also assumed that agitation of the Heron Pond samples dispersed the algae and total phosphorus analysis produced a correct value for phosphorus input. Stemflow was assumed to be negligible in this study. Brinson found it to represent less than 1% of throughfall input.

Heron Pond throughfall average orthophosphate concentration, .046 mg P/l, almost equals values measured in Florida (.05 mg P/l) but is significantly less than that measured under a birch, maple, beech canopy at Hubbard Brook, 0.15 mg/l (Likens et al., 1977). Values might be due to differing sampling techniques. No preservative was added to Heron Pond gages and sampling was at two month intervals; great change in phosphorus form would be expected. Hubbard Brook sampling was done at more frequent intervals; a sampling period of less than or equal to one week was suggested for minimizing problems of contamination and biogeochemical transformation. In addition the Hubbard Brook studies did not include data for precipitation collectors which contained leaves or insect debris. The intent was to have a sufficient number of collectors that at least one sample would be "clean", (Likens et al., 1977). It was found impossible, in Heron Pond, to sample only "clean" containers. All gages contained litter and small insects in varying degrees at each sampling time. As was done for rainfall samples, when analysis of individual samples showed great deviation, any extremely high results were discarded. It can be assumed, however, that throughfall values include some chemical input by detrital pathways. For this study, this input will be considered a valid component of throughfall.

Nitrate concentrations (0.40 mg/l) in Heron Pond rain were 27% as high as those in Hubbard Brook (1.47 mg/l) where acid rain, principally due to atomospheric NO_2, is an increasing problem. Florida rain, averaged only 0.24 mg/l NO_3-N. Ammonia nitrogen values were more similar for the three systems: 0.20, 0.22 and 0.38 mg N/l for Florida, Hubbard Brook and Heron Pond respectively.

Cation concentrations were greater than those found in other systems. Because a mineral oil blank was not run, data may not be valid.

Sulfate concentration in the swamp throughfall, 11.6 mg/l, is significantly higher than rainfall concentrations, 0.01 mg/l, indicating substantial intrasystem recycle of this nutrient by leaching. Similar results were obtained at Hubbard Brook, to a lesser degree. Higher rainfall sulfate concentrations may be due to higher levels of atomospheric SO_2 there.

Heron Pond Water Chemistry

Heron Pond water chemistry is summarized in Table 20 and presented in graphical form (Figs. 34 and 35) (complete water chemistry data is presented in Appendix A). Nutrients show little change in concentration over the annual period with one exception, the flood period; at this time an estimated 1.6×10^6 m^3 of river water mixed briefly with the swamp water and chemical measurements were characterized by concentrations found in the turbid river water. Total solids also peaked, to a lesser degree, as an estimated 8.3 kg of sediment passed over the swamp. The magnitude of flood transport over the swamp is demonstrated by comparison with average storages in the swamp (Table 21).

Relationships to pH - Heron Pond pH averaged 6.1; this is less than the Cache River average and more basic than normal rainfall, suggesting partial buffering. The relationship of pH to wetland character has been discussed at length. Gorham (1967) attributed the shift in dominant ions from the Ca^{++} and HCO_3^- of a circumneutral water to the H^+ of a bog-type to 1) oxidation of sulfur compounds, 2) air pollution H_2SO_4, 3) H^+ displacement by cation exchange and 4) throughfall.

While air pollution sulfates are an extremely low input, as determined by rainfall concentrations, sulfates added by leaching are an important source here. Swamp levels averaging 1.6 mg/l, are lower than rainfall levels; it is likely that anaerobic conditions in the swamp sediment encourage growth of sulfur reducing bacteria. When sediments are disturbed,

Table 20
Comparative Water Chemistry Annual Averages For Swamps and Marshes

Parameter	Heron Pond Sta. 4	Florida[1] Rainwater Dome	Florida[1] Groundwater Dome	Florida[1] Sewage Dome	Louisiana[2] Swamp	Swamp[3] on Natural Stream	Swamp[3] on Channelized Stream	Taylor Slough[4] Florida Everglades	Wisconsin[5] Marsh
Dissolved Oxygen	2.2								
pH	6.1	4.3-4.7	4.9-6.9	4.2-6.3					
Alkalinity	31	0	70	0-174					
Hardness	27								
Turbidity	223	0.38-54	0.6-1.2	0.9-2.4					
Conductivity	110	60-72	131-370	115-500		55	152		415
Ortho-Phosphate	0.158	0.02-1.3	0.08-0.70	.36-4.4	0.15				0.10
Total Soluble P	0.191								
Total P	0.326	0.03-0.57	0.10-0.70	.52-6.8	0.34	.046	.053		0.21
NO_2-N	<.01					-	-		
NO_3-N	<.01	0.01-0.9	0-2.1	0-1.9	0.28	0.047	0.62		< 0.28
NH_3-N	1.00	0.01-0.5	0.01-3.8	.03-6.7	0.25	-	-		0.39
TKN	1.64	1.0-2.0	0.08-10.2	1.5-8.8	1.63	0.48	0.31		3.7
$SO_4^{=}$-S	1.6							6.0	
Dissolved Residue	66							218	
Total Residue	125								
COD	44.8								
K^+	3.3	0.4-1.1	0.9-1.1	4.5-7.2		1.8	1.9	12.8	5.4
Mg^{++}	11.8	1.5-2.5	27.9-35.9	11.4-20.6		1.2	1.6	6.9	28
Na^+	3.2	2.9-5.7	7.5-8.1	23.2-38.9		4.2	4.9	3.5	2.79
Ca^{++}	17.0	1.0-3.2	24.4-35.5	7.8-18.5		2.1	10.6	6.5	44.1

1 Brezonik _et_ _al_. (1974) - 2 Day _et_ _al_. (1977) - 3 Kuenzler (1976) - 4 Waller _et_ _al_. (1975) - 5 Lee _et_ _al_. (1975)

All values expressed as mg/l with the exception of pH (pH units) and conductivity (μmho/cm)

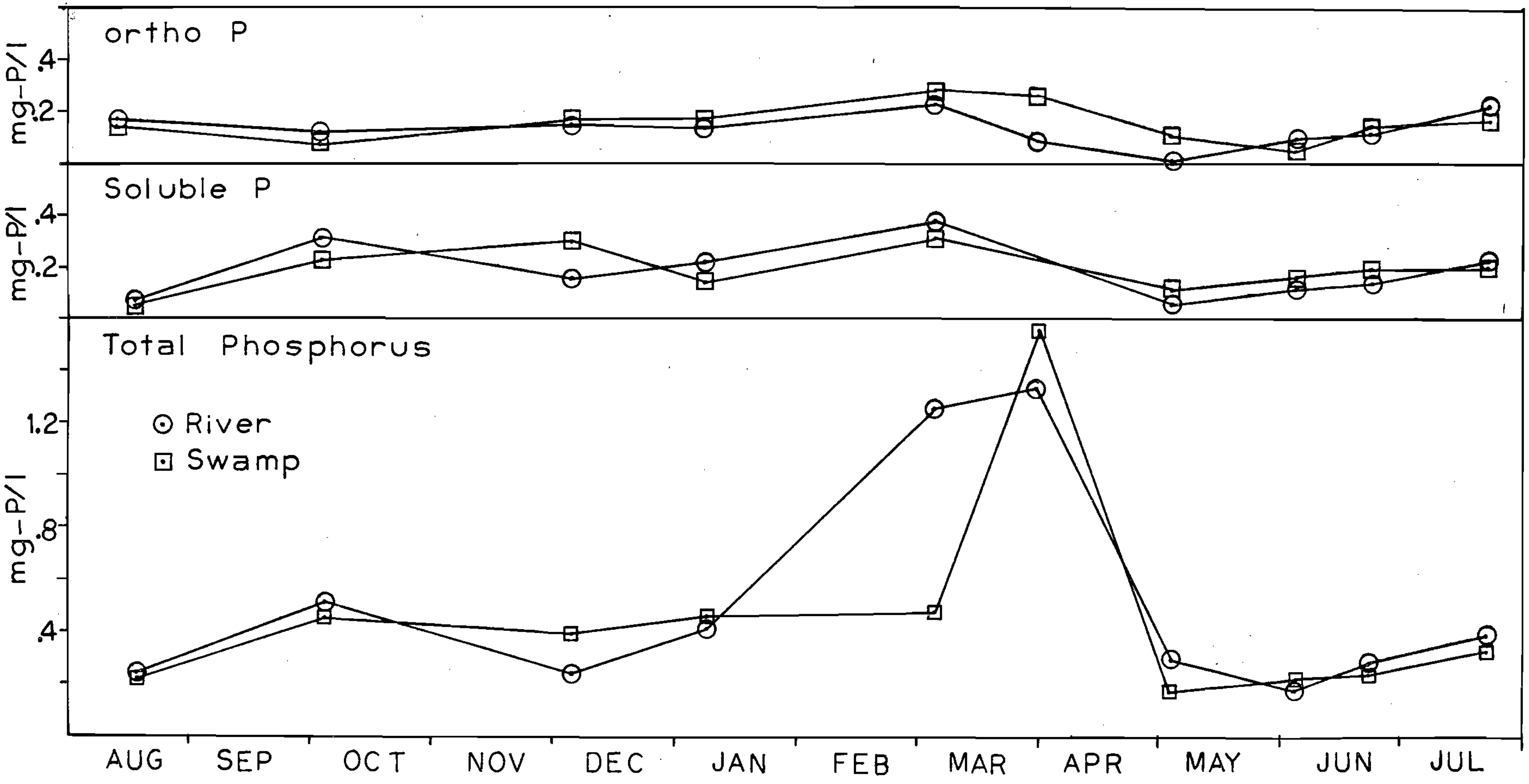

Figure 34. Phosphorus Levels in Heron Pond (Station 4) and Cache Riverage (average of 3 stations) During Study Period

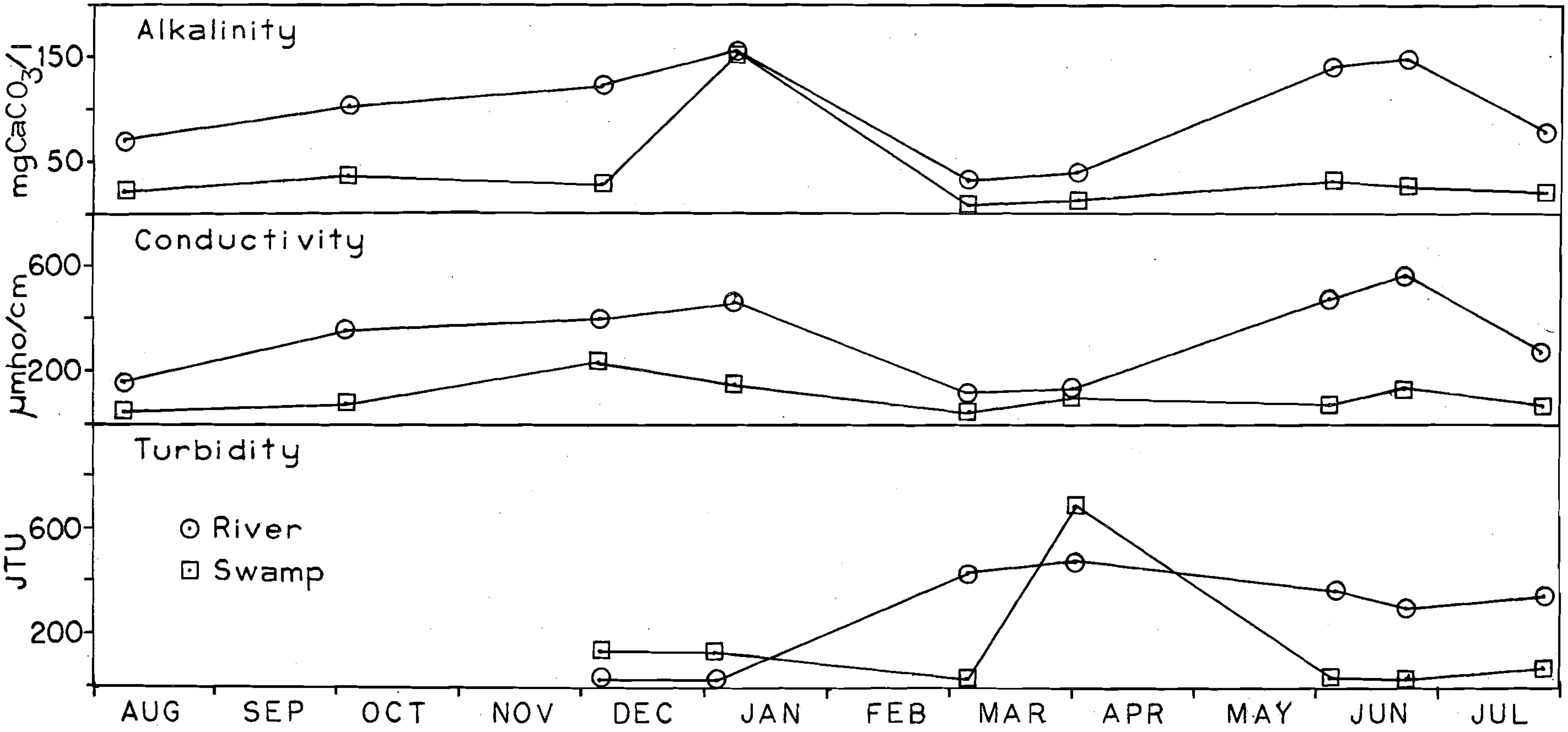

Figure 35. Alkalinity, Conductivity and Turbidity Comparisons Between Heron Pond (Station 4) and Cache River (average of 3 stations) for Study Period

Table 21

The Magnitude of Flood Transport, Demonstrated by Comparison to Normal Storages in the Water Column

Parameter	Storage in Swamp Water Column, gm/m^2	Flow Over Swamp During Flood gm/m^2
Alkalinity	13.7	642
Hardness	11.2	1123
Ortho-phosphate	0.068	13.8
Total P	0.143	80.2
NO_2-N	0.004	0.53
NO_3-N	0.004	0.53
Ammonia-N	0.40	9.6
TKN	0.87	32.1
$SO_4^{=}$-S	0.83	570*
Dissolved Residue	33	5346
Total Residue	94	13,632
COD	19.5	2,245
K^+	1.4	176.4
Mg^{++}	4.9	133.7
Na^+	1.3	144.3
Ca^{++}	7.0	219.2

* Use average river concentration: Swamp value not available.

All values expressed as mg/l with the exception of pH (pH units) and conductivity (μmho/cm)

bubbles appear, accompanied by the odor of H_2S, the product of vegetation decay and sulfate reduction.

Heron Pond ammonia nitrogen levels (1.00 mg/l) are 100 times greater than nitrate levels; formation of the ammonium ion would partially counteract acidity from H_2SO_4. Total nitrogen is 1.64 mg/l. Here levels are higher than Cache River levels. Ammonia levels are higher than those found in a Wisconsin marsh (Lee _et al_., 1975) and approximately equal to levels found in a Florida groundwater and sewage cypress dome (Brezonik, _et al_., 1974). Accumulation of NH_3-N under anaerobic conditions is expected as part of bacterial decay of organic matter. It may be taken up by plants, immobilized in cell materials, adsorbed onto clay or volatilized under alkaline conditions. Only if oxygen is present will mineralization proceed with conversion to nitrate. If this occurs and subsequently nitrates percolate into anaerobic layers (this may occur if microenvironments of aerobic and anaerobic conditions exist) denitrification can occur (Tusneem and Patrick, 1971).

Total nitrogen levels are approximately equal to Florida rainwater dome levels. Comparisons are made in Table 20. Both total and ammonia nitrogen peak at the end of the growing season. Likens _et al_., (1977) found similar seasonal peaks to occur in streams, with NO_3-N maximum at times of minimum biological activity. COD peaks with NH_3-N on autumn, indicating significant accumulation of products of incomplete decomposition.

Dissolved Oxygen - Heron Pond dissolved oxygen averaged 2.2 mg/l. Both cypress and tupelo grow better in saturated, aerated soil, although cypress growth is greater when fertilized with urea than with NO_3-N while tupelo prefers the oxidized nitrate form (Dickson and Broyer, 1972). Watt and Heinselman (1965) reported that channels of water movement in a spruce bog have richer fauna than do more stagnant sections and attributed this to better decomposition of leaf litter and nutrient release in the channel. Oxygen without this nutrient supply did not increase growth. Heinselman (1963), Brinson (1977) and Schlesinger (1977) agreed that a reduced environment and low dissolved oxygen are associated with limited nutrient uptake. Moore and Bellamy (1974) also suggested that lack of oxygen might be important to nutrient usability, but noted that only eight per cent of saturation oxygen was necessary for an "aerobic" reaction to take place.

This is not to say however, that Heron Pond is an oxidized system. Dissolved oxygen is near zero at the sediment water interface, COD levels averaging 49.8 mg/l and the presence of reduced forms of nutrients, notably ammonia nitrogen, characterize the system and suggest diffusion of oxygen or oxygen input as a product of duckweed photosynthesis may limit higher concentration to the upper layer of water; oxidized nutrients may be available only near the water surface.

Phosphorus Solubility - Phosphorus, the element most intensely studied in Heron Pond, is usable as a plant nutrient at levels as low as 0.001 mg/l (Garrels *et al.*, 1975). Concentration in the water column has been shown to be regulated by precipitation reactions, sediment - water exchange and plant uptake. Enfield and Bledsoe (1975) in a study which did not concern reduced conditions, reported that at low pH, ferric and aluminum phosphates control equilibrium concentrations. $AlPO_4$ and $FePO_4$ have minimum solubilities at pH 6 and 5.5 respectively. If present, Al (III) could limit soluble phosphate concentrations to 0.010 mg/l given this equilibriun relationship and pH in Heron Pond. This phosphate level is lower than that currently found in Heron Pond; average orthophosphate concentration is 0.158 mg P/l. Equilibrium phosphate concentration for $FePO_4$ dissolution is approximately 1.0 mg/l at pH 6.0. Neither of these, then, is controlling phosphate levels; aluminium is not present in sufficient quantity, or more precipitation of phosphate would take place, and solubility of the Fe (III) form, in excess of concentrations found in the swamp, suggests it is not the limiting factor in determining concentration. Similarly, under acidic anaerobic conditions, very soluble Fe (II) forms and orthophosphate prevail. While only limited analysis of solubility relationships can be made because analysis for iron and aluminum was not a part of this study, it is likely that iron is present in Heron Pond and plays an important, though not limiting role in phosphorus dynamics. Southern Illinois rivers have iron concentrations near maximum for the state; a five-year average for the Cache River was 8.1 mg/l (total iron) (Nienkerk and Flemal, 1976).

At higher pH, hydroxyl-apatite ($Ca_5(OH)(PO_4)_3$) solubility controls phosphate concentrations, however at pH 6 approximately 1 mg P/l is required for conversion of $CaCO_3$ (assuming saturation levels) to hydroxyl-apatite (Stumm and Morgan, 1970).

<u>Sediment Exchange and Other Forms of Adsorbtion</u> - Both water and sediment concentration control the rate of phosphorus

exchange (Wildung and Schmidt, 1973) although there is little correlation between sediment and water concentrations in undisturbed (unagitated) systems (Williams and Mayer, 1972). Under anaerobic conditions, sediments have been found to act as a buffering system, releasing phosphorus when water concentration is low and removing it when it is high (Patrick and Khalid, 1974). In a lake, deposition is exceeded by regeneration only when overturn causes oxidizing conditions at the sediment/water interface and this can be inhibited in the presence of a barrier of Fe^{+++} (Williams and Mayer, 1972). Oxidation - reduction potential, pH, calcium concentration and agitation of sediments all regulate phosphorus release or adsorbtion (Kramer _et al._, 1972). Uptake by rooted plants may act as a "sink" or "resin" for sediment phosphorus, driving the water/sediment equilibrium reaction toward the sediment. This cycle is completed by return of the nutrients to the water column as canopy leachate or litterfall with subsequent decomposition.

Brinson _et al._, (1977) found microbes attached to detrital leaf litter to adsorb phosphorus, acting as a temporary sink and decreasing turnover time in the nutrient cycle. During the growing season, microbial function reverses; bacteria in the water column may act to keep phosphorus there. In the autumn and spring, particulate organic phosphorus (a phosphorus, aluminum, iron, humic acid complex) was found to be an important form in the Tar River swamp in North Carolina. Soluble organic phosphorus levels in Heron Pond (total soluble phosphorus minus orthophosphate) were maximum in October (0.150 mg/l) and June (0.100 mg/l) with summer values of 0.03 mg/l and winter values near zero, suggesting complexing similar to that found by Brinson.

Total Phosphorus and Absorbed Phosphorus - Total phosphorus concentrations are regulated by mechanisms very different from those controlling soluble phosphorus levels. Phosphorus may be present as part of particulate organic matter or living plants or animals, mineral suspended solids, or adsorbed onto clay particles. Adsorbtion is maximum at pH 5 to 6 (Stumm and Morgan, 1970), the reduced conditions of the swamp sediments should not affect this process which involves attraction of the anionic $PO_4^{=}$ to positively charged clay surfaces.

Total phosphorus in Heron Pond average 0.326 mg/l, but floodwaters averaged 1.56 mg/l on April 1, due to greater levels of suspended material at this time. Standard deviation of total phosphorus concentration (indicative of the magnitude of flood impact) was 0.117 when the flood value was not included and 0.406 when it was included.

Nitrogen - Phosphorus Ratios - Ratios of total nitrogen to total phosphorus have been used as indicators of nutrient limitation. The point above which phosphorus is considered limiting is commonly assumed to be 10.0 mg N/l:1.0 mg P/l. While there is great variation in concentrations in living matter an idealized organic molecule has the ratio 16 atoms N:1 atom P (7 gm N: 1 gm P) (this ratio was proposed by Redfield and is commonly called the Redfield ratio). The ratio for Heron Pond water is 5.1 suggesting an excess of phosphorus. Table 22 compared this value to those for other systems.

Table 22

Ratios of Nitrogen (mg N) to Phosphorus (mg P) for Swamps and Marshes

Ecosystem	Source	Total N/Total P	Inorg. N/ Inorg. P
Heron Pond	(this study)	5.1	6.5
Florida: Fire and Sewage dome	(Mitsch, 1975)	0.54	
Florida: Ground-water dome		3.2	
Florida: Small Fire, low pH		5.1	
Florida: Rain-water dome		13.0	
Unchannelized River Swamp	(Kuenzler 1976)		12.2
Channelized River Swamp	(Kuenzler 1976)		60.5
Louisiana Swamp	(Day *et al.*, 1977)	6.3	1.9
Wisconsin Marsh	(Lee *et al.*, 1975)	19	2.8

Plants as Indicators of Water Chemistry - Plants, by their nutrient uptake mechanisms, their choice of nutrient form (for example, NH_3-N as opposed to NO_3-N), their structural adaptations and adaptations to xerophytic conditions, selectively adapt to a variety of nutrient conditions.

Duckweed appears to be an indicator of a rich nutrient supply. It is capable of luxury consumption of phosphorus (plant tissue concentrations increase in conjunction with increased levels in water), and was found to be an important primary producer in the Florida cypress dome which received sewage, and not in natural domes there (Price, 1975). This suggests Heron Pond nutrient availability may be comparable to a dome receiving sewage and not to southern swamps with predominantly autochthonous nutrient supplies. This may not be related to the nutrient phosphorus, however. Average total phosphorus concentrations were greater in Florida groundwater, rainwater and sewage domes, than in Heron Pond (Brezonik *et al*., 1974).

Absent from Heron Pond are the xerophytic plants, epiphytes and carnivorous plants often found in nutrient deficient bogs. Schlesinger (1977) found an important component of the Okefenokee swamp to be Spanish moss (*Tillandsia usneoides* L.), a vascular epiphyte with two adaptive mechanisms: low tissue nutrient concentrations and the ability to obtain nutrients directly from rainfall. This plant is not only adapted to low nutrient levels, it acts to perpetuate them; it was found to intercept NO_3-N in sufficient levels to cause throughfall concentrations to be less than rainfall concentrations. Carnivorous plants and evergreen shrubs were important components of the shrub layer in Okefenokee; evergreenness, by providing more efficient nutrient use and limiting losses due to litterfall, is another possible adaptation to low nutrient conditions (Monk, 1966). Lake of evergreen shrubs in Heron Pond further differentiates it from bog-like swamps.

Some Characteristics Associated with Nutrient Stress - While phosphorus levels, ammonia-nitrogen levels and duckweed growth are representative of a nutrient rich system, in some respects Heron Pond has characteristics often associated with nutrient impoverishment.

As previously mentioned, a reduced environment and low dissolved oxygen levels result in limited nutrient uptake. Schlesinger (1977) further suggests that the relatively low ratio of cypress leaf biomass to total biomass is an adaptation to low nutrient availability, particularly in light of the fact that, in the trees he studied, return of nutrients to perrenating organs prior to leaffall (73% - 91%) was approximately equal to that of upland tree species in nutrient rich environments. In Heron Pond, average return was found to be only 37% although one autumn measurement suggest return may be as much as 77%. Other adaptions for more efficient nutrient use, suggested by Schlesinger, include low concentrations of nutrients in woody, non-photosynthetic plant parts, and low intraspecific competition (high density single species stands with little evidence of self thinning). Both of the above are characteristic of Heron Pond, the cypress wood leaf phosphorus ratios was .027:1 and stand density is near maximum for a temperate forest as discussed in the Net Primary Productivity and Biomass chapter of this report.

Schlesinger found numerous xerophytic plants in the shrub layer of Okefenokee. Xerophycity has often been related to nutrient deficiency (Marchand, 1975; Watt and Heinselman, 1965; Rigg, 1916). Xerophytic plants were not part of the Heron Pond shrub layer, but the substrate was notably an aerated one, consisting of fallen logs and tree stumps with plants rooted near the water surface. Duckweed, the most important understory producer, appeared to suffer no deficiencies; productivities as determined by sedimentation rates were as high as those in the Florida cypress dome receiving sewage (Struble and Graetz, 1976).

Heron Pond is more acid than the Cache River, suggesting either H^+ production (or release by ion exchange), lower buffering capabilities, or both.

Acid waters are generally nutrient poor and while certain plants may be capable of growth at acid or basic pH, nutrient availability, as affected by pH might select certain plant groups (Cowardin, et al., 1977; Heinselman, 1963). The exchange of H^+ for nutrients is a well documented cause of nutrient poor conditions (Watt and Heinselman, 1965; Gorham, 1967; Heilman, 1966; Schlesinger, 1977).

Removal of nutrients from the water column is selective; both peat and microbes accumulate nitrogen faster than potassium, magnesium and calcium in that order (Schlesinger, 1977). Peat accumulation itself may act as a nutrient sink if nutrients are tied up in non-decomposed materials. Peat, however, was a small part of Heron Pond sediments, although surface layers were up to 30% organic matter. Adjacent marshy areas not included in this study were, however, developing deeper peat layers. Schlesinger, (1977) found similar spacial variation in Okefenokee sediments.

Conductivities of approximately 100 µmho/cm are associated with acid waters while values of 1000 and greater are commonly found in waters of pH greater than 8 (Enfield and Bledsoe, 1975). Heron Pond conductivity averaged 110 µmho/cm and decreased with dilution (Fig.36). Maximum values did not exceed 250, however. It is interesting to note that conductivity and Heron Pond and Cache River orthophosphate concentration are inversely related to water volume and flow. Likens and Bormann, (1972) found Na^+ and silica concentrations in a river to decrease with increased flow while K^+, NO_3-N and H^+ increased. Cation and NO_3-N concentrations in Heron Pond could not be correlated with outflow at Sta. 5 or with swamp stage.

Ca^{++}, Mg^{++}, Hardness, Alkalinity

Despite the above factors which relate more to the availability of nutrient cations than phosphate or other anions, Ca^{++} and Mg^{++} levels of 17.0 mg/l and 11.8 mg/l are similar to those shown in Table 20 for other ecosystems and greatly exceed those for a swamp on a natural stream (2.1 mg/l and 1.6 mg/l) (Kuenzler, 1976). Average swamp Mg^{++} concentration is greater than that in the Cache River, 5.7 mg/l. Lower alkalinity in Heron Pond relative to the river (31 mg $CaCO_3$/l vs 99 mg $CaCO_3$/l) is expected in light of acidic conditions in the swamp. Swamp Ca^{++}, Mg^{++} levels might be attributable to magnesium and calcium phosphate complexes, in

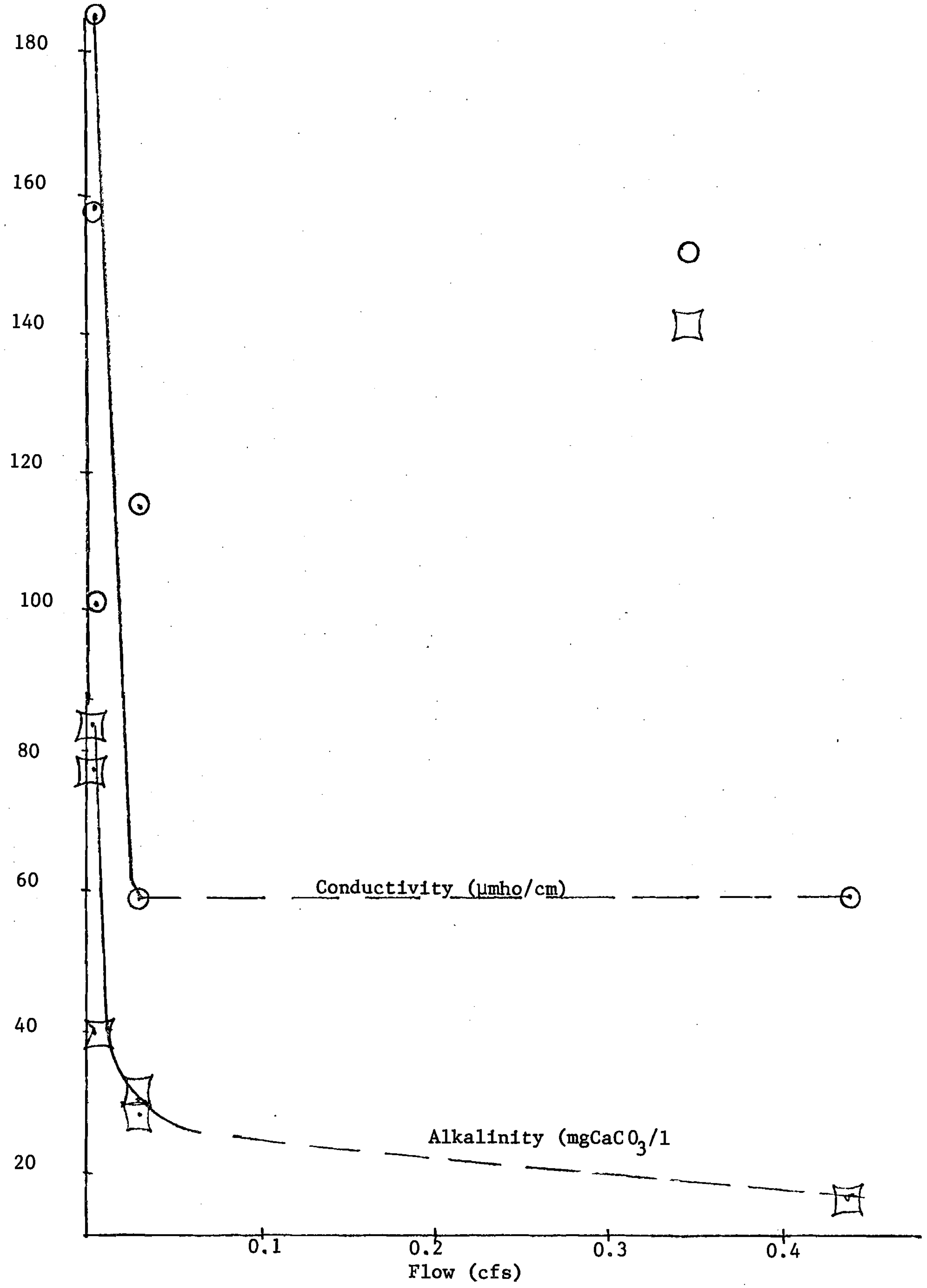

Figure 36. Heron Pond outflow in relation to conductivity and Alkalinity.

addition to carbonate species. Increased solubility of these in acid conditions might explain the higher swamp Mg^{++} levels.

The value for swamp alkalinity might be higher than the true value due to an unreasonably high value for January (Appendix A), which might be attributable to sampling under thick ice. Ca^{++} and Mg^{++} concentrations are intermediate those of a Florida rainwater dome and a groundwater dome (Brezonik _et_ _al_., 1974).

Heron Pond throughfall (cm) minus groundwater input (cm), was plotted against calcium concentration hardness and alkalinity (Fig.37). The relationships were found to be linear. Concentrations could not be significantly correlated to groundwater input alone. From these formulas, it is concluded that major cation concentrations are regulated by groundwater input and rainwater dilution and effects of sediment exchange and pH are minimal.

CONCLUSIONS

The water of Heron Pond has no apparent nutrient deficiency and acid pH, while perhaps inhibiting growth of calciphers such as the common duckweed _Lemna_ _minor_, does not inhibit production in general; two other species of duckweed _Spirodela_ _polyrhiza_ and _Azolla_ _mexicana_ have selected Heron Pond and are important producers. The cypress, are well adapted to the anaerobic conditions of the sediments.

Nutrient input by rainfall and throughfall is approximately equal to input in other systems not receiving rain polluted by atomospheric contaminants. Some conditions, including acid pH,

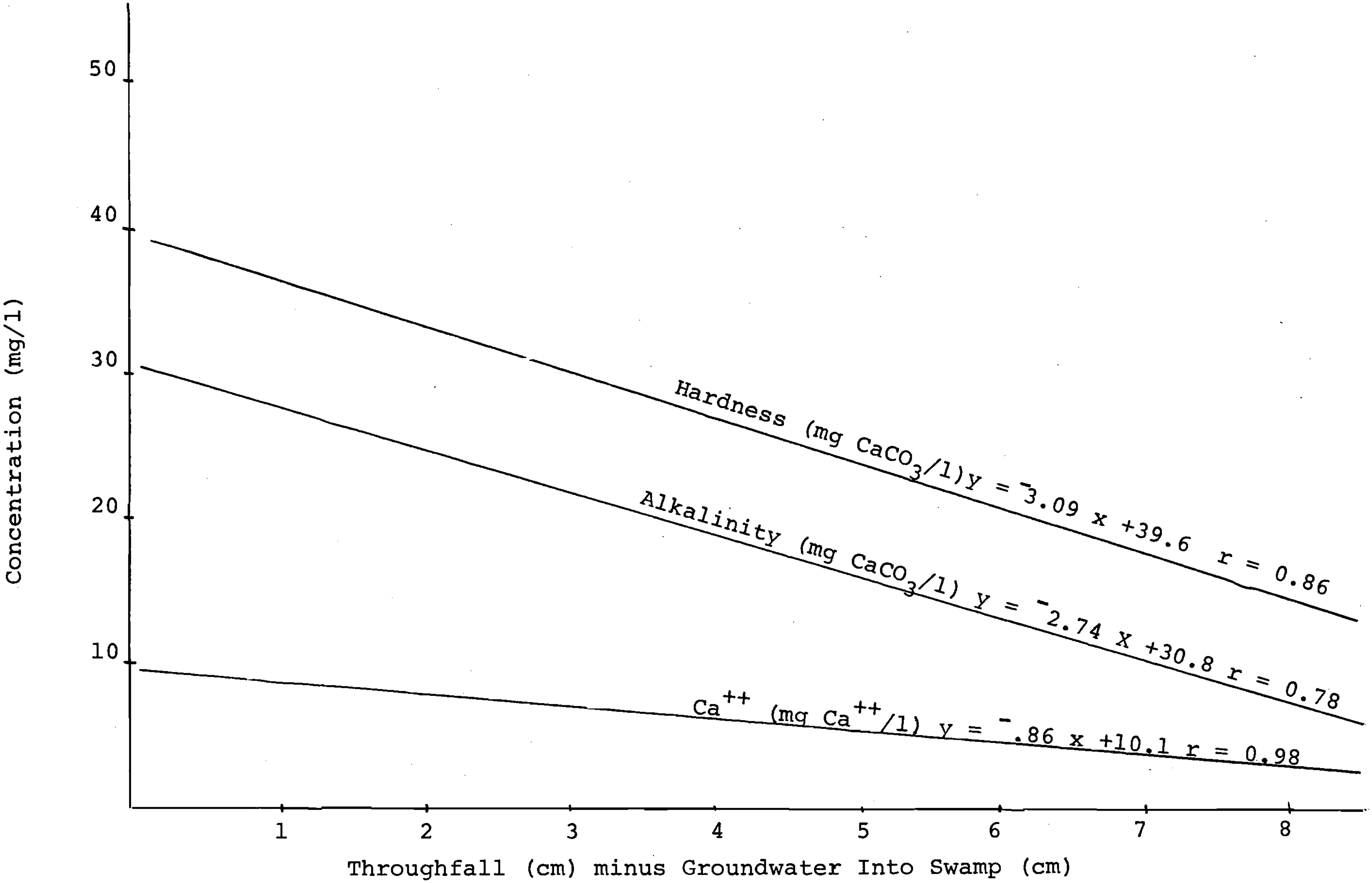

Figure 37. Throughfall and Groundwater Inflow Relationships to Selected Concentrations

low dissolved oxygen, and a reducing environment as indicated by high ammonia levels and apparent reduction of sulfates have been associated with low nutrient availability; most characteristics of Heron Pond water chemistry, however, place it among the more productive forested wetlands. Cation exchange and peat accumulation are not important nutrient sinks in Heron Pond.

Chemical Interactions Between Heron Pond and the Cache River

by

Carol L. Dorge

INTRODUCTION

Heron Pond as a river floodplain swamp has been shown to be a productive ecosystem with abundent nutrients in the water column. It has been compared to other forested wetlands which are not supplied allocthonous nutrients, and found not "bog-like" in respect to nutrient deficiencies which are often associated with swamps.

The study of river/swamp interaction also involves the reverse impact, that of the swamp upon the river, and in addition, more basic questions must be answered, e.g. how do the river and swamp differ and how are they similar?

METHODS

The Cache River was sampled on all days that Heron Pond was, and water chemistry analyses performed with those for Heron Pond and its outflow, according to methodology presented in the water chemistry section of this report. Water chemistry data for the three Cache River stations (Appendix A) were compared statistically using a paired - t - test to determine whether any parameter revealed significant difference between the stations.

River measurements were averaged upon determination that stations were not significantly different. These values were paired with swamp water chemistry measurements (Sta. 4) and with swamp outflow data (Sta. 5) and significant differences determined. Values for April 1, the flood, were included in these calculations.

Outflow values (flow at Sta. 5) for nutrients, solids and COD were calculated, for each sample period, as the product of surface flow (m/period) and concentration (gm/m^3) and summed for annual outflow (gm/m^2-yr). Groundwater flow, expressed as similar units, was similarly multiplied by concentration, and added to overland flow values, for total outflow. Average annual concentration values for swamp outflow were computed using weighted flow values with measured concentrations.

RESULTS

Swamp/River Comparison

The river and swamp were found to be predominantly different in water chemistry (Tables 23 through 26). Twelve parameters were found to be present in lower concentrations. NH_3-N was greater in the swamp, suggesting significant difference between the two systems in oxidation potential. NH_3-N is rapidly converted to NO_3-N by bacteria in aerobic conditions (Tusneem and Patrick, 1971). TKN and COD values were also greater in the swamp and were most likely due to greater levels of bacteria and organic matter

Table 23

Cache River - Heron Pond Outflow Water Chemistry Comparison

	Heron Pond Outflow	Cache River[1]	Cache R. at Forman[2]	Cache R. W. Vienna[3]	Cache R. Post Ck. Cut off[3]
Dissolved Oxygen	4.75	8.9		7.1	8.4
pH	6.6	7.3		7.3	7.5
Alkalinity	39	99	37.3		
Hardness	29	93	56.7		
Turbidity	212	266			
Conductivity	107	394			
Ortho-phosphate	0.171	0.147	0.07		
Total Soluble P	0.234	0.222			
Total P	0.371	0.528*		0.298	0.220
NO_2-N	0.01	0.02			
NO_3-N	0.03	0.11	2.4	0.6	0.4
NH_2-N	0.38	0.23	0.06	0.14	0.16
TKN	1.25	0.97			
$SO_4^=$	6.4	11.0	24.0	38	27
Dissolved Residue	71	112	103	234**	215**
Total Residue	329	317			
COD	38.3	36.5			
K^+	3.0	5.9			
Mg^{++}	3.1	5.7	3.2		
Na^+	2.7	14.7			
Ca^{++}	5.7	28.0	17.4		

[1] aver. 3 stations, this study

[2] Nienkerk and Flemal (1976)

[3] Ill EPA W. Q. Network (1975 - 1976)

* flood ave. conc: 1.332 mg/l

** electrode

All values expressed as mg/l with the exception of pH (pH units) and conductivity (μmho/cm)

Table 24

Water Quality Parameters That Are Probably Lower In The Swamp

Parameter	Number of Samples	Cache River$^+$	Heron Pond	Pond Outflow
pH	4	7.3	6.1*	6.6*
Alkalinity, mgCaCO$_3$/l	8	99	33*	40*
Hardness, mgCaCO$_3$/l	4	55	17	15
Conductivity, µmho/cm	9	352	111*	110*
Total dissolved solids, mg/l	3	180	79	86
$SO_4^{=}$, mg/l	4	18	2*	7
NO_3^--N, mg-N/l	5	0.08	0.01*	0.03**
NO_2^--N, mg-N/l	5	0.04	0.01*	0.01*
K^+ mg/l	7	5.7	3.3**	3.0*
Mg^{++} mg/l	7	11.2	11.8	2.3*
Na^+ mg/l	7	11.7	3.2*	2.4*
Ca^{++} mg/l	7	26.5	14.1*	5.7*

+ River sample average of 3 stations

* Significantly lower than river concentration at 95% level

** Significantly lower than river concentration at 90% level

Table 25

Water Quality Parameters That Are Similar In Swamp And River

Parameter	Number of Samples	Cache River+	Heron Pond	Pond Outflow
Turbidity, JTU	8	266	223	206
Total Solids, mg/l	3	328	226	335
Total Suspended Solids, mg/l	3	225	98	186
Orthophosphate, mg-P/l	8/9	0.148	0.163	0.170
Total Soluble Phosphorus, mg-P/l	8	0.203	0.201	0.238
Total Phosphorus, mg-P/l	8	0.437	0.345	0.368

+ River sample average of 3 stations

Table 26

Water Quality Parameters That are Probably Higher in the Swamp

Parameter	Number of Samples	Cache River[+]	Heron Pond	Pond Outflow
Kjeldahl Nitrogen, mg-N/l	5	1.0	2.1	1.3
NH_3-N, mg-N/l	5	0.17	0.97	0.39
COD	4/3	38	47**	40

\+ River sample average of 3 stations

** Significantly higher than river concentration at 90% level at different stages of decomposition in the swamp.

Greater total cation concentrations, conductivity, dissolved solids, alkalinity and hardness values in the Cache River are most likely due to greater weathering of rock including increased solubility of carbonate compounds. Most sulfate in streams is similarly due to weathering of either gypsum ($CaSO_4 - 2H_2O$) or pyrite (FeS_2) followed by oxidation of the sulfur (Garrels et al., 1975). Mean level of hardness in Cache River basin streams is approximately 100 mg $CaCO_3$/l with alkalinity approximately 50 mg $CaCO_3$/l (Nienkerk and Flemal 1976). Table 23 compares values for these and other parameters measured as part of this study with averages given by Nienkerk and Flemal (1976) and with Illinois Environmental Protection Agency values (1975 - 1976) for the Cache River at West Vienna, Illinois and further downstream in a section which was channelized.

Phosphorus, in all forms measured, varies little in concentration from swamp to river. Orthophosphate values in the river were lower than average during the flood, suggesting a dilution effect, or adsorbtion onto clay particles while total phosphorus was approximately three times greater than normal during the flood season, indicating transport occurs primarily as part of the suspended load.

Inflow - Outflow Relationships

Ecosystems have differing capabilities for nutrient retention. Hubbard Brook, a temperate forest ecosystem, was found to release Ca^{++}, Mg^{++}, K^+, Na^+, $SO_4^=$, Al^{+++}, SiO_2 in quantities greater than those input to the system while affecting net removal of NH_4-N, H^+ and PO_4^{-3}. The primary source of cationic output was attributed to exchange of H^+ for other cations; ammonia removal was attributed to denitrification, (Likens *et al.*, 1977). When export from a cutover forest was compared to that of an uncut forest, export values for the group of ions described above were increased by factors from 1.9 - 22.4 times. Chloride export increased 37 times (Likens and Bormann, 1972).

Similar increased export of nutrients occurred in Rough Sike, a disturbed bog. Drainage of wetlands may also cause massive release of nutrients. A drained marsh may input to a river fifty times the phosphorus contributed by agricultural lands, while a natural marsh may produce no net input of phosphorus (Lee *et al.*, 1975).

More recent studies have focused on the nutrient rich "energy subsidized" river floodplain swamps (fens) or those which receive sewage, either accidentally or intentially. Wharton (1970) showed that dissolved oxygen increased as river waters from the Alcovy River flowed through the Alcovy Swamp in Georgia.

In tests on a southern Louisiana swamp, Engler and Patrick (1974) found nitrate removal of 4.38 mg/l. (A marsh studied simultaneously was found to remove 7.64 mg/l.) They found that this removal rate could be increased by laying down organic matter such as rice straw to improve the habitat of the microorganisms which were doing the work. Bentley (1969) found similar nitrogen reduction in water which passed through a marsh.

Kitchens *et al.*, (1974) found phosphorus to decrease 0.75 - 2.00 times as it flowed through a river floodplain swamp. He demonstrated that this was a biological sink by showing that physical parameters such as turbidity did not change.

Hartland-Rowe and Wright (1975), in a study of a populus, alder, willow and cat-tail "swamp" located downstream of a swamp treatment plant, found the following per cent reductions, 3640 meters from the outfall of the plant, for a study period of June to October:

Parameter	% Reduction
BOD	97.7
TSS	96.8
NH_3-N	96.2
Total P	97.6
Ortho-P	97.5
NO_3^-	98.7
Surfacants	99.2
Total Coliform	98.7

Whether this area should truly be called a swamp, or is a marshy area with some trees in drier spots, is not clear from the article.

Nitrogen and phosphorus uptake was demonstrated to occur in water passing through the Everglades (Waller and Earle, 1975). In the Minnesota bog studied by Reiners (1972), nitrogen was found to be taken up from June to October (the growing season).

A Florida cypress dome with high sewage loading was found to retain 4% of the phosphorus and 76% of the nitrogen which was input; overflow waters carried out the remaining percentages.

Phosphorus was found to increase in the sediments while nitrogen did not (indicating biological denitrification) and the dome produced trees with greater leaf and fruit than similar domes which did not have sewage supplied them. Lower loading rates resulted in retention of essentially all of the nutrients.

Conner and Day (1976) found net export of nutrients from a Louisiana swamp in which the floodplain input has been halted by construction of levees; it is possible here, however, that input from agricultural sources was significant. Net flow of carbon, nitrogen and phosphorus decreased - inflow was greater than outflow .

Wharton (1970) summarized the effects of the "energy subsidy" of riverine swamps: They receive aerobic decomposition and nutrient release in the dry season, with a bloom in productivity during the wet season. As is apparent, the timing of the flood - dry cycle is extremely important. Most Piedmont streams, he claimed, flood during the dry season when damage to growth will be minimized.

Outflow from Heron Pond

While inflow - outflow budgets were not determined for parameters other than phosphorus, outflow by overland flow (Sta. 5) and groundwater was calculated for the following: ortho-PO_4 and total phosphorus, all nitrogen forms, dissolved and total solids, COD, SO_4-S, K^+, Mg^{++}, Na^+ and Ca^{++} (Table 27).

Outflow values are compared to streamflow outflows for various ecosystems described by Likens _et al_., (1977) and Lee _et al_., (1975) in Table 28. Heron Pond outflow values are given both as overland flow only, and as total flow which including

Table 27

Heron Pond Chemical Outflows and Average Outflow Concentrations

	PO_4-P	Total P	NO_2-N	NO_3-N	NH_3-N	Org-N	Total N	Dissolved Solids	Total Solids	COD	SO_4-S	K^+	Mg^{++}	Na^+	Ca^{++}
Weighted Mean, Concentration, mg/l	0.205	0.380	< 0.01	< 0.014	0.537	0.599	1.15	32	316	42.4	5.7	2.6	2.1	2.3	5.3
Overland Outflow gm/m^2-yr	0.140	0.260	< .010	< 0.010	0.371	0.413	0.794	22	216	29.0	3.9	1.78	1.44	1.58	3.63
Groundwater Outflow gm/m^2-yr	0.043	0.080	< 0.003	< 0.003	0.113	0.12	0.24	7	66	8.9	1.2	0.55	0.44	0.48	1.11
Total Outflow gm/m^2-yr	0.183	0.340	< .013	< .013	0.484	0.53	1.03	29	282	37.9	5.1	2.33	1.88	2.06	4.74

All values expressed as mg/l with the exception of pH (pH units) and conductivity (μmho/cm)

Table 28

Ecosystem Comparison of Selected Outflows

Ecosystem	Heron Pond	Heron Pond Overland Flow Only	Temperate Angiospern - deciduous				Temperate, Mostly Coniferous		Temperate bog		Wisconsin Marsh	Tropical	
			Hubbard Brook,	Coweeta, N.C.	Silverstream New Zealand	Toughannock Ck., N. Y.	Carnation Creek, Vancouver, Can.	ELA Ontario Canada	Rough* Sike, England	Maesnant Catchment, Mid Wales		El Verde, Puerto Rico	Rio Negro Brazil
Parameter													
Total-P	0.340	0.260	.019	-	0.03	0.20	0.05	0.05	0.4		0.284		0.1
NO_3-N	<0.013	<0.010									0.14		
NH_3-N	0.484	0.371									0.021		
Total N	1.03	0.794	4.0**	-	1.8	5.6**	1.1**	0.9	3.0		0.16	0.16**	4.7
$SO_4^{=}$-S	5.1	3.9	17.6	-	13	38	28	3.2					
K^+	2.33	1.78	2.4	5.2	13	5.6	4.8	1.2	9.0	2.6		20.8	
Mg^{++}	1.88	1.44	3.3	3.1	13	34.8	10.4	2.4		8.7		15.0	3.0
Na^+	2.06	1.58	7.5	9.7	62	18.9	38.4	3.7	45.2	43.7		64.5	
Ca^{++}	4.74	3.63	13.9	6.9	26	182	57.7	6.0	53.8			43.1	4.7

All Values expressed as gm/m^2-yr

Source of data:

Heron Pond (this study)

Wisconsin Marsh (Lee *et al.*, 1975)

All others (Likens *et al.*, 1977)

* Transport of eroded peat not included

** NO_3-N + NH_3-N

All values expressed as mg/l with the exception of pH (pH units) and conductivity (μmho/cm)

groundwater flow. The latter may be validly compared to Hubbard Brook "streamflow" values; there it was assumed that because of an impermeable formation below the forest floor, all groundwater entered the stream and was measured as outflow from the system.

Total phosphorus export from Heron Pond, 0.340 gm/m^2-yr is greater than that of all non-wetland ecosystems presented in Table 18, and greater than export of 0.108 gm/m^2-yr from Lake Wingra, a eutrophic lake in Wisconsin. Systems which exceed or approach the swamp's output are Rough Sike, a disturbed bog, (0.4 gm P/m^2-yr), and a Wisconsin marsh (0.284 gm/m^2-yr). A phosphorus budget for Heron Pond, however, revealed that net removal of phosphorus takes place (see phosphorus budget report). Swamp phosphorus input to the river when compared to the total quantity transported, by the river is only 0.047%. Loadings for other parameters are even smaller percentages, with the exception of NH_3-N, TKN and COD with relative swamp/river concentration greater than that of phosphorus.

Nitrogen export is low in comparison with other systems. Soluble NO_3-N, an important form of nitrogen input from systems with aerobic conditions, is in low concentrations in Heron Pond. Ammonia is more important; some outflow may be inhibited by adsorbtion of ammonium ion onto clay (Garrels et al., 1975). Over half of nitrogen exported is organic nitrogen.

Sulfate export was far less than average for the systems compared. Average export in the Cache River drainage basin is approximately 0.149 gm/m^2-yr, computed from data for loadings given by Nienkerk and Flemal (1976). Heron Pond export, 5.1 gm/m^2-yr, would not appear to be indicative of a disturbed system. Likens and

Bormann, (1972) found sulfate export to decrease when a temperate forest was clear cut. Export from the Taughannock Creek system was 38 gm/m^2-yr, much greater than from Heron Pond. Cation loading levels were low in comparison with the other systems studied. Export of Ca^{++} from Rough Sike, a disturbed bog, was 14 times greater than from Heron Pond.

DISCUSSION

Heron Pond export values are in general far less than those of disturbed systems. An exception to this is phosphorus, with export exceeding that of the Taughannock Creek, New York ecosystem. Here the difference in nitrogen and phosphorus mobility is apparent. Taughannock exports 5.6 mg/l NO_3-N and NH_3-N in comparison to Heron Pond's 0.50 mg/l, and is said to be receiving agricultural drainage in quantities which exceed natural removal capabilities (Likens _et_ _al_., 1977). Phosphorus export values for the two systems are almost equal.

Phosphorus generally occupies a sedimentary cycle in terrestrial systems, and the aquatic environment of Heron Pond might perhaps make comparison of export only, without consideration of inputs, of limited value, except in comparison to data for other wetlands. Losses in a terrestrial system are most commonly due to weathering, with the additional atomospheric release of those elements with a gaseous phase (carbon, nitrogen and sulfur), as part of their cycle (Likens _et_ _al_., 1977). Both the sulfur and nitrogen cycle have anaerobic conditions required in release to the atomosphere. CO_2 can be expected to be removed due to photosynthetic productivities in the system. Net removal of these in Heron Pond, then, is likely.

Based upon the above factors, it is apparent that comparison by export only may be best used in characterizing nutrient conditions in waters receiving swamp outflow, but not in hypothesizing net removal capabilities. A complete nutrient budget would be required for each element to determine the swamp's true efficiency in utilizing these materials. This was done for phosphorus in another section of this report.

Phosphorus Dynamics in a Swamp Microcosm

by

Carol L. Dorge

INTRODUCTION

Previous discussions of Heron Pond Water chemistry suggest regulation of phosphorus concentration by biological components, or sediment/water exchange. In order to better understand some of these relationships a laboratory experiment was performed.

METHODS

Heron Pond water, sediment and duckweed were transported to the laboratory in five gallon carboys, then thoroughly mixed before the experiment was begun. One inch of sediment was placed in seven five-gallon aquaria (20 cm x 28 cm), while two aquaria were not supplied sediment. All of the aquaria were filled with swamp water and allowed one week to stabilize. After one week, duckweed and/or dry leaf litter was added to selected tanks according to the design scheme presented in Table 29.

Table 29

Design Scheme for Swamp Microcosms

Tank Number	Treatment of system	Interpretation of results
Control Tanks:		
1	Light Water Formalin	Non-biological activity: a) sorbtion onto glass b) phototaxis c) settling not related to biological activity
2	Light Water Formalin Sediment	Exchange from sediments not related to biological activity (calculated in reference to results from tank 1)
3	Light Water	Biological Activity in the water colum (calculated in reference to results from tank 1)
4	Light Water Sediment	Biological Activity in sediment exchange (calculated in reference to results from tanks 1 - 3)
Experimental Tanks:		
5	Light Water Sediment Leaf Litter*	a) Decomposition of leaf litter b) Sedimentation rates c) Δ P concentration in water and sediment trap
6	Light Water Sediment Duckweed	a) P removed by duckweed growth b) Δ P concentration in water and sediment trap
7	Light Water Sediment Duckweed Leaf Litter*	a) Dyanimcs of P when released by litter decomposition in presence of duckweed b) Δ P concentration in water and sediment trap

Table 29 continued

8	Light Water Sediment Duckweed	Same as Tank 6 (replicate)
9	Light Water Sediment Duckweed Leaf Litter - in litter bags**	a) Litter decomposition rates b) Δ P concentration of decomposing litter c) Effect of greater initial litter (15.15 gm dry wt)

---

* equivalent to 90 gm/m^2, (5.10 gm dry wt/tank)

** cypress litter in fiberglass screen "bag", 2.55 gm dry wt/bag

Cool white florescent light bulbs, 80 cm above the water surface, provided the energy source for growth. Two sediment collectors were placed in each tank, one with opening approximately 10 cm below the water surface, and one 5 cm above the sediment surface (Fig.38). The sediment traps were suspended by galvanized steel wire; the opening was covered with a watch glass when traps were brought up for sediment collection and analysis.

Water phosphorus concentration, for replicate samples, and temperature was measured eight times over a two month period. Duckweed, leaf litter and sediment phosphorus concentrations, as well as dissolved oxygen, alkalinity, conductivity and pH were measured less frequently. Methods used were those presented in Table 17 of the Heron Pond Water Chemistry report and those used in the Heron Pond phosphorus budget.

The above experiment was concluded when water phosphorus concentrations appeared to reach equilibrium. Water for all tanks except No. 9 was mixed and replaced. Tanks 6, 7 and 8 were spiked with KH_2PO_4 to achieve levels of 0.10, 0.50 and 1.00 mg P/l respectively. Water and duckweed phosphorus levels were measured. Tank 9, containing litterbags, was untouched in order to continue analysis of decomposition rates.

RESULTS AND DISCUSSION

Phase I

Water column phosphorus data for Phase I of the study is presented in Table 30.

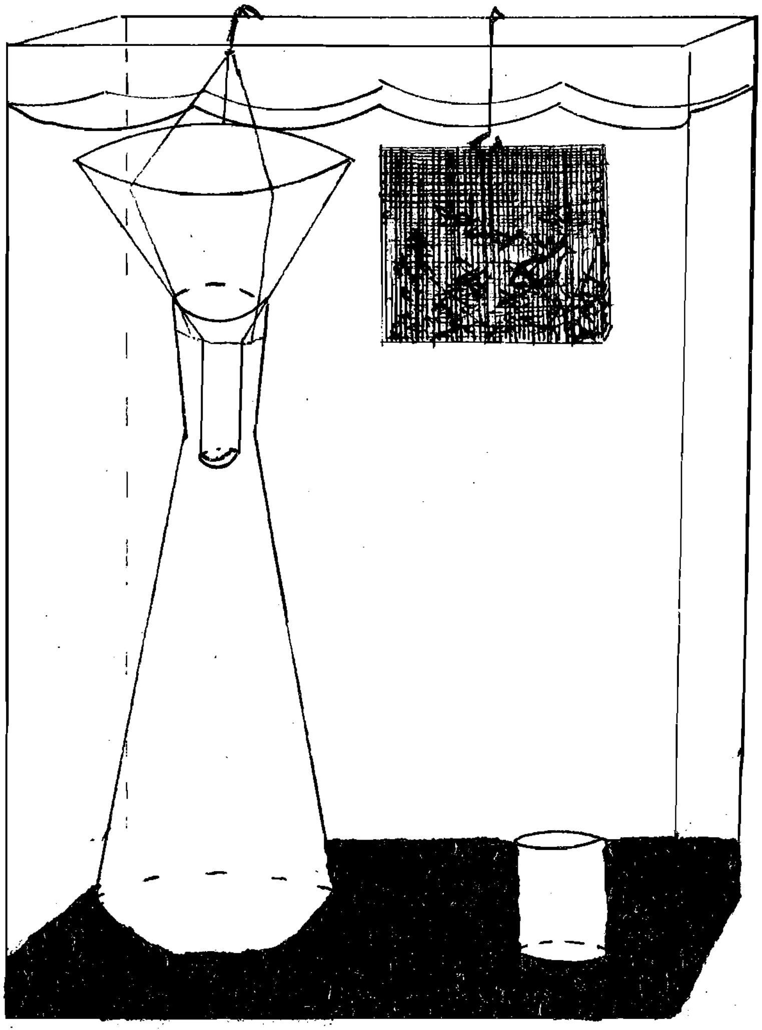

Figure 38. Swamp microcosm with sediment traps and litter bag.

Table 30

PHASE I: COMPARISON OF TANK PHOSPHORUS LEVELS

Tank Number	Ortho-phosphate, µg/l				Total Soluble P, µg/l				Total P, µg/l			
	Initial Conc.	Final Conc.	Average Conc.	Standard Deviation	Initial Conc.	Final Conc.	Average Conc.	Standard Deviation	Initial Conc.	Final Conc.	Average Conc.	Standard Deviation
1	35	16	39.8	18.3	80	15	51.3	27.0	94	30	76.3	29.2
2	27	10	22.7	11.1	68	16	36.7	27.6	102	20	91.2	32.0
3	35	0	21.0	14.9	84	21	49.8	26.2	98	26	66.5	26.3
4	54	11	23.3	20.6	96	26	54.8	30.5	160	34	130.0	56.0
5	25	48	52.0	21.1	120	59	85.3	26.9	160	60	244.4	136.3
6	45	17	64.3	30.6	84	32	101.0	56.9	164	48	182.1	104.6
7	39	32	38.8	7.4	86	38	55.3	21.7	144	12	158.7	159.7
8	39	24	35.9	12.5	94	42	67.3	26.0	170	4	116.0	85.5
9	38	24	34.4	6.7	95	75	83.5	14.2	170	26	183.1	92.9

Temperature in the tanks ranged from 18 - 26°C. Average pH for all tanks was 5.9 with deviation not attributable to different conditions in the tanks (standard deviation = 0.5). Alkalinity averaged 29.1. Early conductivity measurements averaged 114 μmho/cm; later values ranged from 10 μmho/cm to 290 μmho/cm with standard deviation equal to 53.6. It is believed that corrosion of sediment trap wire caused these results. Water phosphorus concentration may have been influenced by reaction with dissolved metals and results of water phosphorus analyses must be interpreted with caution in light of this. Tank phosphorus dynamics will be compared but few conclusions will be drawn.

Average ortho-phosphate concentrations are slightly higher in experimental tanks than control tanks. A more definite trend toward complete removal of phosphate from the water column is observed in the control tanks. Therefore rate of release of ortho-phosphate by litter or duckweed must exceed the rate at which it is removed by adsorption on aquarium glass, or the other variables listed in Table 29. The most stable systems (with minimum deviation) had both litter and duckweed, e.g. tanks 7 and 9. Total soluble phosphorus showed trends similar to those of ortho-phosphate although standard deviation for all measurements was greater.

High total phosphorus in Tank 5 may be due to high levels of particulate matter from decomposing litter. In general, higher levels in the experimental tanks would be caused by this suspended matter. Standard deviation values for the experimental tanks far exceeded those of the control tanks, while ortho-phosphate levels were shown to be less variable in experimental tanks.

Tank 7 had the maximum measured concentration, 0.525 mg/l, intermediate in the study period, when leaf litter appeared to be actively undergoing decomposition.

Phase II

Tanks which were spiked to levels of 1.15 mg P/l returned to natural levels in two weeks (Table 31). Duckweed was analyzed and phosphorus content, was found to be higher in the tank which received the greatest spike.

Litter decomposition, expressed as percent dry wt remaining, is shown in Table 32.

Table 32

Litter Decomposition

No. of Weeks	% dry wt remaining
3	85.5
7	70.3
13	49.0
18	41.0

Very similar rates for decomposition (expressed as change in organic weight only) were obtained by Brinson (1977). In general, lower autumn water temperatures would cause rates to be

Table 31

Phase II: Phosphorus Levels in Spiked Tanks and Duckweed

Tank Number	Initial, µg/l Ortho-phosphate	Initial, µg/l Total P	Final, µg/l Total P	Duckweed mg P/gm dry wt
1	17	10	<4	
2	38	--	<4	
3	46	10	<4	
4	24	14	<4	
5	21	22	<4	2.3
6*	64	78	54	5.5
7**	50	520	22	3.0
8***	1150	1125	57	9.1
9	14	22	54	4.0

* Spike to increase concentration by 0.2 mg/l.

** Spike to increase concentration by 0.5 mg/l.

*** Spike to increase concentration by 1.0 mg/l.

less in a natural environment, than in the laboratory. Phosphorus concentrations of litter bag contents increased over time. Schlesinger (1977) and Brinson (1977) found similar increases and attributed them to adsorbtion on the litter or on microbes attached to the litter, or immobilization by microbes attached to the litter.

Sedimentation Rates

Sedimentation attributed to duckweed productivity, 0.26 gm dry wt/m^2-day was less than values found in natural systems. In another microcosm study (Glandon, 1977) rates, measured by change in biomass over time were 0.86 gm dry wt/m^2-day.

Litter was found to settle in the period of a month, but decomposition was not complete in this period as previously discussed. Suspension of litter bags in the water column might therefore not perfectly replicate the natural system assuming microbial activity is different at the sediment/water interface. Rates are shown in Table 33. The value for litterfall "projected yearly deposition" is purely hypothetical due to seasonal variation in true litterfall rates.

Table 33

Sedimentation Rates

Sample Description	Sample Period	# days	gm dry wt / m^2-day	Projected yearly deposition (gm/m^2-yr)
Duckweed Sed. (Ave. Tanks 6 - 9)	6/17-7/8/77	32	0.28	102
Duckweed Maximum Growth (Tank 8)	6/17-7/8/77	32	0.56	204
Total Sedimentation (Tanks 5 - 7)	6/17-7/8/77	32	1.64	
Litter only[1]	6/17-7/8/77	32	1.55	566[2]
Sed. not due to litter or duckweed (tanks 1,3,4)	6/17-7/8/77	32	0.09	

---

[1] 52% of litter added to tanks initially was measured in this sediment collection.

[2] This value is approximately equal to normal annual litterfall for Heron Pond, 348 gm/m^2-yr.

PHASE 3 - ECOSYSTEM STUDIES

Sedimentation Rates and Sediment Analysis in Heron Pond

by

Carol L. Dorge

and

William J. Mitsch

INTRODUCTION

Heron Pond sediments received limited study in this research; their importance as energy and nutrient storages received primary emphasis. Sediment core analyses were limited to measurement of phosphorus content, organic matter and bulk density. Rate of sediment accumulation in the swamp was also measured. Sediment deposition is due to both autochthonous sources within the swamp and to allochthonous sources, primarily the flooding Cache River. Sediments as they relate to hydrology, swamp productivity, and the phosphorus budget are discussed further in other sections of this report.

METHODS

Sediment Core

Sediment cores approximately 25 cm long were taken from Heron Pond with a K.B design core sampler. Two cores was frozen, then sliced into cylindrical sections and volumes calculated. The sections were than dried at 103°C, dry/wet ratios determined and bulk density computed. The sections were then ashed at 550°C and percent organic matter was calculated. Organic storage in kg/m^2 for the 25 cm surface layer was calculated by integrating the product of bulk density and organic content. This value was converted to energy by using a conversion factor of 4.5 kcal/gm O.M.

Ashed subsamples of the sediment core were covered, allowed to stand for 12 hours in concentrated nitric acid, then heated carefully in the acid for one hour. This extract was analyzed for phosphorus content according to the Ascorbic Acid - Molybdate blue method (Murphy and Riley, 1962). Sediment particle size was measured with a Leeds and Northrup particle analyzer.

Sedimentation Rates

Ten sediment traps (Fig.39), each with area open to collection of 60.1 cm^2, were used to measure sedimentation rates. Two replicate traps were placed at each of 5 sample stations (see Fig. 2 for locations). These data were applied

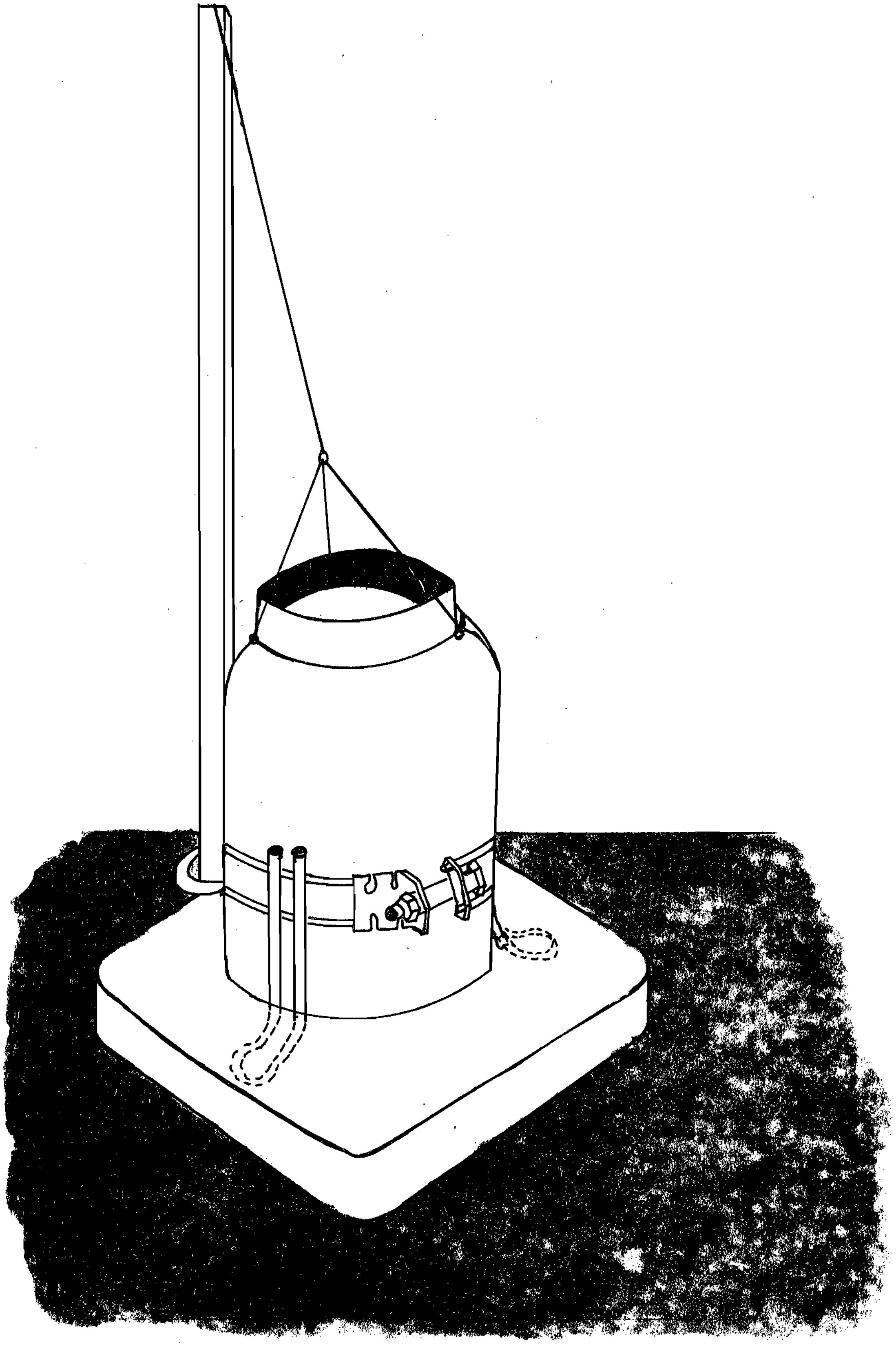

Figure 39. Sediment trap used in Heron Pond study

in calculation of aquatic production, settling of phosphorus, and flood contribution to sedimentation and phosphorus deposition. Traps were sampled 5 times during the study period.

Undisturbed swamp water was siphoned into the traps which were then covered and lowered into position, the cover was then carefully removed. A control was run to measure resuspension during the placement and uplift of the traps and less then 0.5 gm of sediment (7% of minimum collection) was collected. This test was run at a time when swamp water level was significantly higher than trap height; however, measurements of total deposition during seasons of low water level are not significantly higher. Limited data for sedimentation in a Florida dome which was receiving secondary sewage suggest a rate 65% as large as the Heron Pond rate; that study also suggests that some stirring of the sediments may have affected results. (Graetz and Struble, 1975).

Wet and dry weight of sediment trap samples were determined as with the sediment cores. Ashed samples were used to determine organic matter and phosphorus content in the same manner as sediment core analyses. Phosphorus concentration for each sediment trap sample was multiplied by the deposition rate for each period to arrive at values for phosphorus deposition by sedimentation.

Flood contribution to sedimentation was assumed to be the "excess" deposition during the March 3, 1977 - June 2, 1977 sampling period. The normal deposition rate for this time was assumed to equal the average of the rates for the period ending March 5 and the June 2 - July 29 period. This value subtracted from the total deposition gives flood contribution. The volume of water which passed over the swamp multiplied by average solids concentration of floodwater samples gave a value for solids passing over the swamp.

RESULTS

Sediment Core

Sediment core bulk density, and organic matter are presented in Table 34 and graphed vs. depth (Fig. 40). Fig.40 also shows phosphorus concentration with depth. Bulk density, to a depth of 24 cm averaged 0.74 gm dry wt/cm^3 in core 1 and 0.62 gm dry wt/cm^3 in core 2. The increase in bulk density with depth is expected as organic content decreases (Brady, 1974). Percent organic matter averaged 8.96% in core 1 and 26.8% in core 2. This high value for core 2 is attributed to a value of 30% in the surface layer of the core. This value is likely due to recently deposited leaf litter and/or duckweed. (Fresh leaf litter averaged approximately 90% organic matter while duckweed averaged 75 - 80%). Eliminating the high surface value for core 2, average percent organic matter for the core is 7.6%. By contrast, sediment collected in sediment traps had an average 52.5% organic matter. The peat

Table 34

Sediment Core Analyses

Section No.	Section length, cm	Wet weight, gm	$\frac{\text{Dry}}{\text{wet}}$	Bulk density, gm/cm^3	% organic	$\frac{\text{Ash}}{\text{dry}}$
			Core No. 1			
1	3.0	50.6	0.30	0.28	13.6	0.86
2	3.0	51.69	0.47	0.47	11.7	0.88
3	3.3	69.95	0.58	0.73	8.2	0.91
4	4.0	87.65	0.59	0.73	9.7	0.90
5	3.4	77.2	0.57	0.74	8.6	0.92
6	4.0	101.95	0.64	0.94	6.5	0.94
7	3.5	98.8	0.68	1.11	5.7	0.94
			Core No. 2			
1	9.4	136.0	0.20	0.17	30.0	0.70
2	9.0	183.7	0.55	0.65	9.6	0.90
3	8.7	241.9	0.67	1.07	5.5	0.95

Core No. 1:

Bulk density $\bar{x}$ = 0.74

% organic matter $\bar{x}$ = 8.96%

Organic storage = 14.3 kg O.M/m^2

Core No. 2:

Bulk density $\bar{x}$ = 0.62

% organic matter = 26.8%

% organic matter (lower sections) = 7.6%

Organic storage = 15.6 kg O.M./m^2

* Bulk density (gm dry wt/cm^3) = $\frac{\text{Dry}}{\text{Wet}} \times \frac{\text{wet wt (gm)}}{\text{volume (cm}^3\text{)}}$

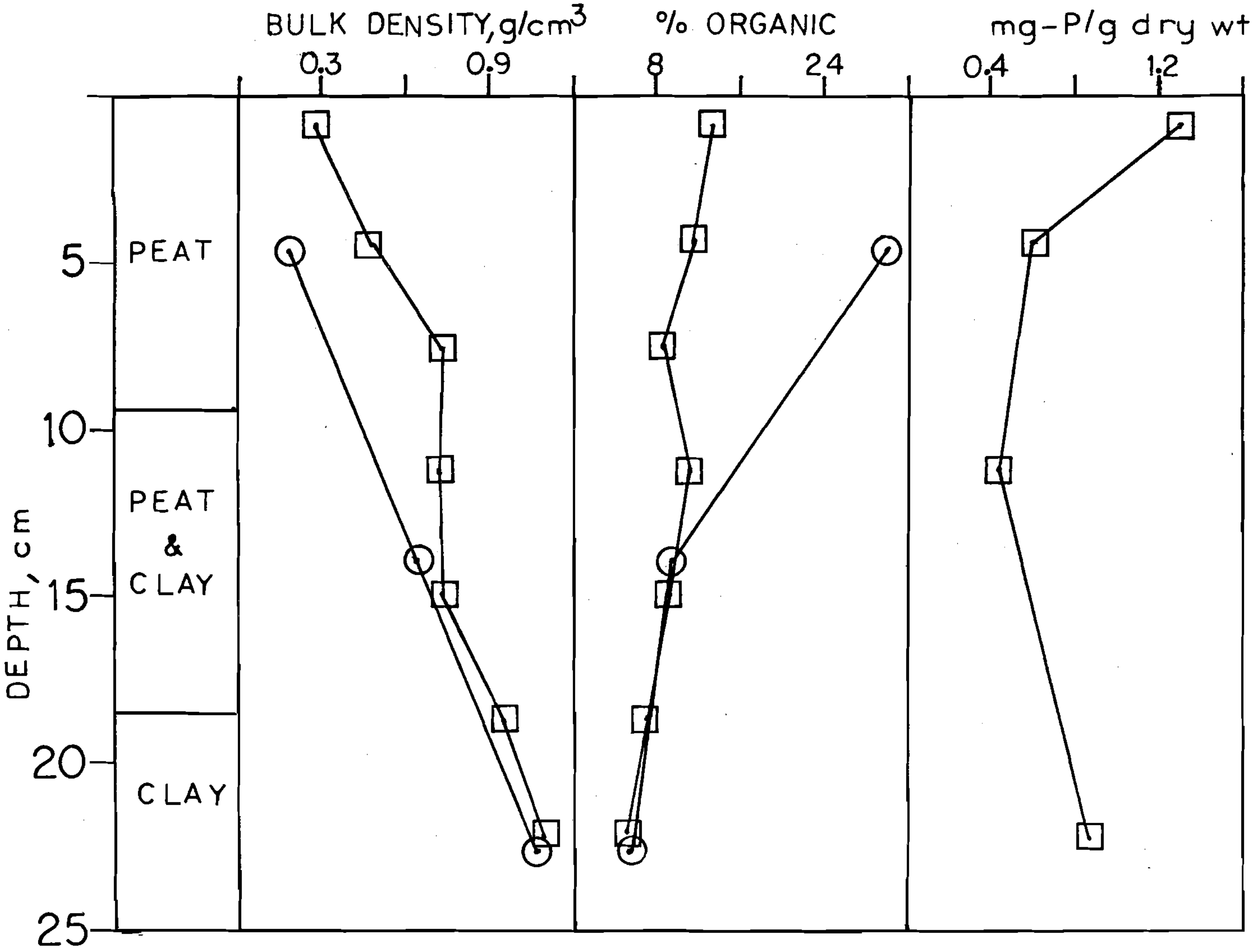

Figure 40. Sediment core profiles from Heron Pond for bulk density, organic content, and phosphorus content.

layer in the sediments is shallow and clay is predominant by a depth of 10 cm. The organic content of the sediment to 25 cm from the two cores averaged 14.95 kg O.M/m^2 or an energy value of 67,300 kcal/m^2. This organic storage is about one-third of the total tree biomass of the swamp (see "Net Primary Productivity and Biomass of Vegetation in Heron Pond" in this report).

Mean particle diameter of sediment in the top 5 cm is 28 μ; this is the size of silt particles. Visual analysis of deeper sediment layers indicate they are predominantly clays; this is characteristic of southern Illinois swamps. The U. S. Department of Agriculture (1964) described Heron Pond soil as Piopolis silty clay loam, a soil with high clay content, low organic matter, plastic when wet and slowly permeable. The swamp, then, is sealed with an impermeable lense of clay that eliminates vertical flow of groundwater.

Sediment core phosphorus content is presented in Fig.40. Maximum concentration, 1.3 mg-P/gm dry wt, was found in the surface layer. Total storage, calculated assuming average bulk density for the 2 cores, was 119 gm-P/m^2 in the upper 25 cm.

Sedimentation Rates

Sedimentation rates measured at individual stations are given in Table 35. Little consistent spatial pattern was noted. Analysis of variance ($\alpha = 0.05$) of differences in station location could not reject the hypothesis that the

Table 35

Sedimentation Rates by Individual Traps For Heron Pond

Period	# days	Ave % Organic	Sediment Deposition, gm/m^2-day by Trap Number											
			1		2		3		4		5		Ave	
			O.M.	Dry	O.M.	Dry	O.M.	Dry	O.M.	Dry	O.M.	Dry	O.M.	Dry
10/3-12/5	63	68	19.7	29.8	18.0	29.7	27.2	33.0	11.1	18.9	-	-	19.0	27.85
12/5-3/5	90	62	7.0	8.7	9.2	11.5	5.0	6.2	5.8	7.4	-	-	6.8	10.9
3/5-6/2	89	25	4.6	11.2	4.2	14.2	-	-	3.4	14.6	3.0	21.6	3.8	15.4
6/2-7/29	57	54	3.9	7.1	4.5	7.5	5.1	10.4	-	-	8.2	14.7	5.4	10.0
7/29-9/17	50	50	4.5	14.0	8.6	11.1	5.5	11.2	4.7	17.2	10.0	15.7	7.0	13.8

O.M. = Organic Matter

sedimentation rates were similar at all stations. Station 1 seemed to be located away from the main flow during flooding, but otherwise had similar values to the others.

Table 36 summarizes weighted averages of total and daily sediment deposition while Fig. 41 presents a bar graph of organic and inorganic portions of the sedimentation rates. Highest rates of sediment deposition were experienced in autumn during the time of maximum litterfall and duckweed deposition. Less noticeable peaks are noted in spring and late summer. Extending the data for a full year, total deposition was calculated to be 5.6 kg/m^2 with organic sedimentation about 2.9 kg/m^2 or 52% of the total. The average sedimentation rate was 15.3 g/m^2-day. Thirty one percent of the total sedimentation and 41 percent of the organic sedimentation occurred during the months of October and December.

The flood contribution to the sedimentation was found to be 447 g/m^2 (see calculation on Table 37). It was estimated that 15 kg/m^2 of sediments passed over the swamp during the flood. Thus about 3 percent of this stream load settled out in Heron Pond. The sediments deposited for this period were low in organics (24.7%) as would be expected in high sediment loaded flood water (see water chemistry section). This suggests that the calculated flood contribution is a low estimate. If the average organic percent before and after the flood is used as the basis for the calculation, the flood is estimated to contribute 787 g/m^2 in total sediments.

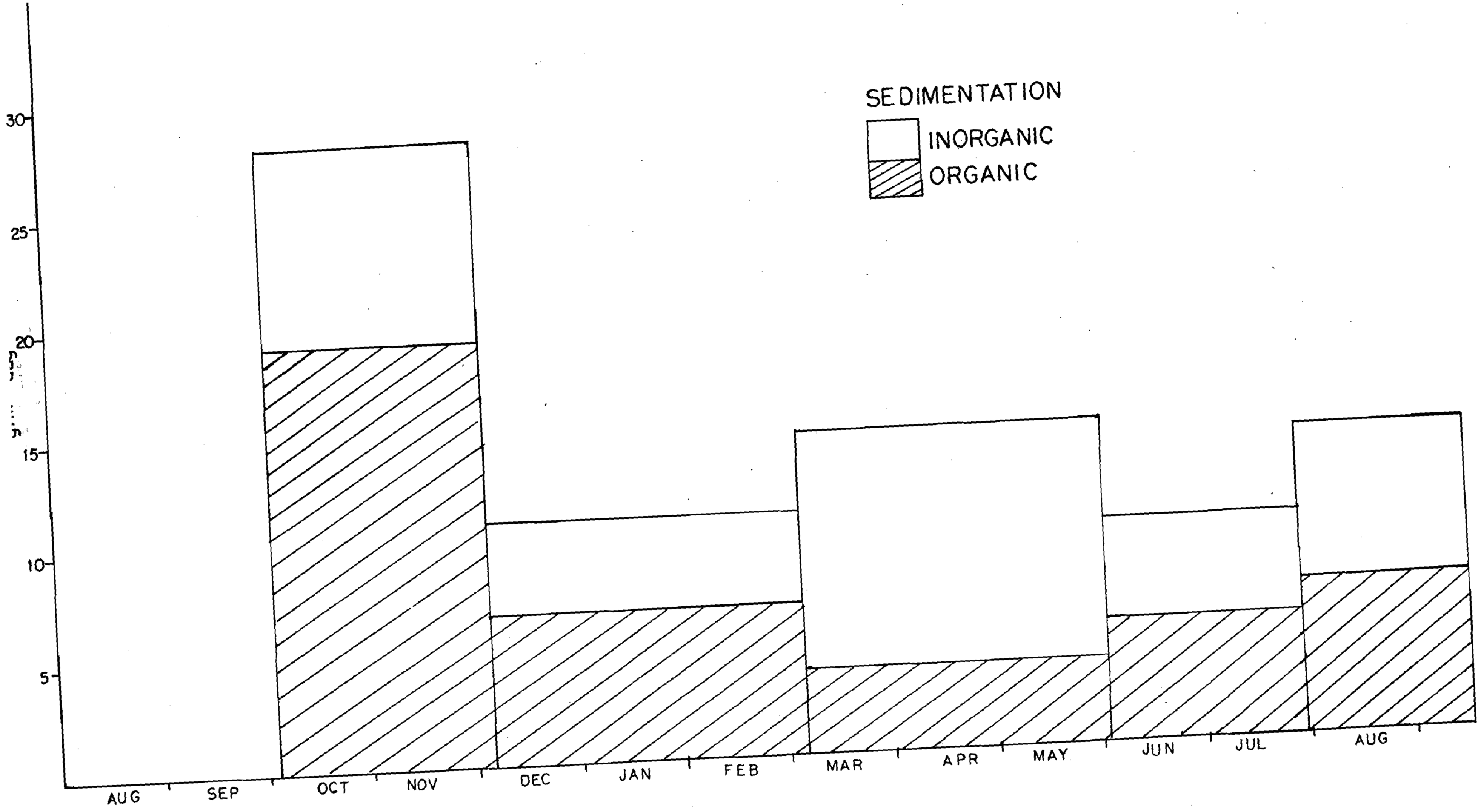

Figure 41. Sedimentation rates as measured by sediment traps in Heron Pond.

Table 36

Summary Sediment and Phosphorus Deposition Rates

Date of Collection	No. of days in sample period	Sediment Deposition		Phosphorus concentration mg-P/gm dry wt	Phosphorus Deposition	
		Total, gm dry wt/m^2	$\frac{\text{gm dry wt}}{\text{m}^2\text{-day}}$		Total, mg/m^2	mg-P/m^2-day
12/5/76	63	1755	27.9	2.0[1]	3509	55.7
3/5/77	90	980	10.9	2.4	2352	26.1
6/2/77	89	1373	15.4	4.5	6188	69.5
7/29/77	57	567	9.9	3.2	1814	31.8
9/17/77	50	690	13.8	2.0	1380	27.6
Total or average	349	5365	15.4	2.8	15243	43.7
Wt. annual values	365	5586	15.3	2.8	15685	43.0

[1] Calculated by extrapolation of phorphorus - organic matter curve.

Table 37

Calculations for Flood Sediment and Phosphorus Deposition

<u>Sediment deposition due to flood</u>

$$\frac{\frac{10.9 \text{ gm dry wt}}{m^2\text{-day}} + \frac{9.9 \text{ gm dry wt}}{m^2\text{-day}}}{2} = \frac{10.4 \text{ gm dry wt}}{m^2\text{-day}}$$

<u>amount not due to flood</u>: (3/5/77-6/2/77)

$$10.4 \frac{\text{gm dry wt}}{m^2\text{-day}} \times 89 \text{ days} = 926 \text{ gm dry wt}/m^2$$

<u>amount due to flood</u>:

$$1373 \text{ gm dry wt}/m^2 - 926 \text{ gm dry wt}/m^2 = 447 \text{ gm dry wt}/m^2$$

<u>Phosphorus deposition due to flood</u>

$$\frac{26.1 \frac{\text{mg-P}}{m^2\text{-day}} + 31.8 \frac{\text{mg-P}}{m^2\text{-day}}}{2} = 28.9 \frac{\text{mg-P}}{m^2\text{-day}}$$

<u>amount not due to flood</u>: (3/5/77-6/2/77)

$$28.9 \frac{\text{mg-P}}{m^2\text{-day}} \times 89 \text{ days} = 2572 \text{ mg-P}/m^2$$

<u>amount due to flood</u>:

$$6188 \text{ mg-P}/m^2 - 2572 \text{ mg-P}/m^2 = 3616 \text{ mg-P}/m^2$$

Phosphorus Deposition

Sediment trap phosphorus content was found to be inversely proportional to organic content (Fig.42). This may be due to the high clay content of the sediments; clay is known for its affinity to phosphorus (Brady, 1974). Deposition rates calculated for each sample period are presented in Table 36. A total of 15.7 g-P/m^2-yr was captured by the sediment trap. Of that, a total of 3.6 g-P/m^2 was calculated to have been contributed by the flood (Table 37). This is shown as a bar graph in Fig.43. Note that when deposition is expressed in terms of phosphorus, the highest rate was experienced at flood time. On a phosphorus balance, the flood passed 80.2 g-P/m^2 over the swamp; thus 4.5 percent of this amount was sedimented out into the swamp.

DISCUSSION

While the sediments are an important reservoir of energy and nutrients in this forested wetland, it was also shown that the fluxes of energy and nutrients are also very high. If one assumes that the surface deposits are represented by the surface sample of core No. 2 (30% organic matter), then the "active" organic layer can be estimated to be 4800 g/m^2. The total organic sedimentation rate was 2900 g/m^2-yr, thus yielding a rapid turnover time of 1.6 years. This is remarkably close to the value of 1.5 years reported by Whittaker (1975) for the temperate deciduous forest. If the sedimentation was overestimated due to resuspension the turnover time would

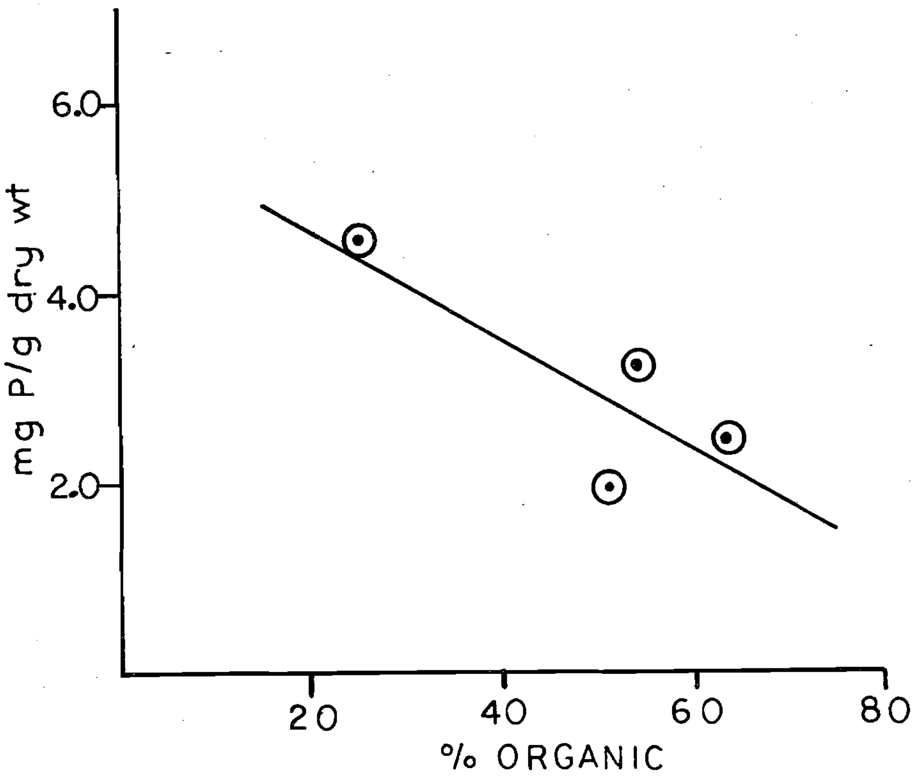

Figure 42. Phosphorus as a function of organic content in Heron Pond sediments.

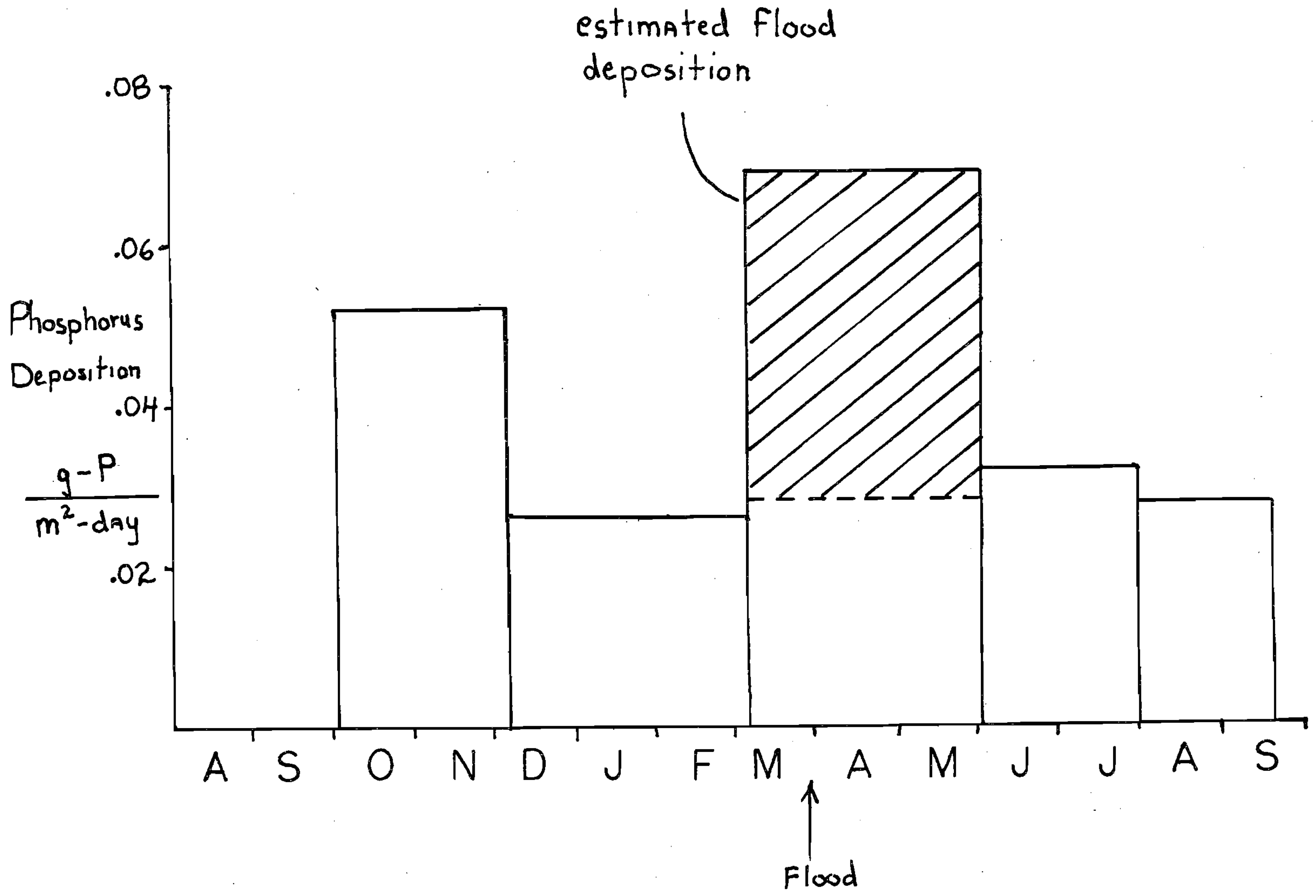

Figure 43. Phosphorus deposition by sedimentation in Heron Pond

be proportionally longer.

The flood had a major part in the phosphorus deposition to the sediments. It was estimated that 3.6 g-P/m^2 was contributed by the flood. This can be compared to the 119 g-P/m^2 in the upper 25 cm of the swamp. Phosphorus values in the sediment trap samples over the flood period were very high (4.5 mg-P/g dry wt.) compared to other sediment trap samples (2.0 - 3.2 mg-P/g dry wt.) and to sediment core samples (0.4 - 1.3 mg-P/g dry wt.). The sink for the sedimented phosphorus is not known but the pattern of decreased phosphorus in the sediment suggests significant uptake by the vegetation; leaching to groundwater has to be minimal with the impermeable clay lense under the swamp and overland flow out of the swamp accounts for a small percentage of the deposition (see water chemistry section).

The sedimentation rates measured in this study are extremely high and mention should be made of possible sources of overestimation. Resuspension during trap installation and recovery, as well as during the entire sampling period, has to be studied carefully. Even though the cypress trees serve as a wind break and thus rarely allow for turbulent conditions in the water, some stirring is possible. Struble and Graetz (1976), in similar measurements in Florida experimental cypress swamps, found lower sedimentation rates (5 - 19 g/m^2-day) than the rates of this study (10 - 28 g/m^2-day) but likewise cautioned that resuspension was probable. They suggested traffic by experimenters in the swamp as a main course;

this was generally not a problem at Heron Pond.

While, for sediments, phosphorus was the only specific chemical parameter studied, it has been shown that swamp sediments are extremely important in other nutrient cycles and in removing nutrients from the water column through cation exchange. The appearance of bubbles accompanied by the odor of hydrogen sulfide when the sediments are disturbed in Heron Pond indicates the presence of sulfur bacteria and an anaerobic environment. The H_2S may contribute to swamp acidity if oxygen is present in the water column and sulfur compounds become oxidized to sulfuric acid (Gorham, 1967). Sediments also affect pH and nutrient availability by the nature of the peat. Sphagnum peat, for instance, through cation exchange, will release hydrogen ions into the water column while removing other ions. This often results in a nutrient deficient environment (Watt and Heinselman, 1965). Sphagnum is not present in Heron Pond (Anderson and White, 1970); however other forms of peat might be performing similar activities, in addition to serving as valuable energy storage.

Net Primary Productivity and Biomass of Vegetation in Heron Pond

by

Carol L. Dorge

and

William J. Mitsch

INTRODUCTION

Wetlands have been described as being among the most productive ecosystems (Westlake, 1963; Whittaker, 1975). Net primary productivity and biomass of the various vegetative components of Heron Pond were measured to determine the structure and function of a cypress-tupelo floodplain forest in Southern Illinois and to compare the values with measurements made elsewhere. Heron Pond is near the northern extreme of this type of bottomland forest. Major vegetative components include baldcypress (Taxodium distichum) and swamp tupelo (Nyssa aquatica) in the canopy, a mat of floating duckweed (described by Anderson and White (1970) as being composed of Azolla mexicana **and** Spirodela polyrhiza) on the water and various shrubs and herbaceous understory on floating logs and tree stumps. A list of the understory vegetation in Heron Pond as described by Anderson and White (1970) is given in Table 38.

METHODS

Duckweed

To measure duckweed biomass, a 0.19 m^2 box with screen bottom and open top was lowered into the water and moved below the surface to an area of undisturbed duckweed; it was then raised, and duckweed collected from the screen. This was repeated 3 times. The composited sampled was weighed wet; a subsample was dried in the lab at 103°C to determine a dry/wet ratio.

Duckweed productivity (D) was calculated from sedimentation values as follows:

$$D = \begin{array}{c}\text{Total Sediment}\\ \text{deposition}\end{array} - \text{Litterfall} - \begin{array}{c}\text{Flood}\\ \text{deposition}\end{array} - \begin{array}{c}\text{Resuspension}\\ \text{Estimate}\end{array}$$

Methods of sediment collection are presented in the section of this report entitled "Sedimentation Rates and Sediment Analysis in Heron Pond".

In order to avoid overestimation of duckweed productivity, an estimate of resuspension into the sediment traps was made. It was assumed that little detrital production occurred both

Table 38

Understory Vegetation in Heron Pond
as Described by Anderson & White (1970)

Herbs & Shrubs

- Moss spp.
- *Bidens discoidea**
- *Triadenum walteri*
- *Lycopus rubellus**
- *Boehmeria cylindrica*
- *Galium obtusum*
- *Rosa palustris**
- *Scutellaria lateriflora*
- *Itea virginica*
- *Cuscuta cuspidata*
- *Cyperus erythrorhizos**
- *Rhus radicans*
- *Impatiens biflora*
- *Carex* sp.
- *Parthenocissus quinquefolia*
- *Smilax* sp.
- *Rubus* sp.
- *Vitis* sp.
- *Lobelia cardinalis*
- *Cyperus esculentus*
- *Cyperus erythrorhizos*
- *Cephalanthus occidentalis**

Seedlings

- *Ulmus* sp.
- *Acer rubrum* var. *Drummondii*
- *Taxodium distichum*

Aquatic Vegetation

- *Azolla mexicana**
- *Spirodela polyrhiza**
- *Ceratophyllum demersum**

---

* Positively identified in this study

during the winter and during late spring period, the average value during these two periods, 10.4 gm/m^2-day, was subtracted from the other periods to give a more realistic measure of duckweed (and total aquatic) net productivity.

Cypress and Tupelo

A point quarter survey (Cottam and Curtis, 1956) provided the basis for biomass and productivity measurements. Ten points, 30 meters apart along a line south from the main platform sample station 4, were established and marked with stakes. Each point defined four quadrats (a north, south, east and west quadrat). Diameter at breast height (DBH), height, distance from the stake and tree species was recorded for the nearest tree (with minimum diameter 10 cm) in each quadrat. One tree at the tenth point, was eliminated from data analysis because a double trunk produced an unrepresentative DBH value. Therefore, a total of 39 trees were evaluated.

Tree biomass was calculated using the parabolic formula for volume Vp:

$$V_p = \frac{\pi r^2 h}{2}$$

r = radius at breast height

h = height

Biomass values were obtained by multiplying calculated volume by density values of 451 kg dry wt/m^3 and 491 kg dry wt/m^3 for cypress and tupelo respectively. These were obtained from values reported in the U. S. Department of Agriculture Wood Handbook (1940) after correcting for moisture content.

To place biomass data on an areal basis, mean area per tree was computed from point-quarter survey distance measurements and multiplied by the number of trees to give a value for sample area. This method was found by Cottam and Curtis (1956) to result in a more accurate value for area than other commonly used sampling techniques.

Tree production was calculated as the sum of the following components: litterfall (L), above-ground woody growth ($\Delta B/\Delta t$) and root growth ($\Delta R/\Delta t$). Litter was collected in 9 litter boxes with an area of 0.19 m^2 each. They were located at randomly selected sites along the transect used for the point-quarter-survey (see Fig. 2). Litter was sampled 7 times and composited during the 12 month study. Litter was dried at 103°C and weighed to determine its contribution in gm dry wt.

Above ground woody growth ($\Delta B/\Delta t$) was determined using tree core analyses of 9 cypress and 10 tupelo and estimating biomass change over the last 5 years.

Using the parbolic formula on an incremental growth basis (Whittaker and Woodwell, 1968), biomass change over the chosen 5 year period for each cored tree is given as:

$$WP = \frac{\rho\pi(r_2^2 - r_1^2)\ h}{2 \cdot 5\ yr}$$

where,

WP = wood production, kg/yr

ρ = density of wood, kg/m^3

r_1, r_2 = tree radii at beginning and end of 5 year period, m

h = tree height, m

The calculated production values for cored trees were graphed as WP vs DBH and from this graph the productivities for surveyed trees were interpolated. These values were placed on an areal basis in the same manner as biomass values, produced a value for above ground wood productivity ($\Delta B/\Delta t$) in gm/m^2-yr.

Root biomass was found by Mitsch (1975) to be 35.6% of total cypress biomass in Florida. In an average temperate forest, root biomass is 20 - 35% of total above-ground biomass (21% of total biomass) while fire adapted trees have 36% of total biomass in their roots (Woodwell and Whittaker, 1968). This coefficient was used to compute both root production and biomass from above-ground productivity and biomass, according to the simplified method presented by Newbould (1967):

$$\frac{\text{Above-ground production}}{\text{Above-ground biomass}} = K \times \frac{\text{Below-ground production}}{\text{Below-ground biomass}}$$

K is assumed to be unity (Newbould, 1967).

Importance values, calculated from relative dominance, relative density and relative frequency were also computed from point quarter survey data (method modified from Cottam and Curtis (1956) as given in Smith (1972)).

Herbaceous Understory

The biomass of leaves of understory shrubs and harvested herbaceous understory vegetation ($\Delta H/\Delta t$) at the end of the growing season was used an an estimate of the minimum productivity value which might be attributed to these plants. This method was used by Schlesinger (1977) and Conner and Day (1976). To ascertain that turnover time of these components of the Heron Pond understory is at least one year, the species list (Anderson and White 1970) was used. Eighteen randomly selected 0.5 m^2 plots were harvested in September.

RESULTS AND DISCUSSION

Duckweed

Duckweed biomass at each sampling time is presented in Fig. 44. A maximum standing crop of 408 gm dry wt/m^2 was found in September 1977 while biomass was zero during winter months. Most of the growing season had values between 100 and 200 gm dry wt/m^2. This is high compared to values measured by Wood (1972) in a southern Illinois pond with duckweed. A maximum increase in biomass of 5.3 gm/m^2-day was measured in September 1977. Total aquatic net production was found by sedimentation measurements to average 3.0 gm dry wt/m^2-day, totalling 1097 gm dry wt/m^2-yr. This was assumed to be due primarily to the floating duckweed. Price (1975) found duckweed production in a Florida cypress dome which was receiving secondary treated sewage, at an equilibrium growth phase to be 2.91 gm wet wt/m^2-day. Assuming a dry/wet ratio of 0.09 (from Heron Pond data), this would equal 0.26 gm dry wt/m^2-day. Glandon and McNabb (1977), in a laboratory experiment, found growth rates averaging 0.86 gm dry wt/m^2-day at approximately 2160 kcal/m^2-day (19,000 lux). The much higher growth rate found at Heron Pond approximates that of a eutrophic marsh system although somewhat lower than a waterhyacinth marsh producing

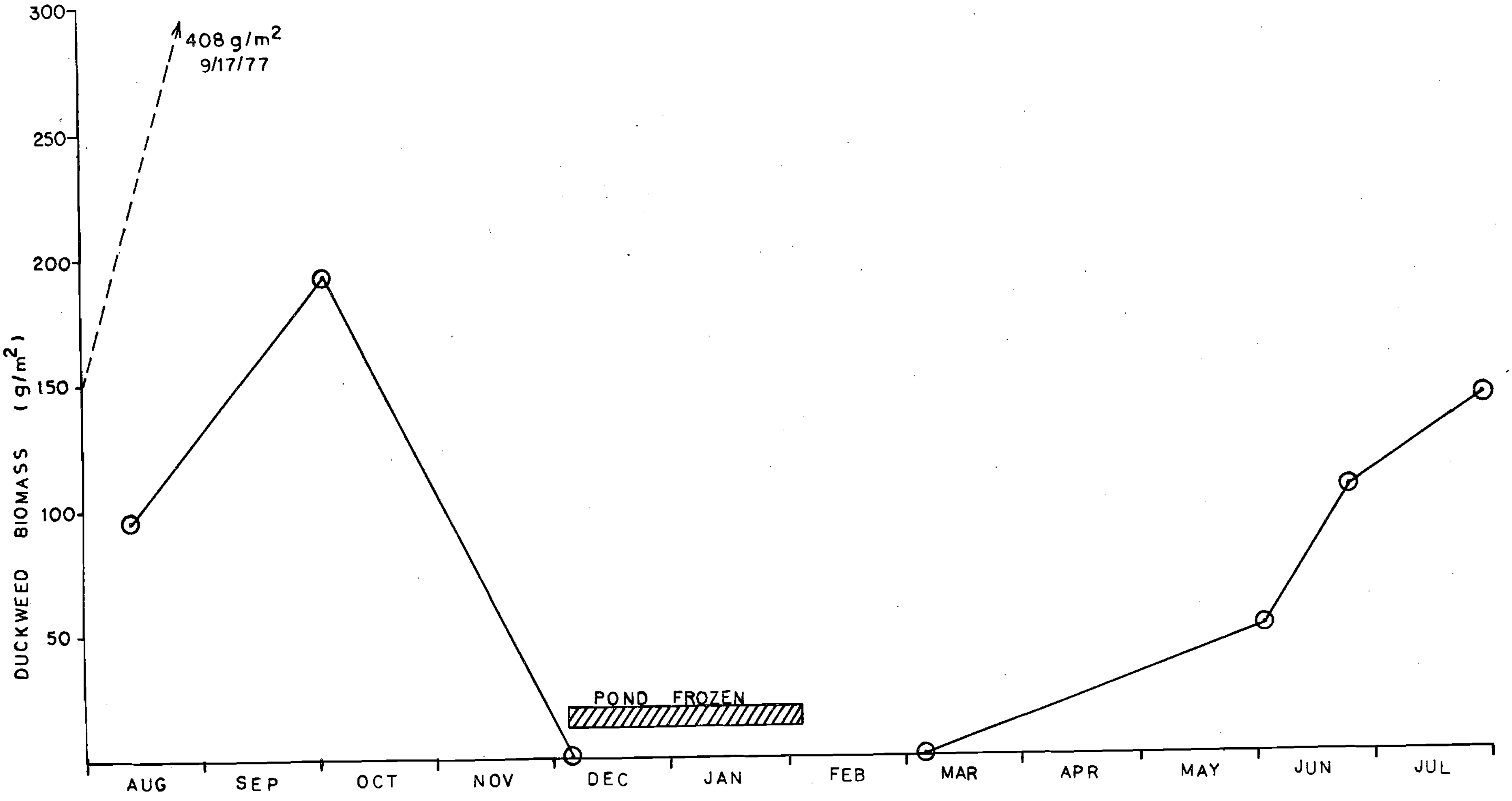

Figure 44. Duckweed biomass (dry weight) during study period in Heron Pond

5044 gm/m^2-yr (Mitsch, 1977) or a reed swamp found to produce 2900 - 4600 gm/m^2-yr (Watt and Heinselman, 1965). Duckweed, in its early growth stages has a doubling time of approximately 2 days (Price, 1975; Glandon and McNabb, (1977). Maximum doubling time measured in Heron Pond was 17 days.

Cypress and Tupelo Productivity

Litterfall data for Heron Pond is presented in bar graph form in Fig. 45. Total annual litterfall was 348 gm dry wt/m^2-yr. This value is much less than the value obtained by Conner and Day (1976) in a cypress tupelo swamp in Louisiana (620 gm dry wt/m^2) and approximates the 310 gm dry wt/m^2-yr found by Schlesinger (1977) in the nutrient-poor Okefenokee swamp in Georgia. Heron Pond annual litterfall, expressed as a percent of total biomass, is 0.8%; this value is also lower than the average for a swamp forest, 1.5 - 2% according to Rodin and Bazilevich (1967). Leaf production in cypress swamps is approximately equal to that of a temperate forest, 300 - 400 gm dry wt/m^2-yr; values for Lac des Allemands, Louisiana (Conner and Day, 1976) and the Tar River swamp, North Carolina, (Brinson, 1977) approach levels in a tropical forest, 900 gm dry wt/m^2-yr (Woodwell and Whittaker, 1968).

Results of tree core analyses are presented in Table 39. These data were plotted as wood productivity vs DBH for both cypress and tupelo (Fig.46). Regressions with the following equations were formulated for cypress and tupelo:

$$y = 0.1829x - 0.66 \quad \text{(cypress)}$$

$$y = 0.5675x - 7.437 \quad \text{(tupelo)}$$

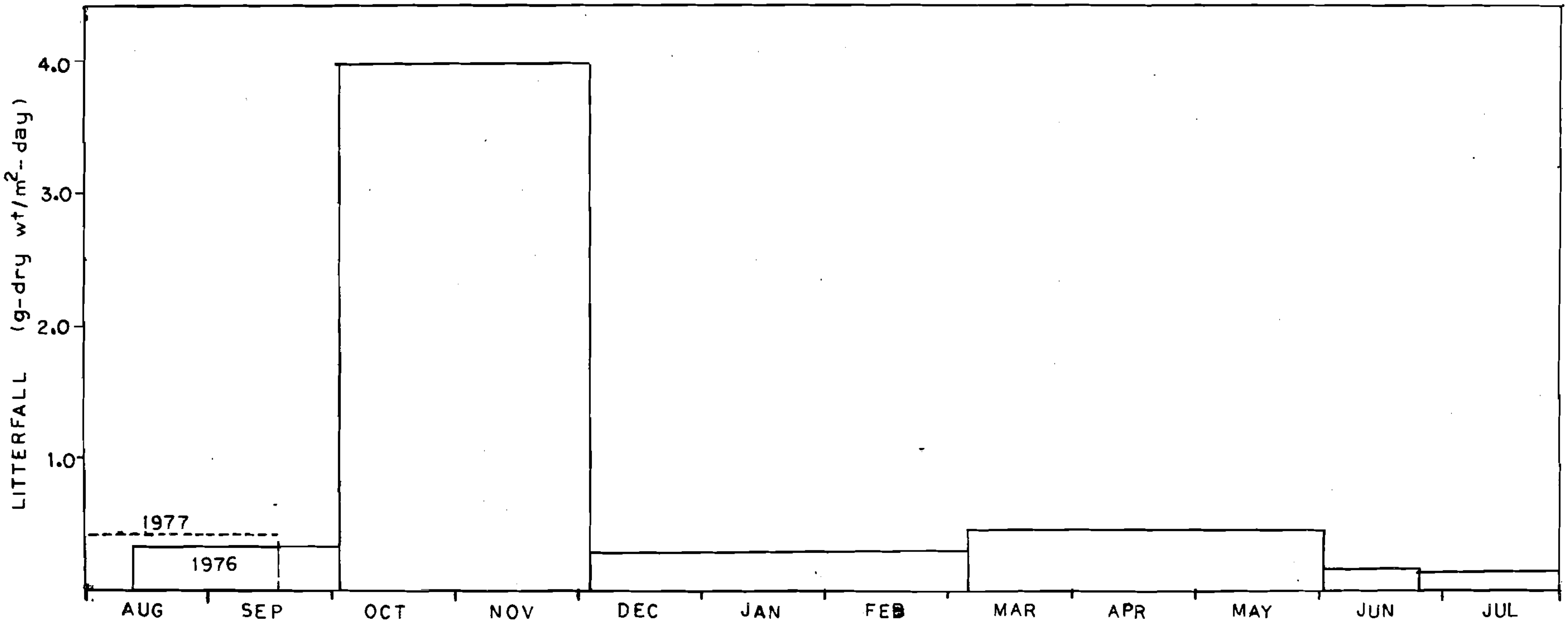

Figure 45. Litterfall rates during study period in Heron Pond

Table 173

Cypress and Tupelo Net Primary Productivity Calculations Based on Tree Core Analysis for the Last 5 Years

Tree Number	Type	Height (m)	DBH (cm)	Basal Area[1] Increase (cm^2/yr)	EVI[2] (m^3/yr)	NPP[3] (kg/yr)
1	Cypress	32	159.5	41.0	.0656	29.6
5	Cypress	29	79.2	21.8	.0316	14.3
12	Cypress	19	35.0	18.9	.0179	8.1
20	Cypress	29	85.3	25.6	.0371	16.7
21	Cypress	26	75.1	29.5	.0384	20.6
27	Cypress	22	46.7	19.4	.0213	9.6
30	Cypress	16	50.8	14.6	.0117	5.3
33	Cypress	18	48.0	20.2	.0182	8.2
39	Cypress	21	79.5	19.4	.0204	9.2
40	Tupelo	12	21.8	8.12	.0049	2.4
41	Tupelo	11	21.0	13.75	.0076	3.7
42	Tupelo	11	25.9	16.54	.0091	4.5
43	Tupelo	12	25.1	14.56	.0087	4.3
44	Tupelo	12	19.4	17.33	.0104	5.1
45	Tupelo	18	26.7	30.32	.0273	13.4
46	Tupelo	13	20.2	15.93	.0104	5.1
47	Tupelo	19	35.6	23.63	.0224	11.0
48	Tupelo	15	28.3	31.29	.0235	11.5
49	Tupelo	12	19.4	9.41	.0056	2.8

1. Basal Area Increase = BAI = $\pi(r_2^2 - r_1^2)/5$ (cm^2/yr)

   Where r_2= present tree radius
   r_1= tree radius 5 years ago

2. EVI = $0.5 \times H \times \frac{BAI}{10000}$ (m^3/yr)

3. NPP = Net Primary Production = ρ EVI

   $\rho = 451$ kg/m^3 (cypress) (USDA, 1940)

   $\rho = 491$ kg/m^2 (tupelo) (USDA, 1940)

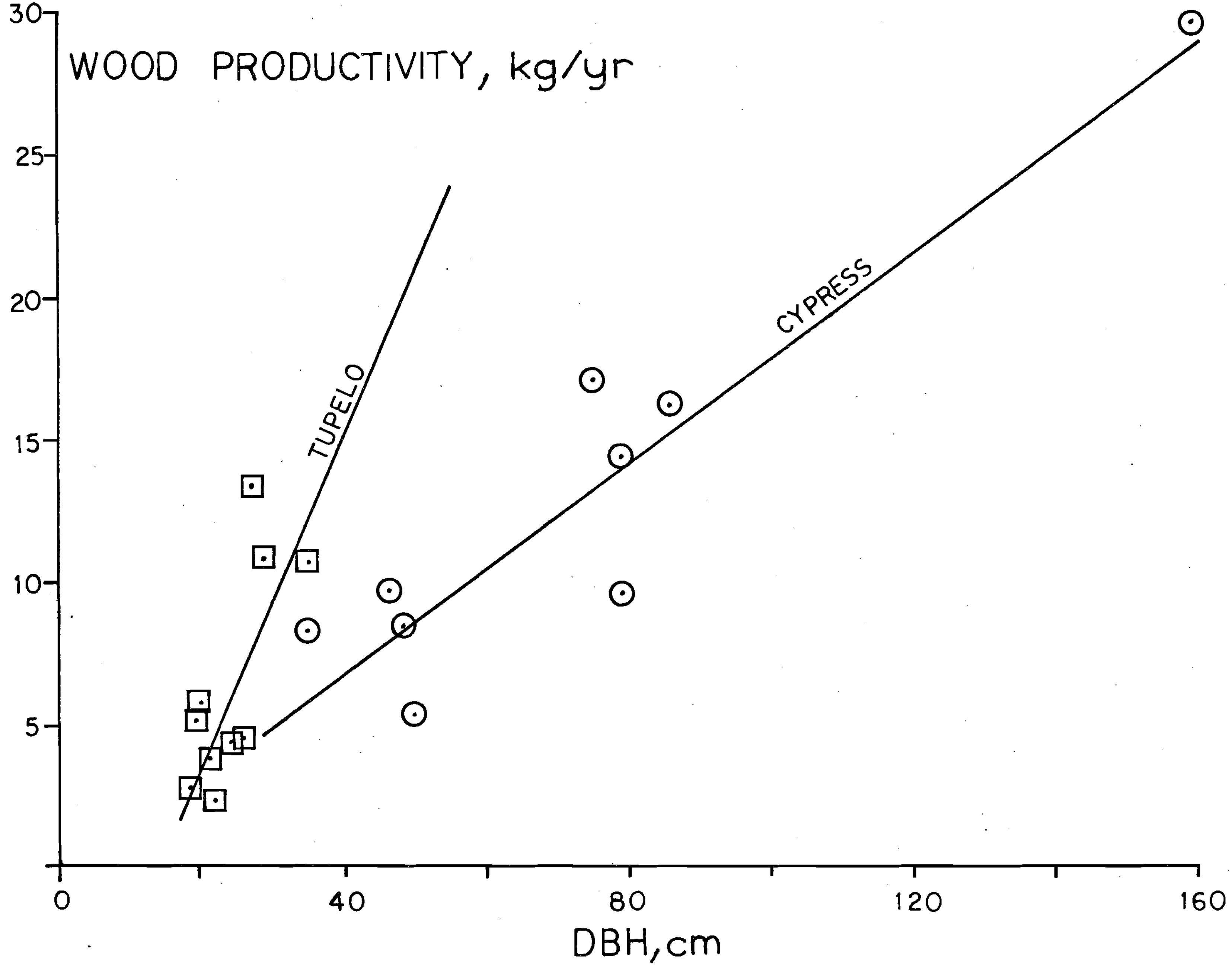

Figure 46. Wood production as calculated from tree ring analysis as a function of DBH.

where,

x = DBH (cm)

y = wood production (kg/yr)

These graphs were used to interpolate the wood production values for all the trees, presented with point quarter survey and biomass data in Table 40. Fig.47 shows that while diameter growth slowed for larger cypress in Heron Pond, increase in basal area approximated a linearly increasing relationship with DBH.

Above-ground wood production for cypress and tupelo were 193 gm dry wt/m^2-yr and 137 gm dry wt/m^2-yr respectively for a total of 330 gm dry wt/m^2-yr. Root productivities were 107 gm dry wt/m^2-yr and 76 gm dry wt/m^2-yr. Total tree production (litter + wood + root) is therefore 861 gm dry wt/m^2-yr. Above - ground production is 678 gm/m^2-yr. Heron Pond above-ground tree productivity is compared to that of selected southeastern swamp ecosystems in Table 41. Net productivity is almost half of that measured in a similar cypress-tupelo swamp in Louisiana by Conner and Day (1976).

Cypress and Tupelo Biomass

Biomass vs. DBH for 28 cypress and 21 tupelo were plotted and compared to a similar data for *Taxodium distichum* var. *nutans* harvested in Florida by Mitsch (1975) (Fig.48). While the Florida trees were smaller than those in Heron Pond, similar regressions were obtained. Despite the greater wood density of tupelo, no difference in biomass vs DBH was found for Heron Pond cypress vs. tupelo and the graph is represented by a single

Table 40

Above-Ground Biomass and Productivity Calculations from Tree Survey in Heron Pond

Page 1 of 2

Tree Number	Type*	Height (m)	DBH (cm)	Distance (m)	Parabolic Volume (m^3)	Biomass (kg dry wt)		Productivity (kg dry wt/yr)	
						Cypress	Tupelo	Cypress	Tupelo
1	1	32	160	2	31.93	14400		29	
2	1	12	120	8	.18	84		4	
3	1	10	15	5	.09	42		3	
4	1	31	157	3	30.0	13509		28	
5	1	29	79	4	7.14	3220		14	
6	1	22	29	2	.72	326		5	
7	1	21	26	1	.57	260		5	
8	1	27	72	7	5.50	2485		13	
9	1	17	22	6	.32	143		4	
10	2	21	43	8	1.54		757		17
11	1	23	44	10	1.72	776		8	
12	1	19	35	5	.92	413		6	
13	1	14	33	6	.60	270		6	
14	1	23	55	3	2.77	1250		10	
15	1	16	29	5	.54	241		5	
16	1	23	58	3	3.08	1389		11	
17	1	27	63	6	4.20	1880		12	
18	1	12	24	2	.28	126		4	
19	2	12	23	11	.26		128		6
20	1	29	85	5	8.28	3736		15	
21	1	26	75	10	5.72	2580		13	
22	2	19	31	14	.73		358		10
23	1	27	88	6	8.27	3730		16	
24	2	21	43	8	1.55		761		17
25	2	20	47	2	1.77		873		18
26	2	19	53	8	2.06		1016		22
27	1	22	47	7	1.88	850		9	
28	2	20	50	3	1.96		969		21
29	2	19	56	8	2.33		1148		24
30	1	16	51	10	1.62	730		10	

Table 40 Cont'd

Above-Ground Biomass and Productivity Calculations from Tree Survey in Heron Pond

Page 2 of 2

Tree Number	Type*	Height (m)	DBH (cm)	Distance (m)	Parabolic Volume (m^3)	Biomass (kg dry wt)		Productivity (kg dry wt/yr)	
						Cypress	Tupelo	Cypress	Tupelo
31	2	14	29	10	.45		223		9
32	1	16	46	13	1.34	605		8	
33	1	18	47	5	1.63	734		9	
34	2	21	61	11	3.09		1522		28
35	1	19	67	4	3.35	1511		12	
36	2	19	57	6	2.46		1211		25
37	1	21	44	6	1.59	717		8	
38	1	21	80	5	5.21	2348		15	
39	1	19	51	5	1.94	876		9	
Total						59231	8966	291	207

* 1 = Cypress

2 = Tupelo

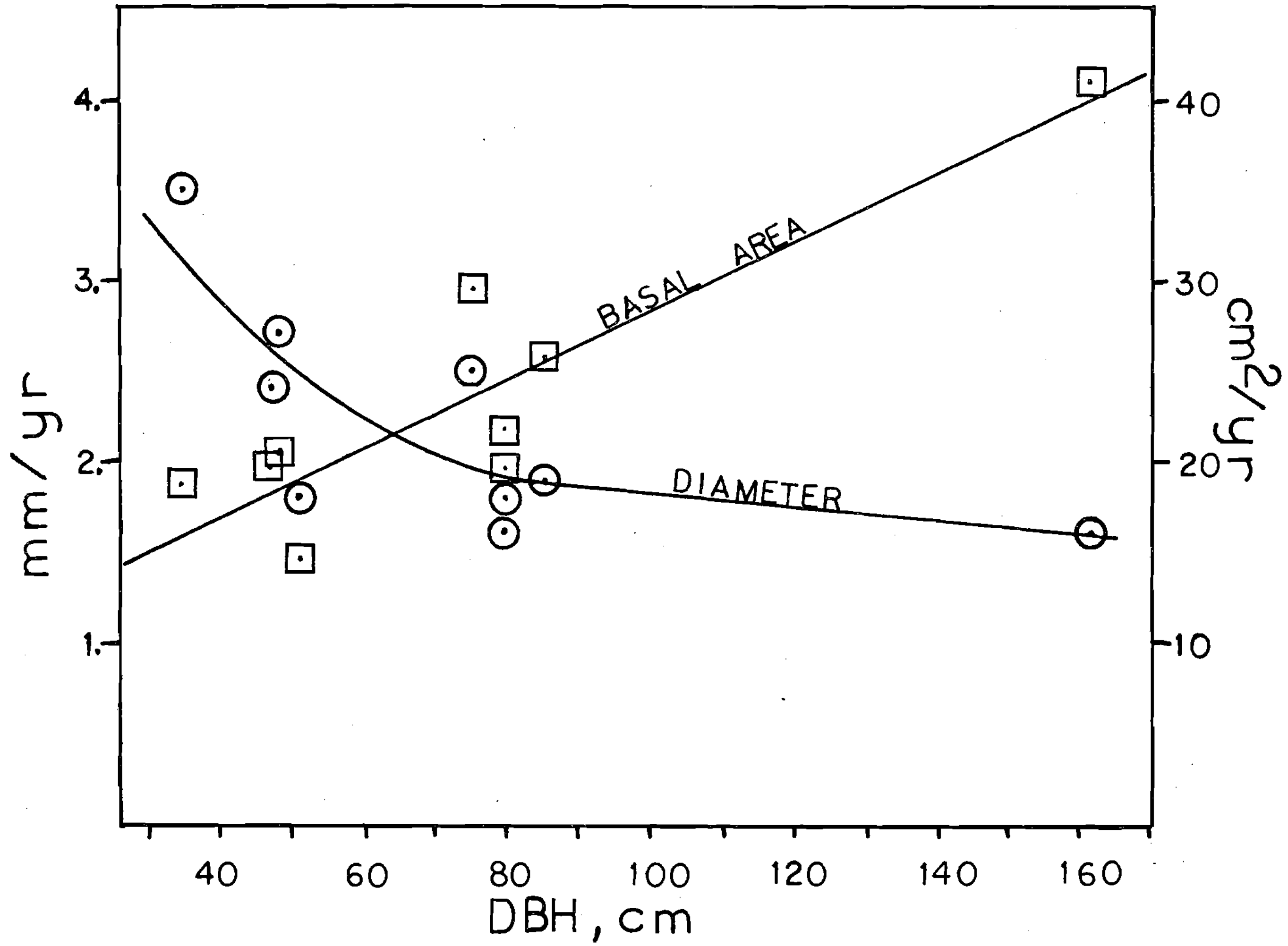

Figure 47. Diameter increase and basal area increase for cypress in Heron Pond as a function of diameter at breast height (DBH).

Table 41

Net Primary Productivity of Trees in Cypress and Tupelo Swamps

System	Reference	Litterfall (gm/m^2-yr)	$\Delta B/\Delta T$ (gm/m^2-yr)	Total Production (gm/m^2-yr)
Heron Pond, IL	This study (Above ground only)	348	330	678
Withlacoochee State Forest, Florida	Mitsch & Ewel (Unpublished)			
Cypress-Hardwood Stands		-	336	-
Cypress-Tupelo Stands		-	289	-
Cypress Pure Stands		-	154	-
Cypress Pine Stands		-	117	-
Alachua County, FL	Mitsch & Ewel (Unpublished)			
Sewage Dome		191	253	444
Groundwater Dome		343	304	647
Drained Dome		-	159	-
Ponded Dome		-	22	-
Okefenokee Swamp, Georgia	Schlesinger (1977)	310	393	703

Table 41 Cont'd

Lac des Allemands Swamp, LA	Conner & Day (1976)			
Cypress-Tupelo		620	500	1120
Bottomland Hardwood Forest		574	800	1374
Big Cypress Swamp, FL	Carter, et. al. (1973)			
Undrained Swamp		373	485	858
Drained Swamp		267	120	387
Tar River				
Tupelo Swamp, NC	Brinson (1977)	609-677	-	-

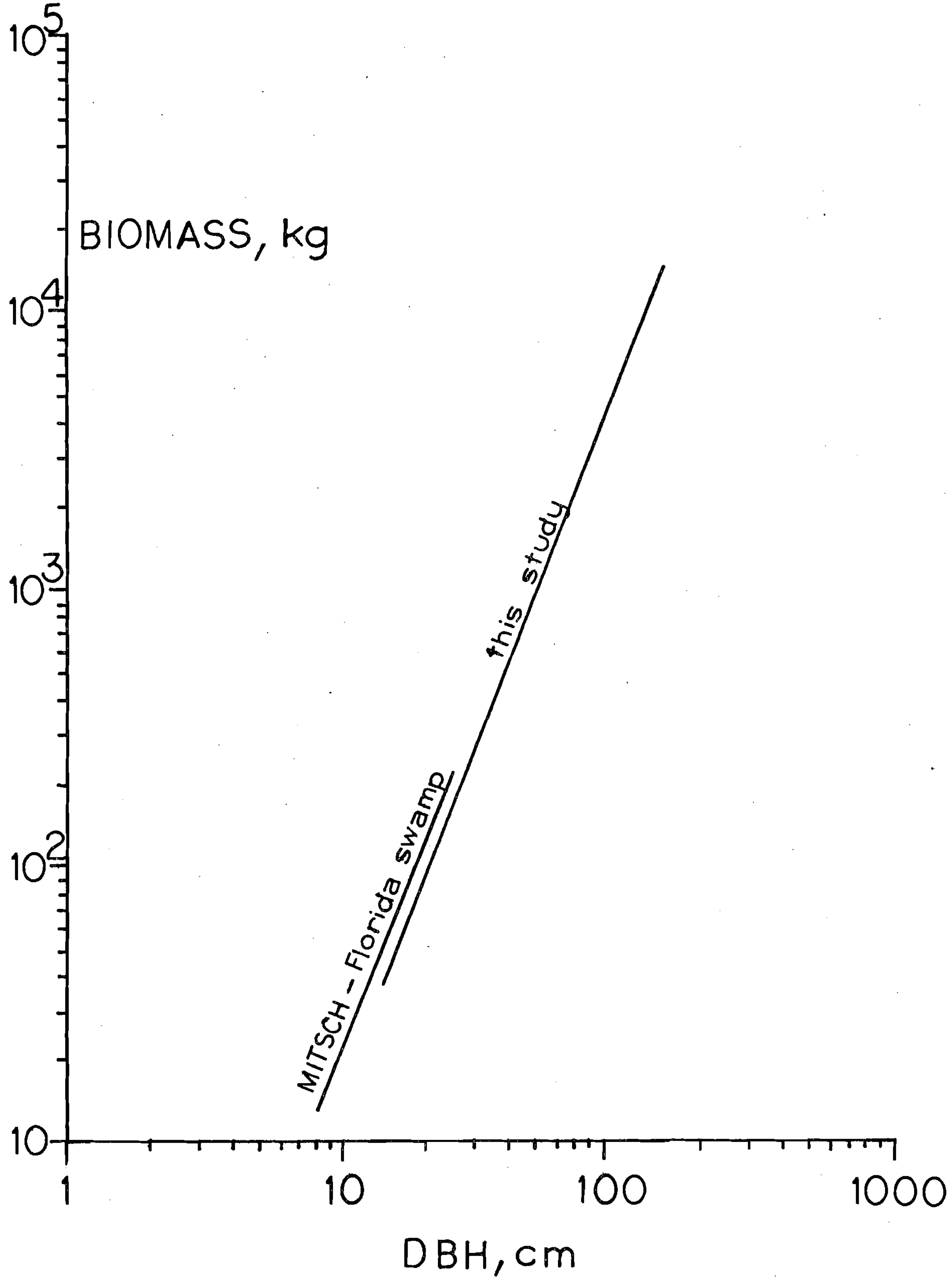

Figure 48. Total tree biomass regression as calculated for cypress and tupelo in Heron Pond. Relationship is compared with data from harvested cypress tree regression by Mitsch (1975).

line of log paper with equation:

$$y = 0.043 x^{2.54}$$

where,

y = biomass (kg)
x = DBH (cm)

Using a value for total sampling acreage of 1514 m^2, cypress and tupelo biomass were found to be 39.1 kg/m^2 and 5.9 kg/m^2 respectively. Average total above-ground biomass of a mature temperate forest is 30 - 50 kg/m^2 (Woodwell and Whittaker, 1968). Mean area per plant is 38.8 m^2. Mitsch and Ewel (unpublished) found cypress biomass to range from 3.1 - 38.0 kg dry wt/m^2 with average value, 13.5 kg dry wt/m^2, in Withlacoochee State Forest, Florida. Cypress-tupelo stands there had average cypress biomass of 19.0 kg dry wt/m^2.

Relative density, relative frequency, relative dominance and importance values for Heron Pond trees are presented in Table 42 and compared to values computed previously in Heron Pond by Anderson and White (1970). Data from this study indicate that tupelo tend to be clumped. Anderson and White did not compute relative frequency and it is likely that, if this were included, their importance values (58.1 for cypress in a cut-over stand and 82.4 in an old growth stand) would shift further in favor of cypress. In general, the results of the two studies compare favorably.

Non-aquatic Understory Production

Harvest of understory vegetation in September produced a yield of 4.5 gm dry wt/m^2, with values ranging from zero - 29

Table 42

Relative Importance of Cypress, Tupelo and Drummond Maple in Heron Pond

	Taxodium distichum			*Nyssa aquatica*			*Acer drummondii*		
	This Study	Cut-over Stand[1]	Old-growth Stand[1]	This Study	Cut-over Stand[1]	Old-growth Stand[1]	This Study	Cut-over Stand[1]	Old-growth Stand[1]
Average DBH (cm)	57.0	63.5	70.6	45.0	25.9	23.2	0.0	18.5	18.4
Average Height (m)	21.1	-	-	18.6	-	-	0.0	-	-
Relative Density	71.8	45.9	70.9	28.2	44.9	24.0	0.0	9.2	5.1
Relative Frequency	62.5	-	-	37.5	-	-	0.0	-	-
Relative Dominance	84.1	70.4	94.0	15.9	27.6	5.3	0.0	2.0	.7
Important Value on basis of 100	72.8	58.1[2]	82.4[2]	27.2	36.3[2]	14.7[2]	0.0	5.6[2]	2.9[2]

[1] Anderson and White (1970)

[2] Does not include relative frequency

gm/m^2 (Table 43). Standard deviation of harvest values for 0.5 m^2 plots was 3.9 with mean, 2.2, indicating vegetation was not uniformly distributed. Vegetation distribution was dependent upon the availability of rotting logs or tree trunks for substrate. Annual productivity of this vegetation strata is thus estimated to be 4.5 gm dry wt/m^2-yr. Similar harvest in a cypress-tupelo swamp by Conner and Day (1976) produced 20 gm dry wt/m^2-yr.

Total Above-ground Production

Total swamp net primary productivity, is estimated to be 1963 gm dry wt/m^2-yr. Duckweed is the dominant producer, contributing 55.9% of the total (Table 44). Historical data for tree growth from tree ring measurements indicate that the period 1971 - 1975 may have been an abnormally low growth period. Beaver activity in the late 1960's raised the swamp water level and was observed to cause an abnormally high tupelo death rate. It is difficult to determine whether beaver activity, flood water volume or another forcing function cause the apparent low tree growth.

It is conceivable that duckweed production increases in response to lower tree growth and more open canopy; Mitsch and Ewel (unpublished), however, found duckweed production to increase rapidly in a Florida sewage dome at the same time that tree growth (measured as change in diameter) appeared to also be increasing. In the Florida study, both cypress domes receiving sewage and groundwater had approximately equivalent growth per tree: 4.2 - 5.0 kg dry wt/tree -yr. Normal growth was 2.5 - 3.5 kg dry wt/tree -yr. Heron Pond tree growth averaged

Table 43

Harvest of Herbaceous Vegetation in Heron Pond

September 17, 1977

Station	gm dry wt
1a	6.57
1b	3.98
2a	0.00
2b	0.00
3a	0.00
3b	0.00
4a	0.12
4b	5.55
5a	5.80
5b	0.00
6a	0.00
6b	0.00
7a	14.60
7b	0.00
8a	0.00
8b	2.63
9a	0.00
9b	1.02
	40.27

Sample plot size: 0.5 m^2

$\bar{x}$ = 2.37 gm dry wt

Standard deviation = 3.869

Average % organic matter = 74%

Herbaceous Production:

$$\frac{4.5 \text{ gm dry wt}}{m^2\text{-yr}}$$

Table 44

Distribution of Net Primary Productivity in Heron Pond

Component		Net Primary Production (gm/m^2 yr)	% of Total Production
Trees		861	43.9
Cypress & Tupelo litter	348		
Cypress Wood	193		
Tupelo Wood	137		
Cypress Roots	107		
Tupelo Roots	76		
Duckweed		1097	55.9
Herbaceous Vegetation		5	0.2
Total		1963	100.

10.4 kg/cypress -yr and 18.8 kg/tupelo -yr, suggesting an environment conducive to high productivities. The cypress in Heron Pond averaged an increase in DBH of 2.2 mm/yr as compared with 2.8 - 3.0 mm/yr in the experimental cypress domes, 3.3 mm/yr for cypress-hardwood association and 1.7 mm/yr for cypress-tupelo associations, all in Florida (Mitsch and Ewel, unpublished). The relative increase is less because the trees are much larger.

In summary, Heron Pond can be compared to other ecosystems and is found to be among the most productive of temperate ecosystems when understory duckweed is included (Table 45). Its value in collection of solar energy may be surpassed only by some marsh systems and fossil fuel energy subsidized agricultural systems. Energy storage in the tree layer, 45 kg dry wt/m^2, is greater than that of most temperate forests (eg. Woodwell and Whittaker, 1968).

Tree productivity itself is low for a swamp of this type and raised water levels may have caused a decrease in production. Few cypress seedlings were seen under the canopy, as cypress seedlings need a period of dry conditions in which to germinate (Demaree, 1932). Although the swamp is near the northern extreme of this type of ecosystem, it seems to have the potential for productivities equal to those typical of more southern climes. The higher water levels have selected for aquatic productivity (duckweed) in lieu of tree productivity.

Table 45

Ecosystem Comparison of Total Net Primary Productivity

	Net Primary Productivity[2] gm/m^2-yr
Floodplain Swamps	
Heron Pond riverine swamp (This study)	1963
Lac des Allemands, Louisiana, (Conner & Day, 1976)	1140
Lac des Allemands, (estimate)[1] Louisiana, (Conner & Day, 1976)	1516
Louisiana bottomland hardwood (Conner & Day, 1976)	1574
Louisiana bottomland hardwood (estimate)[1] (Conner & Day, 1976)	1733
"Southern River Swamp" (Goodwin and Neiring, 1974)	2250
Germany--temperate reed swamp (Watt & Heinselman, 1965)	4600
America--temperate reed swamp (Watt & Heinselman, 1965)	2900
Minnesota cedar swamp (Reiners, 1970)	1070
Southern Florida drained slough (Carter _et al_., 1974)	368
Okefenokee Swamp, Georgia (Schlesinger, 1977)	692
Other Swamps	
Southern Florida cypress dome receiving sewage (Odum, et. al., 1977)	1530
Florida undrained slough (Carter _et al_., 1974)	1170
Other Ecosystems	
Tropical rain forest (Watt & Heinselman, 1965)	3250
Sugarcane (Goodwin and Neiring, 1974)	27010
Temperate forest (Whittaker and Woodwell, 1968)	1200-1500
Louisiana salt marsh (Teal, 1962)	1823
Water hyacinth marsh (Mitsch, 1977)	5044

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[1] estimate based on assumed values for herbaceous growth using literature values for insect consumption.

[2] many values include only above-ground productivity.

Relationships of Flood Volume to Cypress Growth

By

Michael J. Hickey

and

Carol L. Dorge

INTRODUCTION

It is known that variations in ring widths from certain trees can be used to date wood and to provide information on past climates (Schulman, 1956; Fritts *et al.*, 1971). Ring-width variations have recently been used to evaluate environmental factors important to tree growth. For example, climatic variables in the midwest have been shown to affect ring - width growth of oak (Fritts, 1962). This implies that the relative widths of rings from oak may serve as records of past climate. An excellent example of the application of tree ring dating to environmental studies is offered by Stockton and Fritts (1973). Their study related water level records from 1810 - 1967 for Lake Athabasca, Canada to growth of white spruce.

This paper is an attempt to correlate annual tree growth of cypress trees (*Taxodium distichum*) with the annual flood water volume in a cypress tupelo swamp, Heron Pond. A linear regression model has been developed for a twenty-five year period.

METHODS

Ten cypress trees were cored and annual growth rings were identified according to methods described by Stokes and Smiley (1968). Growth was expressed as change in basal area per year and was determined by calculating the area between each ring. To facilitate data handling the annual growth data for the ten trees were averaged and then lumped into five year periods. There were eight five year periods which correspond to the study period of 40 years (1927-1966). Therefore for each five year period (eg. 1962-1966) there is a number corresponding to tree growth given as cm^2/year. The most recent data (1967-76) were left out of the analyses because it is well known that increased water levels due to beaver dams had a negative effect on tree growth in Heron Pond (see net productivity section).

Peak stage and discharge data for the Cache River at Forman, Illinois from 1927-1966 (Table 14) were used to determine the five year flood volume to be correlated with the five year tree data. These five year flood data were calculated by summing all floods in a given five year period with a discharge greater than 4005 cfs. It has been shown that a discharge of greater than 4005 cfs. will cause the Cache River to flood into Heron Pond (see section on river flooding in hydrology section).

Regression and correlation analyses were applied to the data using flood volume as the independent variable and tree growth the dependent variable. The correlation coefficient, r, was computed and the value, r^2 (expressed as a per cent), was used to represent the percent of variation in tree growth which was explained by flood volume.

RESULTS

By superimposing tree growth (cm^2/yr) and flood volume (cfs) vs five year period on the same graph an interesting relationship develops. (Figure 49). For the thirty year period from 1966 to 1937, flood volume and tree growth are somewhat correlated. For the years 1926 to 1936 it appears that an inverse correlation is the case. Data for regression analysis for the thirty year period, 1937 to 1966 is presented in Table 46. After graphing the regression equation for this thirty year period (Figure 50, line 1) it was apparent that one point deviated greatly from the regression line. This point was generated by the last five year period in the thirty year total, 1937 - 1941. Regression and correlation analyses were then performed for the twenty-five year period from 1966 to 1942 and new regression constants and correlation coefficients determined. A high degree of correlation was obtained for tree growth vs flood volume with these data.

DISCUSSION

Tree ring growth and flood water volume were analyzed for a forty year period (1927-1966). Figure 49 shows a significant change in the relationship between tree growth and flood water prior to 1936. The correlation coefficient for

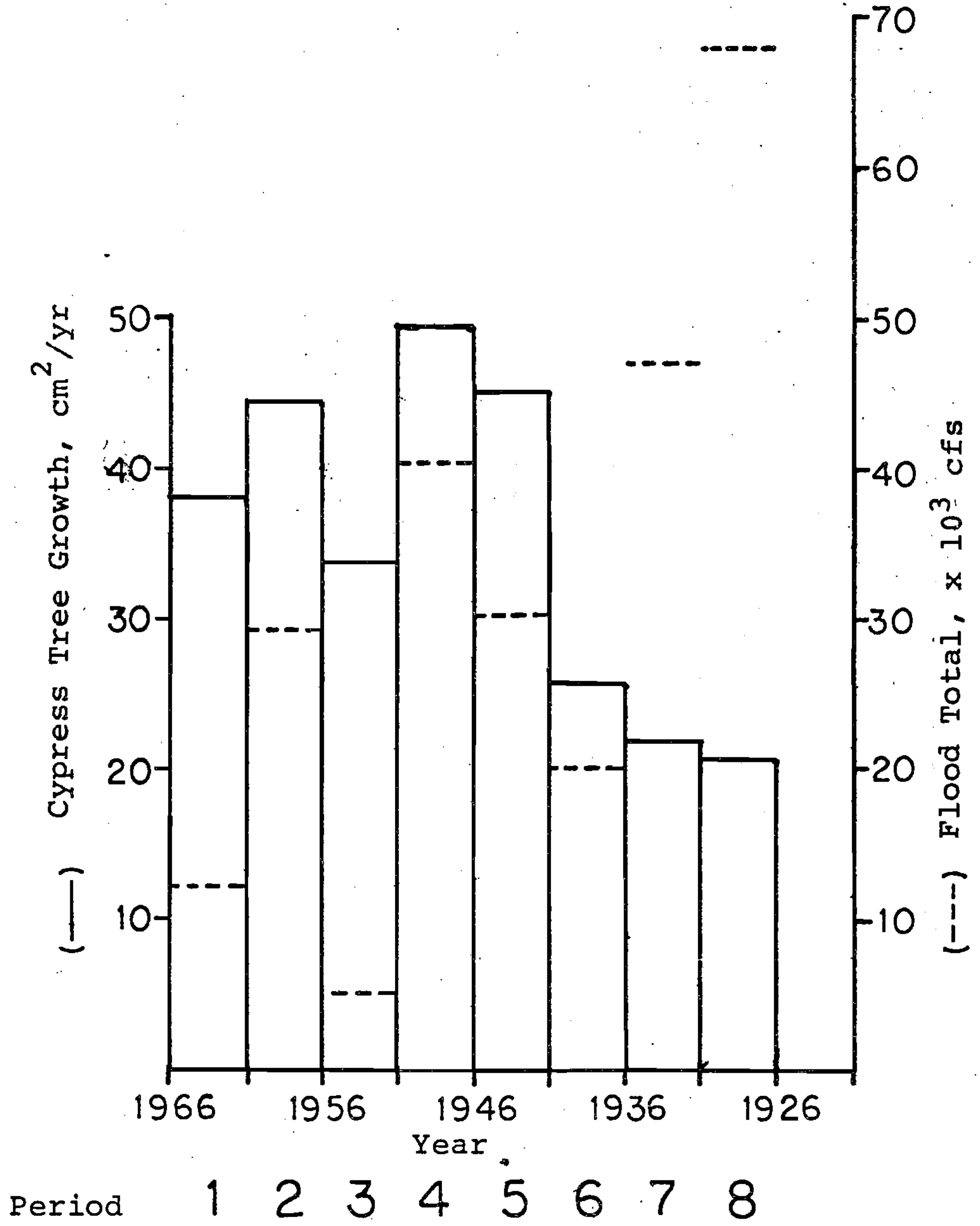


Figure 49 Increase in Cypress Basal area in Heron Pond for 5 year intervals. Also shown is the total of all floods that overflowed into Heron Pond for the same 5 year periods.

Table 46

Regressional Analyses for Tree Growth vs Flood Volume

Period	Year	5 Year Total Flood Water (cfs)	5 Year Tree Growth
1	1962-1966	12,340	38.0
2	1957-1961	29,100	44.4
3	1952-1956	5,010	33.7
4	1947-1951	40,450	49.4
5	1942-1946	30,410	45.2
6	1937-1941	20,110	25.8
7	1932-1936	47,010	21.9
8	1927-1931	68,170	20.7

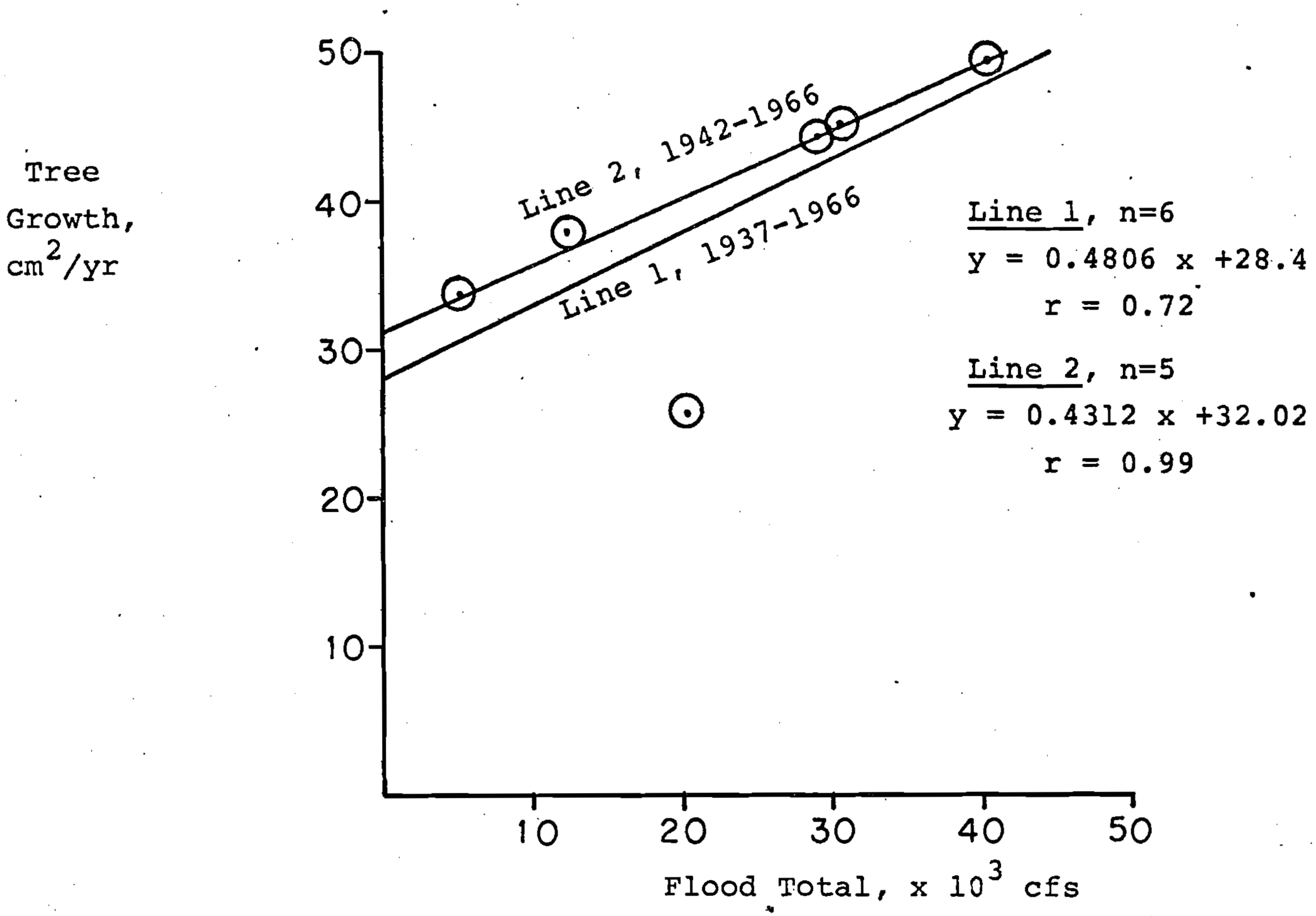


Figure 50 - Relationships between Cache River Flood Volumes and Cypress Tree Growth in Heron Pond for Two Periods.

periods 1 through 6 was calculated to be 0.77. This indicates a positive correlation which is marginally linear. Only 51.4% of the variation in tree growth values can be explained by flood volume variation.

Regressional analysis was performed on the data for the first five periods and the results are shown in Table 46. Remarkable values of 0.99 and 99.8% were obtained for r and r^2% respectively. This r^2% value indicates that 99.8% of the variation in the tree growth is explained by variation in flood volume.

CONCLUSION

It was impossible to incorporate the tree growth and flood values for periods 7 and 8 into the simple linear regression. It is possible that the high flood water values for periods 7 and 8 had a detrimental affect on tree growth but this could not be tested. Mitsch and Ewel (unpublished) in a study of cypress growth in Florida found similar decreases in productivity at high water levels with growth maximum at intermediate levels.

The fact that a correlation coefficient of 0.99 was obtained in relating tree growth to flood volume for the first five study periods seems to indicate an almost certain positive relationship. Including the sixth period reduces the correlation coefficient to 0.72. Addition of periods 7 and 8 would break down all linear relationships. In the period 1936-1941, some variable, which may have been climatic, or may have been a residual effect of pre-1936 conditions, changed to a great extent the correlation between tree growth and flood water volume.

Further study should expand upon data for periods of excess flooding, such as periods 7 and 8 (1926-1936), in order to determine if growth is negatively correlated to flood volume above some threshold level.

PHASE 4 - SYSTEMS ANALYSIS

A Phosphorus Budget for Heron Pond

by

Carol L. Dorge

and

William J. Mitsch

INTRODUCTION

While floodplain swamps have sometimes been accused of imputting undesirable color, organics and associated nutrients to their associated rivers, their function as pollutant source or sink can best be determined if all inputs and outputs are considered and net effects determined. Discussion in the "water chemistry" section of this report described inflow/outflow characteristics of some rivers which pass through wetlands. A more complete study of the phosphorus dynamics of Heron Pond is presented here. It includes precipitation, river flooding, groundwater and runoff input, groundwater and overland flow export as well as intrasystem uptake and recycle through plant growth, litterfall, leaching and sedimentation.

METHODS

Phosphorus Transport in Water

Combining chemical analysis for phosphorus in water with hydrological data, phosphorus transport by the following vectors was calculated: rainfall and throughfall, runoff, groundwater (in and out of Heron Pond), and outflow at Sta. 5, a continually flowing stream with minimum flow 15 m^3/day in October and maximum 5984 m^3/day on March 30, 1977. Comparison to Cache River flows was made. Flows were computed as annual totals, but also separated into seasonal subtotals to better illustrate variation in system dynamics.

Measured phosphorus concentrations (gm/m^3) for eight sample datas were fitted to Sta. 5 outflow values expressed as change in weir height (m/day) and the two multiplied, with the result equal to phosphorus outflow (gm/m^2-sample period). These values were summed to give annual outflow. Concentrations measured April 1, 1977, during the flood, were applied only to the five day flood period. Total phosphorus (1.94 mg/l at Sta. 5), was much greater than ortho-phosphorus (0.211 mg/l), indicating that, during the flood, phosphorus was predominantly part of the suspended load; it was assumed that settling occurred when the river and swamp separated, ending throughflow and that all phosphorus contributed to the swamp by the flood was measured as sediment deposition.

In order to estimate the total flood volume and transport of materials in these waters a curve of Cache River flow vs time was integrated above bankfull discharge. Stage corresponding to this discharge was estimated by two independent methods: 1) analysis of the peak stages in Heron Pond and the Cache River, and 2) a survey of elevations along the levee relative to the Cache River stage at that time. Agreement between the two methods was very good. Flood volume multiplied by phosphorus concentration in floodwaters produced a value for phosphorus carried in these waters.

Inflow and outflow by groundwater and input by runoff were computed as the product of average concentration and average flow. Only one sample of groundwater and one of runoff were analyzed for phosphorus concentration. Groundwater phosphorus input was assumed to be entirely in soluble form. Because disturbances during well sampling may have caused stirring of soil particles and exagerated total phosphorus concentrations, for groundwater phosphorus input well ortho-phosphate concentrations were multiplied by inflows for the entire year and were assumed to represent total input. Heron Pond average outflow concentration was multiplied by groundwater outflow for phosphorus export by groundwater.

Rainfall and throughfall input was computed as the product of average phosphorus concentration and rainfall (cm) from 6 rain gages under the canopy and 4 in the clearing. The final value is converted to the units gm P/m^2-yr. Rain gages contained mineral oil to prevent evaporation and a mixture of ethylene glycol and methanol in the winter months (December - January) to prevent freezing. These materials, at concentrations equivalent to gage concentrations, were analyzed and phosphorus content found to be negligible.

Transport of phosphorus in the Cache River was computed from gage station flow data at Forman, Illinois (sample station 3). Phosphorus flow values were divided by swamp acreage for better comparison with swamp storage (Sta. 4) and outflow (Sta. 5) values.

Other Storages

All plant material was digested in concentrated nitric acid, as described in the sediment study in this report. Standing crop values, obtained from biomass calculations (see biomass and productivity section) were multiplied by appropriate phosphorus concentrations for storage values. The plant materials analyzed for phosphorus included: cypress wood, tupelo wood, cypress needles, duckweed and herbaceous plants (composited). Storage in duckweed was calculated as a weighted average of biomass measurements for each sampling date multiplied by average phosphorus concentration. Sediment storage was calculated as given in the sediment and sedimentation study in this report.

Uptake, Input and Deposition by Primary Producers

Litterfall was analyzed with the plant materials named above, in order to determine phosphorus "cycling" by this mechanism; concentration values were applied to the litterfall rates. Similarly, phosphorus uptake associated with tree growth was computed from NPP rates and tissue phosphorus concentrations. Sediment phosphorus concentrations were correlated with percent organic matter, then deposition rates representative of each sample time were calculated. These calculations were shown in the sedimentation section. Duckweed uptake rates were assumed to be those required to produce the growth measured as duckweed in the biomass and net productivity section.

Water Analysis

Heron Pond, the Cache River, and a stream emptying from the swamp to the river, were sampled at a total of 5 stations (Fig. 2) and analyzed for phosphorus as described in the water chemistry section. Storage of phosphorus in the water column was calculated as the product of phosphorus concentration and swamp volume divided by swamp area (301,440 m^2).

RESULTS AND DISCUSSION

A number of systems including cypress domes and swamps (Mitsch, 1975; Schlesinger, 1977), marshes (Greij and Klein, 1976) and temperate forests (Likens and Bormann, 1972) have been shown to effect net removal of phosphorus. An overall diagram for the annual phosphorus budget in Heron Pond during the study period is given in Fig. 51, with sources given in Table 47.

Sedimentation and Flood Contribution

Soil may act as a source or sink for phosphorus in a swamp (Brinson, 1977); most studies demonstrate the latter, however (Schlesinger, 1977; Heilman, 1968). Most lakes also have net movement of phosphorus into the sediments (Carpenter and Adams, 1977; Williams and Mayer, 1972). Sedimentation was found to be an important sink in Heron Pond. During the brief five day flood period 3.6 mg P/m^2 was deposited. The total load which passed over the swamp at this time was 80.2 gm/m^2 of which 76.6 gm/m^2

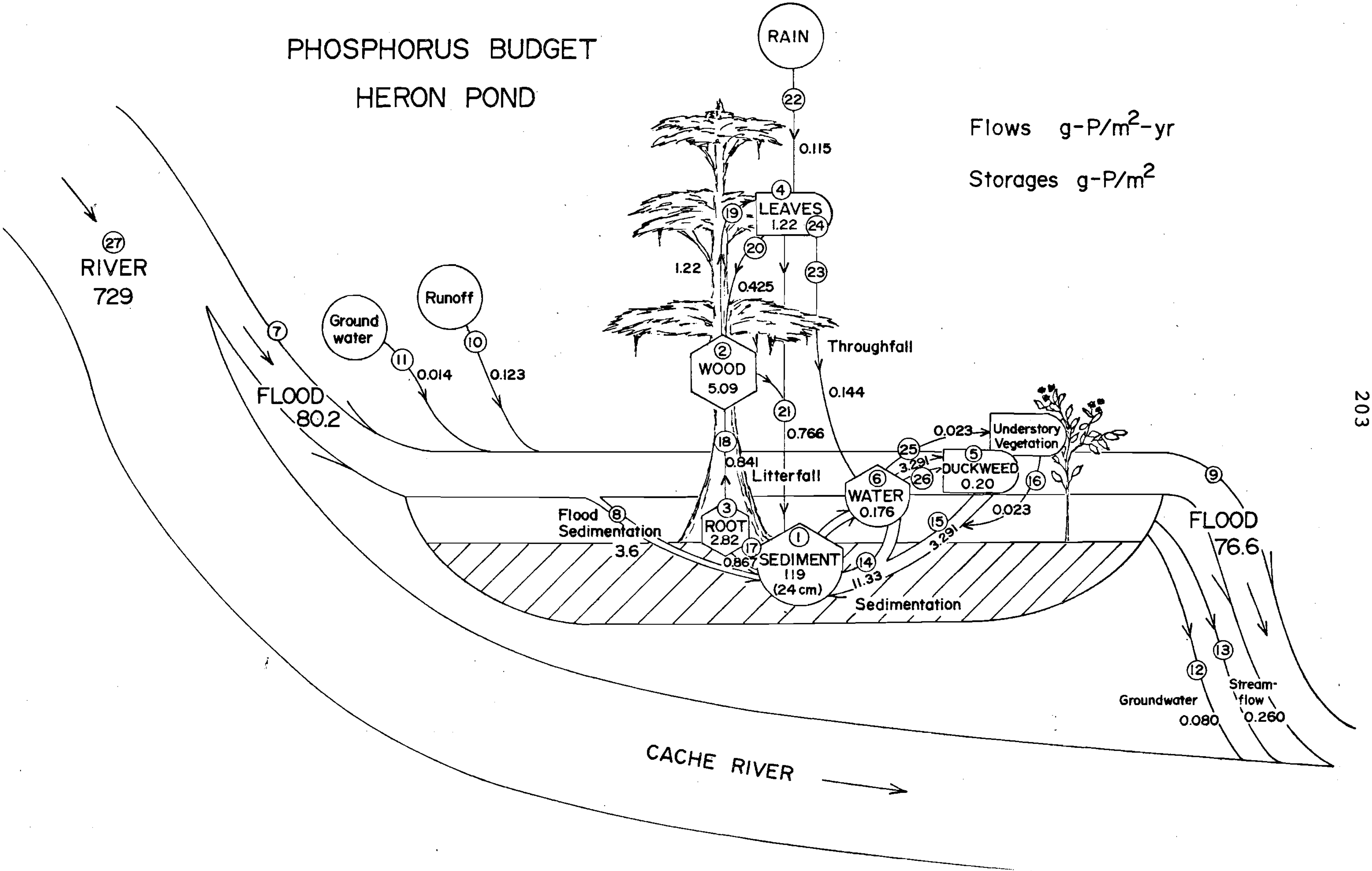


Figure 51. Phosphorus budget for Heron Pond cypress swamp during study period.

Table 47

Sources of Values Used in Phosphorus Budget, Figure 51

Reference Number	Description	Calculation	Value
		Storages, gm P/m^2	
1	Sediment (24 cm depth)	Integration of sediment phosphorus profile	119
2	Cypress and Tupelo Wood	0.10 mg P/gm dry wt x 39.1 kg dry wt/m^2 + 0.20 mg P/gm dry wt x 5.9 kg dry wt/m^2	5.09
3	Cypress and Tupelo Roots	0.10 mg P/gm dry wt x 21.6 kg dry wt/m^2 + 0.20 mg P/gm dry wt x 3.3 kg dry wt/m^2	2.82
4	Cypress and Tupelo Leaves	3.5 mg P/gm dry wt x 348 gm dry wt/m^2	1.22
5	Duckweed	3.0 mg P/gm dry wt x 67 gm dry wt/m^2	0.20
6	Water	Weighted average of concentration (gm P/m^3) x Swamp Stage (m)	0.176
		Flows, gm P/m^2-yr	
7	Flood input	1.6 x 10^{7}m^3/301440m^2 x 1.51 gm P/m^3	80.2
8	Flood sedimentation	refer to sedimentation section	3.6
9	Flood output	Flood input - Flood sedimentation	76.6

Table 47 continued

Reference Number	Description	Calculation	Value
10	Runoff	0.639 m/yr x 0.193 gm P/m^3	0.123
11	Groundwater input	0.22 m/yr x 0.065 gm P/m^3	0.014
12	Groundwater outflow	0.21 m/yr x 0.380 gm P/m^3	0.080
13	Stream outflow	refer to swamp outflow section	0.260
14	Phosphorus sedimentation not due to flood or litterfall	Total sedimentation-Flood sedimentation -Litterfall 15.7 gm P/m^2-yr - 3.6 gm P/m^2-yr -0.766 gm P/m^2-yr	12.1
15	Sedimentation from duckweed production	Duckweed NPP x P concentration 1.097 kg dry wt/m^2-yr x 3.0 mg P/gm dry wt	3.29
16	Understory litterfall and deposition of herbaceous vegetation	4.5 gm dry wt/m^2-yr x 5.1 mg P/gm dry wt	0.023
17	Total tree uptake	Cypress wood and root + Tupelo wood & root + Litterfall + Leaching 0.10 mg P/gm dry wt x 300 gm dry wt/m^2-yr + 0.20 mg P/gm dry wt x 213 gm dry wt/m^2-yr + 0.766 gm P/m^2-yr + 0.029 gm P/m^2-yr	0.867
18	Above-ground tree uptake	Cypress Wood + Tupelo Wood + Litterfall + Leaching 0.10 mg P/gm dry wt x 193 gm dry wt/m^2-yr + 0.20 mg P/gm dry wt x 137 gm dry wt/m^2-yr + 0.766 gm P/m^2-yr + 0.029 gm P/m^2-yr	0.841

Table 47 continued

Reference Number	Description	Calculation	Values
19	Uptake by leaves	3.5 mg P/gm dry wt x 348 gm dry wt/m^2-yr	1.22
20	Return prior to litterfall	Leaf uptake - leachate - litterfall - ΔB 1.22 gm P/m^2-yr - 0.029 gm P/m^2-yr - 0.766 gm P/m^2-yr - 0 gm P/m^2-yr	0.425
21	Litterfall	2.2 mg P/gm dry wt x 348 gm dry wt/m^2-yr	0.766
22	Rainfall	1.08 m/yr x 0.106 gm P/m^3	0.115
23	Throughfall	0.744 m/yr x 0.193 gm P/m^3	0.144
24	Leachate	Throughfall - Rainfall	0.029
25	Understory vegetation uptake	4.5 gm dry wt/m^2-yr x 5.1 mg P/gm dry wt	0.023
26	Duckweed uptake	1.097 kg dry wt/m^2-yr x 3.0 mg P/gm dry wt	3.29
27	Cache River Flow	Weighted average of concentration x flow	729

was not deposited and flowed out as suspended load with the flood waters. This is the largest individual component of Heron Pond's phosphorus budget. Sediment trap collection, which included the above deposition, and duckweed and litter settling, totaled 15.7 gm P/m^2-yr. Question as to possible resuspension during measurement were discussed in the sedimentation section of this report.

Greatest phosphorus storage was also in the sediments, 119 gm P/m^2 in the top 24 cm. Relative storage (as gm P/gm dry wt) probably decreases with depth due to migration of phosphorus upward (Williams and Mayer, 1972). Sebetich (1975) in an experiment with microcosms found 47% of phosphorus in the top 4 mm of sediment in his experimental system.

Rainfall, Groundwater and Surface Flows

Rainfall contributed 0.115 gm P/m^2-yr while leaching added 0.029 gm P/m^2-yr to total 0.144 gm P/m^2-yr as throughfall. As noted in the water chemistry report, rainfall samples varied significantly in concentration (standard deviation = 0.061 mg P/l) and some may have contained pollen or insect matter. If true rainfall concentrations are lower, canopy leaching was probably underestimated. Runoff input was 0.128 gm P/m^2-yr. Groundwater input (0.014 gm P/m^2-yr) was less than groundwater outflow (0.080 gm P/m^2-yr). Both were minimal in comparison with other flows.

Total phosphorus outflow at Sta. 5 was 0.260 gm P/m^2-yr. Of this, 55% was in the ortho-phosphate form, therefore readily available as a plant nutrient. These values, when compared to the load carried by the Cache River represent an addition to the total phosphorus load of only 0.036%.

The maximum daily value for phosphorus outflow, 0.058 gm P/m^2-day occurred March 30, 1977, immediately prior to flow reversal in the stream at Sta. 5 and flooding of Heron Pond by the river. The minimum value, 0.008 gm/m^2-day occurred October 29, 1976. Seasonal change in rainfall, runoff and groundwater input and groundwater and weir outflow is represented diagramatically in Fig. 52.

Plant Tissue Concentrations

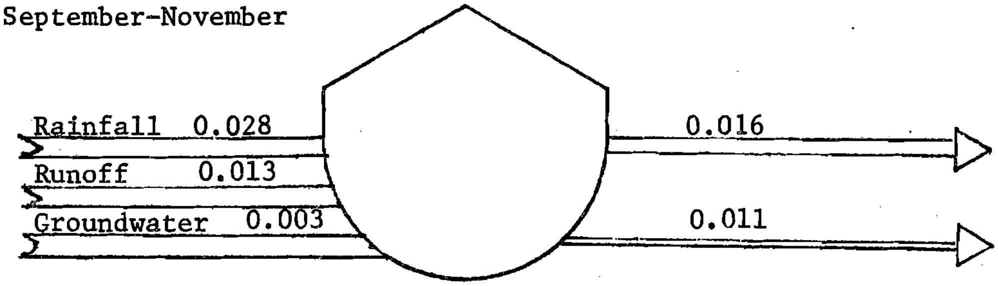
Uptake by primary producers and storage in plant biomass represents an additional "sink" for phosphorus. These capacitors may also serve as indicators of nutrient conditions. Swamp vegetation often has limited access to nutrients due to anaerobic conditions in the root zone, or cationic exchange by the sediments, and various mechanisms for nutrient conservation, including movement of nutrients into the perrenating organs prior to litterfall have been suggested (Moore and Bellamy, 1974; Schlesinger, 1977). Numerous studies have related plant tissue nutrient concentration to environmental conditions; some will be discussed in relation to concentrations found in Heron Pond vegetation. Phosphorus concentrations measured in Heron Pond sediment and vegetation is presented in Table 48 and comparison with values for vegetation in other ecosystems in Table 49.

Phosphorus concentration in cypress wood (0.10 mg P/gm dry wt) is almost equal to that found by Schlesinger (1977) in Okefenokee Swamp, a swamp which he described as nutrient deficient. Foliage concentrations, 3.5 mg P/gm dry wt are greater than those found by Schlesinger, 0.98 mg P/gm dry wt. Schlesinger noted that while foilage accounted for 41% of above-ground tree NPP, 50 - 70% of

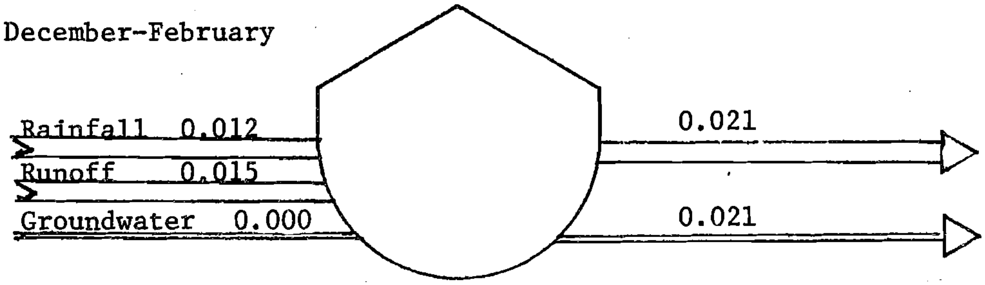
Figure 52

Seasonal Changes in Heron Pond Onflow and Outflow

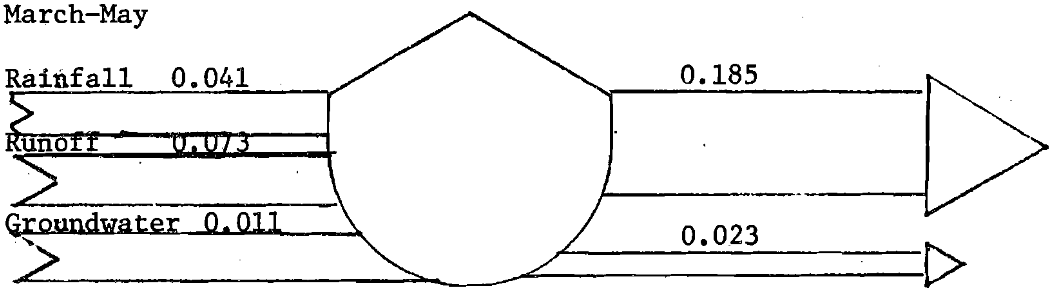
September-November



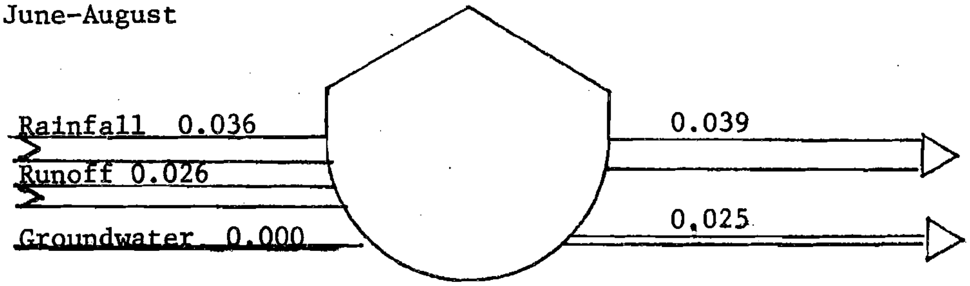
December-February



March-May



June-August



All flows expressed as gm P/m^2

Table 48

Phosphorus Analyses of Ecological Materials in Heron Pond

	Sample Date	Number Samples	mg-P / g ash wt	ash / dry	mg-P / g dry wt	mg-P / gm dry wt
Litter	10/3	1	15.6	-	-	-
	6/1	3	20.0	.130	2.6	2.2
	6/25	1	30.8	.055	1.7	
	7/31	1	35.5	.074	2.6	
	9/17	1	4.0	.193	.8	
Live Cypress Needles	7/31	9	53.4	.066	3.5	3.5
Cypress Wood	6/27	9	14.5	-	-	-
	7/31	3	13.5	.0078	.10	.1
Tupelo Wood	7/30	6	21.7	.0093	.20	.2
Duckweed	10/3	1	14.2	-	-	
	6/2	3	15.0	0.16	2.4	
	6/25	2	16.0	0.26	4.2	3.0
	7/30	1	8.5	0.26	2.2	
Herbaceous Understory	9/17	3	19.6	0.26	5.1	5.1
Sediment Trap	12/5	-	-	0.26	1.0	
	3/5	3	6.4	0.37	2.4	3.0
	6/5	3	6.2	0.73	4.5	
	7/29	5	7.0	0.46	3.2	
	9/17	3	4.0	0.50	2.00	
Sediment (clay)	10/3	5	-	0.91-0.925	0.44-0.85	
(humus)	10/3	1	-	0.70-0.86	1.29	

Table 49

Comparison of Vegetation Phosphorus Concentrations in Heron Pond With Other Ecosystems

Ecosystem	Source of Data	Description of Material Analyzed	Tree Species	P Concentration mgP/gm dry wt
Heron Pond	1	Wood	<u>Taxodium distichum</u>	0.10
" "	1		<u>Nyssa aquatica</u>	0.20
Fl. Sewage Dome # 1	2	Branch	T. <u>distichum</u> <u>v</u> <u>nutans</u>	1.13
Fl. Sewage Dome # 2	2	"	" " "	0.72
Fl. Rainwater Dome	2	"	" " "	0.86
Okefenokee Swamp	3	Wood	" " "	0.09
Old Sphagnum bog (nutrient poor soils)	4	"	<u>Picea excelsa</u>	1.16
		"		
Birch/Alder Forest (nutrient rich soils)	4	"	" "	2.05
		"		
Hubbard Brook Temp. forest	5	"	<u>Acer saccharum</u>	0.1
" "		"	<u>Pinus rubens</u>	0.01
" "		"	<u>P pensylvanica</u>	0.4
Cultivated pine plantation	6	"	<u>P taeda L.</u>	0.1
Heron Pond	1	Foliage	<u>T. distichum</u>	3.5
Fl. Sewage Dome # 1	2	"	" " <u>v</u> <u>nutans</u>	0.97
Fl. Sewage Dome # 2	2	"	" " "	1.54
Fl. Groundwater Dome	2	"	" " "	1.03
Fl. Rainwater Dome	2	"	" " "	1.56
Okefenokee	3	"	" " "	0.98
Cultivated Pine Plantation	6	"	" " "	1.3
N. Taiga Pine Forest	7	"	<u>Pinus sylvestris</u>	0.40
Forest Steppe Spruce Stand	7	"	<u>Picea excelsa</u>	0.50
S. Taiga Larch Stand	7	"	<u>Larix europea</u>	3.30
Hubbard Brook Temp. forest	5	"	<u>A. saccharum</u>	1.8

Table 49 Continued

Hubbard Brook Temp. forest		Foliage	*P. rubens*	1.0
" "		"	*P. pensylvanica*	2.4
Heron Pond	1	Litterfall	*T. distichum*	2.2
Okefenokee	3	"	" " v nutans	.35-.8
Minn. Swamp	8	"		1.18
N. Taiga pine forest	7		*P. sylvestris*	0.40
Forest Steppe Spruce Stand	7		*P. excelsa*	0.66
Central Taiga Spruce/moss Stand	7		*P. excelsa*	1.80
S. Taiga Larch Stand	7		*L. europea*	1.20
Cultivated Pine Plantation	6	Roots	*P. taeda L.*	.47
Hubbard Brook Temp. Forest	5	"	*A. saccharum*	3.7
" "		"	*P. rubens*	0.4
" "		"	*P. pensylvanica*	0.5
Heron Pond	1		Duckweed	3.0
Fl. Sewage Dome # 1	9		"	8.19±.25
Fl. Sewage Dome # 2	9		"	9.96±.27
Fl. Groundwater Dome	9		"	3.69±1.78
Heron Pond	1		Composite of Herbaceous Material	5.1

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[1] This study

[2] Post and Straub (1975)

[3] Schlesinger (1977)

[4] Heilman (1968)

[5] Likens and Bormann (1970)

[6] Wells *et al.*, (unpublished)

[7] Rodin and Bazilevich (1967)

[8] Reiners (1972)

[9] Price (1975)

annual nutrient uptake went to foliage and described this efficiency as a possible adaption to nutrient limitation. In this case, Heron Pond cypress may be considered even more efficient. Foliage accounted for 51% of annual above-ground NPP while phosphorus uptake by foliage was 95% of tree uptake.

Heron Pond root concentrations were assumed to be equal to wood concentrations. In a cultivated loblolly pine plantation with wood concentration equal to that of Heron Pond cypress, root concentrations, 0.47 mg P/gm dry wt, was found to be five times greater than wood (Wells et al., unpub.). In Hubbard Brook (Likens and Bormann, 1970) root concentrations ranged from 1.25 times wood concentration for Pinus pensylvanica to 37 times for Acer saccharum. It is likely, then, that greater root concentration exist in Heron Pond and root phosphorus storage and uptake was underestimated by assuming concentration equal to that of wood.

Heron Pond wood phosphorus concentration is seen not to be abnormal for trees; it is less than Florida branch concentration (Post and Straub, 1975). However, when analyzed separately, branch concentration has been found to be greater than that of the wood (Schlesinger, 1977; Likens and Bormann, 1970).

Cypress foliage concentrations (3.5 mg P/gm dry wt) were greater than all other trees for which data was obtained, and were nearly equivalent to the value 3.30 mg P/gm dry wt, found in southern taiga larch stands (Rodin and Bazilevich, 1967). Concentrations do not always appear to be related to nutrient availability. Florida sewage dome values were found to be less than those for natural domes (Post and Straub, 1975) and were equivalent to values found in Okefenokee Swamp which has been described as having characteristics of nutrient deficiency (Schlesinger, 1977). Nutrient retention by return of twigs prior to leaf-fall, the ratio represented by litterfall concentration:foliage concentration was found to be 0.35:0.98 in Okefenokee and only 2.2:3.5 in this study. From data of Rodin and Bazilevich (1967) in Table 47, values of 0.66:0.50 and 1.80:3.30 were computed for forest - steppe spruce stands and southern taiga larch. The spruce litter is unusual in its greater relative litter concentration. Variation in litter concentrations is likely due to premature abscission which does not allow nutrient reabsorbtion to take place (Gosz _et_ _al._, 1972).

It may be that plants with more rapid turnover are able to respond more quickly to nutrient conditions and are better indicators of impoverishment or excess. Differential uptake based on nutrient availability was demonstrated in a study of _Myriophyllum spicatum_ L. in Lake Wingra, Wisconsin, in which sampling sites near nutrient input points and sites away from those points had significant differences in tissue phosphorus concentration. Levels ranged from 1.3 mg P/gm dry wt to 5.62 mg P/gm dry wt (Carpenter and Adams, 1977).

Duckweed may have a similar rate of luxury uptake in the swamp ecosystem. Duckweed in Florida sewage domes had concentrations of 8 - 10 mg P/gm dry wt compared to 3.69 ± 1.78 in cypress dome receiving groundwater dome (Price, 1975). Heron Pond duckweed had levels of 3.0 mg P/gm dry wt, second in concentration only to cypress foliage with 3.5 mg P/gm dry wt. It is interesting to note that sediment trap samples also averaged 3.0 mg P/gm dry wt, although organic content of sediments averaged 51.6 percent in comparison to 77 and 90 percent in duckweed and litter. This suggests a cycle in which phosphorus is released with decomposition of organic matter, maintaining concentration in the fresh sediment at an average of 3.0 mg/gm dry wt. From sediment trap sample analysis, phosphorus was found to be inversely proportional to organic content, indicating the release of phosphorus described above may precede organic matter decomposition. Phosphorus concentration in the water column is fairly constant. (Refer to "Water Quality" section for discussion of seasonal variation.) For the most part, export and plant uptake is assumed to balance release from decomposing materials.

Plant Uptake, Storage and Litterfall

Using the concentration values calculated (Table 48) and productivity and biomass values given in "Net Primary Productivity and Biomass of Vegetation in Heron Pond", uptake and storage values were determined for all components.

The greatest flows of phosphorus, excluding flood input, were sedimentation and its important components, deposition from duckweed and litterfall. Litterfall contributed 0.766 gm P/m^2-yr and duckweed, 3.291 gm P/m^2-yr.

Storage in cypress and tupelo wood was 3.91 gm P/m^2 and 1.18 gm P/m^2 respectively. Storage in cypress and tupelo roots were 2.16 and 0.66 gm P/m^2. Uptake required for wood and root production was 0.030 and 0.043 gm P/m^2-yr, respectively. Storage in the leaves was found to be 1.22 gm P/m^2. Greater uptake by tupelo is attributed to greater average wood concentration and a higher productivity to biomass ratio than that of cypress.

The understory layer uptake is 0.023 gm P/m^2-yr; storage and return by winter die-off, for purposes of this study, is assumed to be the same. Some accumulation of biomass and net phosphorus accumulation by perrenial shrubs may be occurring in the understory layer, but this value would be negligible.

Another important contribution of the biotic sector is recycle by canopy leaching. In Heron Pond, leaching recycled 0.029 gm P/m^2-yr. This is discussed further in the water chemistry section. Litterfall when compared to canopy leaching contributed 67.4% of phosphorus recycled in Okefenokee swamp (Schlesinger, 1977) and 84.4% in the Tar River tupelo swamp (Brinson, 1977). (Stemflow contributed less than 4% to total phosphorus recycle by trees.) In Heron Pond, litterfall and leaching contributed 96% and 4% of a total 0.795 gm P/m^2-yr. These values are in part a result of the higher average phosphorus concentration of Heron Pond litter.

SUMMARY AND CONCLUSIONS

Measured concentrations for water and vegetative tissue have been found comparable to values in Florida cypress swamps and duckweed production parallels that of a Florida sewage dome, although tissue phosphorus concentrations are less in Heron Pond. Unfortunately, analysis of phosphorus dynamics is not available for many natural swamp ecosystems of greater productivity and comparison, therefore, has focussed on Okefenokee and other systems which have been called nutrient deficient.

Total tree uptake, 0.867 gm P/m^2-yr was found to go predominantly to leaf production. Above ground uptake is 0.841 gm P/m^2-yr and may be compared to the Okefenokee total, 0.23 gm P/m^2-yr (Schlesinger, 1977). Here, also, leaf consumption was the predominant factor. Phosphorus is cycling more rapidly through litterfall in Heron Pond than Okefenokee; this may be indicative of greater nutrient stress in Okefenokee.

Duckweed production, death, decomposition and sedimentation appears to be a rapid and important cycler of phosphorus in the water column.

Total phosphorus input during the flood is the largest single contribution to the system (3.6 gm P/m^2-day), but the potential impact of this great input is dampened by rapid sedimentation of the load and limited release of soluble phosphate from sedimented forms. The deposition of phosphorus by the flood, was shown to be 10.6 times that discharged back to the river as surface flow and groundwater flow during the rest of the year.

Modelling of the Heron Pond Ecosystem

by

Hisashi Ogawa

INTRODUCTION

This report concerns a total view of Heron Pond ecosystem. An ecosystem is in general composed of storages within its components and interactions between the components. The systems model considers important storages and flows, and ultimately applies mathematical relationships to them.

Heron Pond ecosystem has two major autotrophic components: trees (cypress and tupelo) and floating duckweed. The pond sediment is considered a heterotrophic component due to decomposition of accumulated organic matter. The water column plays an important role in regulating pond metabolism. The major forcing functions are solar energy, rain, runoff, groundwater inflow and the flooding river. Special attention was paid to phosphorus in simulation of the ecosystem nutrient budget. These energy and nutrient forces upon entering the system are either stored or pass through the ecosystem.

METHODS

Modelling techniques follow the method developed by Odum (1971) and Odum and Odum (1976), using energy language symbols in a network diagram that shows major flows, pathways and variables within a system as well as their interactions.

DISCUSSION

A model for Heron Pond is shown in Fig. 53. Solar energy is used in the photosynthetic processes of cypress - tupelo trees and duckweed and at the same time, accelerates evapotranspiration. Rainfall is interrupted by the tree canopy and reaches the pond water surface as throughfall. Runoff and groundwater contribute to the water storage. Rain, runoff and groundwater carry phosphorus into the water column where duckweed may remove it for photosynthesis. A comparator shows that when the water level of the river reaches flood stage, flood water comes into the pond. The current associated with the flood has greater capacity to carry solids in suspension which contain higher concentration of phosphorus. Organic matter storage (named ORG in the diagram) in the water column has relatively short turn-over time. Litterfall and dead duckweed settle contributing to sediment storage of organic matter and nutrients. The sedimented organic matter is de-

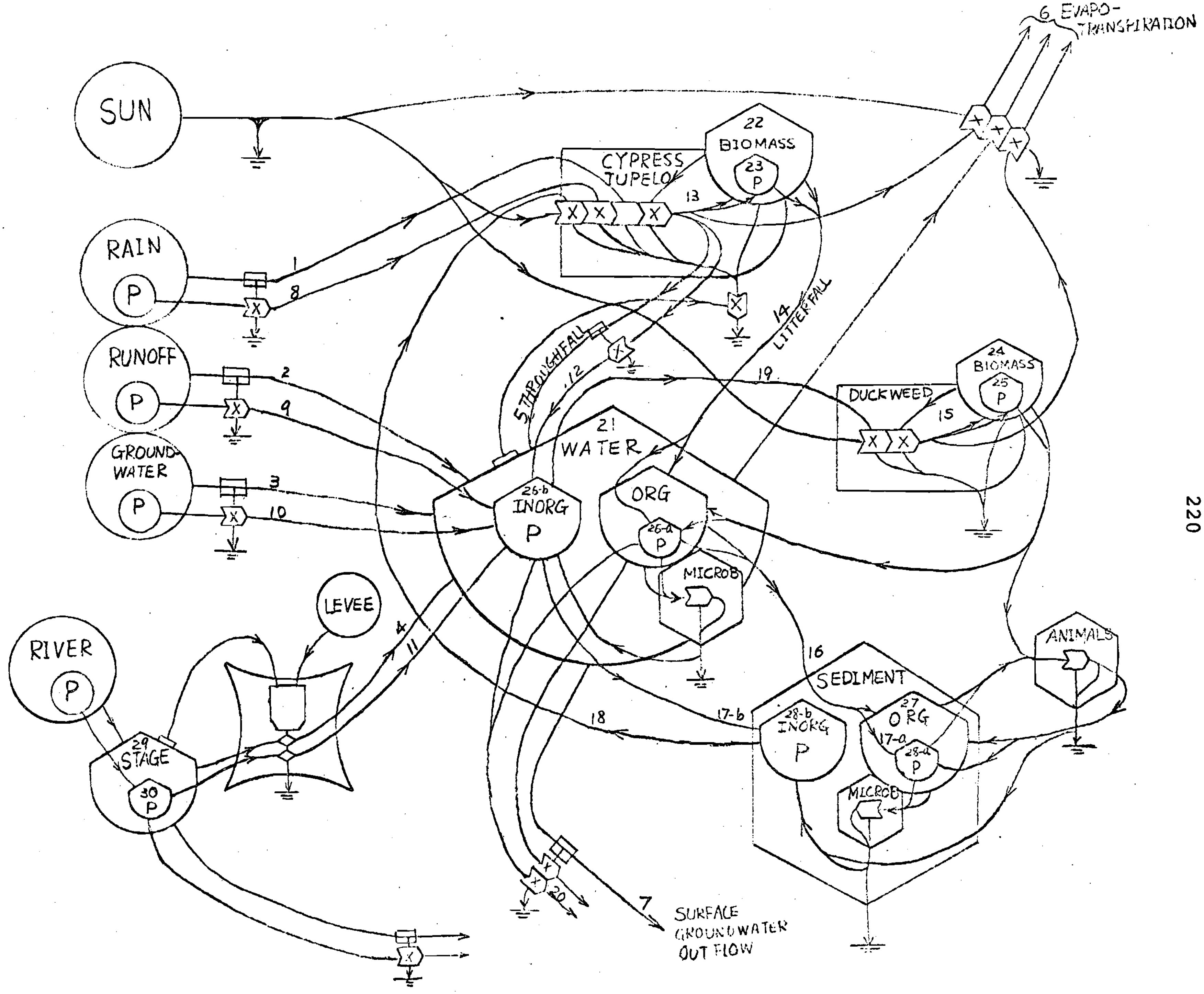

Figure 53. Heron Pond Ecosystem Model. (Numbers indicate major pathways and storages indicated in Table 50).

composed by microbes (named MICROB in the diagram) and phosphorus in the organic matter is then changed into inorganic form. This is in turn used up by the trees.

Similation of this model can assist analysis of the inner workings of the ecosystem as well as effects of the flood. The similation can also be applied to predict reaction of the ecosystem to changing conditions and therefore it can offer a useful means for control and management of the ecosystem. Table 50 gives sources of data necessary for model calibration and subsequent simulation.

TABLE 50

Pathways and Storages for Energy Flow Model Shown in Fig. 53.

Pathways		Investigator
1.	Rain	Wiemhoff
2.	Runoff	Wiemhoff
3.	Groundwater	Wiemhoff
4.	Throughfall	Wiemhoff
5.	Floodwater	Wiemhoff
6.	Evapotranspiration	Wiemhoff
7.	Surface and groundwater outflow	Wiemhoff
8.	Phosphorus in rain	Dorge
9.	Phosphorus in runoff	Dorge
10.	Phosphorus in groundwater	Dorge
11.	Phosphorus in floodwater	Dorge
12.	Phosphorus in throughfall	Dorge
13.	Net primary production (Cypress and Tupelo)	Dorge
14.	Litterfall	Dorge
15.	Net primary production (Duckweed)	Dorge
16.	Sedimentation	Dorge
17.	Total phosphorus sedimentation	Dorge
18.	Soluble inorganic phosphorus uptake by Cypress and Tupelo	Dorge
19.	Soluble inorganic phosphorus uptake by Duckweed	Dorge
20.	Total phosphorus outflow	Dorge
Storages		
21.	Water storage	Wiemhoff
22.	Cypress and Tupelo biomass	Dorge
23.	Phosphorus in Cypress and Tupelo	Dorge
24.	Duckweed biomass	Dorge
25.	Phosphorus in Duckweed	Dorge
26.	Total phosphorus in water	Dorge
27.	Organic matter in sediment	Dorge
28.	Total phosphorus in sediment	Dorge
29.	Water level at stage	Wiemhoff
30.	Phosphorus in river	Dorge

A Hydrology Model for Heron Pond

By

John Wiemhoff

INTRODUCTION

It is now possible to model flow of energy and materials through ecological pathways. With the adjustments of inputs, outputs or storages of the model, one can observe the effect upon the remaining components, since an alteration of one part of the ecosystem usually will either directly or indirectly have an impact on the other parts eventually. This phase of the study describes the hydrologic interactions of Heron Pond with a simple hydrologic model. All storages and flows are listed in cm as related to Heron Pond staff gage.

THE MODEL

The first step in modelling Heron Pond hydrology was to describe the hydrologic system diagramatically. There are various symbolic languages used to describe system components, the one adopted for this study is "energese" (Odum, 1971). Figure 54 describes the model used for Heron Pond with Energy language. The two storages within the system are Heron Pond surface water

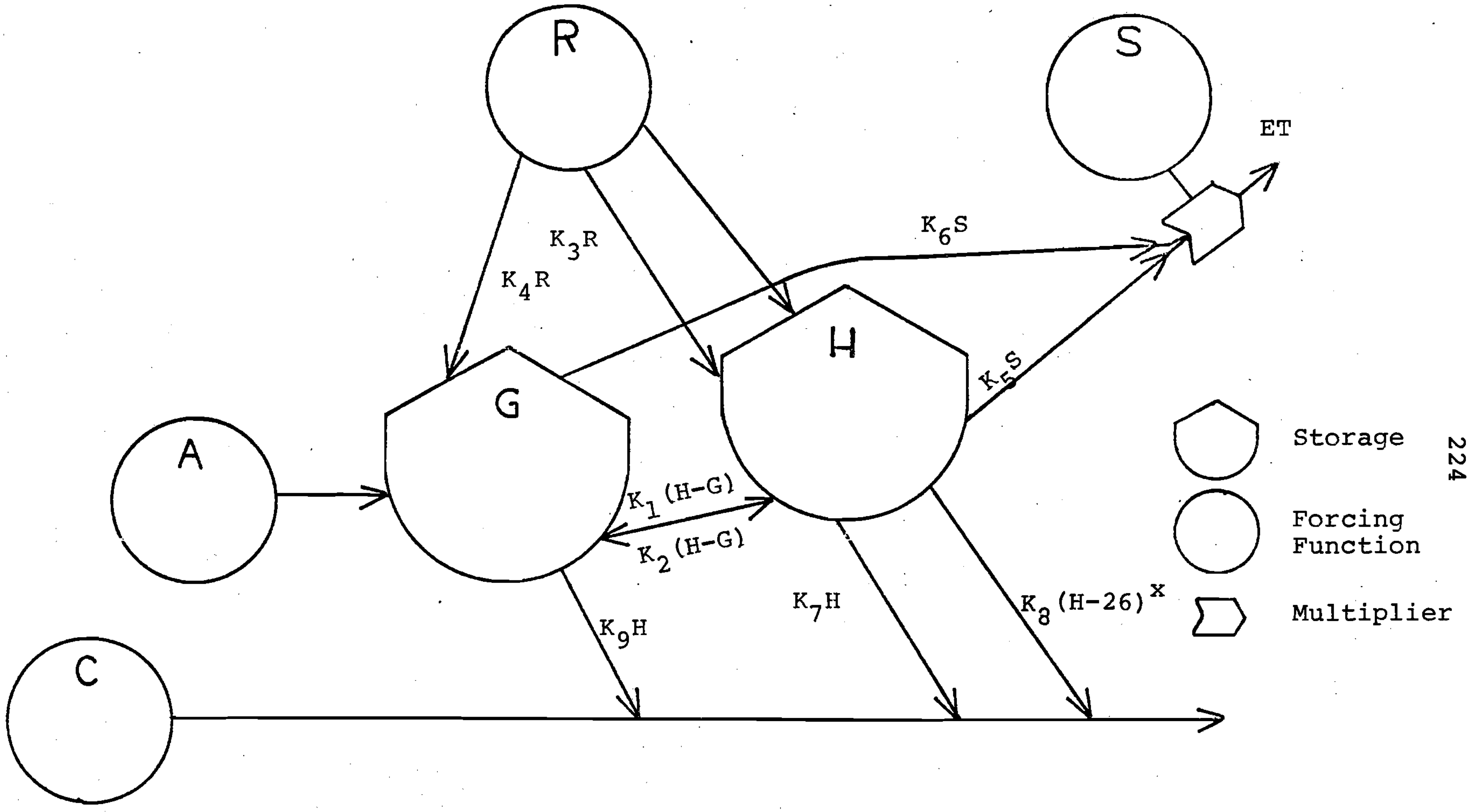

Figure 54. Energy Diagram of Heron Pond Hydrology

and the adjacent groundwater reservoir. The inputs into the swamp are throughfall, runoff, groundwater, and occasionally, flood water from the Cache River. Inputs into the groundwater are infiltration, flows from other groundwater sources, flows from Heron Pond, and occasionally floodwater from the Cache River. Outputs from Heron Pond are evapotranspiration, flow to the adjacent groundwater storage, surface outflow to the Cache River and groundwater seepage to the Cache. Outputs from the groundwater storage are evapotranspiration, flows into Heron Pond and groundwater seepage to the Cache River. The forcing functions, or those components which have relative unlimited supply capabilities, are throughfall (R), the major aquifer of the area (A), the Cache River (C) and solar intensity (S), of which evapotranspiration is a function.

The next step after representing the system diagramatically is to transform the diagram into mathematical equations. The differential equations describing the changes, over time, in the swamp and groundwater respectively are:

$$\frac{dH}{dt} = R + K_3R - K_2(H-G) - K_5S - K_7H - K_8H$$

$$\frac{dG}{at} = A + K_1(H-G) + K_4R - K_6S - K_9G,$$

where,

R = Throughfall (Rain)
H = Heron Pond water level
S = Solar intensity.

The Cache River was not considered in the calculations because the storm which occurred on May 27 - 29, 1977 during the study period, flooded the swamp with rainfall and runoff before the river rose above the bankfull discharge stage. Therefore, strictly hydrologically speaking, the Cache River did not contribute any volume that was retained after river recession.

After developing the mathematical formulae, values were determined for the flows (Table 51). The flow values were taken both from literature, whenever possible, or from the data generated from the water budget phase of this project. For storages and forcing functions, average and maximum values were determined. All forcing functions and flow values were put on a cm/wk basis for uniformity.

It was then necessary to determine the coefficients (K) of the various flows. The method used was to divide the flow rate by the average of the storage component of which that flow is a function. For example:

$$K_5S = 1.4 \qquad S = 2100$$

$$\frac{K_5S}{S} = \frac{1.4}{2100} \qquad K_5 = .001.$$

Using this method, the proportionality constants were determined for all flows (Table 51). Knowing the proportionality constants associated with the different flows and the initial condition of the storages, which in this case were assumed to be the average levels, the model was ready for input into the computer.

THE MODELLING LANGUAGE: CSMP

The computer language used to model the hydrology of Heron Pond is IBM/360 Continuous Systems Modelling Program, or CSMP (IBM, 1972). It is a problem - oriented program designed to

Table 51

Proportionality Constant and Initial Condition Determinations for Heron Pond Model

Type of Component	Symbol	Description	Average Value cm (storage) or cm/wk (flow)	Maximum Value cm (storage) or cm/wk (flow)
Storage	H	Heron Pond Water Level	48	87
	G	Groundwater storage level	50	100
Forcing Functions	R	Rainfall (throughfall)	2.3	3.0
	S	Solar Intensity	2100	4000
	A		0	
	C			
Flows	$K_1(H-G)$	Swamp to Groundwater exchange	.283	
	$K_2(H-G)$	Groundwater to Swamp exchange	.283	
	K_3R	Runoff into Swamp	1.20	
	K_4R	Infiltration into Groundwater	.82	
	K_5S	Evapotranspiration from Swamp	1.4	
	K_6S	Evapotranspiration from Groundwater	0.7	
	$K_7(H-26)^{2.138}$	Surface outflow from Swamp to Cache River	1.4	
	K_8H	Seepage from Swamp to Cache River	.403	
	K_9H	Seepage from Groundwater to Cache River	.403	
Proportionality Constants	K_1		0.51	
	K_2		0.14	
	K_3		0.52	
	K_4		1.28	
	K_5		.001	
	K_6		.001	
	K_7		1.02×10^{-3}	
	K_8		.008	
	K_9		.029	

facilitate the digital simulation of continuous processes, as ecological interactions, on large - scale digital machines. This program provides an application - oriented language that allows these problems to be prepared directly and simply from either a block - diagram representation or a set of ordinary differential equations. The program includes a basic set of functional blocks with which the components of a continuous system may be represented, and accepts application - oriented statements for defining the connections between these functional blocks.

Fortran statements are accepted by the S/360 CSMP format, allowing the user to readily handle non - linear and time varient problems of considerable complexity.

Output in this program is the generation of actual curves of the requested output, which are scaled to fit onto the paper automatically. Below the output curve, at each integration interval, the value of the component of that particular point in the simulation is printed. The maximum and minimum values for the entire simulation of that component are listed above the curve itself.

DATA COLLECTION

Heron Pond has, as determined from the water budget, a mean stage of 48 cm, and floods from the Cache River at 87 cm.

Groundwater, as recorded at well #2 in the water budget, has a mean elevation of 50 cm, slightly higher than Heron Pond, having a maximum of 100 cm.

Rainfall (throughfall) was determined from data secured from Dixon Springs Weather Station. The input rainfall is adjusted from the Dixon Springs data into a sine wave which generates a maximum of 3.0 cm/wk occurring in spring, and a yearly mean of 2.3 cm.

Solar intensity (in Langleys) was also taken from Dixon Springs data and adjusted into a sine wave which generates a maximum solar intensity of 4000 ly/wk in June, and an annual mean of 2100 ly.

All flows into the groundwater storage had to be multiplied by 3.6 since the porosity of the soil is 0.28. When flows come from groundwater to Heron Pond they had to be divided by 3.6.

The average value of flows were determined from the data generated in the water budget phase (Table 12). An exception to what the normal procedure in proportionality constant determination is surface outflow. The surface outflow, being a log function of the Heron Pond water level, was determined by using the same formula used in the water budget phase, but converted from daily calculations to weekly.

PRELIMINARY RESULTS

The CSMP program used in preliminary simulation is shown in Figure 55. Results of water level in Heron Pond and the adjacent groundwater are shown in Figures 56 and 57. The model establishes steady conditions readily and gives values similar to those found in the field study. Further simulations will include experiments with different flooding regiences and watershed changes.

```
               ****CONTINUOUS SYSTEM MODELING PROGRAM****

         ***PROBLEM INPUT STATEMENTS***

*JOHN WIEMHOFF
*TITLE:HERON POND HYDROLOGY
*H=HERON POND WATER LEVEL(CM)
*G=GOUNDWATER LEVEL(CM)
*S=SOLAR INTENSITY(LANGLEYS)
*R=THROUGHFALL(CM)
*C=CACHE RIVER LEVEL(CM)
*K1=SWAMP TO GROUNDWATER EXCHANGE COEFFICIENT
*K2=GROUNDWATER TO SWAMP EXCHANGE COEFICIENT
*K3=RUNOFF COEFFICIENT
*K4=INFILTRATION COEFFICIENT
*K5=SWAMP EVAPOTRANSPIRATION COEFFICIENT
*K6=GROUNDWATER EVAPOTRANSPIRATION COEFFICIENT
*K7=STREAMFLOW COEFFICIENT
*K8=HERON POND SEEPAGE TO RIVER COEFFICIENT
*K9=GROUNDWATER LOSS TO RIVER COEFFICIENT
INITIAL
*INITIAL CONDITIONS
INCON ICH=48
INCON ICG=50
CONST K1=0.51
CONST K2=0.14
CONST K3=0.52
CONST K4=1.28
CONST K5=.001
CONST K6=.001
CONST K7=1.02E-3
CONST K8=.0008
CONST K9=.029
DYNAMIC
YR=SINE(0.0,.12083,0.0)
Z=YR*0.75
R=Z+2.25
YS=SINE(0.0,.12083,4.712389)
T=YS*1800
S=T+2200
A=0
*INTEGRATE
YH=INTGRL(ICH,R+K3*R-K2*(YH-YG)-K5*S-K7*((YH-26)**2.138)-K8*YH)
YG=INTGRL(ICG,K4*R+A+K1*(YH-YG)-K6*S-K9*YG)
TERMINAL
TIMER DELT=1.0,FINTIM=260,PRDEL=4.3333333
PRTPLT YH
PRTPLT YG
PRTPLT R
PRTPLT S
METHOD RKS
LABEL H SWAMP WATER LEVEL (CM)
LABEL G GROUNDWATER LEVEL (CM)
LABEL R RAINFALL (CM)
LABEL S SOLAR INTENSITY (LYS)
END
STOP
```

Figure 55. CSMP program used to simulate Heron Pond hydrology.

```
H SWAMP WATER LEVEL (CM)

                        MINIMUM             YH      VERSUS TIME           MAXIMUM
                        3.3082+01                                        6.3525+01
 TIME          YH         I                                                 I
 0.0000        4.8000+01   ------------------------+
 2.6000+00     5.3595+01   ----------------------------------+
 5.2000+00     5.7986+01   -----------------------------------------+
 7.8000+00     6.1206+01   -----------------------------------------------+
 1.0400+01     6.3074+01   --------------------------------------------------+
 1.3000+01     6.3525+01   --------------------------------------------------+
 1.5600+01     6.2624+01   -------------------------------------------------+
 1.8200+01     6.0526+01   ----------------------------------------------+
 2.0800+01     5.7446+01   -----------------------------------------+
 2.3400+01     5.3640+01   ----------------------------------+
 2.6000+01     4.9391+01   ---------------------------+
 2.8600+01     4.5013+01   --------------------+
 3.1200+01     4.0845+01   ------------+
 3.3800+01     3.7244+01   ------+
 3.6400+01     3.4568+01   --+
 3.9000+01     3.3147+01   +
 4.1600+01     3.3231+01   +
 4.4200+01     3.4930+01   ---+
 4.6800+01     3.8153+01   --------+
 4.9400+01     4.2574+01   ---------------+
 5.2000+01     4.7656+01   ------------------------+
 5.4600+01     5.2748+01   ---------------------------------+
 5.7200+01     5.7222+01   ----------------------------------------+
 5.9800+01     6.0602+01   ----------------------------------------------+
 6.2400+01     6.2614+01   -------------------------------------------------+
 6.5000+01     6.3179+01   --------------------------------------------------+
 6.7600+01     6.2362+01   -------------------------------------------------+
 7.0200+01     6.0326+01   ---------------------------------------------+
 7.2800+01     5.7290+01   ----------------------------------------+
 7.5400+01     5.3514+01   ----------------------------------+
 7.8000+01     4.9287+01   ---------------------------+
 8.0600+01     4.4924+01   --------------------+
 8.3200+01     4.0766+01   ------------+
 8.5800+01     3.7172+01   ------+
 8.8400+01     3.4501+01   --+
 9.1000+01     3.3084+01   +
 9.3600+01     3.3172+01   +
 9.6200+01     3.4874+01   --+
 9.8800+01     3.8101+01   --------+
 1.0140+02     4.2528+01   ---------------+
 1.0400+02     4.7616+01   ------------------------+
```

1st Year

2nd Year

Figure 56. Heron Pond water level simulation for two years under

```
G GROUNDWATER LEVEL (CM)

                        MINIMUM             YG     VERSUS TIME           MAXIMUM
                        3.1264+01                                       6.3278+01
 TIME          YG          I                                                I
 0.0000        5.0000+01   -----------------------------+
 2.6000+00     5.2748+01   ---------------------------------+
 5.2000+00     5.6988+01   ----------------------------------------+
 7.8000+00     6.0510+01   ---------------------------------------------+
 1.0400+01     6.2673+01   -------------------------------------------------+
 1.3000+01     6.3278+01   -------------------------------------------------+
 1.5600+01     6.2351+01   ------------------------------------------------+
 1.8200+01     6.0066+01   --------------------------------------------+
 2.0800+01     5.6688+01   ---------------------------------------+
 2.3400+01     5.2541+01   ---------------------------------+
 2.6000+01     4.7976+01   --------------------------+
 2.8600+01     4.3356+01   ------------------+
 3.1200+01     3.9044+01   ------------+
 3.3800+01     3.5390+01   ------+
 3.6400+01     3.2723+01   --+
 3.9000+01     3.1329+01   +
 4.1600+01     3.1418+01   +
 4.4200+01     3.3086+01   --+
 4.6800+01     3.6263+01   -------+
 4.9400+01     4.0679+01   --------------+
 5.2000+01     4.5862+01   ----------------------+
 5.4600+01     5.1196+01   -------------------------------+
 5.7200+01     5.6028+01   --------------------------------------+
 5.9800+01     5.9798+01   --------------------------------------------+
 6.2400+01     6.2131+01   ------------------------------------------------+
 6.5000+01     6.2868+01   -------------------------------------------------+
 6.7600+01     6.2042+01   ------------------------------------------------+
 7.0200+01     5.9831+01   --------------------------------------------+
 7.2800+01     5.6508+01   ---------------------------------------+
 7.5400+01     5.2399+01   ---------------------------------+
 7.8000+01     4.7861+01   -------------------------+
 8.0600+01     4.3261+01   ------------------+
 8.3200+01     3.8961+01   ------------+
 8.5800+01     3.5317+01   ------+
 8.8400+01     3.2656+01   --+
 9.1000+01     3.1266+01   +
 9.3600+01     3.1360+01   +
 9.6200+01     3.3031+01   --+
 9.8800+01     3.6211+01   -------+
 1.0140+02     4.0631+01   --------------+
 1.0400+02     4.5821+01   ----------------------+
```

1st Year

2nd Year

Figure 57. Groundwater simulation for two years under present

ENERGY CONSERVATION THROUGH INTERFACE ECOSYSTEMS[1]

By

William J. Mitsch

INTRODUCTION

Solar driven ecosystems have always contributed to man's well being. In primitive times, man was but a small part of the system, harvesting what he needed from the forests and rivers, utilizing but a small portion of those ecosystems' energy flows. Later on, early agriculture, forestry, and fishing, all solar based systems, provided the basis for man's activity through the production of food and fiber. As man changed from wood to fossil fuels for his primary fuel source, the Industrial Revolution ushered in a myriad of domestic ecosystems from modern agriculture, forestry, and fisheries to sewage treatment plants (not solar driven, but in many ways similar to heterotrophic rivers). Each of these systems now utilizes significant inputs of fossil fuels in order to allow

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[1] Part of paper by same title presented at the International Conference on Energy Use Management, Tucson, Arizona on October 27, 1977, sponsored by the Interdisciplinary Group for Ecology, Development, and Energy (EDENS) and the University of Arizona.

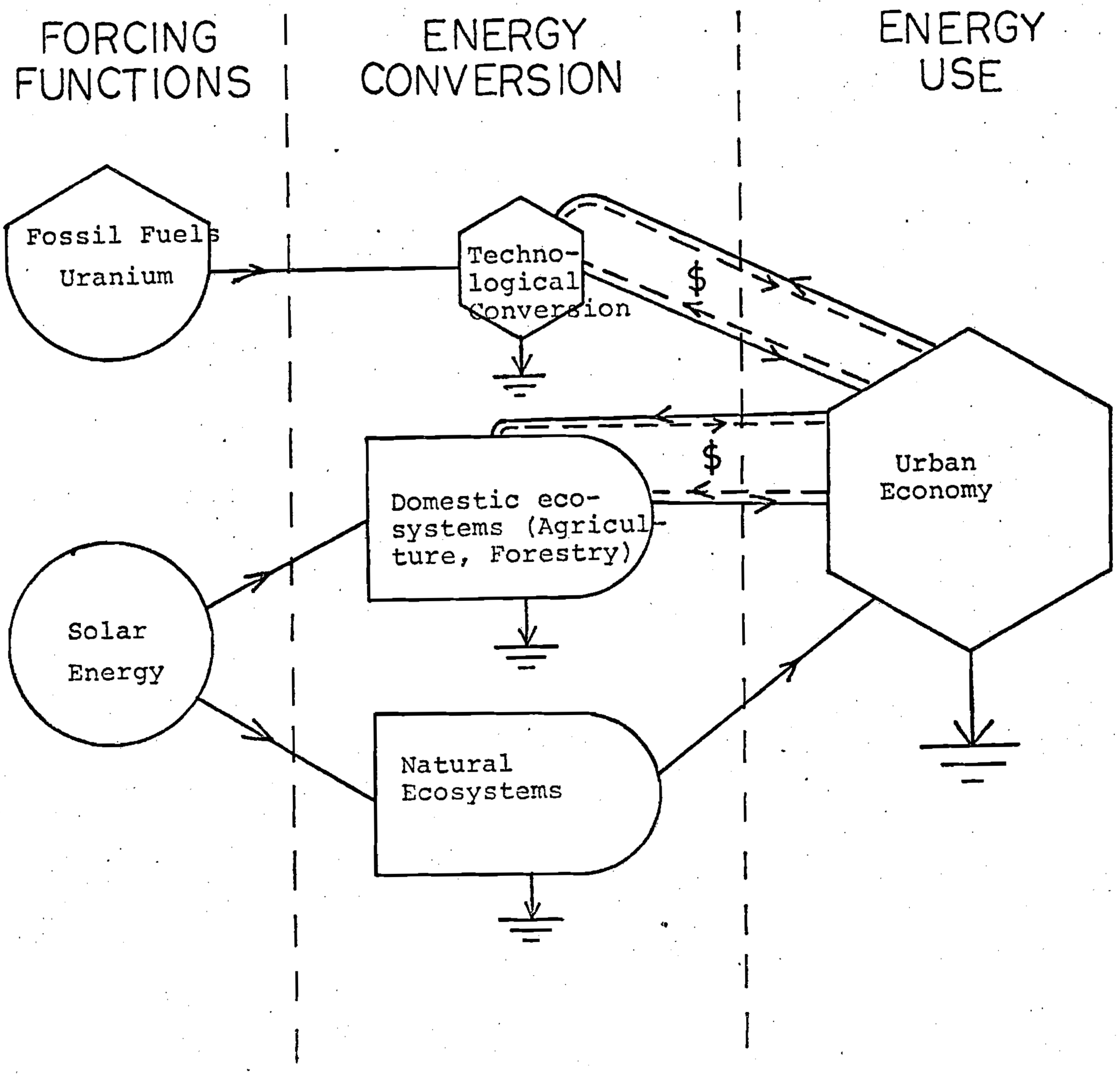

Figure 58. Energy support system for man.

and developed areas. Odum (1973) referred to the "free subsidies" from nature to man while Woodwell (1974) called them "public service functions". They have been discussed as a part of net energy analyses by Gilliland (1975) and in subsequent letters to Science (see 192:8-12). More recently Odum (1977) and Westman (1977) reviewed the topic by asking what the economics of natural ecosystems should be.

In referring to Fig. 58, some questions of the natural ecosystem contribution to man's well being can be asked:

(1) What are the tasks that natural systems perform best for man?

(2) Should the natural energies be manipulated by man to suit his needs, thereby essentially creating more domestic ecosystems, or should nature be left alone to perform these tasks?

(3) What are the economic and hence energetic savings for man that result from these ecosystems. Worded another way, what fossil fuel costs result when man attempts to perform equivalent services?

(4) Is the energy flow in the ecosystem a measure of its "value", either to man and/or the biosphere?

ENERGY COST OF ENVIRONMENTAL TECHNOLOGY

Certain services provided before by nature are beginning to be replaced by high energy technology, particularly in the field of environmental control. While it is true that certain controls are warrented and even necessary to protect human health and sensitive ecosystems, increased pollutant loadings and increased centralization (called regionalization) of discharges have lead to very high burdens on our energy resources. Fig. 2 shows an example of a vertical analysis of energy costs of a simple aeration tank, a device used in many water treatment processes (Khan, 1977). The total cost in the example is 21 x 10^6 BTU. Processed materials alone account for 60% at this cost. Examples of energy costs at advanced wastewater technology are given in Table 52.

One result of our overzealousness to clean up the environment has been a series of laws that put limitations on the discharges allowed into waterways to "zero discharge" by 1983. Khan (1977) has estimated the energy cost of such a policy, if extended to advanced wastewater treatment for both municipal and industrial discharge would imply an equivalent consumption of 1.7 million barrels of oil per day (Table 53). To put this in perspective, this is 4.3% of the total projected national energy consumption projected for 1980 and equals the daily output the Alaska pipeline is expected to yield by the end of 1977 (EOP, 1977).

INTERFACE ECOSYSTEMS

That these technological energy costs for services once provided by natures assimilative capacity are becoming a significant part of our national energy budget gives impetus to the search for ecosystems and ecosystem functions that act as "interface ecosystems" between mans wastes and the rest of nature. While some would argue that this is a traitorous stance to take on the environmental/ecological issues at hand, I present the following arguments for this approach, regardless

Table 52

Summary of Energy Costs of AWT Processes

Process	Energy Cost (MBTU/MG)
Lime Treatment	
a) Low Lime Primary	4.36- 8.84
b) High Lime Primary	20.12-46.06
c) Single Stage Tertiary	10.28-13.69
d) Two Stage Tertiary	29.90-40.07
Recarbonation	1.54- 2.00
Multimedia Filteration	5.62-14.67
Carbon Absorption	
a) Primary Effluents	20.75-38.18
b) Secondary Effluents	9.37-24.18
c) Tertiary Effluents	8.98-24.23
Ammonia Air Stripping	3.98-11.54
Nitrification-Denitrification	18.59-31.01
Break-point Chlorination	40.36-44.55

From Khan (1977)

Table 53

Energy Expense of Water Pollution Cleanup Compared With Other Energy Flows[1]

	Energy Flow 10^6 Barrels oil/day	% of Total
Total U.S. Energy Consumption (1980)	40	-
Alaskan pipeline contribution (1978)	1.7	4.3
Municipal wastewater treatment	0.1	0.2
Municipal-AWT/Industrial/-secondary treatment	0.6	1.4
Zero discharge by Municipal and Industrial	1.7	4.3

[1] Khan (1977)

of the future energy scenario:

(1) If our economy is heading towards an energetic steady state, we may be forced to depend on natural systems to provide functions more than ever. Should this scenario occur, demands for natural areas by land speculators and entrepreneurs might diminish as would liesure time and hence recreational demand for government holdings at natural areas. We would revert to the natural subsidies as a matter of course.

(2) Should our national energy budget continue to rise, more and more rationale will be needed to keep areas in their natural state as land use patterns continue to use up space and fossil fuels continue to replace natural functions. The arguement for conservation alone may diminish as a rationale for preserving natural areas.

The concept of the interface ecosystem involves two types of systems: 1) ecosystems that are altered slightly to perform low energy cost services for use, and 2) ecosystems that provide hidden energy subsidies in their natural state with no overt alteration by man. Examples of both will be given in this paper.

Wetlands as Interface Ecosystems

Wetlands have caught the imagination of ecologists as areas that may have significant economic benefit to man. Gosselink *et al*. (1974) discussed the value of tidal salt marshes as bases of fisheries, oyster aquaculture and tertiary treatment services to man. Wharton (1970) discussed the economics of the "multiple-use environment" associated with southern river swamps.

Past studies of freshwater wetlands have investigated several of the important contributions fo wetlands. Dachnowski-Stokes (1935) long ago suggested peat lands to be useful as "safeguards against drought, floods, erosion, and lowered ground waters". Grant and Patrick (1970) reported on Tinicum marsh near Philadelphia where significant decreases in pollution were noted as water flowed through the marsh. Wisconsin marshes were investigated by Bentley (1969) and Klopatek (1974) for their effects on water quality. Each investigator found seasonal patterns in nutrient discharges from the marshes, suggesting a net uptake of the elements in summer and a net discharge in the nongrowing season. Wharton (1970) documented the role of a southern river swamp in sediment removal while Kitchens _et al_. (1974) found reductions on the order of 50 percent for phosphorus in river water flowing through South Carolina forested wetlands. Brown _et al_. (1974) gave preliminary evidence that a forested wetlands area in central Florida receiving sewage for nineteen years proved to be a nutrient sink with the added benefit of significantly greater tree growth in the sewage-receiving area when compared to a nearby control area.

Recycling in Florida Cypress Domes

The cypress wetlands used in this study are the main research sites in a project entitled "Cypress Wetlands for Water Management, Recycling and Conservation."[1] Commonly referred to as cypress domes or ponds these pockets of cypress trees (*Taxodium distichum* var. *nutans*) are located in areas of low relief with seasonal standing water, amid drier pine flatwoods or plantations.

Secondarily-treated wastewater and groundwater has been applied to several cypress domes near Gainesville, Florida (Fig. 59) as part of the research project since early 1973 while others are being studied in their natural state. Loading rates were tested up to 13 cm/wk with best results achieved at lower rates around 2.5 cm/wk. The domes seem to be able to consistently take the lower loading rates with a minimal overland flow. Little change in the groundwater quality over background is noted downstream of the experimental domes.

Vegetation changes occurred both in the canopy and in the understory. An extensive mat of duckweed (*Lemna purposilla*, *Spriodela oligorhiza*, and *Azolla caroliniana*) developed in the domes receiving sewage. The canopy, primarily cypress trees, showed preliminary favorable growth response to the treated sewage (Table 54).

---

1 - Funded by N.S.F. Grant GI-38721 (RANN Division) and Rockefeller Foundation Grant RF-73029, H. T. Odum and K. C. Ewel, Principal Investigators.

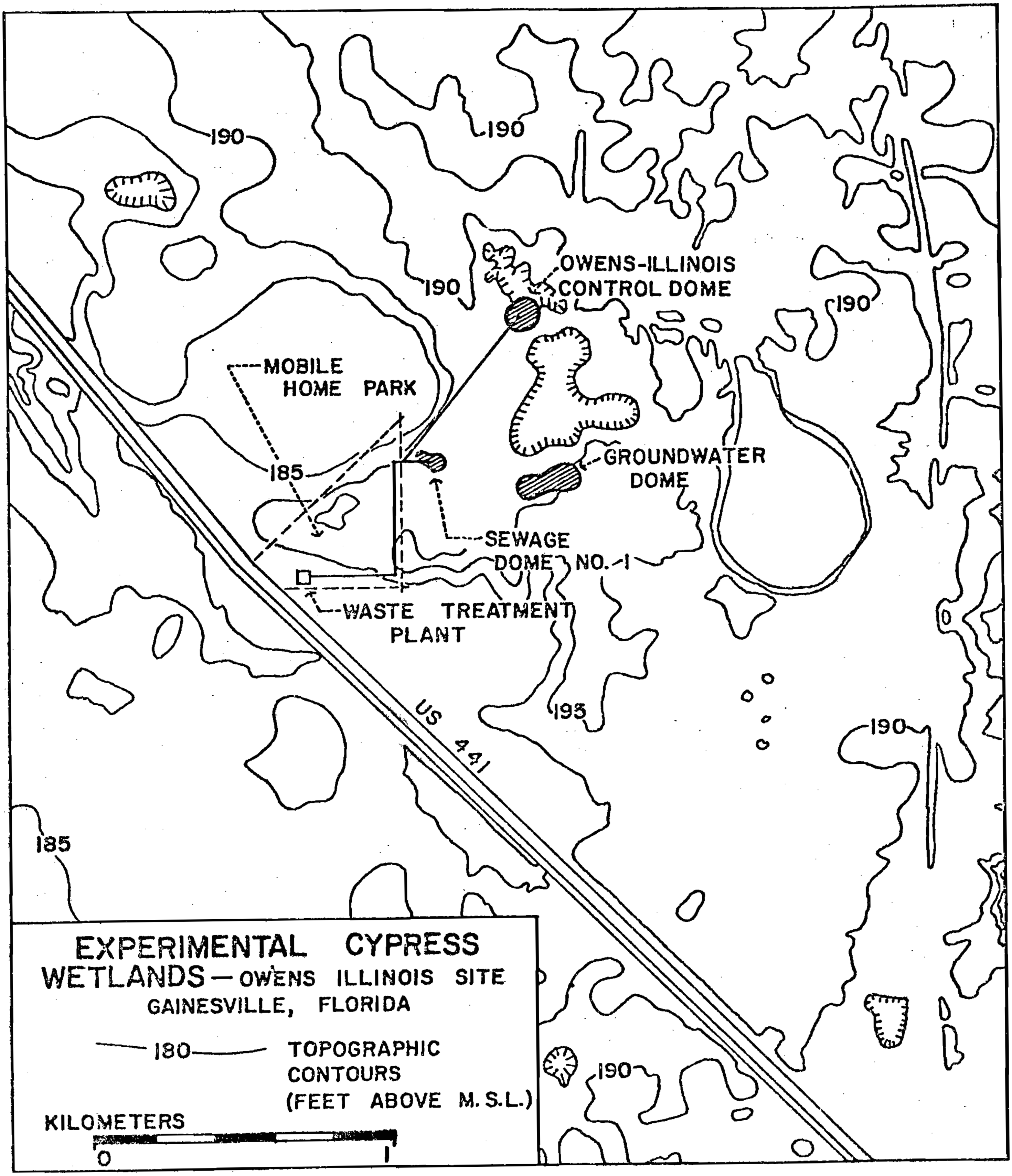

Figure 59. Cypress dome experimental recycling project in Gainesville, Florida.

Table 54

Cypress Tree Growth Data in Alachua County Experimental Domes

Dome	Average Diameter Increase, mm/yr	Increase in Biomass	
		Kg/tree-yr	g/m^2-yr
Sewage Dome No. 1	3.0	5.0	253
Groundwater Dome	2.8	4.2	304
Drained Dome[1]	1.5	3.5	159
Ponded Dome[1]	0.2	1.0	22

---

[1] Values calculated for nearby domes based on 11 years of tree growth data.

The energy value that is required for this system per gallon of wastewater treated is given in Table 55. A considerable savings is recognized whereby the technological alternative of tertiary treatment costs about 7.7 times the energy cost of dome disposal. Both of these costs were determined in the same general manner, utilizing the energy coefficients of Bullard and Herendeen (1975). In addition, the cypress system is recharging groundwater supplies and probably growing cypress trees faster. The technological alternative still has remaining questions of sludge disposal as well.

The natural energy flow, calculated from the gross primary productivity of the dome receiving sewage is also given in Table 55. The number is put in fossil fuel equivalents. The total still comes to less than the energy flow required by technology alone, suggesting that a proper mix of high quality energy (eg. fossil fuels) and low quality energy (sunlight) may achieve results at better energy efficiencies than could be achieved by either source alone.

Heron Pond Value

Similar energy calculations were made for Heron Pond to answer the question: what energy expenses would be necessary to perform similar functions now being carried out by Heron Pond? The services of P removal in sedimentation and flood control are used. It is full well realized that these are hypothetical costs and probably would not be spent if the swamp was replaced with a parking lot. Nevertheless, the environment would be that much more degraded if that were to

Table 55

Energy Value of Florida Cypress Dome Disposal Compared With Tertiary Treatment

	Cypress Dome Disposal	Tertiary Treatment
Fossil Fuel Energy Cost, kcal/gal	3.28[1]	25.3[3]
Natural Energy Subsidy, kcal FFE/gal	3.30[2]	∿ 0

1. Based on dollar cost given in Odum *et al*., (1977).
2. Based on gross primary productivity given in Odum *et al*., (1977), on energy quality factor of 20 kcal GPP/kcal FFE, and 2.5 cm/wk application rate.
3. From Khan (1977).

occur. The energy cost for equivalent phosphorus removal and flood control are given in Table 56. The 578×10^6 kcal/yr is equivalent to 414 barrels of oil per year; the money value of Heron Pond for the services is $18,490/year. This is based on only two of the services this ecosystem provides; perhaps there are others which will increase this total.

CONCLUSIONS

Calculations of the energy waste that results when man does not recognize the value of natural systems are shown. Two wetland examples are given, one where man sets up an interface for nutrient recycling in Florida and the other where natural benefits of a swamp are identified in Southern Illinois. It is hoped that these kind of examples will lead to both conservation of our natural ecosystems and our precious energy supplies by recognizing the value of ecosystem energy flows.

Table 56

Substitute Energy and Money Value of 30 ha Southern Illinois
Cypress - Tupelo Swamp

Value	Energy Value (10^6 kcal FFE/yr)	Money Value ($1000/yr)
Nutrient Removal (P-removal)	261[1]	2.28[2]
Flood Control	326[4]	16.21[3]
TOTAL	587	18.49

1. Based on 3.6 g P/m^2-yr removed from river by swamp (Mitsch *et al.*, in press) and energy cost of P-removal technology of 36.1 BTU/gal (Khan, 1977).
2. Based on $79.92/MG for P-removal (1969 $) (Khan, 1977).
3. Based on $291/acre-ft-yr calculated for flood control (7 resevoirs) on N. Branch Chicago River (U.S.D.A. *et al.*, 1976).
4. Based on dollar cost (note 3) and energy intensity of 0.0796 MBTU/$ for new construction-public utility (Bullard and Herendeen, 1975).

APPENDIX A

HERON POND CHEMISTRY DATA

Station 1 Sheet 1 of 2

Location Cache River North of Swamp

Date	1976			1977	
	8/13	10/3	12/5	1/8	3/5
Flow (cfs)	17	0.55	13	.02	1040
Time of Sampling		1030	1500	1430	1045
Air temperature (°C)		25	0-4	6	16
Water temperature (°C)		16.2	5	0	8.5
Dissolved Oxygen (mg/l)		4.5	12.3	10.4	9.4
pH		7.1	8.3	7.6	-
Alkalinity (mg $CaCO_3$/l)	70	80	92	140	24
Hardness (mg $CaCO_3$/l)		93	119	185	30
Turbidity (JTU)		58	25	17	447
Conductivity (μmho/cm)	151	292	400	445	123
Ortho-phosphate (mg-P/l)	.164	.040	.130	.130	.207
Total Soluble P (mg-P/l)	.072	.240	.140	.230	.460
Total P (mg-P/l)	.254	.350	.210	.440	1.22
NO_2-N (mg-N/l)		.01	.01		.02
NO_3-N (mg-N/l)		.03	.03		.08
Ammonia (mg-N/l)		.29	.24		.09
TKN (mg-N/l)		.80	2.2		.55
$SO_4^=$ (mg/l)		23.6	25.1		12.6
Dissolved Residue (mg/l)		-	-		115
Total Residue (mg/l)		307	-		409
COD (mg/l)		18.0	73.4		53.1
K^+ (mg/l)		6.0	8.4	8.9	4.2
Mg^{++} (mg/l)		4.5	4.6	14.0	3.4
Na^+ (mg/l)		16.0	21.8	25.4	6.1
Ca^{++} (mg/l)		29.8	40.2	57.0	6.2

HERON POND CHEMISTRY DATA

Station 1 Sheet 2 of 2

Location Cache River North of Swamp

	1977				
Date	4/1	5/3	6/4	6/25	7/31
Flow (cfs)	3560	623			
Time of Sampling	1045		1200	1230	
Air temperature (^{o}C)	-		28	28	
Water temperature (^{o}C)	-		18	24	
Dissolved Oxygen (mg/l)	-		-	8.0	
pH	-		-	7.2	
Alkalinity (mg $CaCO_3$/l)	32		146	144	84
Hardness (mg $CaCO_3$/l)	19		128	-	65
Turbidity (JTU)	472		370	242	419
Conductivity (μmho/cm)	120		500	560	280
Ortho-phosphate (mg-P/l)	.137	-	.101	.163	.231
Total Soluble P (mg-P/l)	-	-	.130	.127	.223
Total P (mg-P/l)	2.12	-	.254	.305	.408
NO_2-N (mg-N/l)	.06		.01		.06
NO_3-N (mg-N/l)	.02		.10		.25
Ammonia (mg-N/l)	.24		0.0		.60
TKN (mg-N/l)	1.03		0.6		0.88
$SO_4^{=}$ (mg/l)	13.1		-		9.5
Dissolved Residue (mg/l)	95		-		72
Total Residue (mg/l)	297		-		343
COD (mg/l)	36.4		-		29.5
K^+ (mg/l)	3.2		3.7		4.4
Mg^{++} (mg/l)	2.4		4.7		4.6
Na^+ (mg/l)	2.4		19.0		7.4
Ca^{++} (mg/l)	3.7		43.4		18.3

HERON POND CHEMISTRY DATA

Station 2

Sheet 1 of 2

Location Cache River immediately downstream of Dutchman Creek confluence

	1976			1977	
Date	8/13	10/3	12/5	1/8	3/5
Flow (cfs)	17	0.55	13	.02	1045
Time of Sampling		1230	1730	1530	1045
Air temperature (°C)		16	0-4	2	16
Water temperature (°C)		15.2	1	0	9
Dissolved Oxygen (mg/l)		4.7	11.6	-	-
pH		7.2	6.9	7.2	-
Alkalinity (mg $CaCO_3$/l)	68	125	140	152	31
Hardness (mg $CaCO_3$/l)		99	142	178	30
Turbidity (JTU)		55	15.5	11	406
Conductivity (μmho/cm)	167	358	385	445	109
Ortho-phosphate (mg-P/l)	.166	.160	.10	.13	.253
Total Soluble P (mg-P/l)	.066	.320	.17	.23	.50
Total P (mg-P/l)	.242	.490	.30	.40	1.24
NO_2-N (mg-N/l)		.01	.01		.03
NO_3-N (mg-N/l)		.22	.03		.09
Ammonia (mg-N/l)		.35	.25		.23
TKN (mg-N/l)		1.2	0.7		.85
$SO_4^=$ (mg/l)		17.1	24.4		13.8
Dissolved Residue (mg/l)		-	-		112
Total Residue (mg/l)		279	-		472
COD (mg/l)		24.5	26.3		39.5
K^+ (mg/l)		8.3	8.7	8.9	4.3
Mg^{++} (mg/l)		4.3	10.4	12.9	3.7
Na^+ (mg/l)		22.6	21.2	21.8	6.3
Ca^{++} (mg/l)		32.4	39.6	49.9	5.9

HERON POND CHEMISTRY DATA

Station 2

Sheet 2 of 2

Location Cache River immediately downstream of Dutchman Creek confluence

	1977				
Date	4/1	5/3	6/4	6/25	7/31
Flow (cfs)	3560	623			
Time of Sampling	1230		1200	1445	
Air temperature (°C)			28	28	31
Water temperature (°C)			17	24.5	26
Dissolved Oxygen (mg/l)					
pH				7.3	
Alkalinity (mg $CaCO_3$/l)	40		142	156	78
Hardness (mg $CaCO_3$/l)	19		128		65
Turbidity (JTU)	380		390	341	480
Conductivity (µmho/cm)	157		480	580	270
Ortho-phosphate (mg-P/l)	.053		.100	.082	.223
Total Soluble P (mg-P/l)	-		.129	.149	.260
Total P (mg-P/l)	.719		.134	.303	.358
NO_2-N (mg-N/l)	.01		.01		.05
NO_3-N (mg-N/l)	<.01		.04		.25
Ammonia (mg-N/l)	.08		.0		.45
TKN (mg-N/l)	.5		.6		.97
$SO_4^=$ (mg/l)	10.4		-		9.0
Dissolved Residue (mg/l)	83		-		71
Total Residue (mg/l)	155		-		268
COD (mg/l)	30.4		-		24.7
K^+ (mg/l)	3.0		4.0		4.5
Mg^{++} (mg/l)	2.4		4.7		4.6
Na^+ (mg/l)	3.1		18.1		7.2
Ca^{++} (mg/l)	3.7		43.4		18.3

HERON POND CHEMISTRY DATA

Station 3 Sheet 1 of 2

Location Cache River at Forman Railroad Bridge

	1976			1977	
Date	8/13	10/3	12/5	1/8	3/5
Flow (cfs)	17	0.55	13	.02	1040
Time of Sampling		1330	1800	1600	1230
Air temperature ($^{\circ}C$)			0	0	16
Water temperature ($^{\circ}C$)			0	0	9
Dissolved Oxygen (mg/l)			10.5	-	-
pH			6.6	7.7	-
Alkalinity (mg $CaCO_3$/l)	70	109	136	176	28
Hardness (mg $CaCO_3$/l)		129	114	150	36
Turbidity (JTU)		80	34	11	428
Conductivity (μmho/cm)	166	430	405	490	134
Ortho-phosphate (mg-P/l)	.184	.150	.15	.17	.243
Total Soluble P (mg-P/l)	.066	.360	.18	.20	.270
Total P (mg-P/l)	.236	.680	.20	.40	1.30
NO_2-N (mg-N/l)		.01	.01		.03
NO_3-N (mg-N/l)		.31	.04		.08
Ammonia (mg-N/l)		.47	.25		.16
TKN (mg-N/l)		2.1	1.3		0.8
$SO_4^{=}$ (mg/l)		21.8	26.3		14.3
Dissolved Residue (mg/l)		345	-		92
Total Residue (mg/l)		439	-		397
COD (mg/l)		26.8	51.4		33.8
K^{+} (mg/l)		10.4	8.7	8.9	3.9
Mg^{++} (mg/l)		9.5	4.6	4.6	4.3
Na^{+} (mg/l)		26.4	20.8	24.0	6.6
Ca^{++} (mg/l)		35.8	37.9	52.4	7.2

HERON POND CHEMISTRY DATA

Station 3 Sheet 2 of 2

Location : Cache River at Forman Railroad Bridge

	1977				
Date	4/1	5/3	6/4	6/25	7/31
Flow (cfs)	3560	623			
Time of Sampling	1400		1400	1515	
Air temperature (°C)					
Water temperature (°C)					
Dissolved Oxygen (mg/l)					
pH				7.3	
Alkalinity (mg $CaCO_3$/l)	52		134	144	78
Hardness (mg $CaCO_3$/l)	25		136		58
Turbidity (JTU)	585		350	318	440
Conductivity (μmho/cm)	119		450	545	280
Ortho-phosphate (mg-P/l)	.089	-	.088	.122	.215
Total Soluble P (mg-P/l)		.057	.109	.141	.206
Total P (mg-P/l)	1.156	.288	.150	.225	.395
NO_2-N (mg-N/l)	.03		.02		.03
NO_3-N (mg-N/l)	.09		.03		.27
Ammonia (mg-N/l)	.08		.0		.31
TKN (mg-N/l)	.85		.5		.97
$SO_4^=$ (mg/l)	8.5		-		9.3
Dissolved Residue (mg/l)	85		-		53
Total Residue (mg/l)	199		-		259
COD (mg/l)	38.1		-		42.3
K^+ (mg/l)	3.0		3.8		4.4
Mg^{++} (mg/l)	2.5		9.3		3.8
Na^+ (mg/l)	2.7		18.1		7.8
Ca^{++} (mg/l)	6.0		39.3		17.1

HERON POND CHEMISTRY DATA

Station 4 Sheet 1 of 2

Location Heron Pond Platform

	1976			1977	
Date	8/13	10/3	12/5	1/8	3/5
Stage (cm)		34.20	38.10	38.86	60.66
Time of Sampling		1130	1600	1500	1100
Air temperature (°C)		16	2	5	16
Water temperature (°C)		15	4.5	0	8
Dissolved Oxygen (mg/l)		0.9	2.2	1.3	2.6
pH		6.1	5.8	6.5	
Alkalinity (mg $CaCO_3$/l)	21	36	28	84	12
Hardness (mg $CaCO_3$/l)		23	44	39	10
Turbidity (JTU)		650	145	140	23
Conductivity (μmho/cm)	51	84	240	156	58
Ortho-phosphate (mg-P/l)	.139	.080	-	.170	.279
Total Soluble P (mg-P/l)	.056	.230	.300	.160	.310
Total P (mg-P/l)	.220	.450	.390	.450	.470
NO_2-N (mg-N/l)		.01	.01		< .01
NO_3-N (mg-N/l)		.01	.01		< .01
Ammonia (mg-N/l)		.39	4.13		2.0
TKN (mg-N/l)		1.80	4.7		2.5
$SO_4^=$ (mg/l)		1.0	1.0		4
Dissolved Residue (mg/l)		109	-		29
Total Residue (mg/l)		121	-		59
COD (mg/l)		36.6	66.4		42
K^+ (mg/l)		1.3	7.0	5.4	3.2
Mg^{++} (mg/l)		2.0	4.3	3.8	1.0
Na^+ (mg/l)		2.4	7.8	3.8	1.8
Ca^{++} (mg/l)		5.8	10.6	9.2	2.3

HERON POND CHEMISTRY DATA

Station 4 Sheet 2 of 2

Location Heron Pond Platform

	1977				
Date	4/1	5/3	6/4	6/25	7/31
Stage (cm)	∿ 180	70.06	55.02	46.54	42.06
Time of Sampling	1100	-	1100	1300	-
Air temperature (°C)	-	-	28	-	26
Water temperature (°C)	-	-	16	-	31
Dissolved Oxygen (mg/l)				4.0	
pH				6.0	
Alkalinity (mg $CaCO_3$/l)	12		34	28	22
Hardness (mg $CaCO_3$/l)	21		28		22
Turbidity (JTU)	690		41	28	64
Conductivity (μmho/cm)	102		110	117	70
Ortho-phosphate (mg-P/l)	.258	.113	.056	.152	.172
Total Soluble P (mg-P/l)	-	.114	.159	.188	.203
Total P (mg-P/l)	-	.174	.217	.235	.328
NO_2-N (mg-N/l)	<.01		<.01		<.01
NO_3-N (mg-N/l)	<.01		.01		<.01
Ammonia (mg-N/l)	.18		.10		.17
TKN (mg-N/l)	.60		.90		1.00
$SO_4^=$ (mg/l)					0.5
Dissolved Residue (mg/l)	100				24
Total Residue (mg/l)	255				65
COD (mg/l)	42.0				36.8
K^+ (mg/l)	3.3		2.2		1.0
Mg^{++} (mg/l)	2.5		1.9		1.5
Na^+ (mg/l)	2.7		2.9		.7
Ca^{++} (mg/l)	4.1		8.0		6.3

HERON POND CHEMISTRY DATA

Station 4a

Sheet 1 of 2

Location Heron Pond - 10 m S of platform
sample taken by wading into water

	1976		1977		
Date	10/3	12/5	1/8	3/5	4/1
Stage (cm)	34.20	38.10	38.86	60.60	∿ 1.80
Time of Sampling	1200	1500	1445	1100	1115
Air temperature (^{o}C)		0	6	16	
Water temperature (^{o}C)		5	0	8	
Dissolved Oxygen (mg/l)	0.8	3.7	1.4	2.3	
pH	5.9	5.6	5.5	-	
Alkalinity (mg $CaCO_3$/l)	36	28	8.4	18	13
Hardness (mg $CaCO_3$/l)	26	35	28	13	20
Turbidity (JTU)	380	190	470	128	585
Conductivity (μmho/cm)	85	210	154	55	85
Ortho-phosphate (mg-P/l)	.07	.17	.03	.291	.147
Total Soluble P (mg-P/l)	.14	.37	.20	.31	-
Total P (mg-P/l)	.68	.39	-	1.00	1.813
NO_2-N (mg-N/l)	.01	.01		.01	.03
NO_3-N (mg-N/l)	.01	.01		<.01	<.01
Ammonia (mg-N/l)	1.79	.72		1.6	.12
TKN (mg-N/l)	5.5	3.4		3.1	0.6
$SO_4^=$ (mg/l)	1.0	1.0		12.4	7
Dissolved Residue (mg/l)	73	-		47	73
Total Residue (mg/l)	171	-		149	281
COD (mg/l)	67.0	16.4		82.0	32.5
K^+ (mg/l)	1.9	6.0	5.7	3.3	2.5
Mg^{++} (mg/l)	2.4	3.7	4.0	1.3	2.6
Na^+ (mg/l)	2.5	3.6	3.9	2.0	2.5
Ca^{++} (mg/l)	6.4	8.0	4.5	3.2	3.8

HERON POND CHEMISTRY DATA

Station 4a

Sheet 2 of 2

Location Heron Pond - 10 m S of platform
sample taken by wading into water

	1977				
Date	6/4				
Stage (cm)	55.02				
Time of Sampling	1100				
Air temperature (^{o}C)	28				
Water temperature (^{o}C)	15.5				
Dissolved Oxygen (mg/l)					
pH					
Alkalinity (mg $CaCO_3$/l)	32				
Hardness (mg $CaCO_3$/l)	28				
Turbidity (JTU)	12				
Conductivity (µmho/cm)	95				
Ortho-phosphate (mg-P/l)	.139				
Total Soluble P (mg-P/l)	.180				
Total P (mg-P/l)	.233				
NO_2-N (mg-N/l)	<.01				
NO_3-N (mg-N/l)	<.01				
Ammonia (mg-N/l)	.21				
TKN (mg-N/l)	1.3				
$SO_4^{=}$ (mg/l)					
Dissolved Residue (mg/l)					
Total Residue (mg/l)					
COD (mg/l)					
K^{+} (mg/l)	1.7				
Mg^{++} (mg/l)	1.8				
Na^{+} (mg/l)	2.3				
Ca^{++} (mg/l)	8.2				

HERON POND CHEMISTRY DATA

Station 5 Sheet 1 of 2

Location Heron Pond Outflow

	1976			1977	
Date	8/13	10/3	12/5	1/8	3/5
Stage (cm)		34.20	38.10	38.86	60.66
Time of Sampling		1130	1700	1510	1115
Air temperature (°C)		18.5	0	5	16
Water temperature (°C)		16.7	2	0	9
Dissolved Oxygen (mg/l)		0.7	4.8	6.2	-
pH		6.2	6.6	7.1	-
Alkalinity (mg $CaCO_3$/l)	28	4.0	76	84	16
Hardness (mg $CaCO_3$/l)		32	49	51	13
Turbidity (JTU)		290	148	67	94
Conductivity (μmho/cm)	59	105	185	158	55
Ortho-phosphate (mg-P/l)	.059	.065	.23	.160	.271
Total Soluble P (mg-P/l)	.032	.310	.37	.180	.43
Total P (mg-P/l)	.296	.450	.48	.450	.49
NO_2-N (mg-N/l)		.01	.01		<.01
NO_3-N (mg-N/l)		.12	.01		<.01
Ammonia (mg-N/l)		.22	1.1		1.07
TKN (mg-N/l)		1.0	3.3		1.3
$SO_4^=$ (mg/l)		1.0	16.5		8.1
Dissolved Residue (mg/l)		131	-		31
Total Residue (mg/l)		452	-		247
COD (mg/l)		38.6	26.0		45.8
K^+ (mg/l)		1.7	5.1	4.4	3.4
Mg^{++} (mg/l)		3.1	4.2	5.8	1.6
Na^+ (mg/l)		2.4	4.3	3.9	2.1
Ca^{++} (mg/l)		7.7	2.6	11.0	2.4

HERON POND CHEMISTRY DATA

Station 5 Sheet 2 of 2

Location Heron Pond Outflow

	1977				
Date	4/1	5/3	6/4	6/25	7/31
Stage (cm)	180	70.06	55.02	46.54	42.06
Time of Sampling	1200		1200	1330	
Air temperature (°C)				28	
Water temperature (°C)				25.7	
Dissolved Oxygen (mg/l)				7.3	
pH				6.4	
Alkalinity (mg $CaCO_3$/l)	12	29	30	48	26
Hardness (mg $CaCO_3$/l)	20	29	20		20
Turbidity (JTU)	490		95	184	280
Conductivity (µmho/cm)	120		115	108	84
Ortho-phosphate (mg-P/l)	.211	-	.162	.188	.183
Total Soluble P (mg-P/l)	-	.064	.194	.203	.200
Total P (mg-P/l)	1.94	.176	.273	.313	.395
NO_2-N (mg-N/l)	<.01		.02		.01
NO_3-N (mg-N/l)	<.01		<.01		.01
Ammonia (mg-N/l)	.1		.11		0.32
TKN (mg-N/l)	1.1		.9		0.83
$SO_4^=$ (mg/l)	-				.01
Dissolved Residue (mg/l)	97				24
Total Residue (mg/l)	307				393
COD (mg/l)	35.3				46
K^+ (mg/l)	3.3		2.0		1.1
Mg^{++} (mg/l)	2.6		2.3		2.0
Na^+ (mg/l)	2.5		2.5		.9
Ca^{++} (mg/l)	3.8		7.8		4.9

HERON POND CHEMISTRY DATA

Station Groundwater

Sheet 1 of 1

Location

Date	9-17-77				
	Well 1	Well 2			
Time of Sampling					
Air temperature (°C)					
Water temperature (°C)					
Dissolved Oxygen (mg/l)					
pH					
Alkalinity (mg $CaCO_3$/l)					
Hardness (mg $CaCO_3$/l)					
Turbidity (JTU)					
Conductivity (μmho/cm)					
Ortho-phosphate (mg-P/l)	.070	.060			
Total Soluble P (mg-P/l)					
Total P (mg-P/l)	-	.630			
NO_2-N (mg-N/l)					
NO_3-N (mg-N/l)					
Ammonia (mg-N/l)					
TKN (mg-N/l)					
$SO_4^{=}$ (mg/l)					
Dissolved Residue (mg/l)					
Total Residue (mg/l)					
COD (mg/l)					
K^+ (mg/l)					
Mg^{++} (mg/l)					
Na^+ (mg/l)					
Ca^{++} (mg/l)					

HERON POND CHEMISTRY DATA

Station Rainfall and Throughfall samples

Sheet 1 of 3

Location

Date	12/5/76	6/25/77			
		Gage 1	Gage 2	Gage 4	
Time of Sampling					
Air temperature (°C)					
Water temperature (°C)					
Dissolved Oxygen (mg/l)					
pH					
Alkalinity (mg $CaCO_3$/l)	16				
Hardness (mg $CaCO_3$/l)					
Turbidity (JTU)					
Conductivity (μmho/cm)					
Ortho-phosphate (mg-P/l)	.24	.098	.080	-	
Total Soluble P (mg-P/l)	.14	.197	.093	.090	
Total P (mg-P/l)	.24	.290	.150	.276	
NO_2-N (mg-N/l)					
NO_3-N (mg-N/l)					
Ammonia (mg-N/l)					
TKN (mg-N/l)					
$SO_4^{=}$ (mg/l)					
Dissolved Residue (mg/l)					
Total Residue (mg/l)					
COD (mg/l)					
K^+ (mg/l)					
Mg^{++} (mg/l)					
Na^+ (mg/l)					
Ca^{++} (mg/l)					

HERON POND CHEMISTRY DATA

Station Location Rainfall and Throughfall samples

Sheet 2 of 3

Date	6/25/77 Gage 8	Gage 9	Fresh Rainfall	7/31/77 Through-fall	Fresh Rainfall
Time of Sampling					
Air temperature (^{o}C)					
Water temperature (^{o}C)					
Dissolved Oxygen (mg/l)					
pH					
Alkalinity (mg $CaCO_3$/l)				.6	2.7
Hardness (mg $CaCO_3$/l)				6	4
Turbidity (JTU)					
Conductivity (μmho/cm)				73	30
Ortho-phosphate (mg-P/l)	.220	.108	.020	.016	.003
Total Soluble P (mg-P/l)	.210	.107	.010	-	-
Total P (mg-P/l)	.413	.266	.010	.182	.131
NO_2-N (mg-N/l)				0.01	0.42
NO_3-N (mg-N/l)				0.75	0.40
Ammonia (mg-N/l)				0.38	0.38
TKN (mg-N/l)				1.80	2.78
$SO_4^{=}$ (mg/l)				11.6	< 0.1
Dissolved Residue (mg/l)				40	29
Total Residue (mg/l)				60	44
COD (mg/l)				40.5	70.2
K^{+} (mg/l)				0.1	0.0
Mg^{++} (mg/l)				0.3	0.2
Na^{+} (mg/l)				0.0	0.0
Ca^{++} (mg/l)				2.0	1.4

HERON POND CHEMISTRY DATA

Station Rainfall and Throughfall Samples Sheet 3 of 3

Location

Date	9-17-77				
	Gage 1,2,4	Gage 8,9	Special Sampling	Fresh Rainfall	
Time of Sampling					
Air temperature (°C)					
Water temperature (°C)					
Dissolved Oxygen (mg/l)					
pH					
Alkalinity (mg $CaCO_3$/l)					
Hardness (mg $CaCO_3$/l)					
Turbidity (JTU)					
Conductivity (µmho/cm)	118	22	34	44	
Ortho-phosphate (mg-P/l)	.014	.015	.008	.008	
Total Soluble P (mg-P/l)	-	-	-	-	
Total P (mg-P/l)	.082	.096	.051	.124	
NO_2-N (mg-N/l)					
NO_3-N (mg-N/l)					
Ammonia (mg-N/l)					
TKN (mg-N/l)					
$SO_4^=$ (mg/l)					
Dissolved Residue (mg/l)					
Total Residue (mg/l)					
COD (mg/l)					
K^+ (mg/l)					
Mg^{++} (mg/l)					
Na^+ (mg/l)					
Ca^{++} (mg/l)					

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