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Research Report No. 131

CLASSIFICATION AND MANAGEMENT OF WETLANDS IN THE WESTERN KENTUCKY COAL FIELD

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March 1982

DISCLAIMER

ABSTRACT

This is the first research report of a three-year project on wetland identification and management criteria in the western Kentucky coal field. The region is approximately 12,000 square kilometers and, due to its slight relief, contains many wetlands, some contiguous with surface coal mining operations. The overall objectives of the research project are 1) to identify, classify, and map wetlands in the western Kentucky coal field; 2) to evaluate the major biotic and abiotic factors that affect those wetlands; and 3) to develop strategies for the proper management of those wetlands.

The first report of this three-year project has involved the following tasks related to wetlands in the coal fields of western Kentucky:

1. establishment of three intensive study sites in major wetlands for identification and assessment of management impacts,
2. sampling trips in May, July, and September to the intensive study sites, to measure water quality and ecological structure,
3. development of a classification specifically for wetlands in western Kentucky and an application of the classification to the three intensive study sites, and
4. development of conceptual models of the region, watersheds, and specific ecosystems, and preliminary simulations of a wetland model.

Our specific sites in western Kentucky are Cypress Creek Wetlands in Muhlenberg County, which are affected by mine drainage and channelization; Clear Creek Swamp in Hopkins County, which is affected by mine drainage and higher water levels; and Henderson Sloughs in Henderson County, which are affected by oil wells and clearing for agriculture. Preliminary analysis of field surveys demonstrates that several activities, particularly coal mining and oil extraction, may affect the health of wetlands in western Kentucky. Drainage, logging, channelization, and impoundments have also caused significant alterations.

Field measurements, along with conceptual models, have facilitated the development of a classification scheme for wetlands in western Kentucky. The classification scheme takes into account ecological structure, system hydrology, and major man-made effects. Water quality parameters include pH, temperature, specific conductance, sulfates, turbidity, and dissolved oxygen. Diversity, biomass, density, size distribution, and growth of vegetation were measured. These chemical and biological measurements will be analyzed and compared with standard values to assess the significance of impacts.

The work involves close contact and cooperation with state and federal agencies including the Kentucky Department for Natural Resources and Environmental Protection, the Kentucky Nature Preserves Commission, the Kentucky Department of Fish and Wildlife Resources, the U.S. Fish and Wildlife Service, the Office of Surface Mining and the U.S. Army Corp of Engineers. The research was summarized at meetings in May and in September for representatives from the above agencies.

Descriptors: Wetlands*; Land Classification; Ecosystems

Identifiers: Western Kentucky Coal Field; Wetland Management;
Wetland Model

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INTRODUCTION

Wetlands, both freshwater and coastal, have become recognized as important components of the landscape. Scientists, engineers, public interest groups, and government agencies have become involved in the preservation and careful management of wetlands throughout the United States. The importance of wetlands lies both in the traditional value of wetlands as areas of fish and wildlife protection as well as their roles in water management and pollution control.

Few studies of wetlands have been carried out in Kentucky despite a significant number of wetland areas, particularly in the western part of the state. Major wetlands are found in the Jackson Purchase area of extreme western Kentucky and in the western coal field (see Figure 1). Our study is presently limited to the latter area, an area of about 12,000 square kilometers that has experienced significant coal mining activity for many years. Our scope of work includes wetland classification, mapping, modelling, and data collection for three specific sites within the western coal field. The specific sites were chosen so as to assess a range of impacts on the wetlands, particularly those due to coal mining, oil extraction, drainage, logging and flooding.

Wetlands in Western Kentucky

The Western Kentucky Coal Field (Figure 2) is located in the Shawnee Hills Section of the Interior Low Plateaus Physiographic Province. Most of the region is undulating to hilly with wide, flat, silt-filled alluvial valleys along the Green, Rough, Pond, Tradewater, Barren, and Ohio Rivers (Harker *et al.*, 1980). The relatively flat topography supports a wide variety of wetlands. We have tentatively identified about 40,000 hectares of wetlands

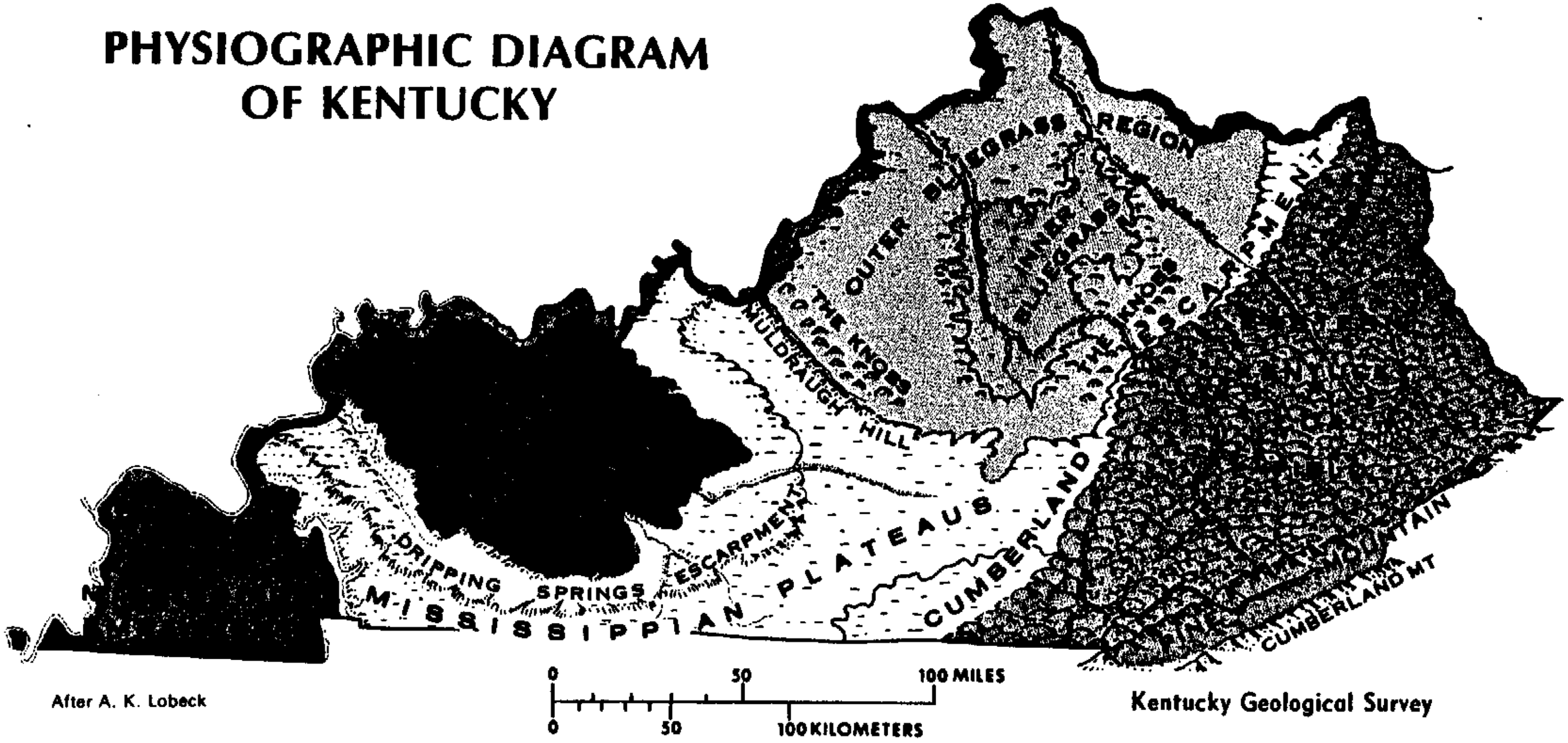

Figure 1. Physiographic Provinces of Kentucky

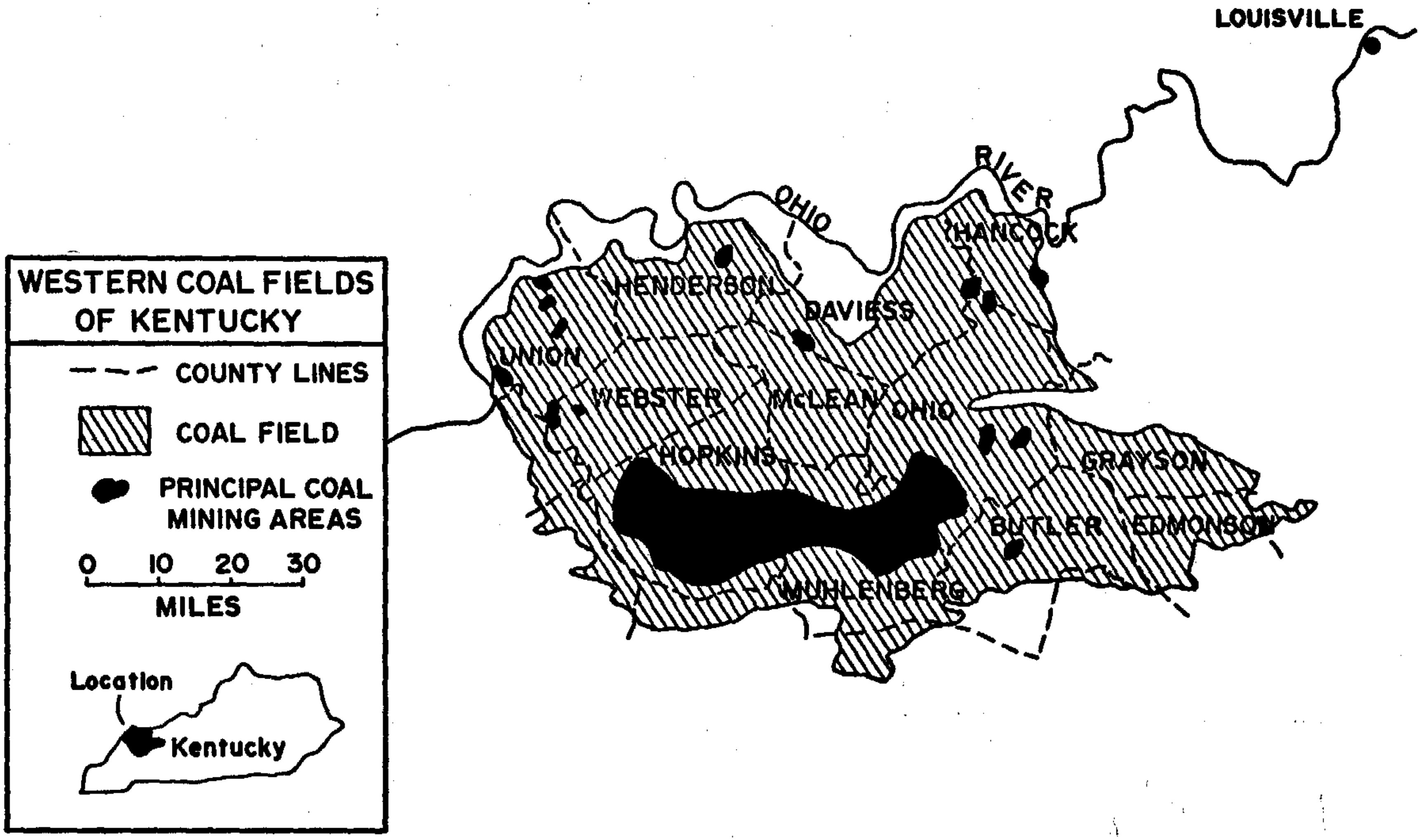

Figure 2. Western Kentucly Coal Field

in the Western Kentucky Coal Field (Table 1). Many of these wetlands are over 2,000 hectares in size.

Coal mining, particularly coal surface mining, has affected many of the wetlands in the region. Acid drainage and sedimentation from mining have adversely impacted the water quality, hydroperiod, and vegetation of some wetlands. Other wetlands have been formed as a direct result of mining activity and thus display characteristics of developing ecosystems. Several wetlands in the region are seemingly not influenced by mining at all. Logging, channelization, conversion to agriculture, beaver dams, and highway construction are other major influences on wetlands in the region.

Little published information has existed until recently on wetlands in the Western Kentucky Coal Field. Harker _et al_. (1980) compiled a notable floristic and faunistic survey of many of the wetland areas in the coal field. Aerial photo and LANDSAT imagery were used by Whinnery (1977) to map Clear Creek Swamp and nearby strip mining areas. Water quality and biotic parameters were examined in a marsh adjacent to Clear Creek Swamp (Neichter, 1972; Leuthart, 1975; Ortiz, 1981). Grubb and Ryder (1972) described the effects of acid drainage on the water resources of the Tradewater River Basin.

Major Impacts on Wetlands in Western Kentucky

Coal Mining - Coal mining is and will continue to be one of the dominant activities in the western Kentucky coal field (Figure 2). The coal field, one of two major mining regions in the state, is part of the Eastern Interior Coal Basin that extends through southwestern Indiana and much of Illinois.

The field comprises about 12,000 square kilometers and has experienced heavy strip mining since the technique was first introduced in Muhlenberg County in 1829. In 1979, the total amount of coal mined in Western Kentucky was 44 million metric tons, with about 23 million metric tons obtained

Table 1

Representative Wetland Areas in the Western Coal Field of Kentucky

Name	County	Size Acre	Description	Reference
Clear Creek Swamp	Hopkins	8,400	created partially by mining; acid drainage into swamp; partially forested	Leuthart (1975) Whinnery (1977)
Weirs Marsh	Hopkins	-	adjacent to Clear Creek Swamp	
Black Lake Bog	Muhlenberg	17,000	adjacent to Little Cypress Creek; evidence of recent changes in elevation	Stine (1977)
Henderson Sloughs	Henderson	5,000	bottomland hardwood forest; disturbed by oil extinction, drainage and agriculture	Goodwin & Niering (1975)
Pond Creek Swamp	Muhlenberg	-	mostly marsh, some recent interest in strip mining was delayed because of swamp	Bell (pers. comm.)
White City Swamp	Hopkins	5,000	owned by Ky. Dept. of Fish and Wildlife Resources; forested and marsh; some abandoned strip mines	Bell (pers. comm.)
Black Lake Bottoms	McLean	12,800		Ky. Dept. Fish & Wild. Res.
Rough River Bottoms	Ohio	7,680		Ky Dept. Fish & Wild. Res.
Rockport Bottoms	Daviess	12,800		Ky. Dept. Fish & Wild. Res.
Goosepond Ditch	Union	26,800		Ky. Dept. Fish & Wild. Res.
	TOTAL	95,480		

through surface mining (Kentucky Department of Mines and Minerals, 1979). Total coal mined in 1979 was down about 20 percent from 1976. However, several synthetic fuel plants have recently been proposed for four locations on the Ohio River adjacent to the Kentucky western coal fields (Louisville Courier-Journal, February 1, 1981). These plants, if built, could increase the annual coal use in western Kentucky by 35 million metric tons per year with much of this coal coming from the Western Kentucky Coal Field.

Coal mining, particularly surface coal mining, can cause significant alteration of bodies of water, including wetlands. Acid drainage and precipitation of ferric hydroxide have been shown to have dramatic effects on aquatic life (Roback and Richardson, 1969; Minear and Tschantz, 1976; Letterman and Mitsch, 1978). The increased runoff and subsequent flooding due to surface mining is a major impact for downstream wetlands. Sedimentation, due to erosion of spoil banks, active mines, and unreclaimed lands, may also cause significant problems in wetlands.

Oil Wells - Some oil drilling has occurred in western Kentucky, particularly in Henderson County near the Ohio River. Approximately 716,000 barrels of oil were obtained from the county in 1978 (Kentucky Department of Mines & Minerals, 1978). While the effects of oil drilling may be less than coal mining per unit of energy obtained, some impacts may be possible. Drainage modification is often necessary when wells are drilled, with subsequent changes in adjacent wetlands. Oil spillage and discharge of brine solutions from active wells may have certain localized yet long term effects on bodies of water, including wetlands.

Channelization - Wetlands, particularly riparian wetlands, will be affected when adjacent streams are straightened for flood control. This activity can prevent flooding and subsequent mineral nourishment of wetlands or, alternatively, it can increase water levels in wetlands due to artificial levees. In both cases, the hydroperiod is altered and the wetland is forced to adapt to the new conditions. Channelization and flood control are widespread throughout the western coal field, particularly in the Cypress Creek watershed.

Agriculture and Lumbering - The clearing of forested wetlands, particularly bottomland hardwood forests, for agriculture and timber production is a significant concern in southeastern United States (Clark and Benforado, 1981). The extent of bottomland hardwood forest removal in Kentucky is not known although Turner (1981) presented preliminary data that showed an actual increase of 5.4 percent in bottomland hardwood forests from 1960 to 1970 in Kentucky. He suggested (personal communication) that this may be due to abandoned farmland reverting back to forest. This increase probably does not represent conditions in the western Kentucky coal field where many wetlands have been converted to agriculture, particularly to soybean farms. Agricultural activity may also affect adjacent wetlands with increased runoff that contains high concentrations of sediments, nutrients, and pesticides.

The Hierarchical Framework

Modern techniques for the management and evaluation of wetlands require that decisions be made using disparate variables at different levels of organization. Such variables can best be dealt with if they are arranged so they interact within the same spatial and temporal context. In order to accomplish such an organizational task effectively, hierarchical models are often useful. Hierarchies have often been used to describe natural systems (Pattee, 1973; Simon, 1973), including various wetlands (Patten *et al*., 1976; Bosserman, 1979).

Upper levels of such a hierarchical model involve variables that change over a broad spatial extent and a long time period, while lower levels involve more resolved variables that change over a smaller spatial and a quicker time scale. For example, while the variables that describe an ecosystem can vary over several hectares on a week by week basis, the variables that describe an organism can vary over several square meters on a minute by minute basis. Generally, there is more than one way to model a hierarchical system; however, during research activities the questions asked by observers provide constraints and guidance for model development. Hypotheses about system behavior can be developed in conjunction with the hierarchical model and then can be tested with an appropriate experimental design (O'Neill, 1975). In this research project a hierarchical model provides a framework by which management strategies for particular wetlands and their most important impacts can be developed and assessed. Techniques will then be developed which provide an integrated management strategy that incorporates each level of organization. Within our hierarchical framework, three levels of organization have been identified as being important to wetland assessment (Figure 3): regional, watershed, and ecosystem.

Regional - The upper, most-inclusive level that we identified is the regional level, which encompasses the entire western coal field. Regional modelling is essential for dealing with large scale problems that involve energy procurement, development, and transportation. Among variables which are relevant to wetland management at this level are the location, number, and area of wetlands and other land categories. Man-induced impacts, such as agriculture, mining, and lumbering, tend to cause changes in these variables.

The conceptual model of the regional level was developed to describe transfer of land area between categories of land use (Figure 4). The main

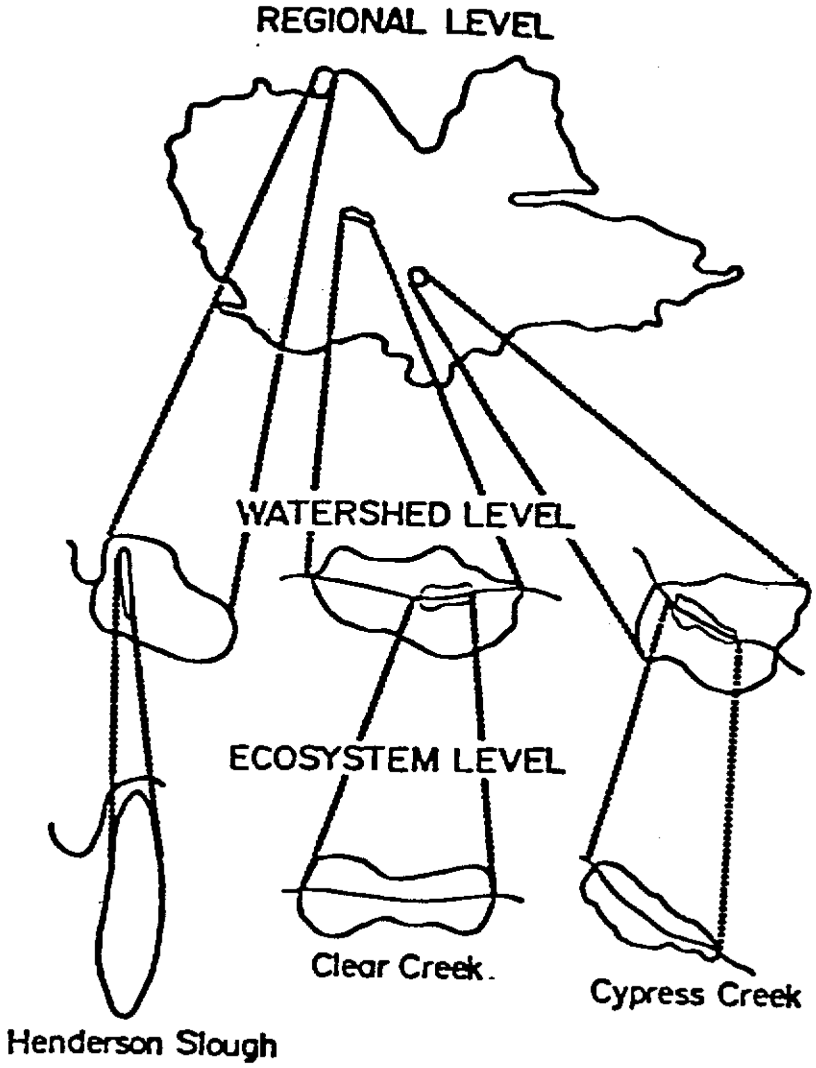

Figure 3. Hierarchy of Regional, Watershed and Ecosystem Levels

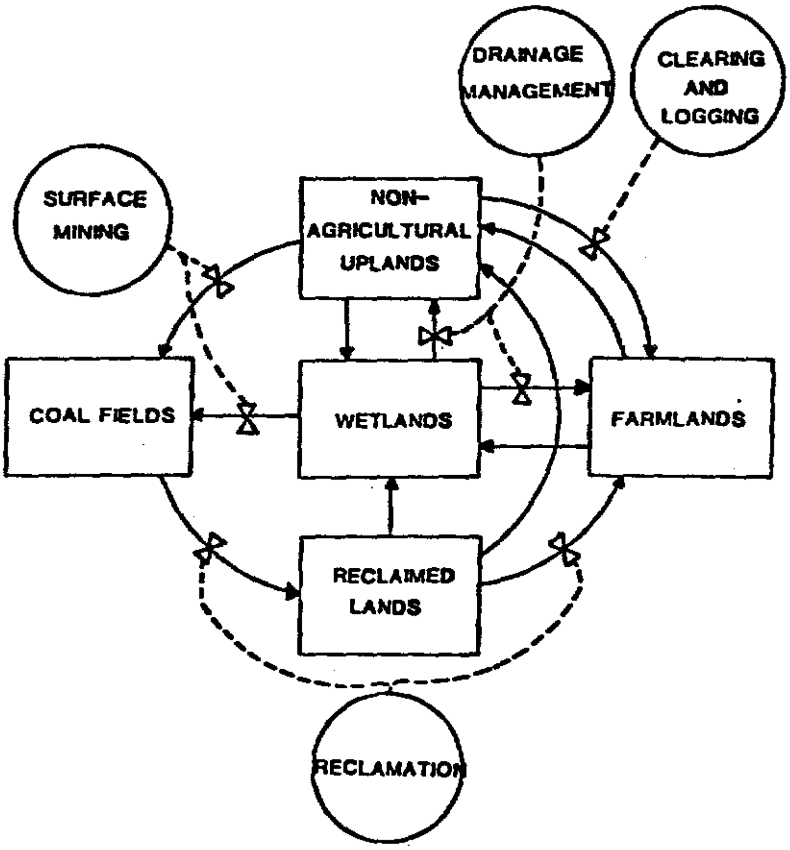

Figure 4. Regional Model of Western Kentucky Coal Field

land use divisions found in the western Kentucky coal fields are non-agricultural upland ecosystems, wetland ecosystems, farmland, stripped coal fields, and reclaimed land. Non-agricultural uplands are defined as land with predominantly mesophytic or xerophytic vegetation, and with mainly nonhydric soil that is not flooded or saturated at some time each year. Stripped coal fields include active mines and abandoned mines that have not yet been reclaimed.

Major management impacts that affect the region are mining operations, logging and clearing activity, reclamation operations, and drainage manipulation. These impacts work in a unidirectional manner causing wetlands to become non-agricultural uplands, farmlands, or coal fields; coal fields to become reclaimed land; reclaimed land to become farmland; and non-agricultural uplands to become coal fields or farmlands. Flows which oppose the depicted flows are due to natural ecosystem succession (i.e., farmlands to non-agricultural uplands) and are not directly controlled by management activities.

<u>Watersheds</u> - At the second level of the hierarchy, the entire region is regarded as being partitioned into <u>watersheds</u> which contain the wetlands. Watersheds are an important unit in ecological studies because they are well defined and affect inputs to aquatic ecosystems (Odum, E.P., 1971; Bormann and Likens, 1969). A watershed is a hydrological and geological unit that is identified by the regional topography; therefore, the characteristics of a watershed are closely related to many relevant variables of interest: surface runoff, stream flow, water level, and flow volume. Because inorganic and organic materials are carried in water, they depend on watershed characteristics and can be examined at this level. Chemical and hydrologic parameters can be examined for each study site in order to properly

characterize wetland behavior at this level of organization. Impacts include levee construction, channelization, and land use in the uplands. Many impacts affect inputs and outputs of wetlands and thereby help to determine wetland characteristics.

Water flow through a watershed of the western Kentucky coal field is described by a conceptual hydrologic model (Figure 5). The main compartments through which water moves are streams, bottomland hardwood forests, and marshes and swamps.

Streams include flowing, open water within a channel and exclude trees, shrubs, and emergent vegetation. Bottomland hardwood forests are areas that are flooded or saturated with water at some time of the year. The vegetation type can be any number of flood-tolerant hardwoods which are present in the area. Marshes and swamps are characterized by emergent hydrophytes and standing water for most of the growing season (Cowardin _et_ _al_., 1979).

Major impacts on water flow are channelization and land use, mining activity, logging activity, and levee building. Mining activity can affect water flow by actual disruption of the terrain or by increasing sediment loads.

Ecosystems - Specific _wetland_ _ecosystems_ occur at the lowest level of our hierarchical framework. An ecosystem can be defined as a set of interacting organisms with their physical and chemical environment. In the wetland ecosystems, we have chosen to examine the community structure, the energy and nutrient flows among various ecosystem components and the important physical and chemical factors.

Each of the major wetlands that we have chosen to examine has a significantly different community structure and is affected by different impacts; therefore, they are modelled separately. Descriptions of models for individual wetlands are in Results and Discussion.

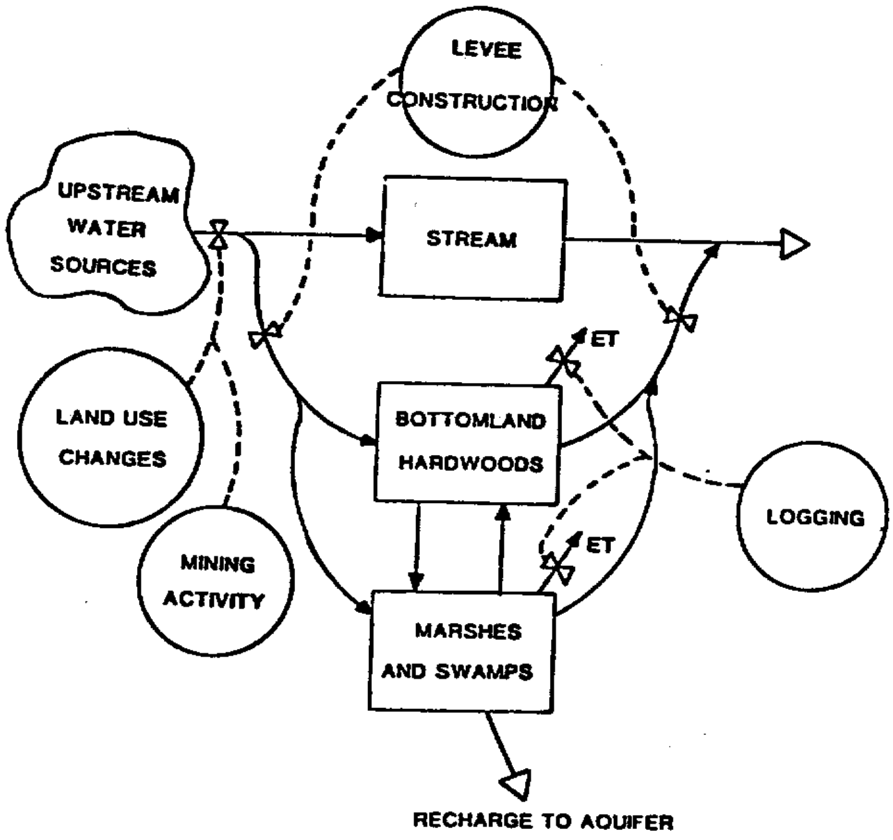

Figure 5. Watershed Model for Western Kentucky Coal Field

Other Wetland Studies

Much recent attention has been paid to wetlands as unique and useful natural areas on the American landscape. Inland wetlands are recognized as important wildlife habitats (Martin *et al*., 1953; Shaw and Fredine, 1956), recreational areas (Wharton, 1970; Goodwin and Niering, 1975), and pollution treatment units (Odum *et al*., 1977; Kadlec, 1978; Deghi *et al*., 1980).

Water quality in streams, rivers, lakes, and aquifers is affected by the presence of surrounding wetlands (Wharton, 1970; Lee *et al*., 1975; Mitsch *et al*., 1979a). Wetlands filter heavy metals, nutrients, and sediment (Grant and Patrick, 1969; Mitsch *et al*., 1979a, 1979b, 1979c; Bosserman, 1980). A large array of impacts threatens wetlands, including highway construction, mining, industrial pollution, agriculture, and urbanization. Despite their known usefulness and threats to their existence, little research has been done to examine many wetland properties. Coastal wetlands have been studied heavily and are now the foci of many large research efforts. However, inland wetlands have received much less attention. Major inland freshwater wetland studies have taken place in Florida (Odum, 1977; Mitsch and Ewel, 1979; Brown, 1981), Georgia (Patten *et al*., 1976; Bosserman, 1980), Michigan (Kadlec *et al*., 1977; Kadlec, 1978), North Carolina (Kuenzler *et al*., 1977), Louisiana (Conner and Day, 1976), and Illinois (Mitsch *et al*., 1979a).

Classification of Wetlands

Wetlands have been classified since the early 1900's, beginning with peatland classification in Europe and North America. The United States Fish and Wildlife Service has published two major classification schemes for wetlands in the United States, both as contributions to wetland inventories. An early version (Martin *et al*., 1953; Shaw and Fredine, 1956) described twenty wetland types based on flooding frequency and depth and on salinity regimes. A recent "Classification of Wetlands and Deepwater Habitats of the United States" (Cowardin et al., 1979) uses a hierarchical approach of five systems (marine, estuarine, riverine, lacustrine, and palustrine), subsystems, classes, subclasses, dominance types, and special modifiers to more precisely define particular wetlands and deepwater ecosystems.

Other regional wetland classifications have been developed in North America for North Dakota (Stewart and Kantrud, 1971), northeastern United States (Golet and Larson, 1974), western Canada (Millar, 1976), and Florida (Wharton et al., 1976). A classification of coastal ecosystems of the United States based on energy sources and stresses (Odum et al., 1974) contains several types of marine and estuarine wetlands.

Models of Wetlands

Conceptual and diagrammatic models can be useful tools for the identification and summary of environmental impact on ecosystems (Odum, 1972; Hall and Day, 1977; Farnworth et al., 1979). Even if they are not developed further into mathematical simulation models, these models 1) serve as guides for identifying critical ecological processes, 2) focus subsequent field and laboratory research on pertinent measurements, and 3) summarize environmental impacts on one or a few pages.

Simulation and analysis of computer models may be useful for examining wetland behavior and displaying effects of impact and management. Mitsch et al. (1982) present a review of simulation models for freshwater wetlands in North America. In such simulation models, the wetland is represented by a set of mathematical equations which describe some of its most important characteristics. Ecosystems such as wetlands are often too large and operate too slowly to examine within an appropriate space-time scale so effects of management alternatives or impacts can be examined only after long periods of time. On a computer, however, simulations of these effects can be examined in a few minutes. With printouts, a number of alternative scenarios can usually be compared simultaneously.

Several types of computers and computing languages are generally available for ecosystem modelling. Analog computers, which are capable of simulating only small models, can give exact, continuous solutions in a short period of time. Effects of rapidly changing parameters can be viewed visually. Large mainframe computers, such as the IBM 360/370, can run complex ecosystem models in short periods of time while microcomputers, such as the APPLE II and the Radioshack TRS 80, can run small models in moderate lengths of time. There are a number of computer types between these two extremes. Among the advantages of microcomputers are their portability, accessibility to researchers, graphic capabilities, simplicity of operation, and economy. Many microcomputers can be directly connected to a television set for displaying output. There are many advantages to using small models, such as understandability, stability, and the facility with which they can be simulated.

For many models, general purpose computer languages such as FORTRAN IV and BASIC are useful. With these languages, one has great flexibility in programming integration procedures and formatting outputs. FORTRAN and BASIC are usually compatible with both mainframe and microcomputers. For more complex models, simulation languages such as DYNAMO and CSMP (Continuous Systems Modeling Program) are useful. Many essential modelling procedures such as integration techniques are built into these languages. They therefore allow the construction of models in a straightforward and simple fashion. DYNAMO was specifically built for simulating industrial, social and economic situations. The famous 'Limits to Growth' model (Forrester, 1971) and various global 'World' (Meadows et al., 1972) models were done using DYNAMO. Because of DYNAMO's crude modelling procedures, however, simulations are relatively imprecise. It does, however, have good capabilities for displaying output. CSMP, which was designed for engineering applications, has more sophisticated and precise modelling procedures. Both languages greatly facilitate the mathematical modelling of ecosystems; however, they are generally available only on large, mainframe computers.

Intensive Study Areas

Three major wetland areas in the Western Kentucky coal field were chosen for detailed study because of significant or unique features. General locations of the sites are shown in Figure 6. Much of the following information comes from Harker et al. (1980).

Henderson Sloughs - These wetlands are located along the Ohio River in Henderson and Union Counties and are annually flooded by the river. These wetlands are elongated sloughs divided by low ridges and roughly parallel to the direction of the river. Much of the region has been drained for agriculture and significant environmental impact may result from oil drilling in the region. No coal mining impact is apparent. The major community found in the seasonally-inundated sloughs is dominated by *Acer saccharinum* (silver maple) and *Fraxinus pennsylvanica* (green ash). Some permanent ponds supporting *Taxodium distichum* (bald cypress) or various aquatic macrophytes are also present. These wetlands are one of only two Kentucky wetlands cited by Goodwin and Niering (1975) in their survey of major wetlands in the United States.

Cypress Creek Wetlands - These riparian wetlands are found along 15 kilometers of Little Cypress and Cypress Creeks in Muhlenberg County. A major feature is the presence of *Taxodium distichum* (bald cypress) communities. The

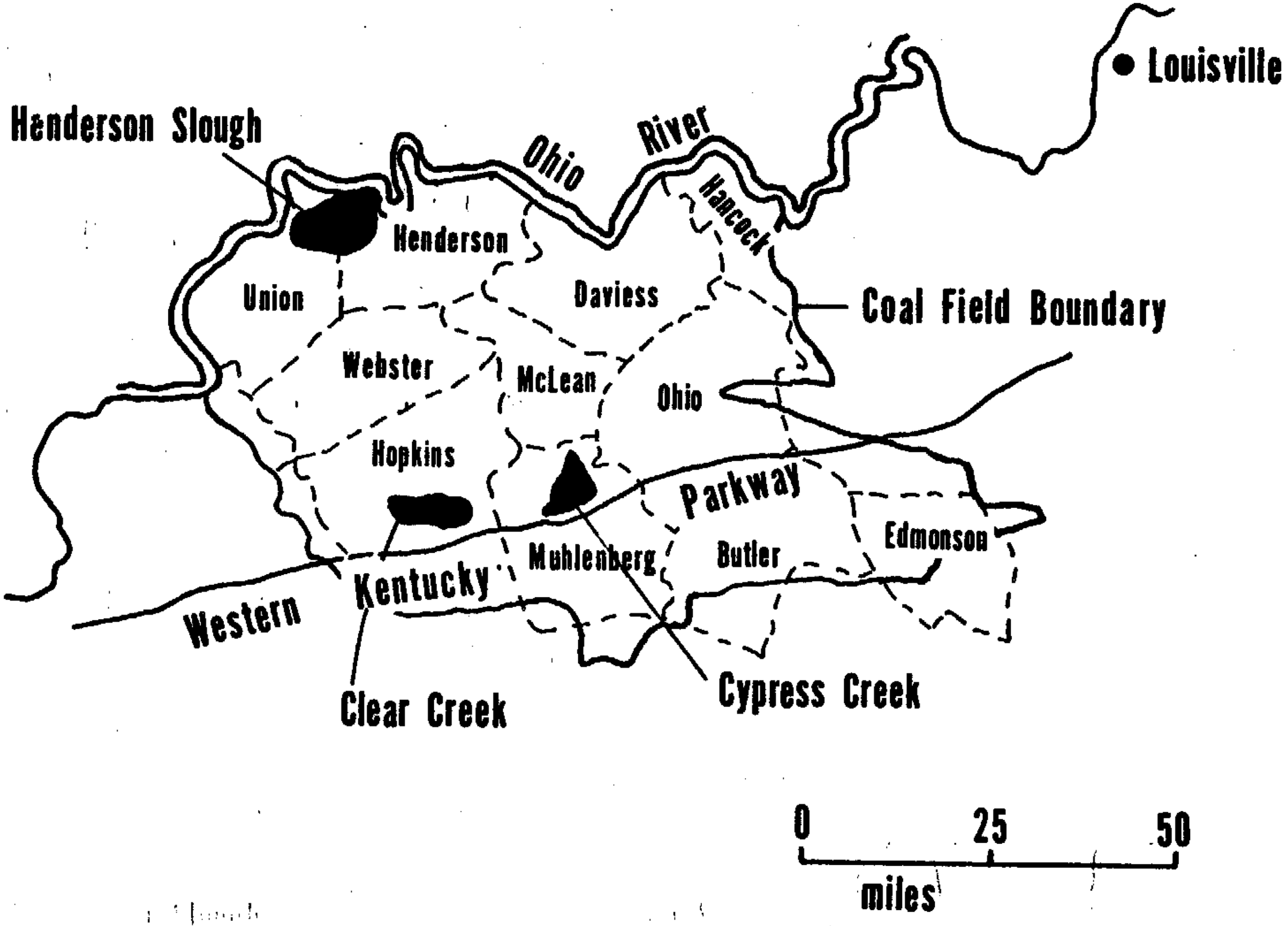

Figure 6. Location of Intensive Study Wetland Sites

cypress stands are among the most extensive and best developed in the interior of western Kentucky and represent some of the eastern-most cypress in the Mississippi-Ohio Basin. Swamp forest communities of *Betula nigra* and *Acer rubrum* and marshes of *Typha* sp. (cattail) are also found in this study area. There are signs of mine drainage although channelization and levee construction on all of the major streams appear to have caused the most impact. Cypress Creek wetlands are an important waterfowl area, especially for mallards and wood ducks.

Clear Creek Swamp - This wetland, over 3400 hectares in size, is the largest extant wetland system in the Western Kentucky Coal Field. It is located in Hopkins County west of Madisonville. The wetland has been severely affected by a combination of logging, altered hydroperiod and, notably, surface mining of coal. Major wetland communities include young forest thickets of *Betula nigra* (river birch) and *Acer rubrum* (red maple), open water communities interspersed with *Cephalanthus occidentalis* (buttonbush), and stands of *Liquidambar styraciflua* (sweetgum).

MATERIALS AND METHODS

Classification Scheme

A classification for wetlands in western Kentucky was developed with the following criteria in mind: 1) simplicity, 2) flexibility, and 3) inclusion of ecological stress. The classification scheme is summarized in Table 2 and Figure 7. The major types of wetlands (palustrine) systems include seven types frequently found in our study sites. This simple system is compatible with the classification scheme developed by Cowardin *et al*. (1979) but does not include as much detail. Environmental modifiers (Figure 7) describe, in the form of a two-by-two matrix, the flooding regime and environmental impacts on the wetlands. Along one axis, the flooding conditions are defined as unaltered (I) or altered (II). The other axis describes environmental impacts in general on the wetland with A indicating low impact and B indicating significant impact. Thus an environmental modifier of II-B indicates a wetland with an altered hydroperiod and significant environmental impact. A modifier of I-A, on the other hand, indicates a wetland in near-natural conditions. The impact can be further defined with a numbering scheme (1 through 6) to indicate coal mine drainage, oil wells, logging, agricultural runoff, urban influence, or other impacts. An example of a classification is shown in Figure 7.

Wetland Mapping

Maps were developed to show major wetland ecosystems and other land use patterns within watershed boundaries of the three study areas. The mapping was based on the classification scheme described in Table 2. Watershed maps were drawn from 7 1/2 minute USGS topographic maps (1:24,000). Wetland boundaries and types were identified from land use overlays supplied by the

Table 2

Major Classifications Used in Wetland Mapping in Western Kentucky

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PALUSTRINE SYSTEMS

- Persistent Emergent Wetland
  - Typha Marsh
  - Phragmites Marsh
  - Mixed Emergent Marsh
- Forested Wetland
  - Cypress Swamp
    - deep
    - shallow
  - Bottomland Hardwood
    - frequently flooded
    - infrequently flooded

OTHER

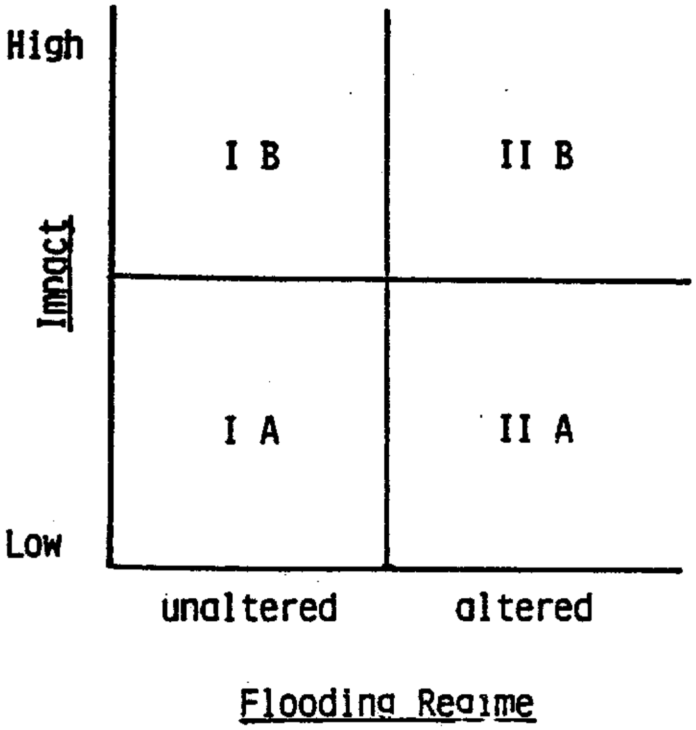
- Agricultural Areas
- Residential and Commerical Areas
- Coal Mines
  - active/abandoned
  - reclaimed
- Upland Wooded Areas

Environmental Protection Agency and from color aerial photography (1:24,000). The color photography, from recent (1979-80) flights over the entire Western Kentucky coal field, was made available by the Kentucky Nature Preserve Commission. In many cases, ground truth observation in the field were used to verify the identification of wetland types. Figure 8 summarizes the process of mapping the wetlands.

Water Quality Sampling and Analysis

Surface waters were sampled at Stations 1 through 5 at Henderson Sloughs (Figure 9), Stations 1 through 3B at Cypress Creek (Figure 10) and Stations 1 through 3 at Clear Creek (Figure 11). Samples were taken on 19-20 June,

MAPPING CLASSIFICATION - IMPACTS



Impact Modifiers

1. Coal Mine Drainage
2. Oil Well
3. Logging/Harvesting
4. Agricultural Runoff
5. Urban
6. Other

EXAMPLE

Deep Cypress Swamp IB-1

Cypress swamp with normal hydroperiod but affected by coal drainage

Figure 7. Classification Scheme Used for Identification of Wetland Impact

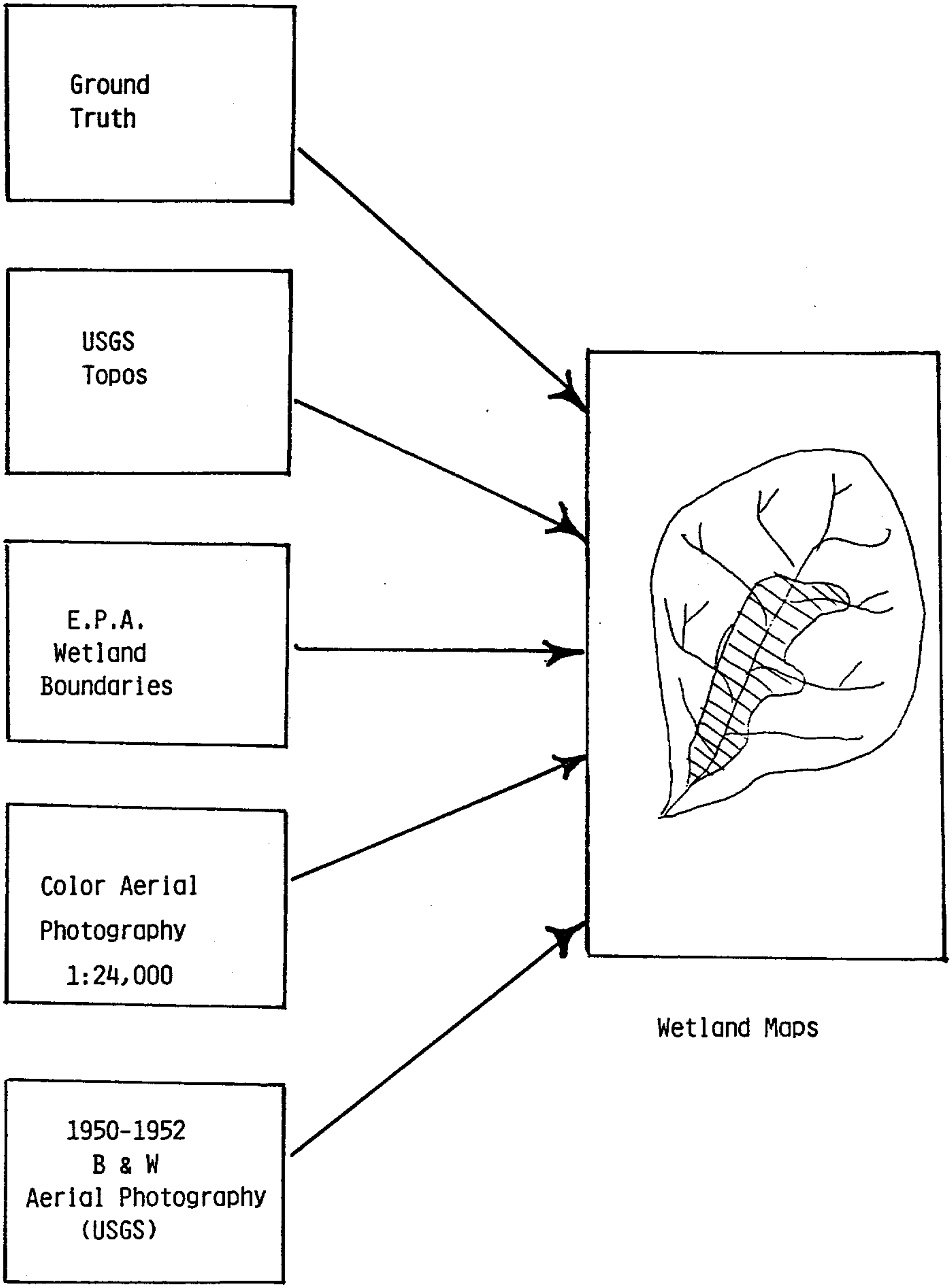


Figure 8. Method for Wetland Mapping

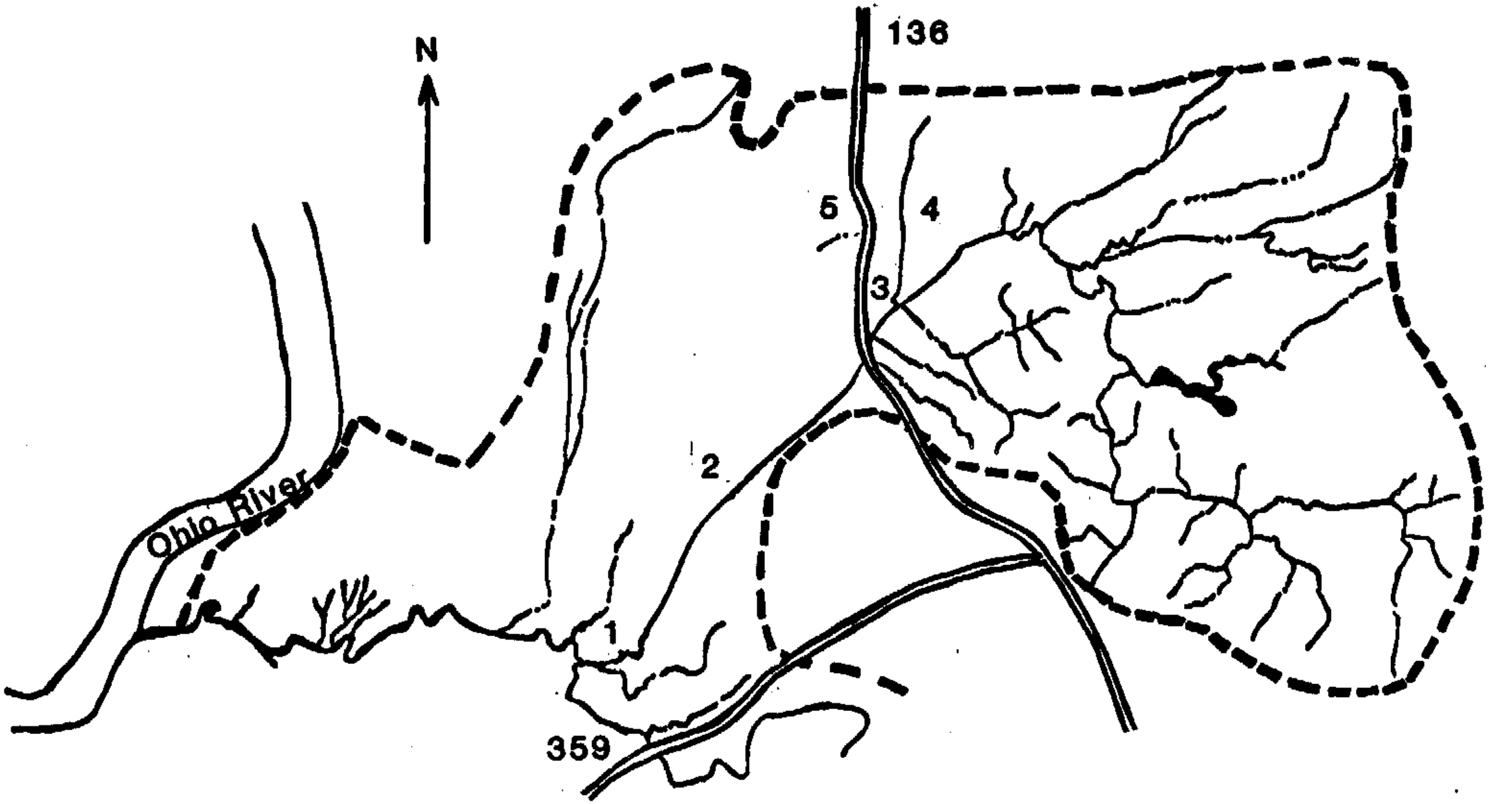


Figure 9. Sampling Stations in Henderson Sloughs Study Area

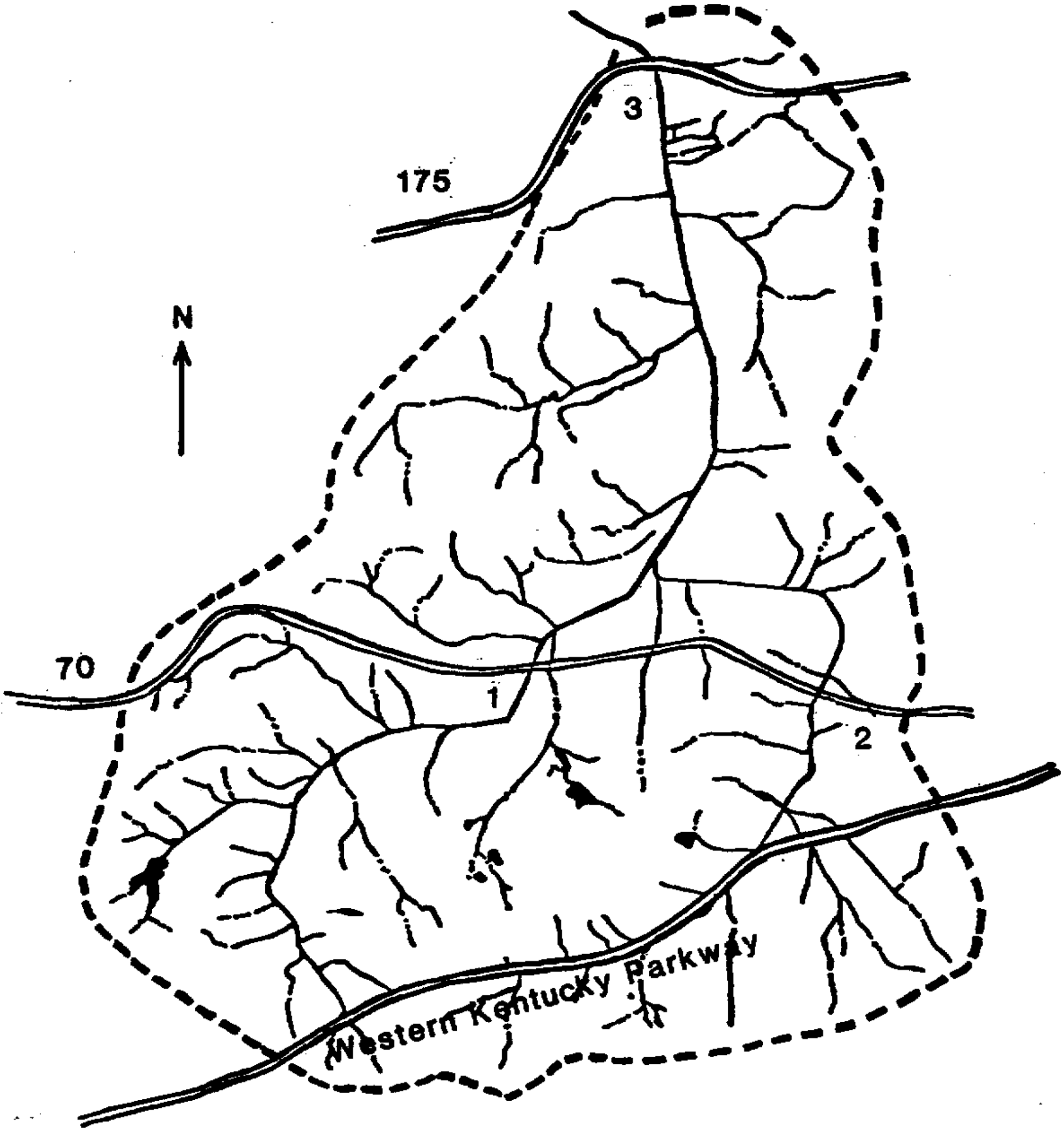


Figure 10. Sampling Stations in Cypress Creek Study Area

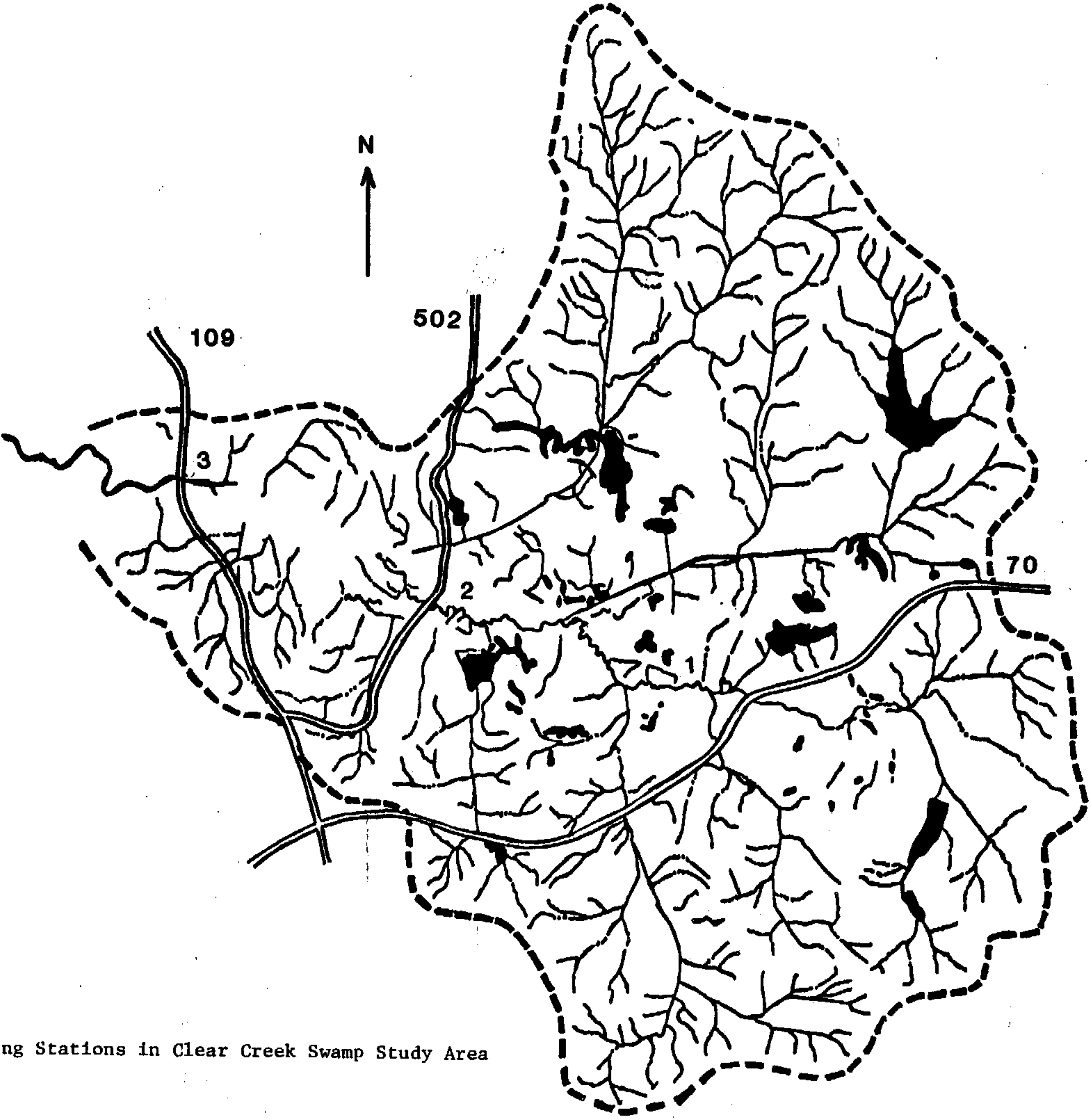


Figure 11. Sampling Stations in Clear Creek Swamp Study Area

22-24 July, and 18-19 September, 1981. Water conditions during these periods ranged from flooding to normal-low pool situations.

Samples were taken using a five and one half foot polyvinyl chloride (PVC) extension pipe on which clean, acid washed polyethylene bottles were placed. Holes, 3/4 inch in diameter, were made in the pipe 2 inches above the insertion of the bottle neck, allowing undisturbed water to flow directly into the bottle. This sampling device, used in other wetlands studies, allows the taking of samples away from points of disturbance and contamination by sampling personnel. At all sites, two samples were taken, composited, and immediately transported on ice to the lab, where they were stored at 4°C until examination. No preservatives were used.

Samples were analyzed according to standard procedures (APHA, 1975). Temperature, pH, dissolved oxygen, and conductivity were measured directly in the field with appropriate meters. Turbidity and sulfates were measured by turbidimeter and spectrophotometer, respectively. Table 3 summarizes parameters and methods used in this study.

Vegetation Analysis

The intensive study sites were selected with the aid of 1:24,000 color aerial photographs and topographic maps. Subsequent ground surveys located sampling plots within the sites. At each bottomland or shallow water site, a 100 meter transect was placed within site boundaries. Points were marked at 10 meter intervals for point-quarter vegetation analysis (Cottam *et al*. 1953; Cottam and Curtis, 1956). Rectangular plots were established at cypress swamps using an optical rangefinder.

The point-quarter method of vegetation analysis consists of identifying the closest tree in the four quarters at each point, recording distance from

Table 3

Methods Used for Water Quality Analysis

Parameter	Equipment/Analysis Technique
Turbidity (NTU)	HACH Turbidimeter Model 2100A (lab)
pH	Elan Engineering pH Meter (field)
Temperature	YSI Model 57 Dissolved Oxygen Meter (field)
Dissolved Oxygen	YSI Model 57 Dissolved Oxygen Meter (field)
Conductivity	Beckman Conductivity Meter (field)
Sulfates SO_4	Perkin-Elmer UV-VIS Spectrophotometer Barium Chloride Method (lab)

the point and measuring tree diameter at breast height (dbh). From these data, the following were calculated: absolute and relative density, absolute and relative frequency, basal area, and relative dominance. Importance values, measures of the influence a species exerts upon a community, were calculated by summing relative frequency (RF), relative density (RDens), and relative dominance (RDom) for each species. Herbaceous vegetation was characterized by species name and relative abundance (i.e., heavy, medium, sparse). Simpson's (1949) diversity index was calculated for the tree community at each site:

$$\text{Simpson's } D = 1 - \frac{\Sigma[N_j(N_j-1)]}{N(N-1)}$$

where,

N_j = number of trees of the j^{th} species

N = total number of trees sampled

Aquatic macrophytes were harvested from 0.5 m^2 plots at selected sites. Total sample and subsample wet weights were recorded. Subsamples were returned to the lab, air-dryed for two weeks, then oven-dried (90°C for 24 hours). Dry weights were recorded and dry/wet ratios calculated. Multiplication of the dry/wet ratio by total sample wet weight yielded an estimate of biomass in grams dry weight. Multiple samples were averaged to obtain mean dry weight per square meter for a species.

Modelling Languages

Conceptual models were depicted with two modelling languages. Symbols used in this paper are shown in Figure 12, where analogous Energese (Odum and Odum, 1976) and DYNAMO (Forrester, 1961) symbols are presented side by side.

In Energese, each energy module represents a dominant mode of processing energy such as autotrophy, heterotrophy, or passive storage. Solid lines demonstrate energy flows between model components and information interactions. Circles depict factors such as energy inputs, perturbations, or management efforts which originate outside the boundary of the system. Workgates indicate the interaction of two or more forces. In DYNAMO, state variables which represent storages are shown as boxes. Solid lines depict material flows while dotted lines depict information flows. Valves on these lines demonstrate points of control where external factors affect material and information flows between storages. In DYNAMO, circles are called auxiliary variables. Components of DYNAMO can be represented hierarchically by putting boxes within boxes and separating lines at the box boundary.

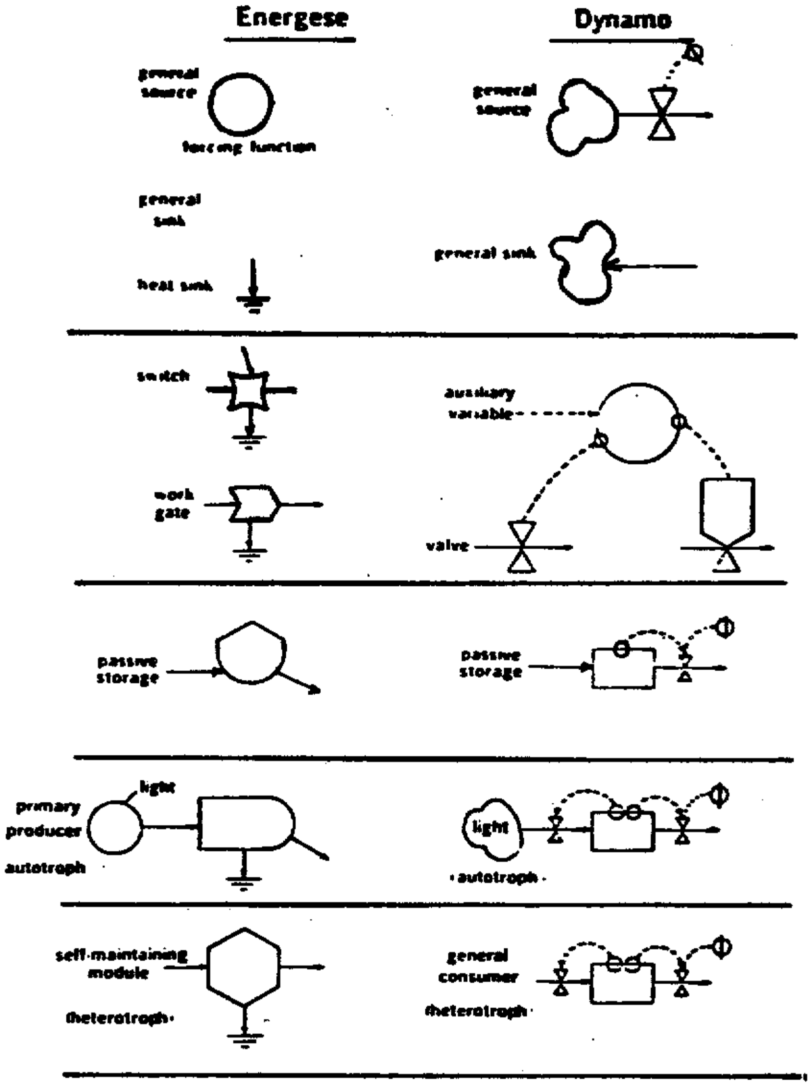


Figure 12. Modeling Symbols Used in This Study

RESULTS AND DISCUSSION

Henderson Sloughs

Mapping and Classification - The wetland map of the Henderson Slough study area is shown in Figure 13. The parallel pattern of elongated cypress sloughs and bottomland hardwood forests is easily discernable in the western half of the watershed. The upland areas that are less frequently flooded have mostly been converted to agricultural fields although one large upland wooded area is found near the center of the watershed. There is only a very small residential area in the eastern extreme of the drainage basin.

Hydrology - Hydrology of the Henderson Slough watershed is dominated by sloughs with standing water or very slowly flowing water (Figure 14). During the spring, the Ohio River often exceeds its banks and floods the entire region, with drainage generally flowing from northeast to southwest. During the remainder of the season, Pond Creek, shown in Figure 14, carries the major portion of the drainage from our study region. The stream channel is poorly defined in certain locations and flooding of adjacent wetlands and agricultural fields is frequent.

Ecosystem Model - The conceptual model of Henderson Slough (Figure 15) shows the influence of the annual flooding of the Ohio River on riparian wetlands. The flooding river contributes nutrients and organics to the elongated sloughs. This typical river-bottom hardwood habitat consists of bottomland hardwood forests, wooded sloughs, and open water areas. The bottomland hardwood forest of slightly raised elevation is primarily composed of oak-hickory (Quercus sp., Carya ovata) and maple-ash (Acer rubrum, A. saccharinum, Fraxinus pennsylvanica, F. americana) associations (Goodwin and Niering, 1975; Quarterman and Powell, 1978). In the wooded sloughs, Fraxinus pennsylvanica, Betula nigra (river birch), Taxodium distichum (bald cypress),

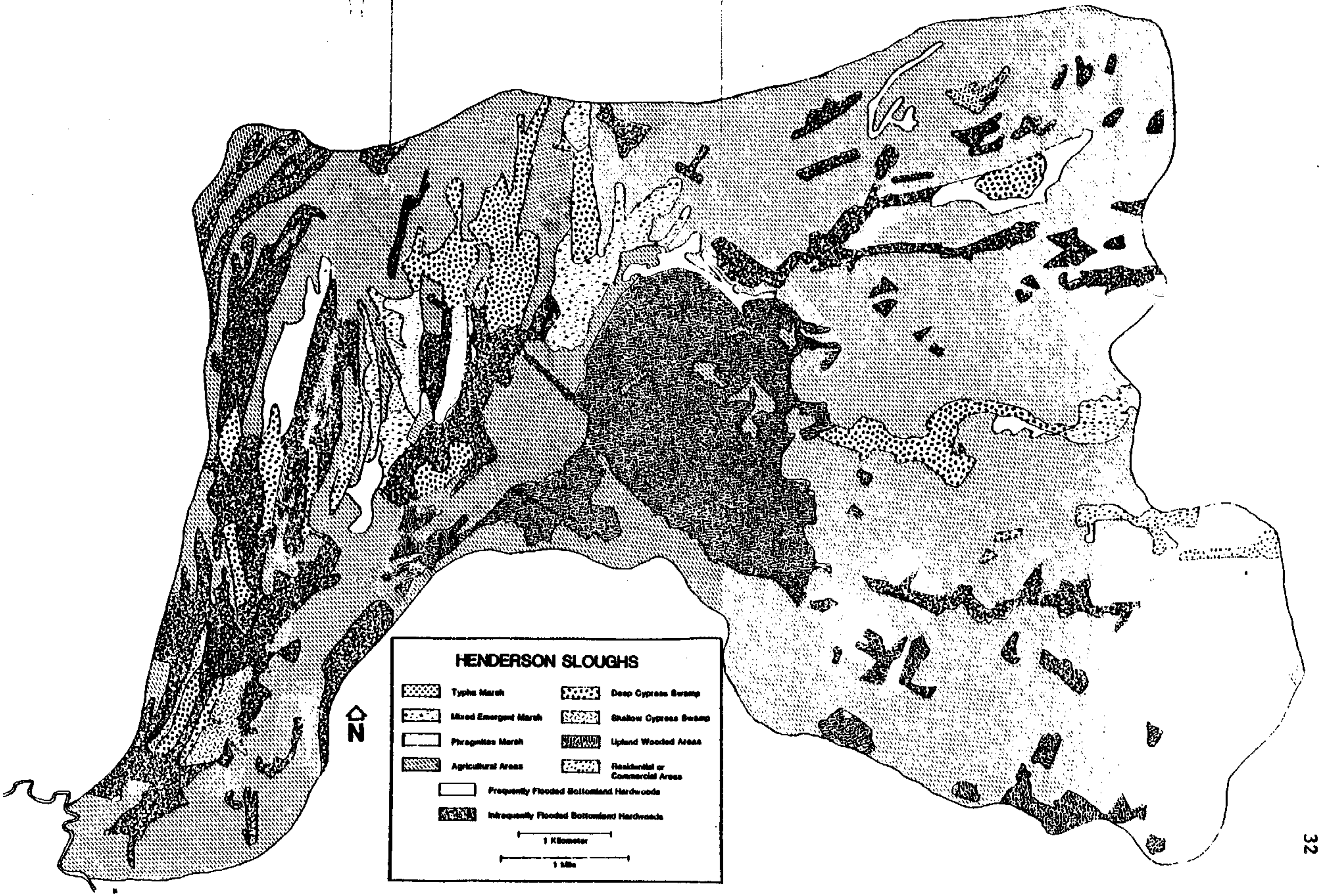


Figure 13. Wetland Map of Henderson Sloughs Drainage Basin

Figure 14. Stream Map of Henderson Sloughs Drainage Basin. Scale is the Same as Figure 13.

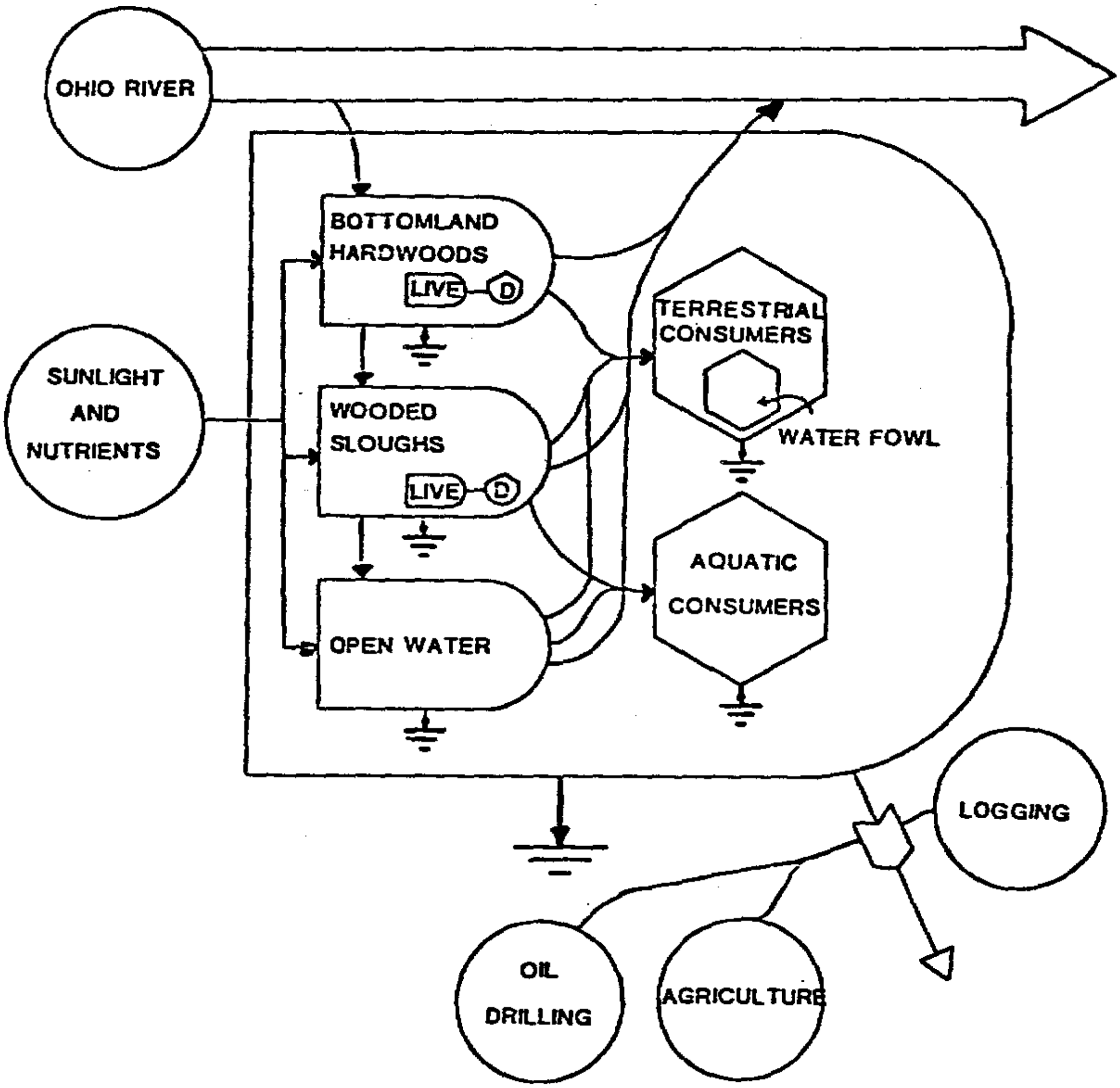


Figure 15. Ecosystem Model of Henderson Sloughs

and *Liquidambar styraciflua* (sweet gum) are the dominant species. Both of these areas contain a living population and a standing dead crop of the above species. The open water areas are often interspersed with stands of bald cypress (*Taxodium distichum*). Rare Kentucky plant species may also be found in these wetlands. The rare species are *Decodon verticillatus* (swamp loosestrife), *Echinodorus rostratus* (Burhead), *Pontederia cordata* (pickerel weed), and *Utricularia gibba* (humped bladderwort) (Harker *et al.*, 1980).

Impacts which are represented in the model are oil drilling operations, agricultural activities, and timber harvesting. Oil operations cause chemical and mechanical damages to the area and to wildlife through overflows of crude and brine (Goodwin and Niering 1975). Public funded agricultural practices and subsidies encourage drainage and clearing. Timber harvesting also has an impact on the area.

Water Quality - Water quality was collected from selected sloughs, from flooded bottomland hardwoods, and from Pond Creek, the primary drainage channel for the sloughs area. Samples were taken during flooding conditions and during normal to low pool conditions. It was of interest to compare slough and bottomland waters with that of the main channel. The primary interest, however, was not to compare sites but to gain knowledge on the cumulative water quality of the entire sloughs region. Therefore, the Pond Creek stream samples are thought to provide the broadest and most encompassing water quality data for the sloughs drainage basin.

Table 4 gives water quality data for the Henderson Sloughs area for three sampling trips. Refer to Figure 9 for location of the sampling sites. Since site 1 is a bottomland hardwood forest site, data are limited to a sample in June when the forest was inundated; for the remaining dates, the site was found to have no standing water. Water samples for site 1B were taken from the main

Table 4

Water Quality of Selected Sites in Henderson Sloughs

Site Number	Date	Time (EDT)	Turbidity (NTU)	pH	Temperature (°C)	Dis.O_2 (mg/l)	Cond. (umhos)	$SO_4^=$ (mg/l)
1	19 June	9:00 A.M.	5.45	---	23.9	1.95	---	---
	22 July	1:30 P.M.	---	---	---	---	---	---
	14 Sept.		---	---	---	---	---	---
1B	19 June	9.25 A.M.	4.1	7.05	23.55	1.65	500	---
	22 July	1:40 P.M.	15.5	6.2	25.0	5.3	420	19.3
	19 Sept.	10:15 A.M.	5.95	7.4	15.8	3.7	430	13.05
2	19 June	10:30 A.M.	2.05	6.7	22.5	1.9	700	---
	22 July	2:00 P.M.	2.0	6.4	25.4	1.9	200	17.35
	19 Sept.	11:00 A.M.	4.55	7.4	15.7	3.6	720	13.3
2B	19 Sept.	12:00 N.	1.5	6.6	16.2	5.8	550	9.7
3	19 June	12:00 N.	1.35	6.8	21.6	2.05	590	---
	22 July	5:45 P.M.	2.1	6.5	17.0	4.2	1800	23.3
	19 Sept.	2:00 P.M.	2.15	6.6	17.2	5.0	1500	41.8
4	19 June	1:15 P.M.	3.4	6.55	23.0	3.62	330	---
	22 July	5:15 P.M.	2.1	6.1	29.0	12.2	520	12.0
	19 Sept.	1:00 P.M.	1.75	6.5	19.0	10.0	500	10.5
5	19 June	2:00 P.M.	3.2	6.4	25.0	5.3	3000	---
	22 July	4:30 P.M.	1.9	6.5	32.2	10.4	4500	24.75
	19 Sept.	12:30 P.M.	1.65	6.4	18.8	8.8	7000	56.85

channel of Pond Creek; the site was the most downstream point for Henderson Sloughs. Samples for sites 2 and 3 were also taken from the main channel of Pond Creek, at middle and upper reaches of the drainage basin respectively. Site 2B, a deep cypress slough, was added as a sampling site in September. Sites 4 and 5 are individual sloughs which drain into Pond Creek. The two differ greatly, however, in water quality.

Turbidity values for Henderson Sloughs water fall into the expected range for wetland areas where, by nature, moderately turbid conditions persist. An extremely high value, 15.5, was observed at site 1B during July and is thought to be attributable to evaporation and the reduced flow conditions of summer. Temperature and pH of these waters also fall into the range of expected or normal values. Temperatures varied with the season, while pH values remained relatively constant throughout. Dissolved oxygen reached a peak in July in the still sloughs and was highest in September in the streams. This may be due to the large numbers of aquatic macrophytes and algae which were at peak productivity at this time. Decline of this productivity in fall is evidenced by lower dissolved oxygen levels observed in September in the sloughs.

Conductivity measurements suggest an impact of oil drilling operations on the Sloughs area. Site 5, a still slough, is directly affected by a nearby oil well which disposes of salt brines in the wetland. These brines flow directly into the slough via a ditch and lead to specific conductance readings of 3,000 to 7,000 umho/cm. This is diluted downstream at sites 3, 2 and 1; site 4, which is not hydrologically connected to the brine discharge, shows normal conductivity readings. Sulfates are in normal ranges in most areas but show slightly higher values in the heavy brine areas (sites 3 and 5).

Vegetation - Four of the Henderson sites were chosen for vegetation analysis. One of the sites is a bottomland hardwood forest, one is a shallow water cypress-ash swamp and two are deep cypress swamps. Henderson Site 1 is a bottomland hardwood forest located near the confluence of Pond Creek and Highland Creek. Henderson Site 2A is a forested wetland with longer hydroperiod then the bottomland hardwood site and lies adjacent to the middle reach of Pond Creek. Henderson Site 2B is located directly upstream from Site 2A and is a deep cypress swamp. Another cypress swamp, Henderson Site 5, lies between the Ohio River and the upper reaches of Pond Creek, adjacent to Route 136.

Henderson Site 1 is a typical bottomland forest of the Henderson Sloughs area. It is bordered on the east by agricultural land and, on the west, by one of the many, permanently-flooded sloughs of the region. *Acer saccharinum* (silver maple) is the dominant canopy species with an importance value of 117 (Table 5) and is present at 80% of the points along the transect.

Table 5

Structure and Composition of Vegetation at Henderson Site 1.

Species	Relative Frequency	Relative Density	Relative Dominance	Importance Value
Acer saccharinum	30.8	32.5	53.7	117.0
Carpinus caroliniana	23.1	25.0	4.7	52.8
Fraxinus pennsylvanica	11.5	15.0	13.3	39.8
Acer rubram	7.7	7.5	21.4	36.6
Carya cordiformis	7.7	7.5	4.7	19.9
Quercus bicolor	7.7	5.0	1.3	14.0
Almus americana	7.7	5.0	0.4	13.1
Carya ovata	3.8	2.5	0.5	6.8

Total Density (trees/ha) = 1080
Total tree species = 8
Simpson's D=0.81

Other canopy species, including *Fraxinus pennsylvanica* (green ash) and *Acer rubrum* (red maple), are only occasionally encountered and have importance values of 39.8 and 36.6, respectively. These more water tolerant species are not as important at this site as at wetter sites. This site is inundated only during the annual spring flooding of the Ohio River, allowing dominance by less water tolerant species.

The understory is dominated by *Carpinus caroliniana* (American hornbeam), present at 60% of the points and comprising 25% of all trees recorded from this site. Its importance value of 52.8 is higher than all other species except *A. saccharinum*. Other primary understory constituents are *A. rubrum*,

A. saccharinum, Carya cordiformis (pignut hickory), Quercus bicolor (swamp white oak) and Ulmus americana (American elm). The herbaceous layer is not well developed with Lonicera japonica (honeysuckle), Pilea pumila (clearweed), and Eupatorium rugosum (white snakeroot) as the principal species. Henderson Site 1 exhibits the highest density (1080 trees/ha) and the highest diversity (D=0.81) of any similar site.

The shallow bottomland swamp of Henderson Site 2A is frequently inundated and is generally much wetter than Site 1. Table 6 shows the shift of dominance from less water tolerant to highly water tolerant species. Fraxinus pennsylvanica and Taxodium distichum (bald cypress) share dominance of the canopy layer with a combined importance value of 245.4. These species occur at 100% and 90% of the points, respectively. All other species are recorded only once from the transect. Several tree species are present at this site at an average density of 660 trees per hectare and a diversity of 0.73 on Simpson's index.

The understory layer is completely dominated by the shrub, Cephalanthus occidentalis (buttonbush). Due to the discontinuous canopy, the herbaceous

Table 6

Structure and Composition of Vegetation at Henderson Site 2A

Species	Relative Frequency	Relative Density	Relative Dominance	Importance Value
Fraxinus pennsylvanica	41.7	50.0	34.9	127.6
Taxodium distichum	37.5	37.5	42.8	117.8
Salix nigra	4.2	2.5	8.2	14.9
Platanus occidentalis	4.2	2.5	6.4	13.1
Populus heterophylla	4.2	2.5	3.6	10.3
Quercus bicolor	4.2	2.5	2.9	9.6
Liquidambar styraciflua	4.2	2.5	0.8	7.5

Total Density (trees/ha) = 660
Total tree species = 7
Simpson's D= 0.726

layer is well developed. Saururus cernuus (lizard's tail) is, by far, the most abundant plant in the herbaceous layer. Other common herbaceous plants of this site are Leersia oryzoides (rice cutgrass), Sagittaria latifolia (arrowhead), and Acorus calamus (sweet flag). In the standing water, duckweed (Lemna minor), water fern (Azolla caroliniana), and hornwort (Ceratophyllum demersum) are present. The abundance of aquatic macrophytes indicates an extremely wet site.

Site 2B is a well developed deep cypress swamp with an average density of 290 trees per hectare. The trees do not form a continuous canopy and there are large areas of open water. Taxodium distichum is the only tree species in the swamp. The trees fall into five size classes between 10 cm dbh and 60 cm dbh (Table 7). The distribution centers around the two classes between 20 cm dbh and 40 cm dbh. Seventy-one per cent of the trees fall in these two classes with a mean diameter of 30.3 cm. The heights of the trees range from 4.5 m to 13.9 m with a mean height of 9.5 meters. There are few aquatic

Table 7

Size Class Distribution of Taxodium distichum at Three Sites in Henderson Sloughs and Cypress Creek

Size Class (cm dbh)	Number of trees		
	Henderson Site 2B	Henderson Site 5	Cypress Creek Site 3B
0- 9.9	0	0	26
10-19.9	8	1	13
20-29.9	15	1	0
30-39.9	19	3	0
40-49.9	5	4	1
50-59.9	1	0	0
60-69.9	0	2	0
70-79.9	0	2	0

Total density (trees/ha):
Henderson Site 2B = 290
Henderson Site 5 = 130
Cypress Creek Site 3B = 795

macrophytes present at the sample site. None occur in the deeper areas and only Nelumbo lutea (American lotus), Acorus calamus, and Sagittaria latifolia are common along the shoreline.

The deep cypress swamp sampled at Henderson Site 5 is heavily impacted by brine from nearby oil operations. Many of the smaller bald cypress trees are dead and the density of living trees is lower than at Site 2B (130 trees/ha). Table 7 shows the size class distribution of Taxodium distichum in the sample plot. Eighty-five per cent of the trees are greater than 30 cm in diameter. The range of diameters is 16.5 cm to 77.3 cm with a mean dbh of 46.4 cm. The heights of the trees range from 2.6 m to 10.9 m with a mean height of 7.7 meters. The only aquatic macrophyte occurring in the plot is Nelumbo lutea. Samples of N. lutea were harvested and the biomass of the standing crop in mid July was estimated to be 60 grams dry weight per square meter.

Cypress Creek

Mapping and Classification - The wetland map for the Cypress Creek study region is shown in Figure 16. Wetlands in this region are found along Cypress Creek and its tributaries. Major types of wetlands include mixed emergent marsh, Typha marsh, and shallow and deep cypress swamps. Bottomland hardwood forests are found in very narrow bands along the major streams. A major part of this watershed is dominated by active surface coal mining. There are also substantial areas of reclaimed surface mines. The town of Central City is a major residential area in the eastern part of the drainage basin.

Hydrology - Cypress Creek and its major tributary, Little Cypress Creek, are the major surface drainage conduits in the study site. The drainage pattern is shown in Figure 17. The streams are channelized along most of their lengths in the study area. They are prone to rapid spates of flooding during high rainfall and frequently exceed their channels and spill into

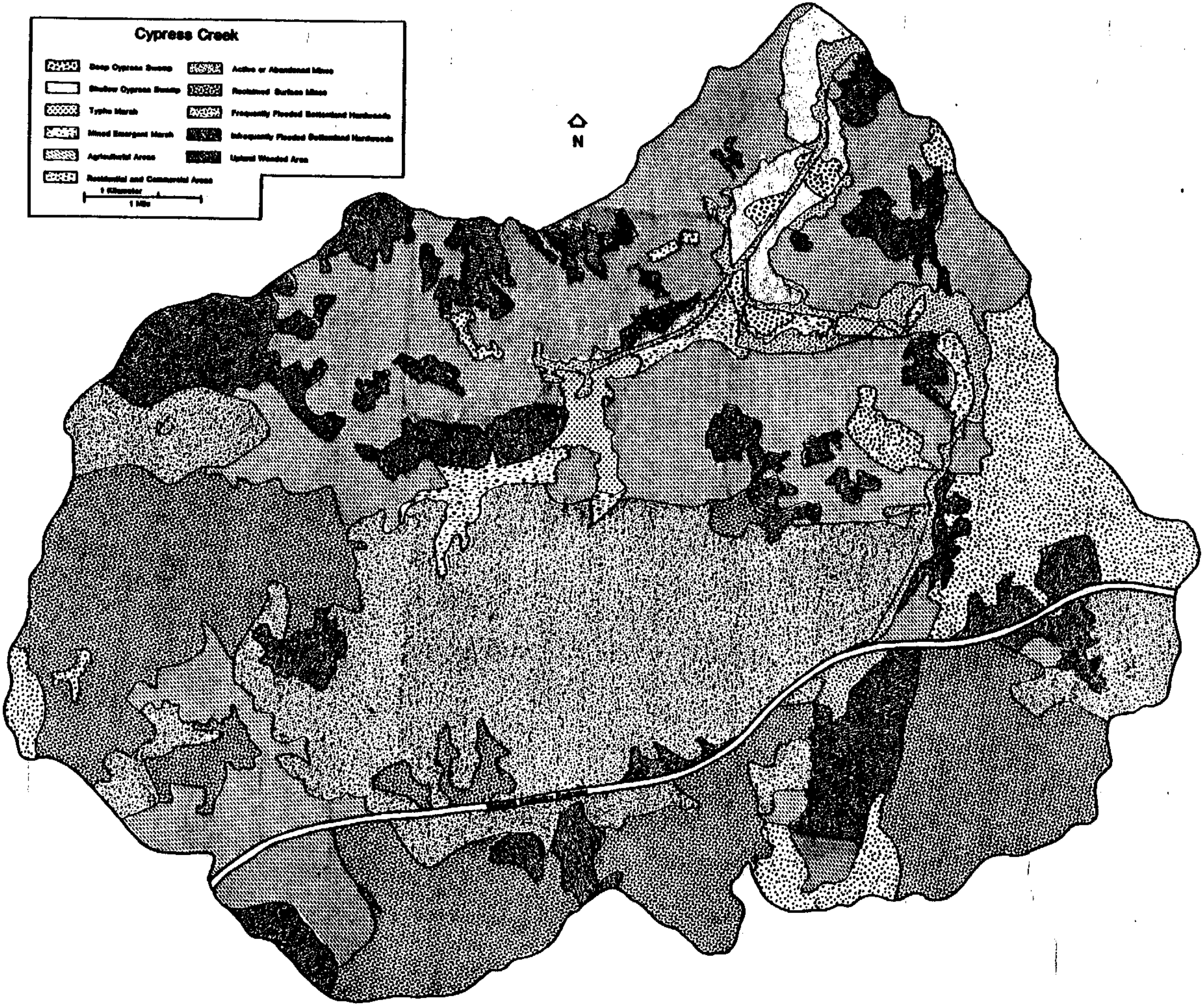


Figure 16. Wetland Map of Cypress Creek Drainage Basin.

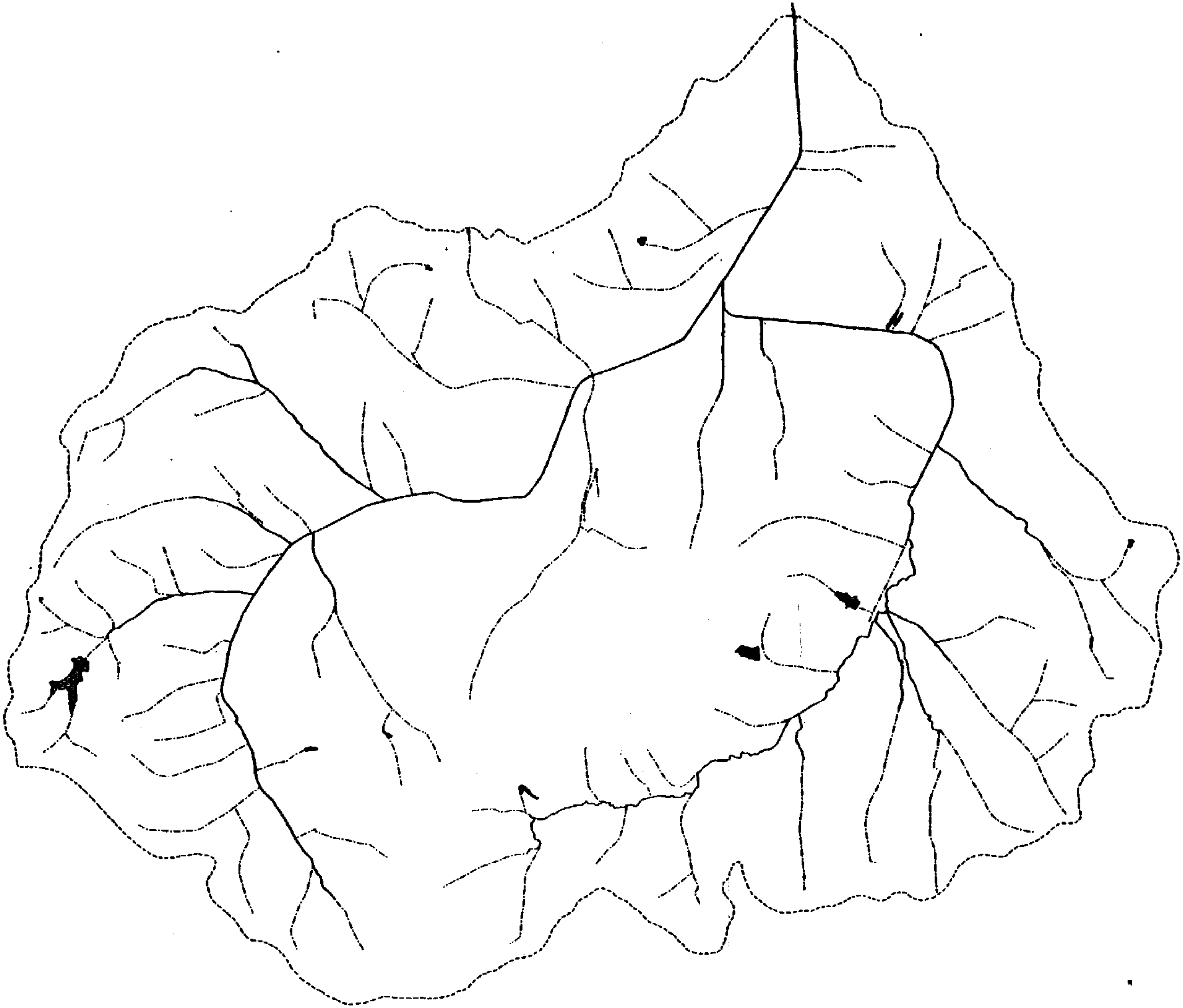


Figure 17. Stream Map of Cypress Creek Drainage Basin. Scale is Same as Figure 16.

adjacent wetlands and riparian ecosystems. The wetlands in the watershed were probably more extensive prior to channelization, but several wetlands are impounded behind artificial levees of the channelized streams.

Ecosystem Model - A conceptual model of the Cypress Creek ecosystem (Figure 18) demonstrates the effects of upstream mining activity on energy flow through the system. The communities found in this area are *Typha* marsh, scrub cypress, bottomland hardwood, and two creeks: Cypress and Little Cypress. This wetland area is considered a high quality area which supports populations of restricted or declining wildlife species (Harker *et al*., 1980).

The main canopy tree of the scrub cypress community is *Taxodium distichum* with scattered *Fraxinus profunda* (red ash) and *Acer rubrum.* The bottomland hardwood association, where flooding is only for a short period, is dominated by *Acer rubrum*, *Platanus occidentalis*, *Salix nigra*, and *Betula nigra*.

Major impacts on this wetland are channelization, agricultural activities, and mining operations. Both Cypress Creek and Little Cypress Creek have been channelized. Mining operations occur upstream from this system, causing some acid and sediment additions to the systems. Cypress Creek may act as a biological filter that reduces the effects of the upstream mining activity. Direct effects on the wetland have been through clearing for farmland and channelization of the streams.

Water Quality - Water quality data were collected from the Cypress Creek area much the same as it was for Henderson Sloughs. Samples were taken from the central channel, Cypress Creek, and from adjacent still wetlands, particularly a shallow cypress swamp. Sampling also occurred during high and low flow periods. The primary interest was to gain knowledge of the cumulative water quality for the drainage basin and to demonstrate wetland-stream interrelationships.

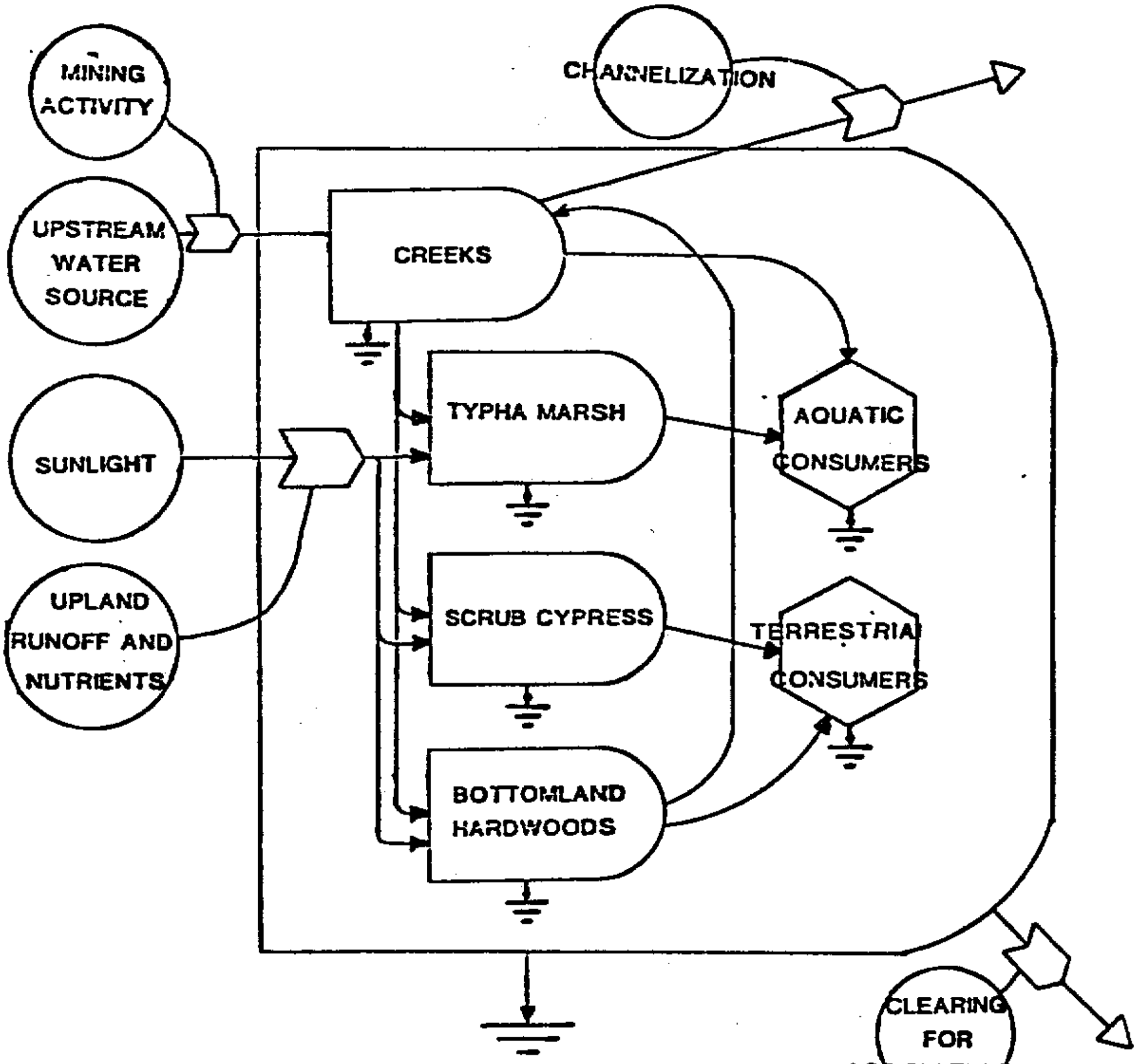


Figure 18. Ecosystem Model of Cypress Creek Wetlands

Table 8 gives water quality for the Cypress Creek area and Figure 10 shows sampling sites. Site 1 is located upstream on the western main fork of Cypress Creek. Site 2, located on the eastern main fork, and site 1 comprise the headwater samples for the entire system. Site 3 is located approximately 7 km downstream from the confluence of the eastern and western branches. Site 3B is located in a shallow cypress swamp adjacent to stream site 3. These two sites are known to be connected during flooding.

Turbidity values for Cypress Creek waters were normal throughout the sampling period with the exception of site 2 during the June flood. At this time waters of the east branch of Cypress Creek were particularly turbid. This may have been due to mining-related erosion or the urban influence of nearby Central City, Kentucky. Values for pH in Cypress Creek are surprisingly normal (6.3-7.4) despite the fact that other parameters suggest a lower pH. Surface mining effluents are probably neutralized upstream, resulting in higher pH readings. Water temperatures are in the expected range, elevated over the summer and lower in the fall. Dissolved oxygen seems to have reached peak values in September. Cypress Creek is unlike Henderson Sloughs, which had peak oxygen readings in July and showed lower values for September.

Conductivity and sulfate values for Cypress Creek show significant effects by coal mining. Disturbed substrate and mine runoff upstream of sites 1-3 probably caused increased values of these parameters in the stream water. Only at site 3B, which is less frequently affected by mine effluents, were the values near background levels in June and July. During September, water from the stream (site 3) flowed into the adjacent swamp (site 3B), increasing dramatically the levels of conductivity, dissolved oxygen, and sulfates in the wetlands. The wetland may be acting as a sink for certain mine wastes.

Table 8

Water Quality of Selected Sites in Cypress Creek Wetlands

Site Number	Date	Time (EDT)	Turbidity (NTU)	pH	Temperature (°C)	Dis.O_2 (mg/l)	Cond. (umhos)	$SO_4^=$ (mg/l)
1	20 June	10.45 A.M.	1.0	6.5	22.5	6.7	2750	----
	24 July	9:30 A.M.	1.3	6.6	26.5	6.2	2500	620.5
	18 Sept.	6:00 P.M.	1.2	7.2	19.0	11.4	2900	853
2	20 June	11:45 A.M.	10.0	6.5	22.0	7.5	2400	----
	24 July	10:15 A.M.	0.45	6.9	27.5	8.3	4500	482
	18 Sept.	5:30 P.M.	4.45	7.4	18.4	10.0	330	7895
3	20 June	12:15 P.M.	1.4	6.8	22.5	6.7	1700	000
	24 July	10:45 A.M.	0.85	6.9	26.8	5.1	2600	690
	18 Sept.	3:00 P.M.	0.45	7.1	17.0	8.0	2200	809
3B	20 June	1:00 P.M.	0.5	6.3	23.5	3.1	880	----
	24 July	12:15 P.M.	2.7	7.4	24.5	2.2	490	13.1
	18 Sept.	4:00 P.M.	0.9	6.8	17.5	7.1	2300	675.0

Vegetation - The Cypress Creek wetland system is a mosaic of swamps and marshes lying along both Cypress Creek and Little Cypress Creek. Three representative sites were chosen for vegetation analysis. Cypress Creek Site 1 is an extensive *Typha* marsh along Cypress Creek and adjacent to Route 70. Sites 3A and 3B are located near the Route 81 bridge over Cypress Creek. Site 3A is a riparian bottomland hardwood forest while Site 3B is an adjacent shallow cypress swamp.

Cypress Creek Site 1 lies directly downstream from an active surface mine. The marsh is almost totally *Typha latifolia* with only a few scattered small trees. The trees present are *Acer rubrum* and *Fraxinus pennsylvanica* and are only 1 to 3 m in height. Samples of *T. latifolia* were harvested in July for biomass determination. The average standing crop of the five sample, was 1060 grams dry weight per square meter.

The bottomland hardwood site 3A is part of a narrow band of riparian forest which follows most of Cypress and Little Cypress Creeks. The stream has been channelized through much of its length and, consequently, the restricted floodplain is frequently inundated for short periods. The forest floor is littered with large branches and fallen trees. Although the canopy is continuous, the forest is not dense with a total density of only 470 trees per hectare.

The site is dominated by Acer rubrum, present at all points and with an importance value of 115.1 (Table 9). The remainder of the tree species are present at 30% or less of the transect points, thereby lessening their influence upon the community. However, individuals of Platanus occidentalis (sycamore) are large (mean dbh = 45 cm) which increases their relative dominance and creates an importance value of 53.5. Importance values of less than 30 were calculated for all other species. Other canopy constituents are

Table 9

Structure and Composition of Vegetation at Cypress Creek Site 3A

Species	Relative Frequency	Relative Density	Relative Dominance	Importance Value
Acer rubrum	33.3	42.5	39.3	115.1
Platanus occidentalis	10.0	10.0	33.5	53.5
Salix nigra	10.0	7.5	11.4	28.9
Betula nigra	10.0	10.0	6.4	26.4
Liquidambar styraciflua	10.0	10.0	2.7	22.7
Fraxinus pennsylvanica	10.0	7.5	4.8	22.3
Ulmus americana	6.7	5.0	0.5	12.2
Carya cordiformis	3.3	2.5	0.6	6.4
Fraxinus profunda	3.3	2.5	0.5	6.3
Quercus palustris	3.3	2.5	0.4	6.2

Total Density (trees/ha) = 470
Total tree species = 10
Simpson's D = 0.79

Salix nigra (black willow), Betula nigra (river birch), and Liquidambar styraciflua (sweet gum). Principal understory trees are A. rubrum, Fraxinus pennsylvanica, F. profunda (pumpkin ash), and Ulmus americana. The tree community is relatively diverse. Ten species of trees were recorded with Simpson's diversity index calculated at 0.79. The herbaceous layer is moderately developed. In descending abundance, the primary species in that layer are Commelina virginica (Virginia dayflower), Leersia oryzoides, Rhus radicans (poison ivy), and Lobelia cardinalis (cardinal flower).

Cypress Creek Site 3B is a shallow cypress swamp adjacent to the flood plain of the stream. All living trees in the plot are Taxodium distichum. There are small dead trees of Acer rubrum and Fraxinus profunda along the transect and a few living individuals scattered in other parts of the site. Although the density of bald cypress trees is 795 trees per hectare, no canopy is formed. The trees are generally small, with a mean dbh of 10.9 cm, and are clustered in small groups. Only one tree greater than 20 cm in diameter was recorded (dbh = 47.2 cm) and 65% of the trees were less than 10 cm in diameter (Table 7). Cephalanthus occidentalis is the common understory constituent. The herbaceous layer is totally covered by Polygonum hydropiperiodes (smartweed) with occasional stands of Typha x glauca interspersed. The biomass of P. hydropiperoides was estimated to be 460 grams dry weight per square meter in July.

Clear Creek

Mapping and Classification - Figure 19 illustrates the major wetlands and other land uses in our Clear Creek Study area. Major wetlands, primarily mixed emergent marshes, are found along the main stem of Clear Creek where flow is sluggish and slow. Frequently flooded bottomland hardwood forests are found in narrow bands along portions of the marshes. Active and abandoned

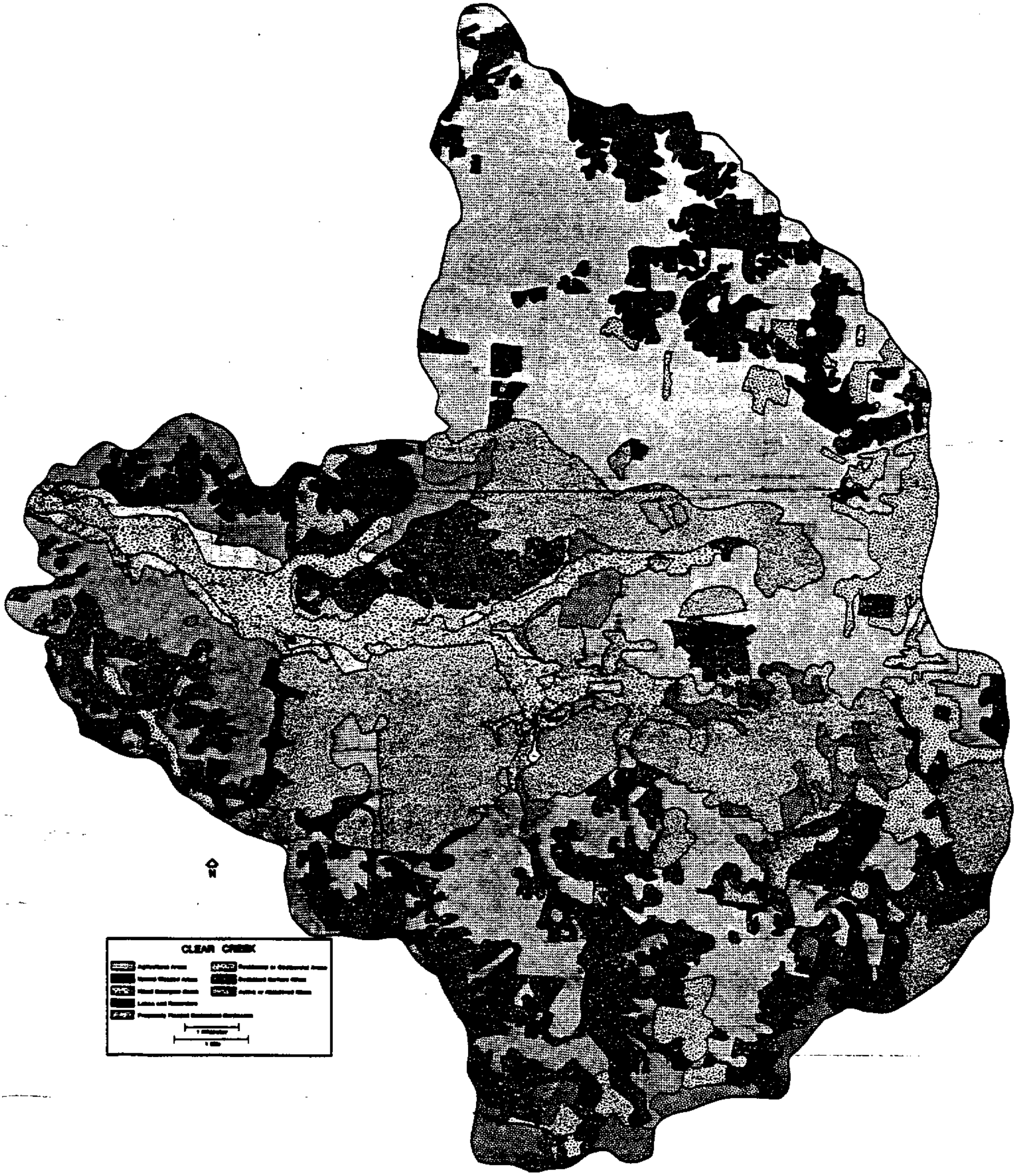


Figure 19. Wetland Map of Clear Creek Drainage Basin

coal mines dominate the southern half of the watershed while agricultural fields and upland forests are found in the northern third of the watershed.

Hydrology - The hydrology of this study site is dominated by the wide, slowly flowing Clear Creek. The major drainage pattern is shown in Figure 20. The creek flows into the Tradewater River, and water is often backed up in Clear Creek due to a very low gradient. Beaver dams have further contributed to flooding and sluggish flow in Clear Creek. Many tributaries to Clear Creek are channelized and drain agricultural and coal fields.

Ecosystem Model - Energy flow through a wetland affected by coal mining is shown in a conceptual model of Clear Creek Swamp in western Kentucky in Figure 21. The main autotrophic communities found in the Clear Creek system are a sweet gum community, birch/ash thicket, open water, and cattail marsh.

The sweet gum communities are dominated by mature, monospecific stands of *Liquidambar styraciflua* (sweet gum). There are three associations within the birch/ash thicket community. One association is predominantly *Betula nigra* (river birch) and *Acer rubrum* (red maple). The second association is characterized by *Fraxinus pennsylvanica* (green ash) and *Acer rubrum*. The third distinct association is composed of *Liquidambar styraciflua* and *Acer rubrum*. Open water areas are edged by the sedges *Eleocharis quadrangulata* (spike rush) and *Rhynchospora corniculata*. The dominant species of cattail found in the marsh areas is *Typha latifolia*.

The main forcing functions acting on the system are water flow (including nutrients) and sunlight. Mining, drainage management, and logging activities are the major impacts on the system. Mining can be divided into three types of impact: sedimentation, acid mine drainage, and destruction of the ecosystem by strip mining.

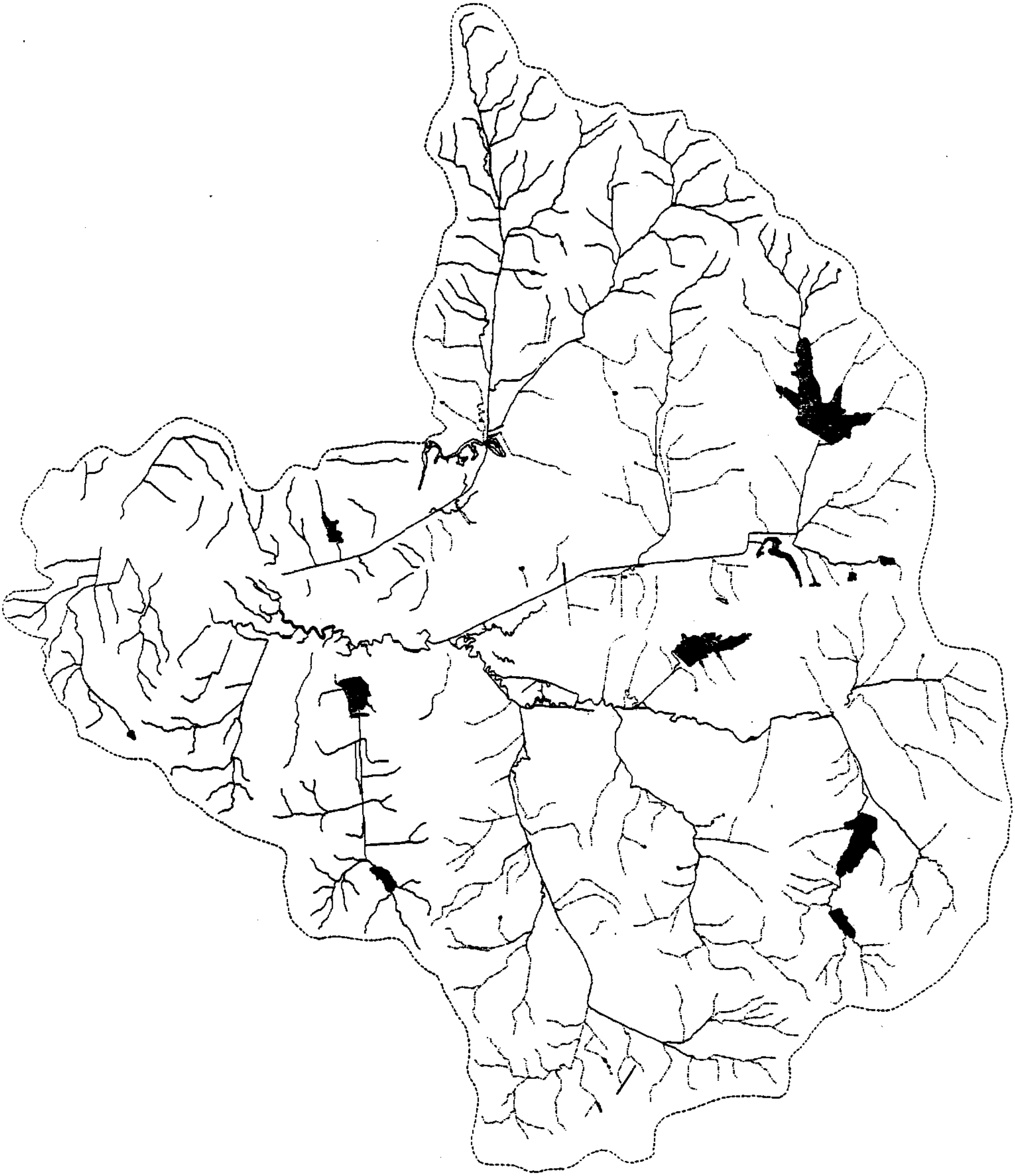


Figure 20. Stream Map of Clear Creek Drainage Basin. Scale is same as Figure 19.

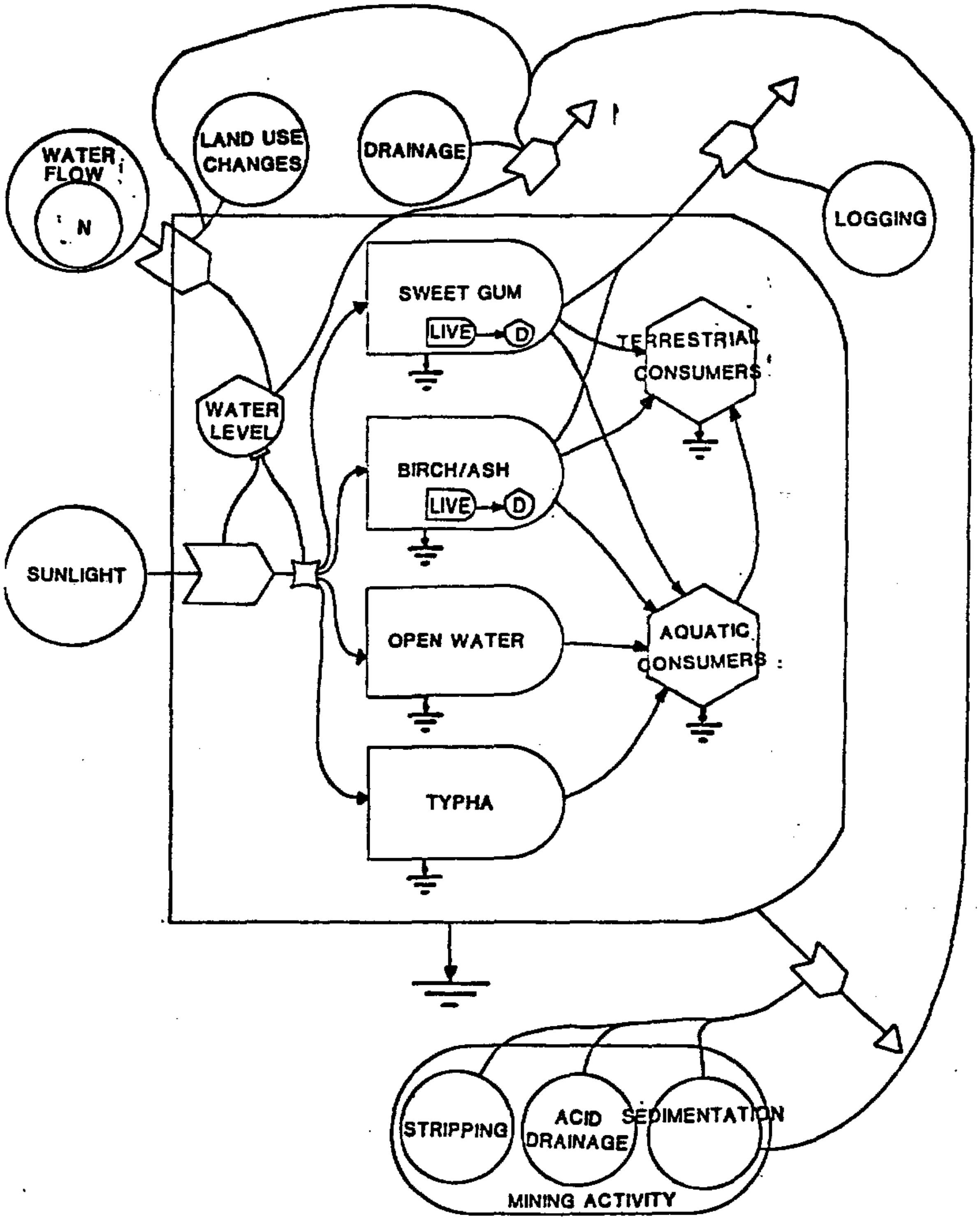


Figure 21. Ecosystem Model of Clear Creek Wetlands

Upstream land use changes also affect the flow of water and nutrients through the Clear Creek system. Inflow of water, which controls the water level of the wetland, affects the proportion of the system that makes up the various communities. This control is indicated in the diagram with a switching function. A successional change due to water level change is important in the flow of energy through the system. A storage of dead trees is shown in both the sweet gum and birch/ash communities due to the longevity of dead standing timber after water levels rise and kill the trees.

Water Quality - Water quality data were collected at three stream sites along Clear Creek swamp. These samples are thought to be sufficient in number since the entire area demonstrates little variability, being a patchy habitat throughout. This greatly contrasts with both Cypress Creek and Henderson Sloughs which have several definable wetland types distributed along a central channel.

Table 10 gives water quality data and Figure 11 shows the location of sampling sites. Site 1 is located upstream, site 2 is at midstream and site 3 is the downstream sampling point; all are within the central channel. No still swamp or marsh areas were sampled in this study area due to the unusually uniform structure of this system.

Turbidity data for the Clear Creek watershed present no unusual or unexpected values. Levels tend to increase slightly downstream. Values for pH indicate the severity of impact from surface mining in the Clear Creek basin. Values as low as 3.6 were recorded at site 1, rendering it sterile and uninhabitable to most aquatic organisms. Downstream, however, pH values seem to moderate but are slightly below optimal conditions.

Water temperatures were high over the summer (26-27°C) and began to drop by September. Open areas, such as sites 2 and 3, tended to exhibit higher

Table 10

Water Quality for Selected Sites in Clear Creek Swamp

Site Number	Date	Time (EDT)	Turbidity (NTU)	pH	Temperature (°C)	Dis.O_2 (mg/l)	Cond. (umhos)	SO_4= (mg/l)
1	19 June	4:20 P.M.	3.5	3.9	23.0	7.5	2100	—
	23 July	1:45 P.M.	0.4	3.8	25.0	5.1	2500	635
	19 Sept.	5:15 P.M.	0.3	3.6	17.3	6.0	3000	926
2	19 June	5:00 P.M.	0.6	6.4	25.0	6.5	2600	—
	24 July	10:30 A.M.	2.2	5.3	26.0	6.2	2800	578.5
	19 Sept.	4:45 P.M.	2.05	6.5	20.3	9.3	3500	666
3	19 June	5:45 P.M.	4.75	6.2	23.5	3.4	440	—
	24 July	1:00 P.M.	1.0	4.5	27.0	4.1	1100	569
	19 Sept.	5:50 P.M.	3.35	6.2	20.2	7.9	1400	612.5

reading than did site 1 which was shaded. Dissolved oxygen readings showed some fluctuation over the sampling period. The overall tendency was toward a peak in late summer.

Conductivity and sulfate values for Clear Creek exhibit the same severe influence of surface mining as did Cypress Creek. Extremely high conductivity and sulfate readings were recorded for all sites throughout the sampling period. Both parameters decreased slightly at site 3. During the June high water conditions, conductivity at site 3 was greatly moderated due to the diluting effect of flood waters.

Vegetation - Two sites of the Clear Creek wetland system were surveyed for vegetation. Clear Creek Site 2 is a frequently inundated bottomland hardwood forest located on the floodplain near Watson Bridge on Route 502. Clear Creek Site 3 is a permanently inundated mixed aquatic macrophyte community located downstream of site 2 south of the junction of Routes 1034 and 109.

An Acer rubrum-Liquidambar styraciflua (red maple-sweet gum) community dominates the floodplain of the middle portion of Clear Creek (Site 2). Acer rubrum, present at all transect points, and Liquidambar styraciflua, present at 80% of the points, are dominants of the canopy with a composite importance value of 245.7 (Table 11). Canopy species of much lesser importance are Betula nigra (river birch), Nyssa sylvatica (black gum), and Ulmus americana (American elm). Understory components (trees <4.0 cm dbh) are saplings of Acer rubrum and Ulmus americana. Along the stream border, which is represented by points at each end of the transect, Betula nigra increases in importance, often producing thickets of young trees.

Table 11

Composition and Structure of Vegetation in Clear Creek Site 2

Species	Relative Frequency	Relative Density	Relative Dominance	Importance Value
Acer rubrum	40	57.5	51.2	148.7
Liquidambar styraciflua	32	22.5	42.5	97.0
Betula nigra	16	12.5	4.8	33.3
Nyssa sylvatica	8	5.0	1.2	14.2
Ulmus americana	4	2.5	0.3	6.8

Total density (trees/ha) = 850
Total tree species = 5
Simpson's D = 0.62

Site 2 is frequently inundated. On sampling visits of June 19 and September 19, the site was covered by over 40 cm of water. On the sampling visit of July 24, the site was not inundated; however, the water level was very near the surface. Due to the extremely wet conditions and frequent floods, very few herbaceous species are present. Only sparsely distributed individuals of Pilea pumila (clearweed), Rhus radicans (poison ivy), and Carex sp. (sedge) were found on the July visit. Very few seedlings were noted at the site, also probably due to the frequent floods. The site, as a whole, is generally open, with a total density of approximately 850 trees/hectare. The litter layer is discontinuous due to the flushing of the floods. Deposits of ferric hydroxide are apparent throughout, especially where there are pools of standing water. The site also exhibits low diversity (D = 0.62) and low tree density compared with other bottomland hardwood sites.

Site 3 is a predominantly open body of water with a mosaic of monospecific beds of aquatic macrophytes scattered in shallow area. One of the dominant species in the area is Saururus cernuus (Lizard tail). The stands of S. cernuus are dense, with the plant spreading by means of rhizomes. Another important species at this site and in other parts of the wetland is Typha latifolia (common cattail). As another species which propagates vegetatively, it also occurs in nearly monospecific stands. Other species occupying less area at the site are Dulichium arundinaceum (three-way sedge) and Eleocharis quadrangulata (spike rush). Submersed in deeper water were occasional mats of Sphagnum sp. No estimation of areal cover of the vegetation at Site 3 was determined.

Biomass of herbaceous vegetation was determined for samples harvested in July. The dry weight of multiple samples per species was averaged and reported as mean dry weight in grams/square meter. Table 12 shows that Typha latifolia had the greatest standing crop with Saururus cernuus next in biomass. A great portion of the dry weight of these species was due to the large underground parts.

Table 12

Biomass of Aquatic Macrophytes at Clear Creek Site 3

Species	No. of samples	Mean dry wt. (g/m^2)
Typha latifolia	2	940
Saururus cernuus	3	785
Dulichium arundinaceum	2	610
Eleocharis quadrangulata	2	400

Wetland Simulation Model

At this point in the research, a simulation model was constructed and examined. The model, which is shown in Figure 22, encompasses only the aquatic portion of the wetland ecosystems. The compartments in this model are primary producers (PP), zooplankton (Z), fish (F), benthic invertebrates (BI), and detritus (D). Storages in the model are in kcal m^{-2}, while flows are in kcal m^{-2} y^{-1}. Energy sources to the system are light energy (S) for photosynthesis and allochthonous organic material (A) from the watershed, from the terrestrial component of the wetland, and from upstream. As with many shallow, aquatic ecosystems, the detrital food chain is regarded as being dominant over the grazing food chain. Acid mine drainage (AMD) is included as a controlling factor in the model; its influence is shown as lines to workgates on various energy flows. Effects of acid mine drainage are represented as increasing the stress on organisms through increased respiration, increased mortality, and decreased photosynthesis. Also, acid mine drainage is represented as causing a shift to a more detrital-based system; this shift is accomplished by increasing rates of detrital-feeding and decreasing rates of primary productivity. Such phenomena occur because of changes in species and detrital compositions due to increased acidity.

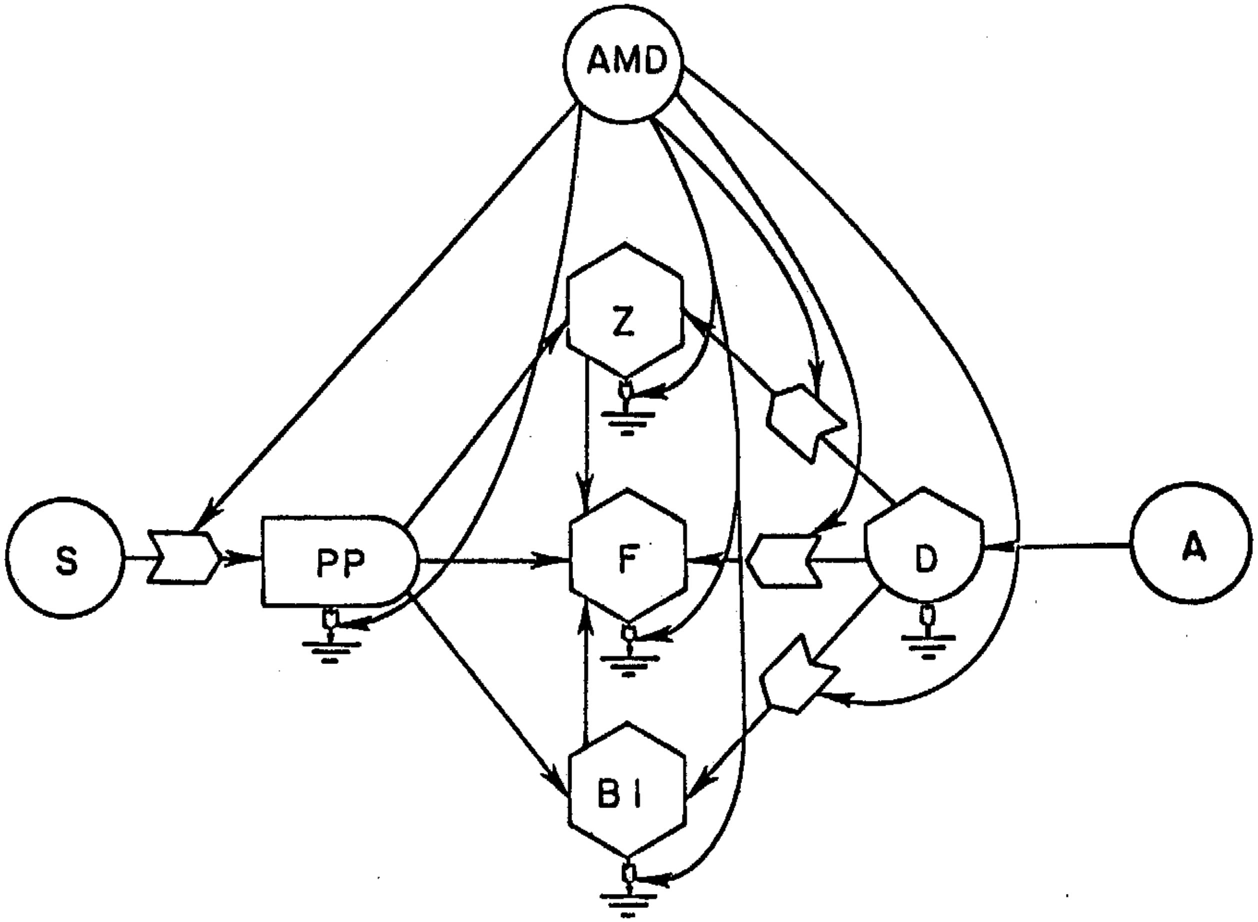


Figure 22. Simulation Model of Aquatic Portion of Wetland Ecosystem

In its present state, the model is linear and donor-controlled, indicating that fluxes between compartments are directly proportional to the size of the donor compartment. A more sophisticated and realistic model would have more complicated formulations. Values have been taken largely from the literature (Jorgensen, 1979; E.P. Odum, 1971) and represent 'within the ballpark' estimates. Initial conditions and rate parameters are shown in Table 13. As research progresses, data from field studies will be used to calibrate the model. Simulations were done in DYNAMO (Forrester, 1961; Pugh, 1970) and CSMP (IBM, 1968).

Table 13

Value of Initial Conditions and Coefficients in
Aquatic Ecosystem Simulation Model

Initial Conditions

PP	—	energy standing stock of primary producers	2000 kcal m^{-2}
Z	—	energy standing stock of zooplankton	500 "
BI	—	energy standing stock of benthic invertebrates	500 "
F	—	energy standing stock of fish	600 "
D	—	energy standing stock of detritus	3000 "

Coefficients

SPP	—	efficienty of light utilization	0.1 y^{-1}
PBI	—	grazing of primary producers by benthic invertebrates	0.1 "
PF	—	grazing of primary producers by fish	0.1 "
PZ	—	grazing of primary producers by zooplankton	0.1 "
RPPR	—	respiration of primary producers	0.5 "
S	—	input of light	20000 kcal m^{-2} y^{-1}
A	—	input of allochthonous organic matter	30000
DZR	—	eating of detritus by zooplankton	0.1 y^{-1}
ZF	—	eating of zooplankton by fish	0.1 "
RZR	—	respiration of zooplankton	0.5 "
BIF	—	eating of benthic invertebrates by fish	0.1 "
DFR	—	eating of detritus by fish	0.1 "
RFR	—	respiration of fish	0.5 "
DBIR	—	eating of detritus by benthic invertebrates	0.1 "
RBIR	—	respiration of benthic invertebrates	0.5 "
AD	—	conversion of allochthonous material into detritus	0.5 "
RD	—	respiration of detritus (with decomposers)	0.5 "

The effects of acid mine drainage are incorporated as factors (e.g., AMD = 0.75, 0.50, 0.25 and 0.0) that are multiplied by the affected energy flows. Each value of AMD represents a different level of effect; for example, when AMD = 1.0 there is no effect, and when the AMD factor is 0.0, the flow is completely shut off.

As the model presently exists, it is a hypothesis about the way that a general aquatic ecosystem operates; therefore, it should mimic the behavior of the aquatic portions of the study sites. Several experiments have been done by varying the way acid mine drainage affects the model. Effects of various levels of AMD on primary producers, detritus, zooplankton, benthic invertebrates, and fish are shown in Figure 23 a-d. The curves for AMD = 1.0 depict the normal simulation when no impact has occurred. Steady state values for various compartments are attained in 10-20 years. As the effects of acid mine drainage increase, primary producers decrease while detritus, zooplankton, benthic invertebrates, and fish increase. This phenomenon represents the shift towards a more detrital-based food web due to increased stress on the system. Steady state is reattained in 10 years.

A sensitivity analysis has been done by individually increasing various inputs and parameters 10% and assessing the effect on state variables. Results of these analyses are shown in Table 14 for different levels of acid mine drainage. Increasing solar input 10% has the greatest effect on primary producers and has no effect on detritus. On the other hand, increasing the input of allochthonous materials has the greatest effect on detritus but causes no change in primary producers. When there is no acid mine drainage (AMD = 1.0), the solar input causes larger changes than when there is acid mine drainage effect (AMD = 0.5). Conversely, changing allochthonous inputs causes greater changes when there is an acid mine drainage effect. These results reflect the shift to a detrital-based food web when impacted by acid.

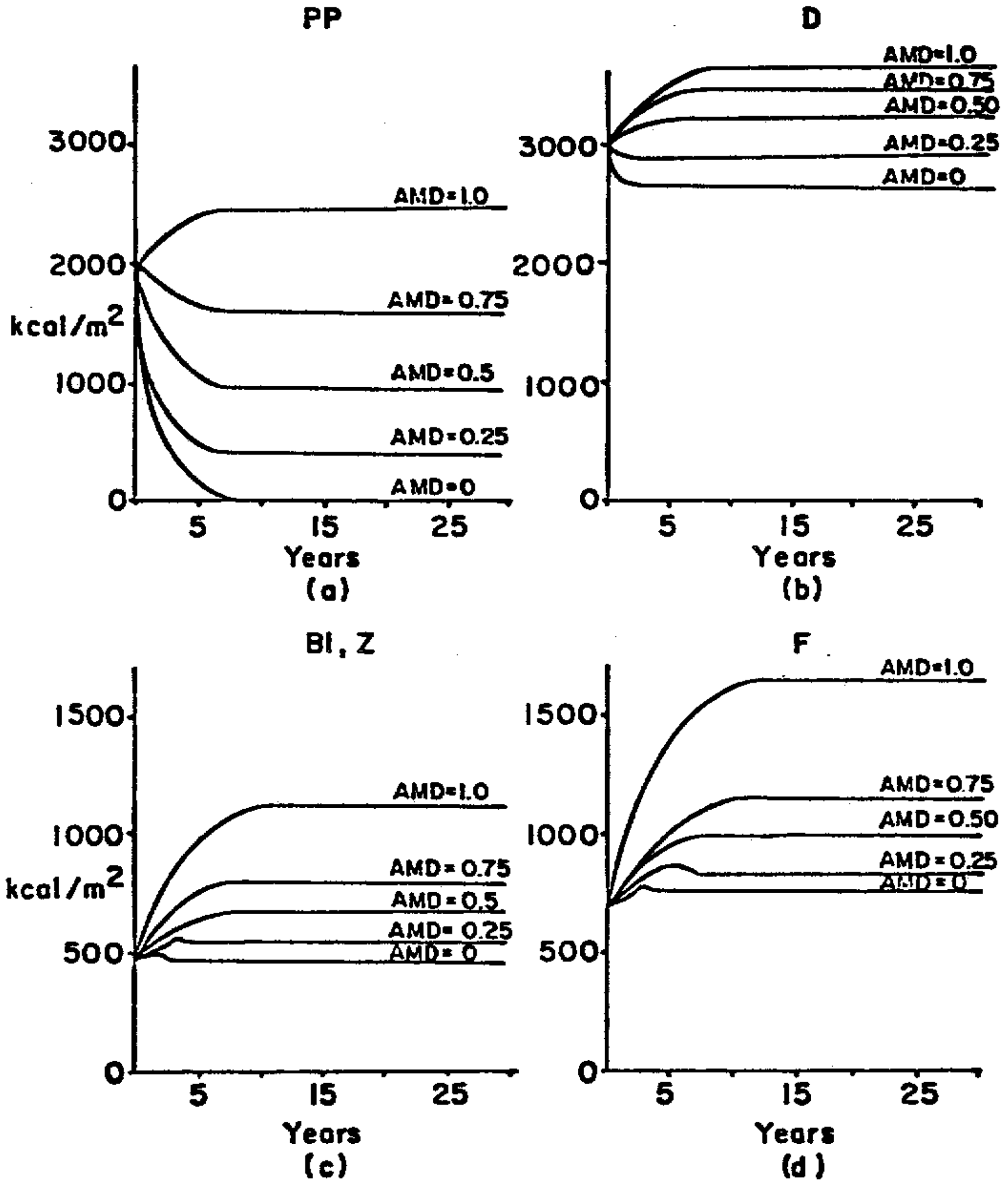


Figure 23. Simulation Results for Model for a) Primary Producers, b) Detritus, c) Benthic Invertebrates, Zooplankton, d) fish. AMD is acid mine drainage with AMD = 1.0 for no effect and AMD = 0.0 for complete effect.

Table 14

Sensitivity (% change) of Energy Standing Stocks to 10% Increase in Inputs of Light and Allochthonous Organic Matter

AMD = 1.0

Standing stocks (kcal m^{-2})	% Changes Due To Increasing Light	% Changes Due to Increasing Allochthonous Organic Matter
PP (Primary producers)	10.0	0
Z (Zooplankton)	3.9	6.0
F (Fish)	4.0	6.0
BI (Benthic Invertebrates)	3.9	6.0
D (Detritus)	0.0	10.0

AMD= 0.5

Standing stocks (kcal m^{-2})	% Changes Due To Increasing Light	% Changes Due to Increasing Allochthonous Organic Matter
PP	10.1	0
Z	1.8	8.4
F	1.7	8.3
BI	1.8	8.4
D	0.0	10.0

Five rate coefficients have also been increased 10% at two levels of acid mine drainage (AMD = 1, AMD = 0.75) in Table 15. These coefficients are DBIR (energy conversion efficiency from detritus to invertebrates), RPPR (rate of energy loss from primary production), SPP (photosynthetic efficiency of primary producers), RFR (rate of energy loss from fish), and AD (rate of energy storage in detritus from allochthonous materials). Results of these analyses are shown in Table 15. Increasing the parameters which control energy input to the system (AD, SPP) causes the largest changes in state variables. An increase in AD and SPP causes positive increases (or no change) in all

Table 15

Sensitivity (% change) of Energy Standing Stocks to 10% Increase in Selected Coefficients of Transfer Between Compartments

AMD = 1.0

Coefficient (y^{-1})	Description of Coefficient	% Changes in Standing Stocks				
		PP	Z	F	BI	D
DBIR	eating of detritus by benthic invertebrates	0.0	-1.0	0.0	5.2	1.2
RPPR	respiration of primary producers	-5.9	-2.4	-2.4	-2.4	0.0
SPP	efficiency of light utilization by primary producers	10.0	3.9	4.0	3.9	0.0
RFR	respiration of fish	0.0	0.0	-9.1	0.0	0.0
AD	conversion of allochthonous material into detritus	0.0	6.0	6.0	6.0	10.0

AMD = 0.75

Coefficient (y^{-1})	Description of Coefficient	% Changes in Standing Stocks				
		PP	Z	F	BI	D
DBIR	eating of detritus by benthic invertebrates	0.0	-1.0	-0.2	4.9	-1.1
RPPR	respiration of primary producers	-5.0	-1.5	-1.4	-1.5	0.0
SPP	efficiency of light utilization by primary producers	9.7	2.7	2.7	2.7	0.0
RFR	respiration of fish	0.0	0.0	-7.4	0.0	0.0
AD	conversion of allochthonous material into detritus	0.0	7.2	7.2	7.2	10.0

compartments. An increase in RPPR and RFR causes a decrease (or no change) in all compartments, whereas an increase in DBIR causes an increase in BI and decrease in Z, D, and F. Acid mine drainage decreases the sensitivity of the model to changes in all parameters except for changes in detrital availability. The model is more sensitive to changes in detrital availability in the model affected by acid drainage.

Two switches were added to the model to approximate a realistic situation management. The scenario is as follows: an undisturbed wetland at steady state is impacted by acid mine drainage at year 5. At year 10, the inflow of allochthonous materials increases 10% due to upstream mortality and increased runoff. At year 15, a management program is implemented and acid mine drainage is diverted or treated. The simulations of this model to 50 years are shown in Figures 24a and 24b. Only the simulations where AMD = 0.75 and 0 are shown since all other simulations are similar and between these two. At year 5, primary production begins to decrease immediately with the consumer levels falling after a short delay. The consumers do not decrease as much as might be expected due to an increase in detritus at year 10. Recovery begins at year 15 with an initial sharp increase and a slower recovery after year 20. The simulated system returns to steady state by the fiftieth year.

A similar model to the ones described above was constructed and simulated on an Apple II computer. Again, the model was largely linear and donor controlled, with the same compartments as in Figure 23. The Apple computer offers the advantage of graphically displaying results on a color TV. One can therefore set up various impact and management scenarios which can be quickly computed and visualized. An additional advantage is that the Apple II computer can be carried easily and can be set up for demonstration purposes. It therefore can be used as a valuable tool for educating wetland managers and

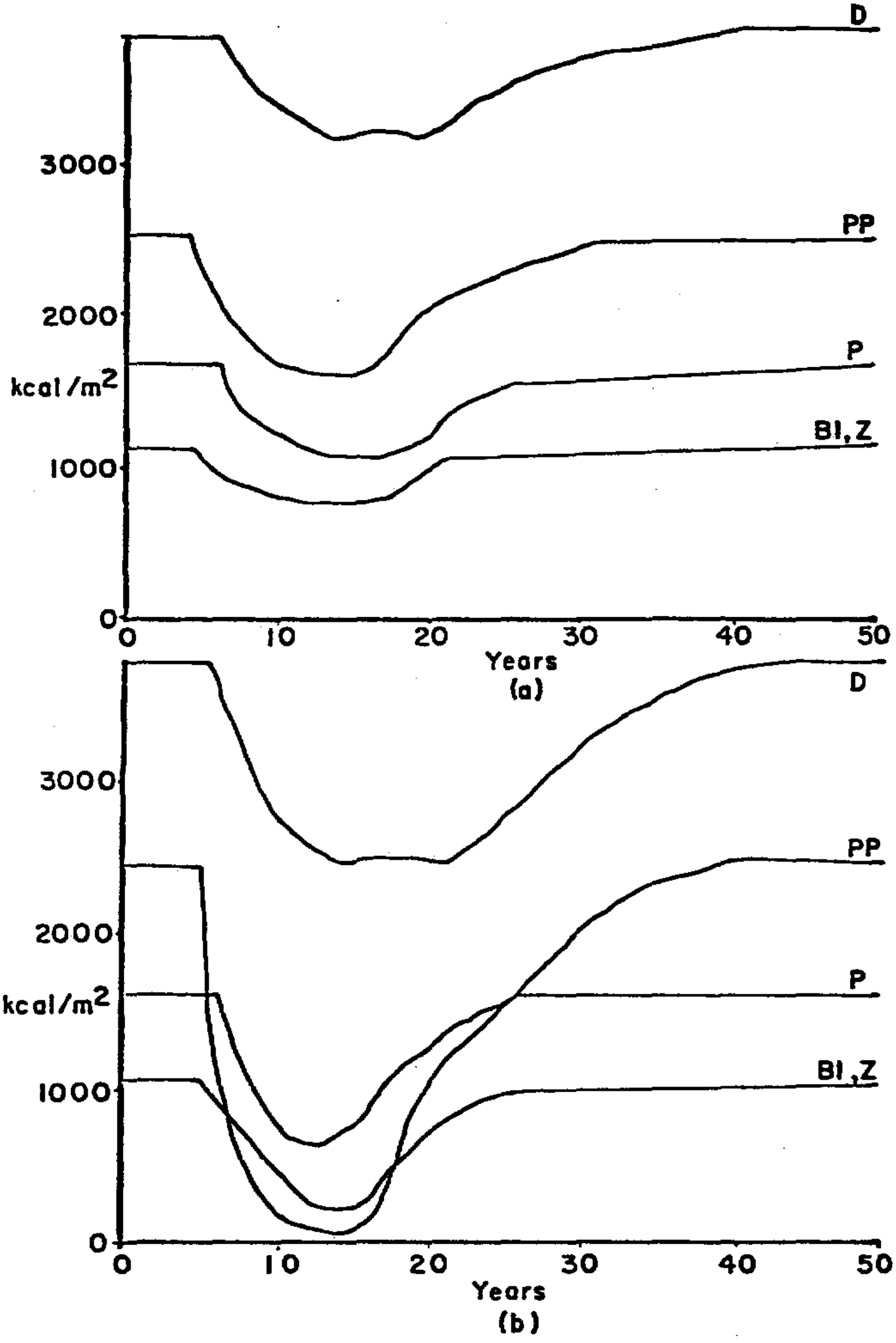


Figure 24. Simulation of model for acid mine drainage at year 5, increase in allochthonous organic matter input at year 10, and treatment of acid mine drainage at year 15. a) for AMD=0.75, b) for AMD=0.0.

public audiences. Results of manipulating a wetland can be assessed in a few minutes rather than waiting to see what happens in the real world. Ecosystem succession that often occurs in decades in reality can be simulated in seconds on such a computer. Such technology is inexpensive and relatively accessible to many agencies. It can easily be adapted for management purposes.

The Hierarchical Approach and Wetland Management

Management techniques and evaluation procedures are being developed that will correspond to the levels of organization identified in our hierarchical model (Figure 3). Careful coordination of these techniques is required in order to achieve a harmonious balance between natural and human needs.

Regional - At the regional level, which encompasses the entire western coal field, impacts involve the destruction or creation of wetlands through human activities. Managing the coal region should involve control of such variables as number, location, areal extent, and types of wetlands in the region. Certain wetland types are valuable components of the regional landscape because of recreational use, wildlife production, flood protection, water quality control, and lumbering. Other wetland types may contribute little to environmental quality of the region. Values of various wetland types must be assessed before their management can be accomplished. A number of techniques have been developed for evaluating wetlands (Wharton, 1970; Gosselink *et al.*, 1974; Mitsch *et al.*, 1979b; Schamberg *et al.*, 1980). These methods will be adopted or new techniques will be developed in order to properly assess the western Kentucky wetlands. The values of different wetland types can be incorporated into a scheme which examines the entire mosaic of ecosystem types in the region. Even if a particular wetland type is valuable in terms of wildlife production, an excess of such acreage can lower its value by adversely affecting the development of other land uses. Maintenance of an optimal acreage and distribution of each wetland type is a useful goal to be pursued at this level of organization. Maps of the wetlands and conceptual models such as shown in Figure 4 will be useful for generating such management strategies.

As with other biological phenomena, value with respect to the amount of total acreage of a particular wetland type in a region can best be described with a hump-backed curve (Figure 25). The value of a wetland type tends to increase with total acreage until an optimum is reached and then the value tends to decrease. An area which is too small provides suboptimal conditions for maintenance of wildlife diversity and production, recreation, and timber production (Odum, 1973; Smith, 1980). On the other hand, if the total area is too large, that wetland category competes with other useful land categories. Each land use type can be represented by a similar Value/Total Acreage curve. A strategy of management at the regional level would be to obtain an optimal mosaic of all land types, including various wetland categories. A curve which describes the value of a wetland category with a broad peak would be desirable in order to maximize flexibility in decision-making and to accommodate the diverse opinions of interest groups. An assessment of the wetland value in terms of desired acreage would be useful and should involve various government agencies, coal companies, researchers, and community leaders.

Wetland Reclamation - Another management strategy which can be pursued at the regional level is to reclaim wetlands from mined areas. Wetlands tend to develop in any location where a depression has been created in the ground and where water can accumulate. Indeed, many wetlands in the western Kentucky coal fields were originally established by man's activities in mining, highway construction, and water control. By applying simple reclamation techniques to

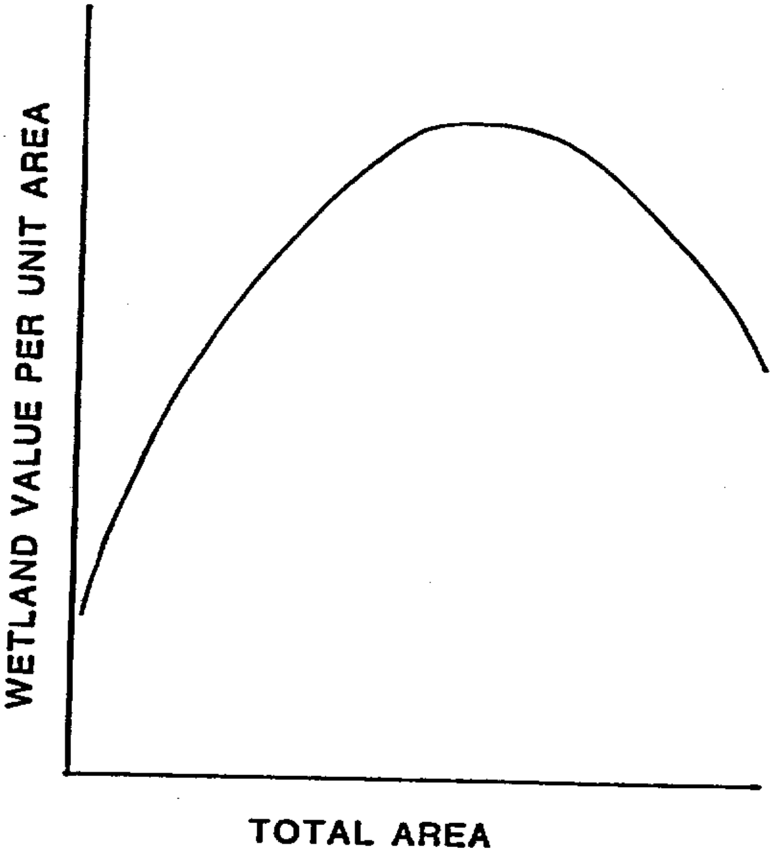


Figure 25. Possible relationship between wetland value and total area of wetlands to region.

mined lands, wetlands can be generated in an effective and economical fashion. Such techniques would include the establishment of depressions and holding ponds introduction of wetland species, modification of drainage patterns through channelization and levee construction, and maintenance of wetland/upland ecotones. These techniques would probably be more economical than traditional techniques of restoring the land to original contours and revegetating with a few species. A diverse mosaic of reclaimed ecosystem types would be more stable and more valuable than the undiverse ecosystems created by present reclamation techniques.

Watersheds - Management techniques at the watershed level involve the modification of runoff from surrounding lands and mined areas, of rivers associated with wetlands, and of water levels and water flow rates in the wetlands. Runoff from the surrounding watershed is a major source of water, nutrients, sediments, and organic materials for many wetlands. The magnitude of these sources affects productivity and diversity in aquatic situations. Sediments, for example, increase turbidity and abrasion and can thereby decrease primary and secondary production. Nutrients, on the other hand, tend to increase production and successional rates but decrease the diversity of species. Impacts of coal mining, lumbering, and highway construction are varied and include changes in sediment load and type, elemental concentrations, water level and water flow characteristics. Acid mine drainage, a common problem in mining areas, has deleterious effects on many organisms and processes in wetlands. Many of these effects can be reduced by diverting water to holding ponds where it can be held while sedimentation and biotic processes reduce the sediment load and harmful elemental concentrations. Such techniques are important if the potentially affected wetland is a valuable wildlife management area which is sensitive to this impact. However, rather than diverting water from wetlands, some wetlands can be used and maintained as interface ecosystems between man and other aquatic ecosystems in order to improve water quality before it goes further downstream (Mitsch, 1977). Wetlands tend to slow water movement, reduce sediment load, take up nutrients, and in other ways reduce the magnitude of effects that are transmitted through hydrological processes. The location of wetlands in relation to disturbed areas is important in considering their use in this regard. Again, evaluation of wetlands must be made in order to assess which wetland should be protected from particular impacts and which ones should be used to buffer impact.

Ecosystems - At the ecosystem level, the various impacts affect flows between ecosystem components. Certain components of a wetland ecosystem are more tolerant to such impacts than others. Organisms which are sensitive may be eliminated or substantially reduced, while others may become more abundant because of increased nutrients, reduced competition, or reduced predation. The sensitivities of various wetland components and processes must be assessed in order to make decisions about the management of wetlands at this level. Those organisms which are most sensitive and valuable should be protected, while those which are insensitive and invaluable may not need protection. Wetlands which are insensitive to impacts can be established and located in order to buffer the impact of activities. To an extent, many of these wetlands are self-designing and require little management; however, plants and animals can be introduced which tolerate the modified conditions in impacted marshes. Typha, the cattail, and other aquatic plants can be introduced successfully into a wetland. Other reclamation techniques which should encourage colonization of organisms are the addition of treated sewage wastewater and fertilizers or lime to wetlands and other reclaimed areas or the creation of corridors through which immigrating organisms can pass. Addition of sewage materials would stimulate productivity, alter successional rates, and indirectly reduce effects of acid mine drainage; it would also provide a use for some of the municipal wastes that are accumulating in Kentucky's cities. Sewage recycling with wetlands has already been successfully demonstrated in Florida (Odum _et al._, 1977; Deghi _et al._, 1980) and Michigan (Kadlec _et al._, 1977).

Management strategies should also include pathways and rates of succession in wetlands. Ecosystems are not static objects but will eventually change into another ecosystem type through successional processes. By identifying the successional sequences and the factors affecting them, management strategies can be adopted which accelerate, or set back, successional states in order to maintain the most valuable types of habitat and species composition.

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