Daniel E. Kroes. **OCCURENCE OF JURISDICTIONAL WETLANDS ON RIVERINE FLOODPLAINS ALONG A CLIMATIC GRADIENT.** (Under the direction of Dr. Mark M. Brinson) Department of Biology, February 2001.

The purpose of this study is to examine the relationship between the occurrence of jurisdictional wetlands in floodplains and the water balance of climate along a humid to arid continuum. Two regions were studied. The first included 36 mid-reach streams encompassing an area from Cope, Colorado to Chariton, Iowa. This region was chosen because of the broad range in potential evapotranspiration (PET) ratio, from 0.70 to 1.75. The second included 16 headwater streams in eastern North Carolina with PET ratios ranging from 0.83 to 0.67. PET ratios were estimated using Holdridge's life zone formula based on precipitation and temperature data at nearby sites. Wetland boundaries were determined using field delineation along transects perpendicular to the direction of stream flow. The width of jurisdictional wetlands was compared with flood-prone width (FPW) and expressed as a percent. Streams with a PET ratio greater than 0.98 did not have wetlands associated with them. PET ratio was the most important factor in wetland and vegetation occurrence. Soil texture, duration of overbank flow, and stream order did not correlate with percentage of FPW that was wetland. An increase in PET ratio resulted in an exponential decrease in the percentage of the FPW that is wetland. Greater channel cross-sectional areas correlated with greater wetland widths in both study regions. As the precipitation in the central plains decreased, the number of prevalent woody species decreased. In North Carolina the number of prevalent woody species decreased as the PET ratio decreased. Hydrologic sources differ between the central plain floodplains and those of the North Carolina floodplains. North Carolina coastal

plain riparian wetlands are formed and maintained by groundwater. Increasing stream order corresponds to wetter conditions on the floodplain. In the central plains, the exponential trend in the percentage of the FPW that is wetland indicates positive feedback between groundwater and streamflow. Wetland status of riparian floodplains in the central plains relies upon this feedback.

OCCURRENCE OF JURISDICTIONAL WETLANDS ON RIVERINE FLOODPLAINS ALONG A CLIMATIC GRADIENT

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Master of Science in Biology

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Daniel E. Kroes
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Table of Contents

List of Tables

List of Figures

Introduction

It is important for us to expand our knowledge of the factors that control and maintain riverine wetlands in order for us to more fully understand the impact of our activities upon them. The climatic control of riverine wetlands has largely been overlooked, particularly in subhumid regions. The vast majority of floodplain wetland studies have been conducted either on streams located in humid regions that are fed by local sources or in arid regions receiving flows from the mountains (Auble et al. 1994, Shafroth et al. 1998). The factors (overbank flow duration, stream order, drainage basin area, and soil) believed to control riverine wetland development and maintenance have been conceived at the extremes of the climatic gradient without considering the intermediate subhumid to humid condition. Most of these factors have not been studied along a climatic gradient from regions where the streambed itself lacks the hydrologic regime of a wetland, to regions where the majority of the floodplain is wetland. This study examines the occurrence of wetlands along a humid to subhumid gradient.

Along any latitudinal cross section of the United States, there is a distinct change in vegetation and runoff caused by the interaction of precipitation and evapotranspiration (ET). From the naturally forested Atlantic Coast, the climatic potential to support forests on uplands continues westward until approximately 95° to 97° west longitude. Between 95° and 97° west longitude natural upland vegetation undergoes a gradual change from upland forest to tall grass prairie due to a reduction in precipitation (Kuchler 1967). The zone of change from forest to tall grass prairie has been historically modified and maintained by fire. Wet and dry periods result in decreased and increased frequency of fire causing the forest / tall grass prairie transition zone to move west and east.

Gallery forests along high order streams in the central plain states of North America represent the western-most extent of eastern deciduous forests (Abrams 1985, Rice 1965). Gallery forests develop in the parts of a drainage basin where fire becomes infrequent due to increased water supplies (Abrams and Gibson 1991). Low order stream channels in subhumid grasslands do not originate under forested canopies. In prairie, the support of canopy trees along higher-ordered streams is associated with the decreased fire frequency in the riparian corridor (Reichman 1987).

Just east of the Rocky Mountains, tall grass prairie is replaced by short grass prairie. Arid and semiarid regions generally occur at lower elevations among mountain ranges separated by higher altitude montane forests, although there are many exceptions to this generalized vegetation pattern. Exceptions include more moist climates of higher altitudes and windward sides of the Rockies and Sierras, along the Pacific Coast, and the Pacific Northwest (Kuchler 1967, USDC 1968, Bailey 1976). The longitudinal pattern of vegetation described above is greatly influenced by the relationship between actual ET and precipitation (Kuchler 1967, Holdridge et al. 1971).

Actual ET is the amount of water that is evaporated and transpired from all surfaces (plant, soil, water, etc.). Potential evapotranspiration (PET) is the maximum amount of water that could potentially be evaporated and transpired from plants and surfaces at a given temperature and / or degree of solar radiation regime if there were no limitation in water supply. The relationship between PET and precipitation can be best visualized utilizing the PET ratio (PET divided by precipitation). A PET ratio of 1.0 indicates a balance between PET and precipitation. Subhumid climates have a PET ratio greater than 1.0, grading to arid as the ratio increases. Vegetation reflects this change by a species change toward increasing tolerance of dry conditions. Humid climates have a PET ratio less than 1.0, grading to superhumid as the ratio decreases with vegetation species changing towards a decreasing tolerance of dry conditions (Figure 1). Likewise, flow in streams can be linked to climate (rainfall and ET) assuming that there are no overriding effects caused by geomorphology or geology (Figure 2) (Riggs and Harvey 1990, Mitsch and Gosselink 1993). In order to evaluate the relationship between precipitation and streamflow, consider a hypothetical watershed that is homogenous in precipitation and ET. The soils of the watershed act as a reservoir for storage of water and subsequent release as ET, and depending on certain conditions, may discharge groundwater to the stream.

Augmentation or reduction of baseflow (the discharge in a stream not related to storm activity) or the duration of overbank flow by any of several conditions can cause streamflow to depart from the ideal, hypothetical, climatically controlled condition. This departure may allow riverine wetlands to be maintained in a climate or hydrologic setting where they might not otherwise exist, or wetlands might not exist in areas where they could normally. Conditions that may cause departure from normal include watersheds with low permeability surfaces and supplementation of streamflow. Watersheds with low permeability materials have a higher percentage of runoff resulting in lessened groundwater recharge and ET (Riggs and Harvey 1990). Watersheds with areas of low

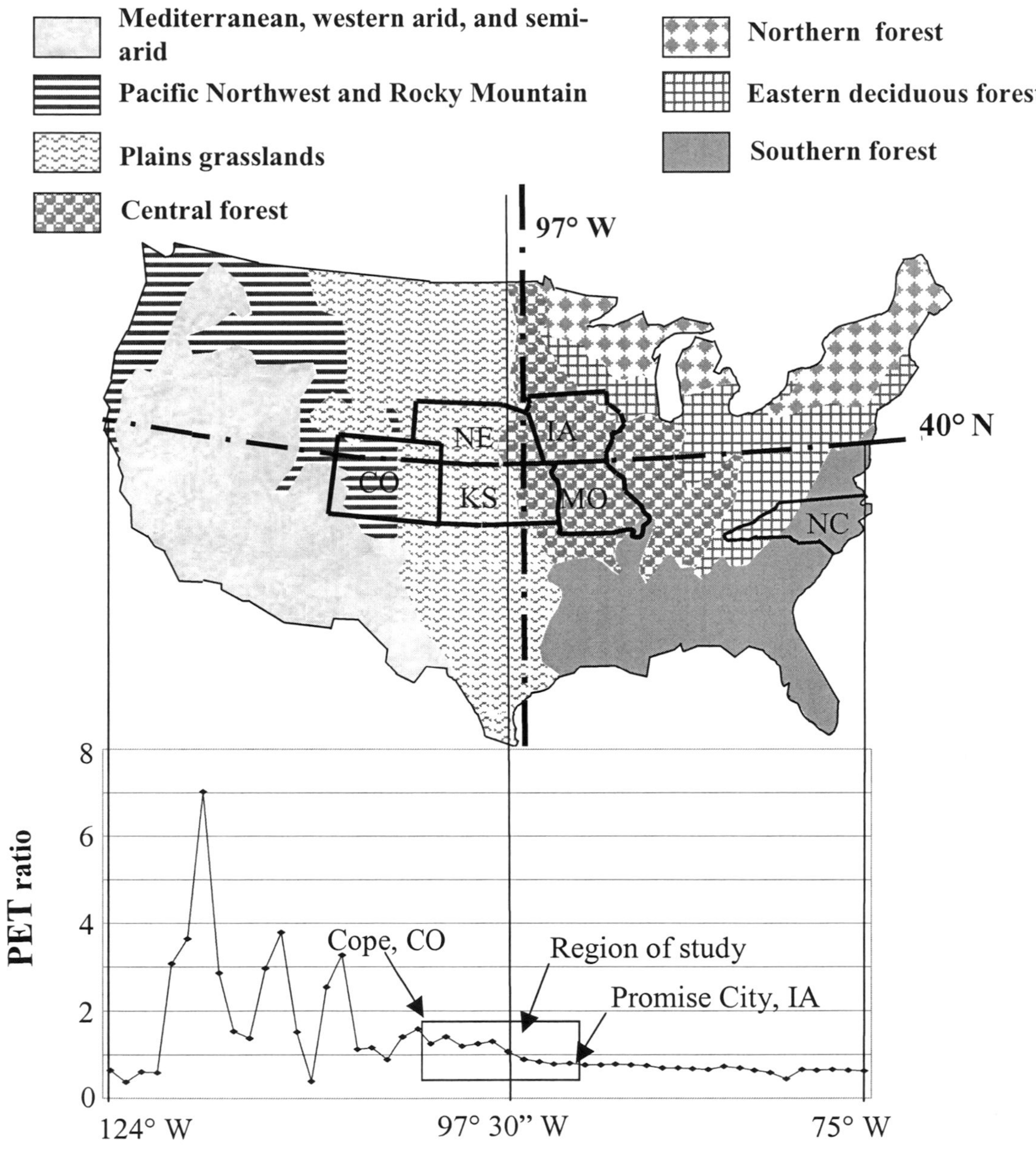

Figure 1. The vegetation regions of the United States as compared with the PET ratio along 40° N latitude, modified from Bailey (1976). PET ratios remain fairly constant between the east coast and about 97° W until precipitation begins to decrease in the rain shadow of the Rockies. The western limit of upland forest coincides with the PET ratio of 1.0.

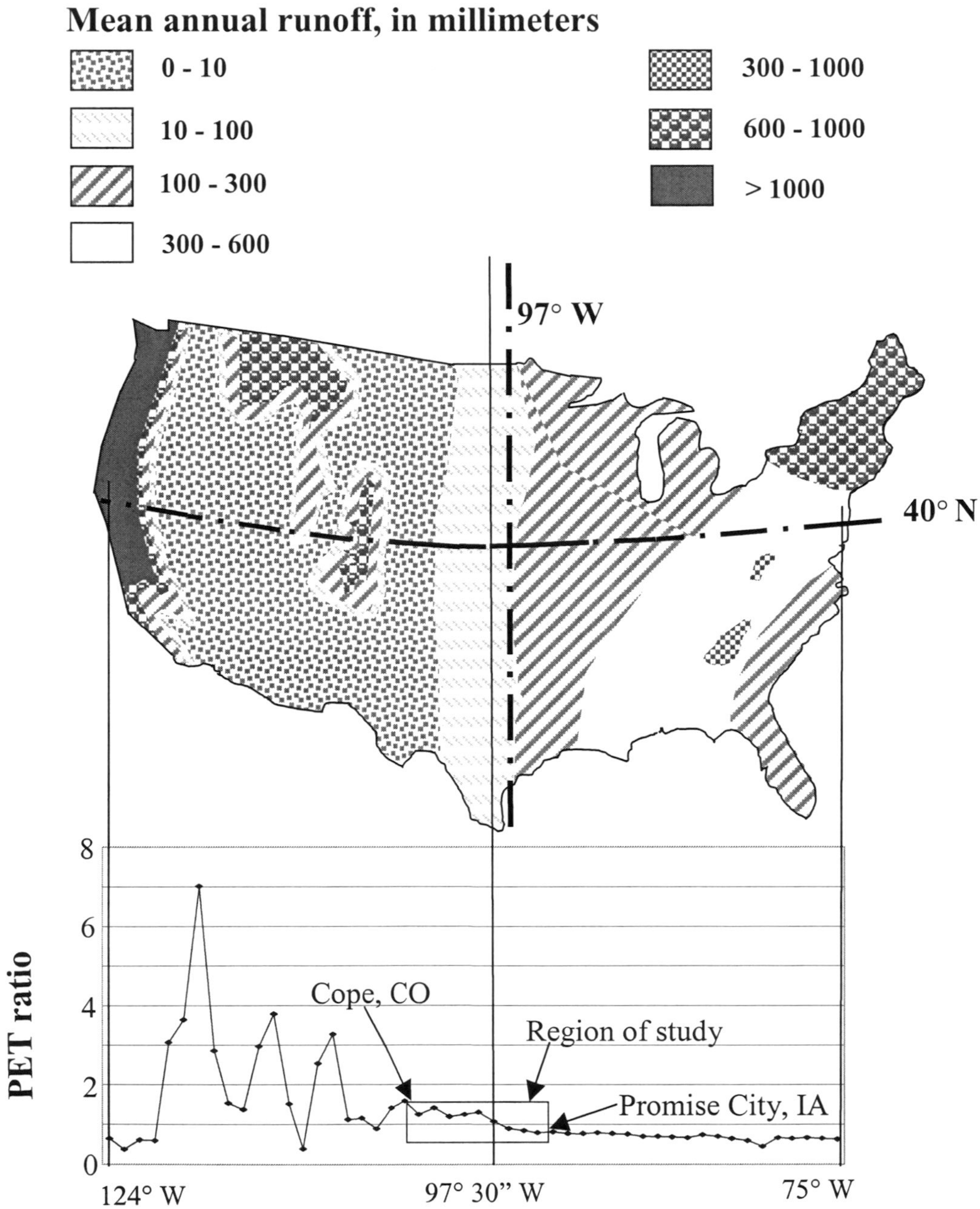

Figure 2. Mean annual runoff as compared with the PET ratio, modified from Riggs and Harvey (1990). Runoff decreases with increasing PET ratios. When compared with Figure 1, the transition from forested to grass dominated uplands occurs at slightly less than 100 mm of runoff per year.

permeability tend to have increased magnitude of flood discharge and shorter durations of stormflows when compared to watersheds with highly permeable soils. An example of low permeability watersheds can be seen along streams in areas with clay soils, such as the Brazos River, Texas (NWS 1995).

Deep aquifer discharge can supplement streamflows through springs. Supplemented streamflow can also be found at any stream receiving significant return flow from irrigation. If a stream has parts of its drainage basin in the mountains, glacial melting and montane snowmelt can represent water sources originating from a different physiographic region. Water from these sources increases baseflow and the duration of overbank flow beyond what downstream segments could otherwise support. Supplementation of flow may support areas otherwise not hydrologically suited for riverine wetlands. The Platte River, receiving discharge from the Rocky Mountains, supports riverine wetlands in regions where few would be without supplemented flow (Johnson 1998, USFWS 1998a).

Geomorphic Features and Their Relationship to Discharge

Bankfull discharge is the maximum water transporting capacity of a stream channel, beyond which inundation of some portion of the flood-prone area (FPA) occurs (Figure 3). The FPA is the area contained within twice the vertical distance from the deepest point of the channel (thalweg) to the top of the stream bank (bankfull). On average, this inundation of the FPA occurs at an interval of 1.5 years in the United States, with a variable duration (Leopold et al. 1964).

The return interval of bankfull stage is influenced by many factors. For some

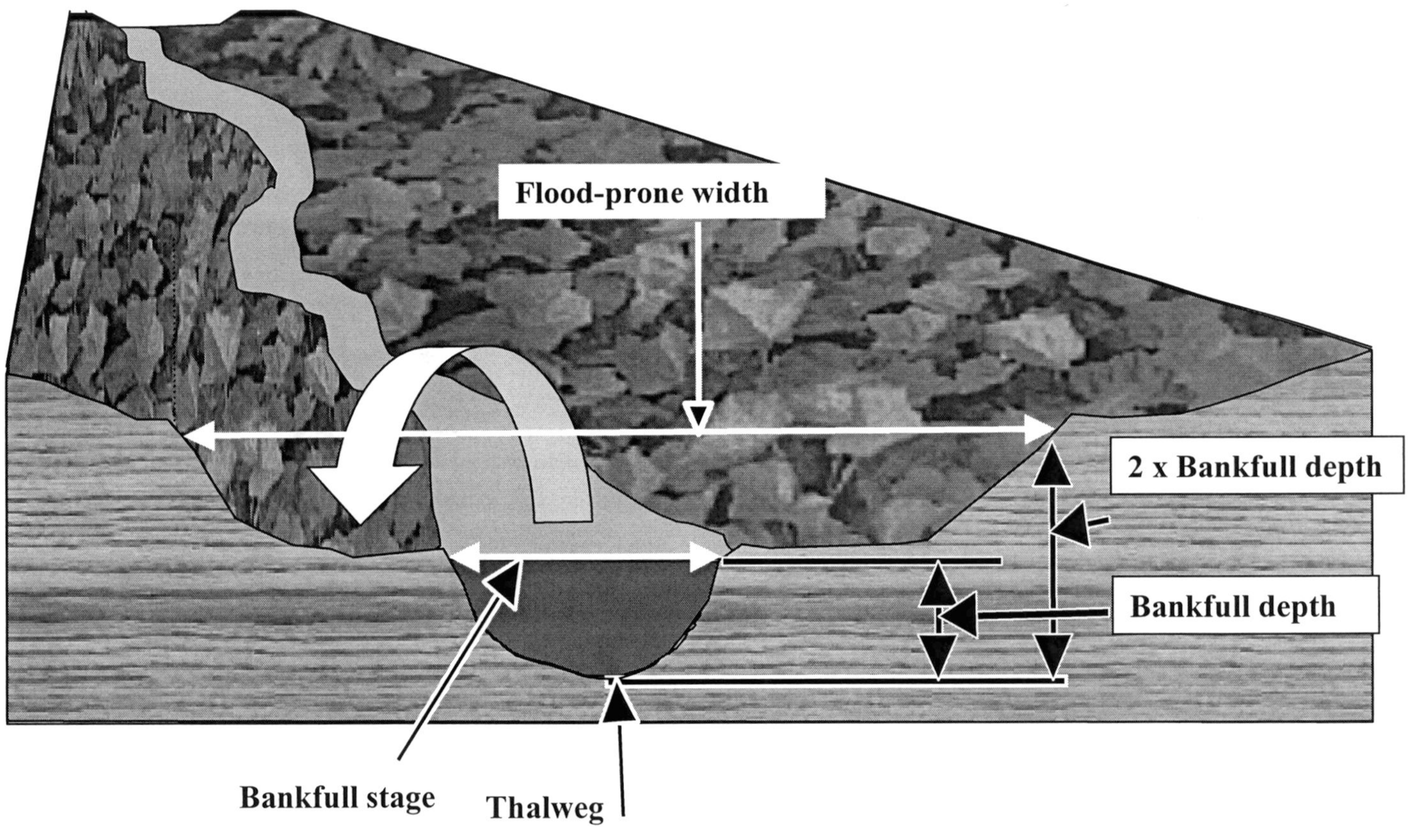

Figure 3. Bankfull discharge of a stream is the discharge required to fill the active channel. Discharges greater than bankfull result in inundation of some portion of the floodplain.

streams in arid regions, the return interval may be greater than 30 years due to extreme variability in precipitation events (Leopold et al. 1964, Williams 1978, Leopold 1994, Rosgen 1996). Often, a longer return interval of bankfull stage is a result of a disequilibrium in sediment load or discharge resulting from an entrenchment of the stream into the alluvium (Leopold 1994, Burke and Nutter 1995). For example, as soil is eroded from uplands it may become deposited on floodplains and streambeds resulting in a higher relative elevation for both the floodplain and streambed, initially resulting in greater and more frequent flooding (Trimble 1970). When the upland soils are stabilized, the output of sediment from the stream system exceeds the input. This disequilibrium causes the stream to erode the streambed first and the floodplain later. Until a new floodplain is formed at a level supported by floodplain forming discharges, there is an abnormally deep stream channel that requires a greater discharge to reach bankfull stage. This abnormally deep channel results in longer return intervals and greater elevational differences between the water surface and floodplain surface (Figure 4). The reduced duration and frequency of flooding and elevational differences may negatively impact wetlands as the hydroperiod (duration of saturation) of the floodplain is reduced.

The duration of overbank flow is influenced by many factors including drainage basin area and configuration. Drainage basin area greatly influences the magnitude and duration of flooding (Leopold 1994). Larger drainage basins tend to have greater flood duration and magnitude than smaller drainage basins with the same overbank return interval. Somewhat related to drainage basin area is stream order. High order streams in a drainage basin generally have greater flow year round than lower order streams with

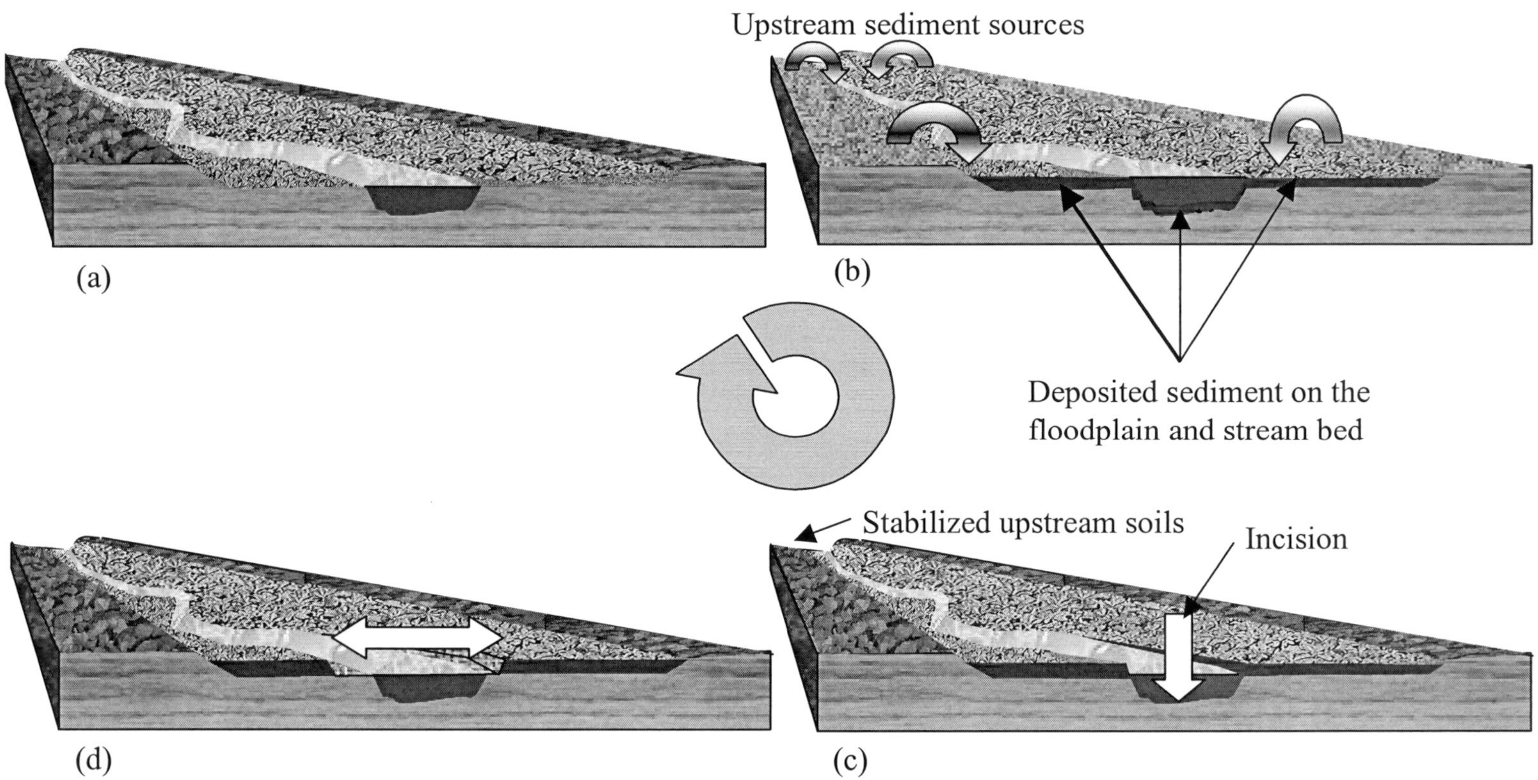

Figure 4. The process of entrenchment can be triggered in many ways, one of which is destabilization of uplands. (a) An undisturbed stream and floodplain. (b) When upland soils are destabilized, the rate of sedimentation is increased into the stream system resulting in an increased base level and flooding. (c) When uplands are stabilized, or the rate of sediment output is decreased, the stream erodes the bed. This results in an abnormally deep bankfull stage (entrenchment). (d) Over time the stream will form a new floodplain, leaving the old floodplain as a terrace (after Leopold 1994).

relatively comparable basin characteristics. The gaining (groundwater contribution to streamflow) or losing (streamflow contribution to groundwater) nature of the stream may also influence flood duration. Losing streams tend to have a shorter duration of flooding than gaining streams due to the loss of stream discharge to the groundwater system (Figure 5) (Fetter 1980, Heath 1983). These factors (drainage basin area, stream order, and the gaining / losing nature of the stream) may have an influence on the formation and maintenance of floodplain wetlands.

Wetlands on Riverine Floodplains

Fluvial processes create floodplains that are transitional between uplands and the stream. Floodplains tend to be wetter than the surrounding uplands due to their lower geomorphic position and their proximity to the water table and stream channel. Wetland portions of floodplains are regulated under the Clean Water Act as waters of the United States. However, portions of many floodplains do not always fall into the jurisdictional wetland (hereafter referred to as wetlands) category as defined by the US Army Corp of Engineers (USACE) (Environmental Laboratory 1987).

Riverine wetlands differ from other types of wetlands in that they occur in flood-prone areas (FPA) and riparian corridors associated with stream channels (Brinson 1993a). Because of the association of riverine wetlands with stream channels, the throughput and transformations of nutrients, sediments, and water are generally much greater than most other wetland types. The dominant sources of water for riverine wetlands are overbank flow and groundwater discharge. Additional water sources may include precipitation, interflow (unsaturated groundwater flow), and overland flow from

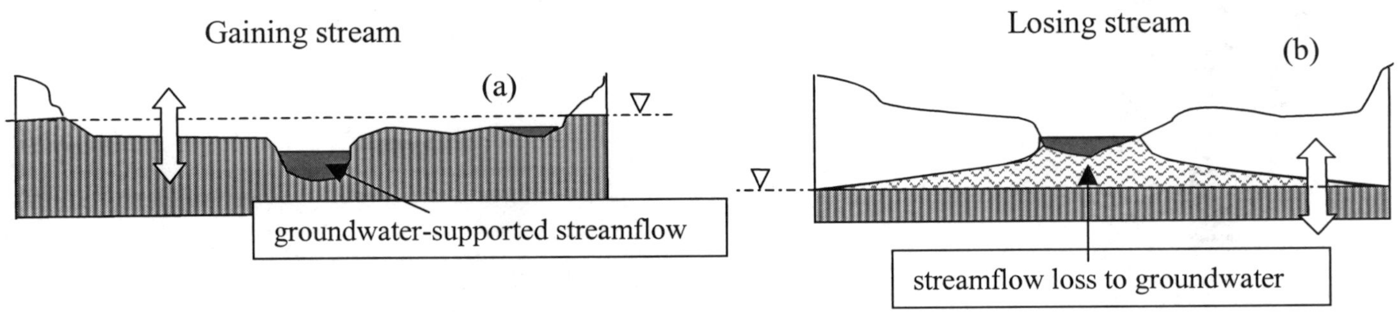

Figure 5. Cross-sections of streams contrasting mechanisms of floodplain hydrologic regimes. (a) In regions where groundwater levels are high, streamflow is maintained by groundwater (gaining). (b) In regions where groundwater levels are low, streamflow is lost to the groundwater table (losing). Vertical arrows depict the range in water table levels. ∇ = water table level.

adjacent uplands (Brinson 1993b). The hydrologic regime of floodplains are partially determined by the period of time at which the discharge of the stream exceeds bankfull, with flooding ranging from being nearly permanent to intermittently inundated or saturated (Larson et al. 1981). In arid climates, overbank flow and groundwater recharge from the stream channel may support wetlands in FPAs along perennial streams. Rare, perennial streams in arid regions are usually fed by water from springs or from areas outside the arid area (mountains, humid regions, etc.) (Agnew and Anderson 1992).

The National Wetlands Inventory (NWI) maps (Figure 6) can be used to remotely estimate the extent and area of riverine wetlands at study sites similar to the approach used by Cashin (1990) and Stolt and Baker (1995). However, NWI maps may not be accurate due to inaccuracies created during the mapping process of remotely sensed data and the inability to distinguish small wetland areas (Stolt and Baker 1995). Riverine wetlands are especially subject to this inaccuracy due to their narrow width.

Wetlands are jurisdictionally delineated by evaluating vegetation, soil, and hydrology. To be considered hydrophytic, vegetation in wetlands must be adapted to saturated or inundated conditions (Tiner 1991). The indicator status of hydrophytes adapted to these conditions is listed in regional publications of the US Fish and Wildlife Service (Reed 1988). Hydric soils develop under conditions where soil oxygen is depleted in response to saturated conditions over long periods of time during the growing season. In order for an area to meet the hydrologic requirement for a wetland, soil must be continuously saturated within 30 cm of the surface for 14 days of the growing season, for greater than 50 percent of years (Environmental Laboratory 1987).

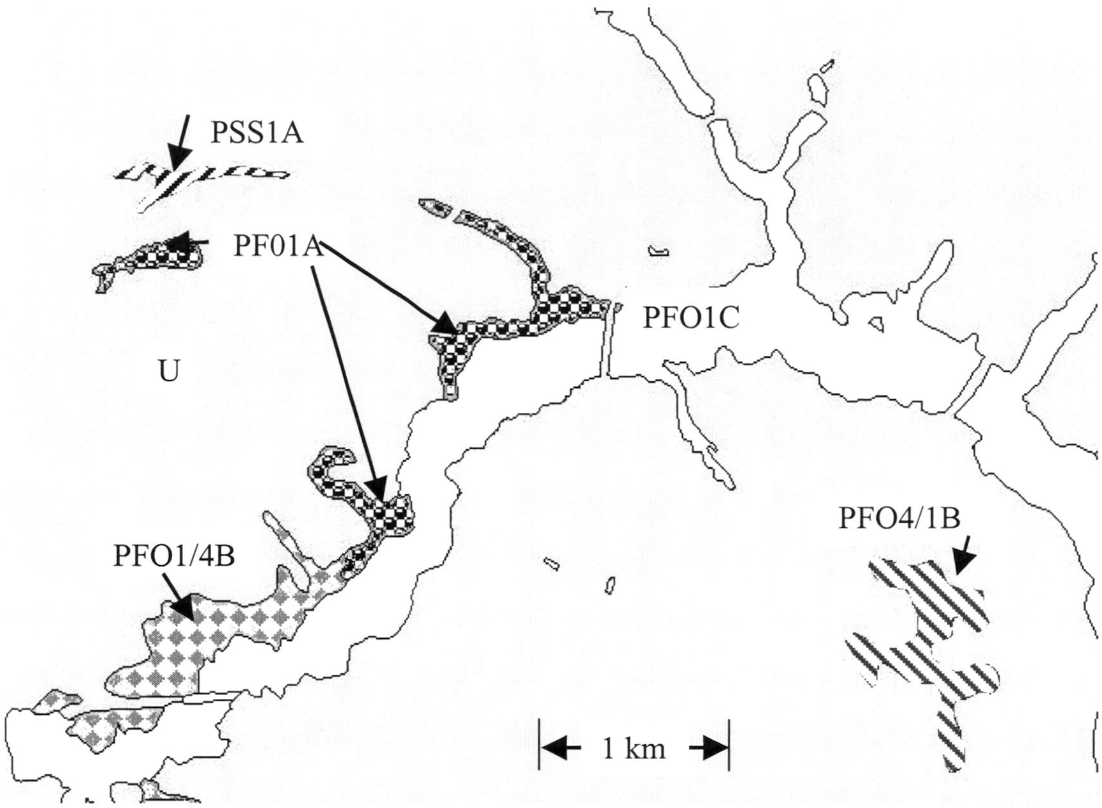

Figure 6. An excerpt from the Old Ford, North Carolina NWI quadrangle in Arcdata format as viewed through ArcView 3.0 featuring Big Swamp and tributaries arcing across the excerpt. Different wetland types are represented by different shades and colors. In this figure upland is represented by the shade covering the majority of the figure. U = uplands, PF01A = palustrine forest, broad-leaved deciduous, temporarily flooded, PF01C = palustrine forest, broad-leaved deciduous, seasonally flooded, PFO1/4B = palustrine forest, broad-leaved deciduous / needle-leaved evergreen, saturated, PFO4/1B = palustrine forest, needle-leaved evergreen / broad-leaved deciduous, saturated, PSS1A = palustrine scrub-shrub, broad-leaved deciduous, temporarily flooded (USFWS 1998b).

Due to the logistical problems and cost associated with continuous measurement of the water table, hydric soil indicators, rather than water table measurements, are usually used to indicate hydroperiod. The depth to the water table and its associated capillary fringe along intermittent and ephemeral streams prevent the formation of hydric soil indicators within 30 cm of the soil surface. In such cases the upper 30 cm of soil is seldom saturated. This aerated condition prevents the accumulation of organic carbon and the corresponding development and maintenance of low redox potentials (Gambrell and Patrick 1978). During overbank flow events in arid climates, duration of inundation may be insufficient to maintain anoxic conditions for a period of time sufficient to produce gleying, mottling, and a buildup of organic material in the soil, thus, preventing the formation and maintenance of jurisdictional wetlands (Diers and Anderson 1984).

Proposed Relationship

In the United States, along a gradient from the humid east to the arid west, precipitation decreases and the PET remains relatively constant (within a range of 200 mm, except in montane regions) along any one latitude. Therefore, within any defined drainage basin size, the prevalence of wetlands in floodplains (measured as a percent of FPA) should gradually decrease with increasing PET ratio, if all other factors remain constant.

I hypothesize that there is an ecotone where several factors (PET ratio, flood duration, groundwater discharge, and others) change and converge to cause riverine wetlands to be a significant percent of the FPA. I expect this percentage change to be sharp as the PET ratio decreases because: (1) precipitation not used by ET contributes to soil moisture in uplands leading to a groundwater contribution to the FPA, and (2) groundwater input not used by ET in the FPA results in groundwater contribution to the stream. Variable source area (Hewlett 1961) input increases downstream baseflow and the duration of overbank flow creating a positive feedback effect as the water table rises in the FPA. The combination of these factors may interact exponentially with decreases in the PET ratio until the entire FPA is wetland, which may extend beyond the FPA (Figure 7). This feedback hypothesis would be invalid if the correlation of PET ratio with the percent of the FPW that is wetland does not show an exponential curve. Some exceptions to the feedback hypothesis might occur in situations where conditions other than overbank flow and normal groundwater discharges dominate the FPA.

In areas where the PET ratio exceeds 1.0, a moisture deficit occurs. This deficit affects climatically controlled streams through a reduction in the duration of flooding and the amount of soil moisture. There is probably a threshold value of overbank flood duration in riparian areas that must occur for wetlands to be maintained in these areas. In the humid east, riverine wetlands are partially maintained through saturation near the soil surface from a high water table and capillary fringe (Patterson et al. 1985, Cole et al. 1997). The relative contributions of water sources in the humid climates of the east differ from those of the subhumid central plains. Runoff decreases in the central plains causing streams and floodplains to rely on upstream sources of water in the form of overbank flow if they are to maintain wetland status (Riggs and Harvey 1990).

At the longitude where PET exceeds precipitation (PET ratio > 1) (97° W), the zone of soil saturation along many streams may seldom meet the jurisdictional

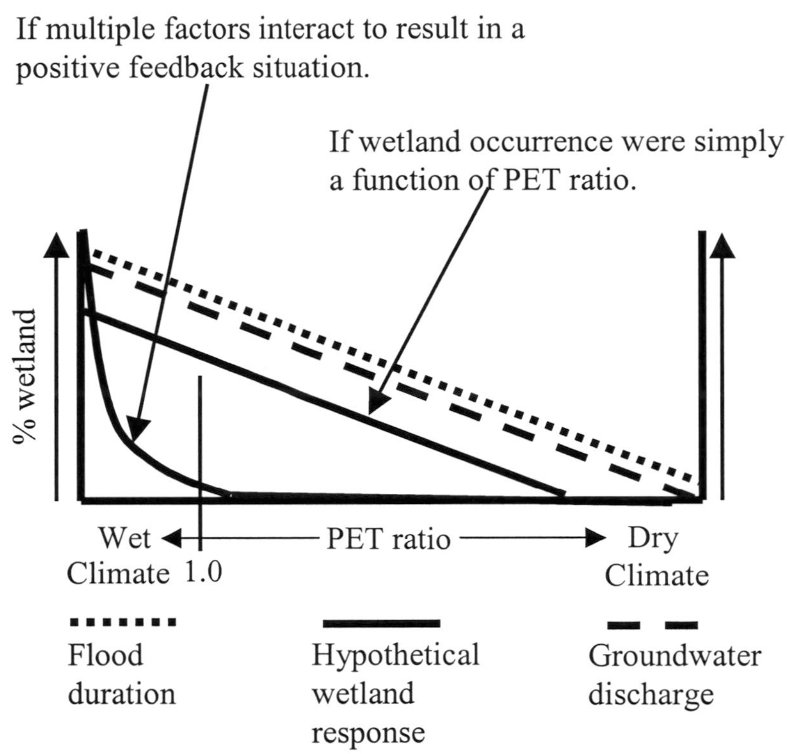

Figure 7. A dimensionless, conceptual model showing the hypothetical relationship between the PET ratio and the percent of the FPW that is wetland. If the PET ratio increased at a uniform rate from wet to dry, then the percentage of the FPW that is wetland would decrease as the PET ratio increased to 1.0, assuming that no other factors are influencing the occurrence of riverine wetlands. If multiple factors interact in a positive feedback manner, then wetlands would decrease exponentially as the PET ratio increases. Increased flood duration and locally high groundwater tables would shift the PET ratio where wetlands occur.

requirement of 30 cm for 14 days of the growing season. Differing hydraulic conductivities of various soils and hydraulic gradients through the floodplain may drastically influence the duration of soil anoxia. The intermittent to ephemeral nature of losing streams in subhumid regions may not support groundwater levels for a duration sufficient to support wetland conditions. Without sufficient hydroperiod from overbank flooding, I expect that hydrophytes may be missing or confined to the channel banks.

Exactly how much flooding is required to support wetlands in subhumid regions has yet to be verified. If overbank flow duration and the zone of saturation levels are a function of the PET ratio, then at some PET ratio, overbank flooding and zone of saturation levels are reduced to the point at which jurisdictional wetlands do not exist within a given drainage basin area. It is my intent to characterize the controlling factors in the development and maintenance of riparian wetlands. Characterization was done by examining several factors that may influence the development and maintenance of riparian wetlands: stream order, drainage basin area, soil, and overbank flow duration. These factors were then compared with wetland and vegetation measurements and occurrences along a PET ratio gradient from humid to subhumid.

Methods

Study Sites

Central plain study sites were selected along 40° N latitude to include the climate change from humid to subhumid centering on the region where potential vegetation changes from forest to grassland between 94° W and 103° W longitude (Kuchler 1967) (Figure 8, Table 1). This transect was selected as representative, coinciding with the western limit of upland forests. This region was also selected due to the large number of currently operating USGS stream monitoring stations.

The region of study included 36 streams encompassing an area from Chariton, Iowa, to Cope, Colorado (38° 30' to 41° 30' N latitude). A variety of drainage basins ranging in size from 10.6 km^2 to 1260 km^2 were selected in order to compare between different watershed areas from humid to subhumid. Criteria for selecting the 23 USGS gaged sites were based on sites having a synchronous period of record (October 1983-September 1993) for mean daily discharge and minor to no alteration to the stream channel. This period of time was chosen in order to estimate non-El Niño, climatic conditions. The 13 ungaged sites were selected using USGS topographic maps and field reconnaissance. Based on field visits, sites were rejected that were channelized, received back flooding from dams, received significant augmentation of flow as return flow from municipalities or agriculture, or had active beaver dams. Preference was given to non-agriculturally altered reaches of streams.

Sixteen streams in North Carolina were selected from headwater streams sampled by Rheinhardt et al. (1998) (Figure 9, Table 2). These streams were selected in order to

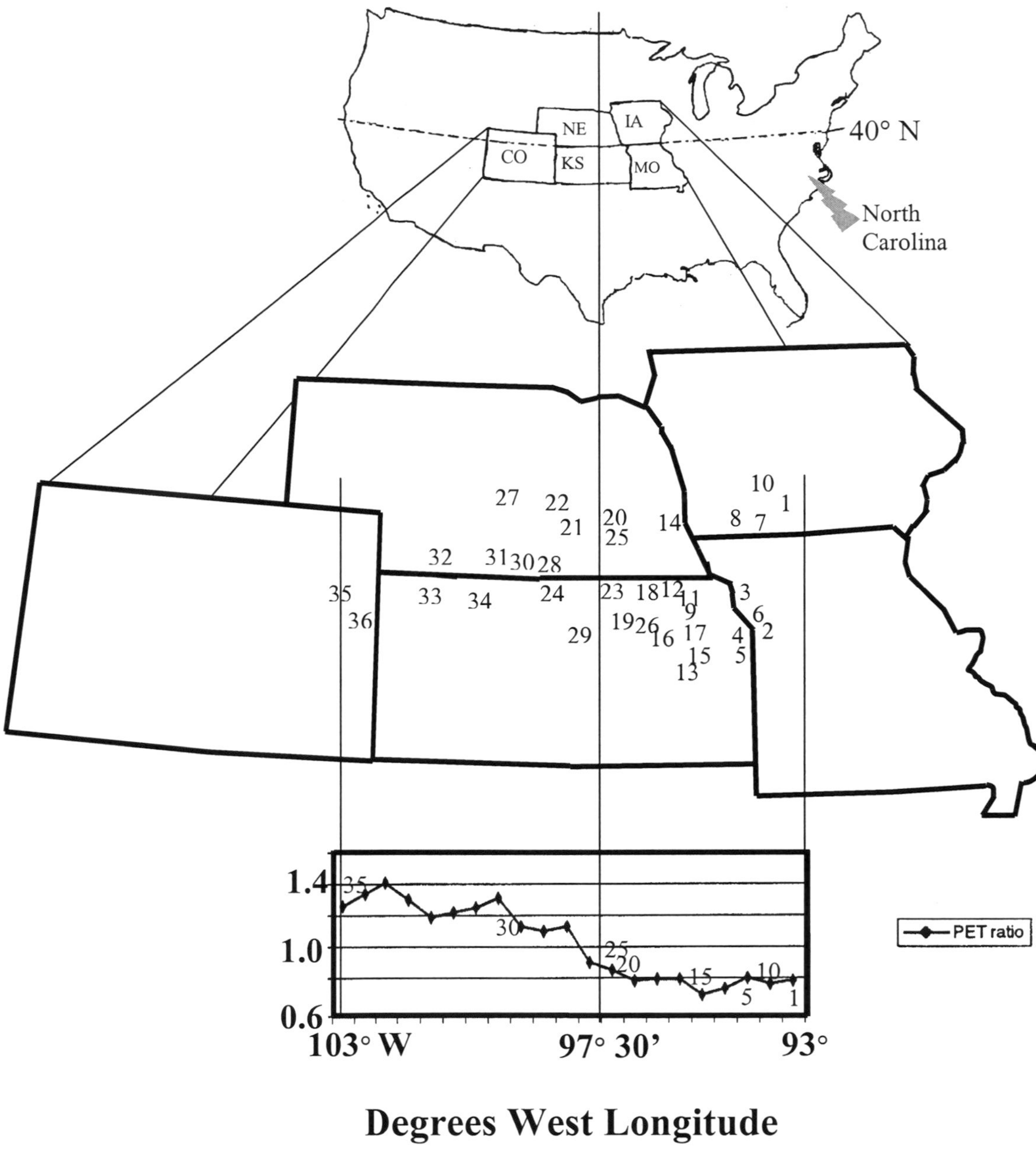

Figure 8. Study sites in the central plain region. PET ratios along 40º N latitude. PET ratios greater than 1.0 indicate a water deficit. PET ratios of individual sites vary from this plot due to differing locations of the closest station to the individual study sites.

Table 1. Study site name, location, PET ratio, USGS gaging station, and National Climatic Data Center weather station for the central plain study sites. Latitude (N), longitude (W).

Site #	stream	latitude	longitude	PET ratio	USGS gaging stn.	NCDC weather stn.
1	White Breast Ck.	41.06.886	93.22.109	0.71	--	1394
2	Blue R. @ Grandview	38.59.874	94.31.777	0.72	06893500	4359
3	Little Platte R.	39.23.393	94.37.392	0.72	--	7862
4	Indian Ck.	38.56.331	94.40.537	0.72	06893300	5972
5	Blue R., upstr.	38.48.750	94.40.517	0.72	06893080	5972
6	Trib to Little Blue R.	39.06.366	94.19.380	0.73	--	4850
7	Elk Ck.	40.43.300	93.56.317	0.73	--	536
8	102 River	40.35.202	94.47.017	0.73	06819185	576
9	Soldier Ck.	39.26.929	95.57.122	0.78	06889160	1529
10	Badger Ck.	41.27.178	93.46.321	0.78	--	2203
11	Soldier Ck., upstr.	39.33.950	95.57.750	0.78	06889140	1529
12	Turkey Ck.	39.56.867	96.06..500	0.78	06814000	1408
13	Salt Ck.	38.36.533	95.38.283	0.79	06911500	4912
14	Weeping Water Ck.	40.47.583	95.54.667	0.80	06806500	5810
15	110 Mile Ck.	38.38.404	95.32.726	0.80	--	6498
16	Mill Ck.	39.03.790	96.10.574	0.80	06888500	8563
17	Soldier Ck. @ Grove	39.12.133	95.52.417	0.80	06889200	7007
18	Little Timber Ck.	39.43.424	96.24.233	0.85	--	5063
19	Chapman Ck.	39.01.867	97.02.400	0.87	06878000	5306
20	Rock Ck.	41.01.775	96.33.171	0.88	06803530	5362
21	Wildcat Ck.	41.00.173	97.21.654	0.89	--	8328
22	Big Blue R.	41.06.211	97.20.819	0.89	--	8328
23	Mill Ck.	39.48.833	97.02.033	0.90	06884200	8578
24	White Rock Ck.	39.53.917	98.15.083	0.93	06854000	4982
25	Stevens Ck.	40.51.417	96.35.700	0.93	06803520	4815
26	Kings Ck.	39.06.117	96.35.700	0.95	06879650	8259
27	Turkey Ck.	41.09.400	98.33.367	0.98	06784800	7515
28	Elm Ck.	40.05.333	98.26.117	1.04	06852000	3395
29	Salt Ck.	39.08.500	97.50.167	1.05	06876700	5363
30	Thompson Ck.	40.05.350	98.45.633	1.13	06851500	7070
31	Coates Ck.	40.06.132	98.54.295	1.17	--	3595
32	Driftwood Ck.	40.08.827	100.40.489	1.21	06836500	5310
33	S Fk Sappa Ck.	39.40.370	100.43.300	1.25	06844900	5906
34	Bow Ck.	39.33.767	99.17.067	1.31	06871500	6374
35	Arikaree R.	39.39.961	102.50.687	1.35	--	4380
36	N Fk Smoky Hill R.	39.19.818	102.16.528	1.75	--	1121

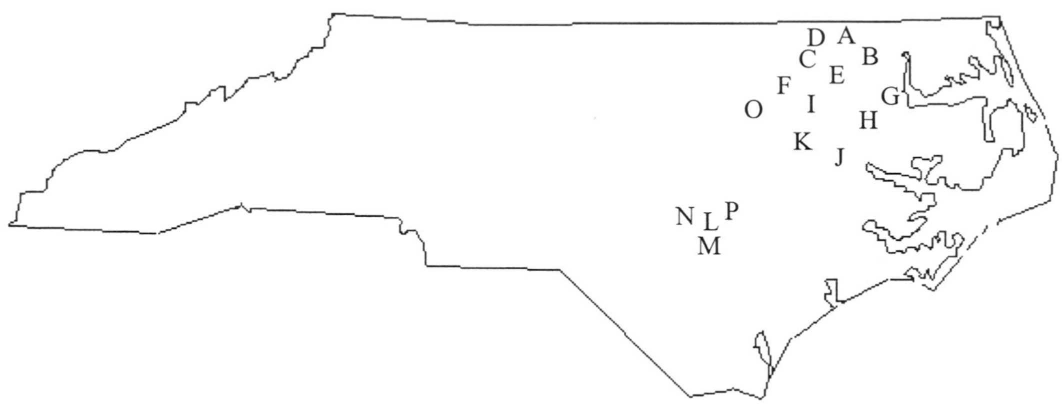

Figure 9. North Carolina study sites are located in the coastal plain region. The PET ratios for these sites ranged from 0.83 to 0.67.

Table 2. Study site name, location, PET ratio and National Climatic Data Center weather station for the North Carolina study sites. Latitude (N), Longitude (W).

Site id.	stream	latitude	longitude	PET ratio	NCDC weather stn.
A	Trib to Corduroy Swamp	36.28.583	77.15.967	0.67	5996
B	Bluewater Branch	36.20.700	77.03.917	0.67	5996
C	Lobelia Run	36.25.050	77.25.533	0.75	4456
D	Collie Creek	36.22.750	77.27.733	0.75	4456
E	Trib to Sandy Run	36.12.600	77.15.150	0.76	4962
F	Pecan Grove Slough	36.06.833	77.29.533	0.76	4962
G	Trib to Wildcat	36.10.266	76.58.667	0.76	4962
H	Big Swamp	35.59.017	77.01.683	0.78	9440
I	Etheridge Swamp	35.58.383	77.18.250	0.78	9440
J	Phillipi Branch	35.35.250	77.15.667	0.78	3638
K	Otter Creek	35.43.033	77.31.083	0.78	3638
L	Trib to Six Runs	34.51.717	78.10.367	0.81	1881
M	Bulltail Creek	34.44.483	78.12.150	0.81	9423
N	Trib to Crane Creek	34.55.367	78.16.567	0.81	9423
O	Elm City	35.48.950	77.47.367	0.82	9476
P	Spicer Preserve Creek	34.58.967	77.58.467	0.83	9081

test and perfect the methods of analysis with previously studied sites. When compared with the region where 40° N latitude intersects the East Coast, North Carolina streams have a lower stream gradient with a warmer climate. PET ratios are comparable. These first through fourth order streams were all ungaged and located on the humid inner coastal plain of North Carolina. The same criteria utilized in the central plains for rejection or acceptance of sites were applied in the selection of North Carolina sites except for the discharge data, because none were available.

Determination of PET Ratio

Potential evapotranspiration is the amount of water returned to the atmosphere as vapor through the combined effects of evaporation and transpiration, if the water supply is unlimited. PET can be measured by several direct methods, or estimated using one of several equations (Gray et al. 1970). The most accurate way to estimate PET would be to measure the factors influencing PET (solar radiation, wind velocity, vegetation, surface correction, temperature, water availability, etc.) on site for a period of time sufficient to determine an average year. For the purpose of this study, PET was estimated as described by Holdridge et al. (1971) from the mean annual biotemperature multiplied by 58.93. The Holdridge equation gives values similar to the Thornthwaite and Holzman (1942) equation without the calculation of sunshine duration and annual heat index. Mean annual biotemperature was calculated from the weighted monthly averages of minimum and maximum daily temperatures. For months averaging less than 0° C, a value of 0° C was inserted in place of a negative number. These monthly values were then totaled for the years 1983 – 1993 and averaged to determine the annual PET. Average annual precipitation was calculated from average daily rainfall. Potential evapotranspiration was then divided by average precipitation to determine PET ratio (Holdridge et al. 1971). Data for these calculations were obtained from a CD-ROM database containing climatic data taken by the National Climatic Data Center (NCDC) (Earthinfo 1995a) from the closest monitored weather station to each study site (< 35 km). Sites were assigned numbers (central plains) and letters (North Carolina) based upon increasing PET ratios (Figures 8 and 9).

Determination of Bankfull Depth

Flood stages for many streams are determined from data reported by the National Weather Service (NWS) (1997). However, the NWS estimates for flood stage are, in many cases, the stage at which flood damage occurs, which is not necessarily directly related to bankfull stage. Flood stage is also listed for some streams by the USGS station records. However, USGS stages are subject to vagaries in the definition of "flooding" and bankfull (Williams 1978; Burke and Nutter 1995; P. Turnipseed personal communication 1997). For more accurate data on flood stage, bankfull must be determined in the field (Rosgen 1996).

Average bankfull depth was determined by analysis of individual stream cross-sections within a reach of channel equal in length to 20 bankfull channel widths (Rosgen 1996). Obvious visual indicators of bankfull (top of the point bar, vegetation change, topographic break, change in size distribution of surface materials, and change in debris deposited between rocks) were measured along 3 cross-sections at intervals of 10 bankfull widths (Figure 10) (Leopold 1994, Rosgen 1996). The bankfull depth was

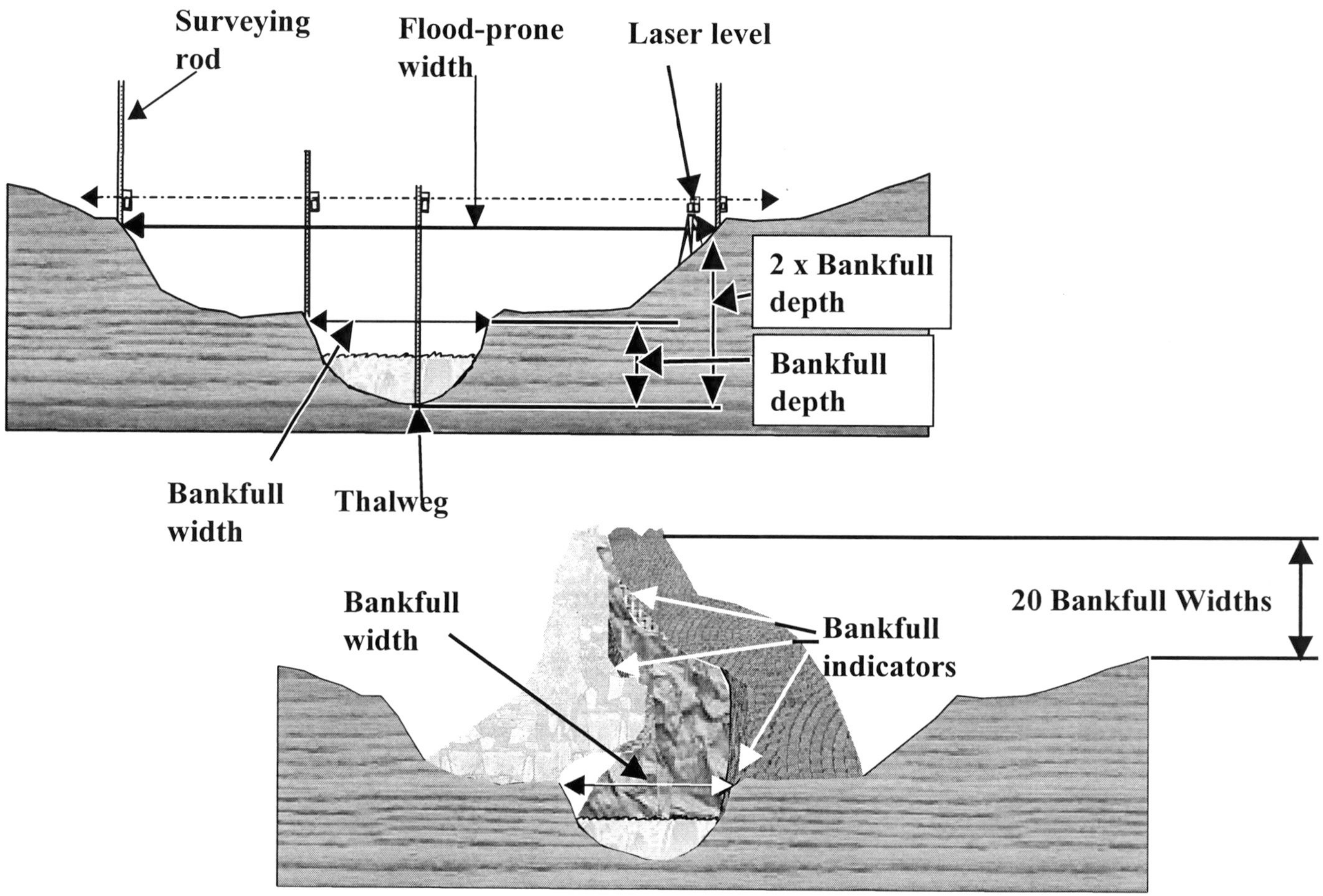

Figure 10. Bankfull depth is the depth from bankfull stage to the thalweg of the stream. Bankfull depth was determined from bankfull indicators at three cross sections within the reach in order to determine average bankfull depth. In this study, an interval of 10 bankfull widths was used between cross-sections. The flood-prone width is the width of floodplain at twice bankfull depth. Modified from Rosgen (1996).

averaged for the 3 cross-sections to determine the average bankfull depth. This average bankfull depth was used to calculate bankfull discharge from stage / discharge curves and tables created by USGS state representatives J. E. Putnam (KS), D.A. Eash (IA), G.B. Engel (NE), and L.A. Waite (MO). Bankfull discharge was then compared with USGS stream discharge records (Earthinfo 1995b).

Determination of bankfull depth proved to be difficult after heavy rainfalls and for higher order streams. The large amounts of rainfall in the Great Plains during early summer 1998 due to El Niño caused frequent flooding at many study sites. Most sites had been flooded within a week prior to my visits. Analysis of floodplains was not prevented unless the rainfall had occurred within a couple days and the flow still exceeded bankfull. One site had to be visited three times in order to complete the analysis. When stream movement was slow, with a depth greater than 1.85 m from the thalweg to surface, depth was measured by marking the water surface on a surveying rod after finding the thalweg.

Difficulties were also encountered while entering and exiting the stream. Steep banks of clay or loam were extremely slippery because they were often saturated with water from precipitation, ground water discharge, high streamflows, or from my dripping clothing. Two methods of access were used: (1) Steps were cut into the banks using a shovel and on streams with high banks, and (2) Rappelling rope was tied to trees in order to give a handhold and increase traction. Rappelling rope was used at one site in order to secure myself to a tree so that the equipment and I would not be washed downstream while finding the thalweg and measuring bankfull depth. These methods greatly increased the speed and efficiency of the surveying and measurement of bankfull depth and wetland width.

Delineation of Wetlands

Typically, the procedure of reach selection, vegetation analysis, and soil sampling were accomplished simultaneously. The initial site examination involved a geomorphic survey either from the channel or along the bank in order to determine if alteration had occurred and to select a representative reach of stream. Streams were examined for a distance ranging from 500 m to 2 km depending on stream width and the amount of variation present in the geomorphology and vegetation. During this initial examination, species that were prevalent were noted and soil samples were examined periodically. If the site was suitable, closer examination of the vegetation and soil was done along transects during the measurement of flood-prone width and wetland width.

Prevalent and dominant plant species were identified and then tallied. Species that represented greater than 10 percent of the community were considered to be prevalent. Species that comprised greater than 20 percent of the community, covered the greatest percentage of area, or constituted the perceived majority of basal area were considered to be dominant. Species were given indicator status (Obligate upland (UPL) found in uplands 99% of time; Facultative upland (FACU) in uplands 67 – 99%; Facultative (FAC) found in wetlands 34 – 66%; Facultative wetland (FACW) found in wetlands 67 – 99%; Obligate wetland (OBL) found in wetlands 99%) (nomenclature used for following listings) based on their frequency of occurrence in wetlands in the specified region as listed in the national list of plant species that occur in wetlands (Reed 1988).

These indicator statuses were then given ecological index (EI) values (UPL = 5, FACU = 4, FAC = 3, FACW = 2, OBL = 1) and averaged (Wentworth et al. 1988). The number of species that were prevalent and dominant determined species richness.

Soil samples were taken from several locations within the reach of FPA. Soils were examined for hydric conditions (mottles, oxidized pore linings, organic streaking, sulfidic odor, and the current state of hydration) within 30 cm of the soil surface. Matrix and mottle color were determined using Munsell soil color charts (GretagMacbeth 1996). The texture of soils was determined in the field at several locations in the FPA according to the Thein (1979) method. This method of determining texture utilizes the cohesiveness and grain size of the soil to categorize it into a texture type. For regressional analysis, the soil textures were given numerical values from fine to coarse (Taylor et al. 1999).

Field Analysis of Percentage of Wetlands

The edge of the flood-prone width (FPW) was surveyed, marked, and measured. On both sides of the stream, measurements were taken of the wetland width along 3 or more transects perpendicular to the floodplain direction at intervals of 10 bankfull widths or less. Delineation was conducted similarly to the United States Army Corps of Engineers 1987 protocol (Environmental Laboratory 1987). At all streams, vegetation, soil, primary, and secondary wetland indicators were taken into consideration while making the wetland determination. For large floodplains, the same method of determination for bankfull depth and flood-prone depth was used but measurements of the FPW were taken from the roadway. In all cases, wetland widths were measured along at least 3 transects, averaged and divided by the average FPW and expressed as a percent.

Determination of Overbank and Above Average Flow Duration

Bankfull discharges were estimated using tables and curves created for the gaged streams by the state USGS offices. Mean daily discharges for the period of October 1983 - September 1993 (Earthinfo 1995b) were then compared with this bankfull discharge. The total number of days during this period that average daily discharge exceeded bankfull discharge was tallied for the 10-year period and averaged.

Elk Creek near Decatur City, Iowa (site 7) will be used as an example of this procedure. Site 7 has an average bankfull depth of 3.04 m. In the expanded-precision rating table, the discharge required to meet bankfull depth is 109.2 m^3/s. In the Earthinfo (1995b) CD-ROM listing of USGS stream data, mean daily discharges were compared with the bankfull discharge. Days that average discharge equaled or exceeded bankfull discharge were counted. During the period of October 1983 - September 1993, 3 days exceeded 109.2 m^3/s for an average of 0.3 days/year for the 10-year period.

Duration of above average flow was determined by comparison of the average daily discharge for the period of October 1983 – September 1993 with the individual days (Earthinfo 1995b). Days that exceeded the average were tallied and averaged to determine the average number of days exceeding average discharge.

Hydrograph Separation

Six gaged streams were selected in order to estimate and compare the groundwater input to stream discharge across the climatic gradient. Three of these streams (sites 2, 12, and 16) were located in humid regions and three (sites 30, 33, and 34) were in subhumid regions. Hydrographs were created for these six streams from a synchronous time period from March - September 1993. Baseflow separations were calculated using the fixed base method (Fetter 1994). Days after peak $(N) = 0.8(A)^{0.2}$ were determined

where N = days from peak discharge

A = drainage basin area (km^2).

The average baseflow was calculated by removing the ascending and descending (days after peak) limbs of stormflow events and averaging the remaining discharges.

Map Analysis

Stream order was determined by analysis of USGS 1:24000 topographic maps using Strahler's ordering system (1957). Maps were in digital raster graphic (DRG) format obtained on-line for Missouri, Kansas, and Nebraska. Maps for Colorado and Iowa were obtained from the USGS in DRG format on CD-ROM. Maps were analyzed using ArcView 3.0 software. Streams, represented by dashed or solid blue lines, with no upstream bifurcation, were designated as first order. Stream orders were then compared with other quantitative data.

Analysis of Data

Data were analyzed using SPSS 8.0. Percentages were converted to proportions and transformed using an arcsine transformation in SPSS. Scatter plots were created for all quantitative data and regression lines were drawn with the best fit using Microsoft

Excel 97. Outliers were removed in the analysis of percentage wetland based on the presence of non-climatic influences limiting or enhancing wetland status. Sites without trees were removed in the EI analysis. In the wetland width analysis for the central plains, one outlier was removed that had exceptional wetland width for cross-sectional width and one that had exceptionally low wetland width to cross-sectional area. In wetland width analysis for North Carolina, Otter Creek was removed due to atypical stream characteristics. P - values were determined using SPSS and listed for significant correlations. Vegetation was analyzed by EI and comparison of Jaccard similarity (Odum 1971). Jaccard similarity (S) = 2 (C) / (A+ B)

where A = number of species at site A

B = number of species at site B

C = number of species common to both sites

Ecological index and Jaccard similarity of prevalent species were compared between adjacent sites when ordered by increasing values of PET ratios, latitude, longitude, stream order, soil texture, cross-sectional area, drainage basin area, percent wetland, and wetland width (m).

Results

PET Ratio Effects

Potential evapotranspiration (PET) ratios for the central plain streams ranged from 0.71 to 1.75. Streamflow patterns varied with PET ratios from perennial (lower PET ratio) to ephemeral (higher PET ratios). PET ratios explained variations better than simply precipitation in 3 of 4 comparisons (Figures 11 and 12). Vegetation in the floodplains ranged from forest dominated by silver maple (*Acer saccharinum*) and stinging nettle (*Urtica gracilis*) to upland grasses, cottonwood (*Populus sargentii*), and honey locust (*Gleditsia triacanthus*).

PET ratios did not significantly correlate with the ecological index (EI) of sites ($r^2 = 0.03$) (Figure 11a). No sites had an EI average of less than 2.6 above the PET ratio of 0.98 (Table 3). As PET ratios increased forbs and, on some floodplains, shrubs were replaced in the flood-prone width (FPW) by upland grasses and prickley pear cacti (*Opuntia* sp.) as the dominant forms of understory vegetation. The number of woody species that were prevalent in the flood-prone area (FPA) decreased as precipitation decreased ($r^2 = 0.55$) (Figure 12a). Tree species that are considered to be wetland vegetation (FAC+ to OBL) became uncommon at streams with a PET ratio above 0.90. It was observed that these species also tended to be found closer to the stream as the PET ratio increased. Most wetland vegetation above the PET ratio of 1.04 was located within close proximity of the channel.

Urtica gracilis (FACW) and *Laportea canadensis* (FACW) dominated most floodplains with PET ratios up to 0.80. Trees that were FACW (*Acer saccharinum,*

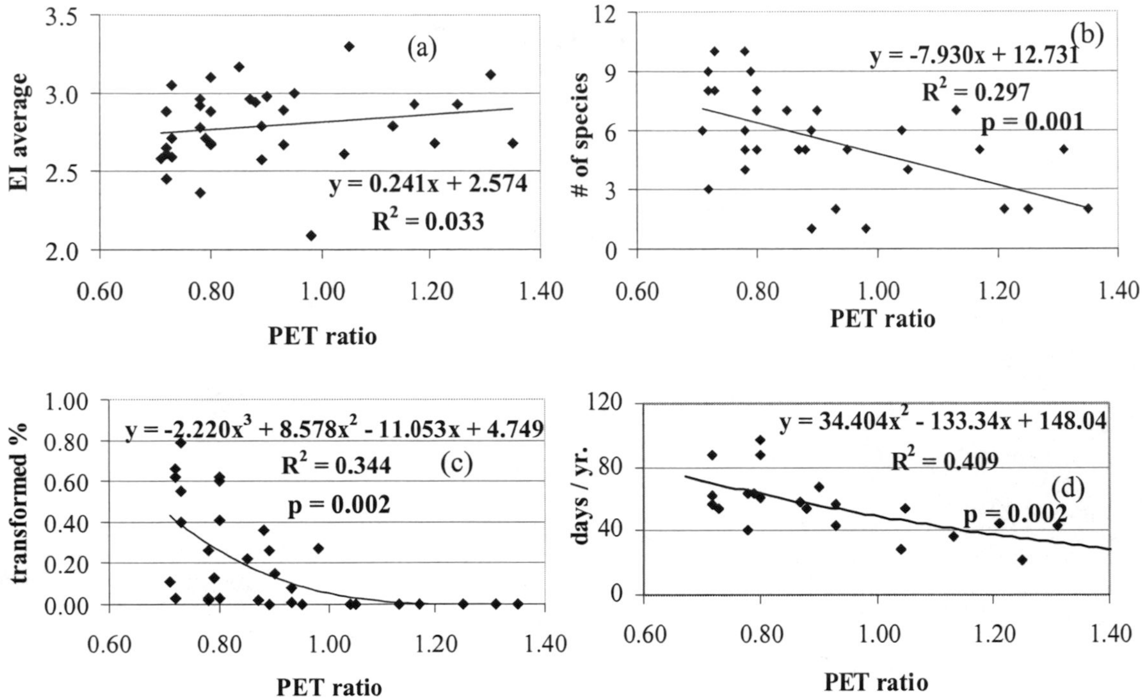

Figure 11. The relationship between the PET ratio and four variables at the central plain sites: (a) ecological indices, (b) the number of prevalent woody species, (c) the percent of the FPW that is wetland, and (d) the duration of flow exceeding average discharge. Outliers were removed as indicated in methods.

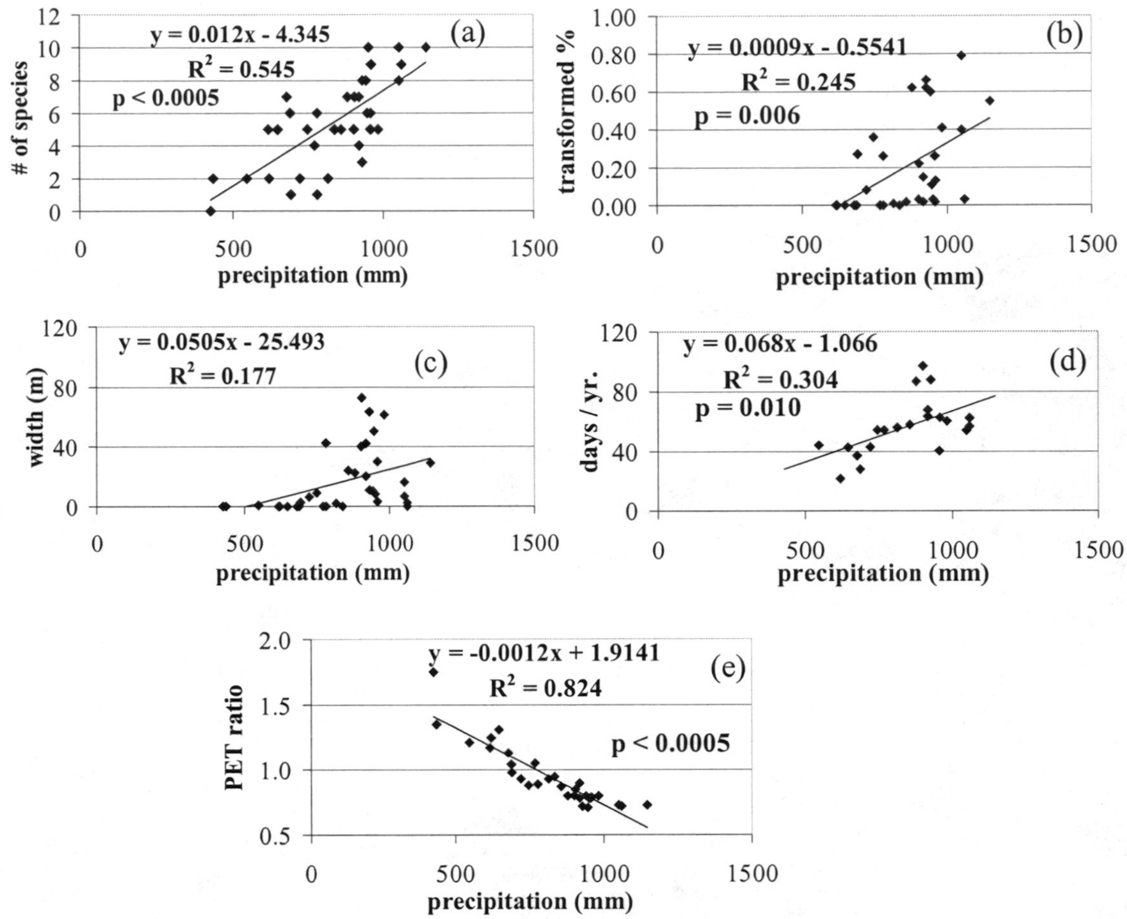

Figure 12. The relationship between precipitation and five variables at the central plain sites: (a) the richness of woody species, (b) the percentage of the floodplain that is wetland, (c) wetland width, (d) the duration of above average flow, and (e) PET ratios. Although PET ratios and precipitation were closely related, PET ratios do a better job of explaining variations than precipitation alone.

Table 3. Factors influencing the occurrence of vegetation at the central plain study sites. n/a = not available.

Site number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
PET ratio	0.71	0.72	0.72	0.72	0.72	0.73	0.73	0.73	0.78	0.78	0.78	0.78	0.79	0.80	0.80	0.80	0.80	0.85
Bkfl fl duration/yr	n/a	4.2	n/a	0.2	0.3	0.3	n/a	n/a	n/a	n/a	0.1	2.5	0.9	1.7	n/a	2.0	0.9	n/a
Above avg days	n/a	88	n/a	57	62	88	n/a	54	n/a	n/a	40	64	63	87	n/a	97	60	n/a
Wetland width (m)	50	63	11	2	0	29	7	16	149	8	3	20	30	22	10	40	61	73
Percent wetland	11	78	71	3	0	62	100	42	27	3	2	2	13	72	69	3	43	22
Strahler order	5	5	5	3	5	5	3	4	4	5	4	5	4	5	5	5	6	4
# species	15	20	10	14	17	16	17	19	11	19	17	12	15	10	17	9	8	12
EI	2.58	2.88	2.45	2.65	2.61	2.71	3.05	2.59	2.36	2.96	2.92	2.78	2.71	3.10	2.68	2.67	2.88	3.17
Precipitation (mm)	946	928	928	1060	1060	1147	1050	1050	957	950	957	918	958	879	941	900	982	904
Woody species	6	8	3	9	9	10	10	8	5	10	6	4	9	7	8	5	5	7
Drainage area (km^2)	n/a	487	606	119	68.9	136	n/a	221	128	n/a	43.8	715	287	624	n/a	824	407	n/a
Site number	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
PET ratio	0.87	0.88	0.89	0.89	0.90	0.93	0.93	0.95	0.98	1.04	1.05	1.13	1.17	1.21	1.25	1.31	1.35	1.75
Bkfl fl duration/yr	3.7	1.8	n/a	n/a	3.8	1.5	2.4	0.0	2.3	2.5	2.5	1.3	n/a	3.2	0.2	0.4	n/a	n/a
Above avg days	58	55	n/a	n/a	68	43	56	94	70	28	54	37	n/a	44	22	43	n/a	n/a
Wetland width (m)	24	9	0	43	42	6	2	0	3	0	0	0	0	1	0	0	0	0
Percent wetland	2	38	0	27	15	8	1	0	28	0	0	0	0	16	0	0	0	0
Strahler order	5	5	3	4	5	5	5	3	4	4	6	5	3	4	4	4	5	4
# species	8	10	10	4	12	5	7	13	8	12	11	14	9	4	4	6	5	3
EI	2.96	2.94	2.79	2.57	2.98	2.67	2.89	3.00	2.09	2.61	3.30	2.79	2.93	2.68	2.93	3.12	2.68	4.00
Precipitation (mm)	857	746	779	779	917	721	813	835	690	687	768	678	616	546	620	646	437	427
Woody species	5	5	6	1	7	2	2	5	1	6	4	7	5	2	2	5	2	0
Drainage area (km^2)	777	308	n/a	n/a	891	894	124	10.6	171	102	995	723	n/a	932	1160	883	n/a	n/a

Platanus occidentalis, and *Celtis laevigata*) and OBL (*Salix exiqua*) were dominant at sites with PET ratios of less than 0.89. *Acer negundo* (FAC) was common on many floodplains with PET ratios between 0.72 and 1.31. *Populus sargentii* (FACU), *Ulmus rubra* (FAC), and *Gleditsia triacanthus* (FAC) dominated floodplains with PET ratios above 0.90. Floodplain vegetation showed the greatest average site to site Jaccard similarity (54%) when arranged by PET ratio. Equivalent averages for other variables were percent wetland: 30%, wetland width: 30%, latitude: 33%, longitude: 42%, stream order: 47%, drainage basin area: 43%, overbank flow duration: 40%, cross-sectional area: 43% (Appendix A).

The percentage of FPW that is wetland decreased sharply as the PET ratio increased to 0.98 ($r^2 = 0.34$) (Figures 11c). The highest PET ratio at which wetlands occurred was 1.21 (16 %) along Driftwood Creek in Nebraska. The wetlands along this stream appeared to have been supported by agricultural return flows. During the 4 hours it took to conduct the FPA analysis, the stream stage rose 15 cm, coinciding with the afternoon flood irrigation of the surrounding fields. The additional input brought the stream stage to within 20 cm of bankfull. This site would have been eliminated from study if the existing conditions had been known prior to the completion of sampling. The next driest site to have wetlands was at a PET ratio of 0.98.

All central plain sites had wetlands associated with them until a PET ratio of 0.93 except for two streams (Table 4). The Blue River upstream site (PET ratio = 0.72), in Kansas lacked wetlands because the stream was cut into limestone and did not have soil on one side of the stream. On the other side of the stream, the soils in the FPA were

Table 4. Wetland widths, flood-prone widths and percentage of width that is wetland for the central plain and North Carolina sites. n/a = not available.

Site number	1	2	3	4	5	6	7	8	9
PET ratio	0.71	0.72	0.72	0.72	0.72	0.73	0.73	0.73	0.78
Flood-prone width (m)	459	81	15	81	19	47	7	38	550
Wetland width (m)	50	63	11	2	0	29	7	16	149
Percent wetland	11	78	71	3	0	62	100	42	27

Site number	10	11	12	13	14	15	16	17	18
PET ratio	0.78	0.78	0.78	0.79	0.80	0.80	0.80	0.80	0.85
Flood-prone width (m)	280	156	1007	231	31	15	1340	143	330
Wetland width (m)	8	3	20	30	22	10	40	61	73
Percent wetland	3	2	2	13	72	69	3	43	22

Site number	19	20	21	22	23	24	25	26	27
PET ratio	0.87	0.88	0.89	0.89	0.90	0.93	0.93	0.95	0.98
Flood-prone width (m)	1206	24	121	158	280	75	194	67	10
Wetland width (m)	24	9	0	43	42	6	2	0	3
Percent wetland	2	38	0	27	15	8	1	0	28

Site number	28	29	30	31	32	33	34	35	36
PET ratio	1.04	1.05	1.13	1.17	1.21	1.25	1.31	1.35	1.75
Flood-prone width (m)	155	458	331	6	5	350	41	49	10
Wetland width (m)	0	0	0	0	1	0	0	0	0
Percent wetland	0	0	0	0	16	0	0	0	0

Site id.	A	B	C	D	E	F	G	H	I
PET ratio	0.67	0.67	0.75	0.75	0.76	0.76	0.76	0.78	0.78
Flood-prone width (m)	85	74	73	56	18	31	131	413	216
Wetland width (m)	85	74	73	56	18	31	131	413	216
Percent wetland	100	100	100	100	100	100	100	100	100

Site id.	J	K	L	M	N	O	P
PET ratio	0.78	0.78	0.81	0.81	0.81	0.82	0.83
Flood-prone width (m)	30	104	44	117	44	74	13
Wetland width (m)	29	87	44	117	44	74	13
Percent wetland	96	84	100	100	100	100	100

isolated from normal streamflow due to the horizontal layering of the bedrock. Wildcat Creek (PET ratio = 0.89) in Nebraska for unknown reasons did not have wetlands associated with it within the study reach. Wildcat Creek was ephemeral and had a FPA composed of silty clay. The majority of this stream's watershed had been converted to agricultural fields with plow lines running through the channel.

PET ratios for the North Carolina sites ranged from 0.67 to 0.83. Upland vegetation was composed of oak – hickory – pine (*Quercus – Carya – Pinus*) forest. Streamflow patterns varied with stream order and drainage basin area from intermittent to perennial. Floodplain forests were composed primarily of red maple (*Acer rubrum*), water tupelo (*Nyssa aquatica)* (in wettest sites), and swamp tupelo (*Nyssa biflora*).

All sites in North Carolina had an EI average of less than 2.5 with a slight decrease as the PET ratio decreased ($r^2 = 0.15$) (Figure 13a). Herbaceous vegetation remained similar in indicator status at most sites. However, trees were more sensitive to the decrease in the PET ratio. At streams with higher PET ratios (0.78-0.83), trees such as loblolly pine (*Pinus taeda*) (FAC), sweetgum (*Liquidambar styraciflua*) (FAC+), and sourwood (*Oxydendron arboreum*) (FACU) were common in the FPA. As the PET ratio decreased below 0.78, these species became less common and were replaced by red maple (*Acer rubrum*) (OBL), water tupelo (*Nyssa aquatica*) (OBL), and swamp tupelo (*Nyssa biflora*) (OBL). These three OBL trees were common on most FPAs with increasing dominance as PET ratios decreased. In North Carolina the number of prevalent woody species in the FPA increased with increasing PET ratios ($r^2 = 0.19$) (Figure 13b). The number of prevalent herbaceous species remained fairly constant

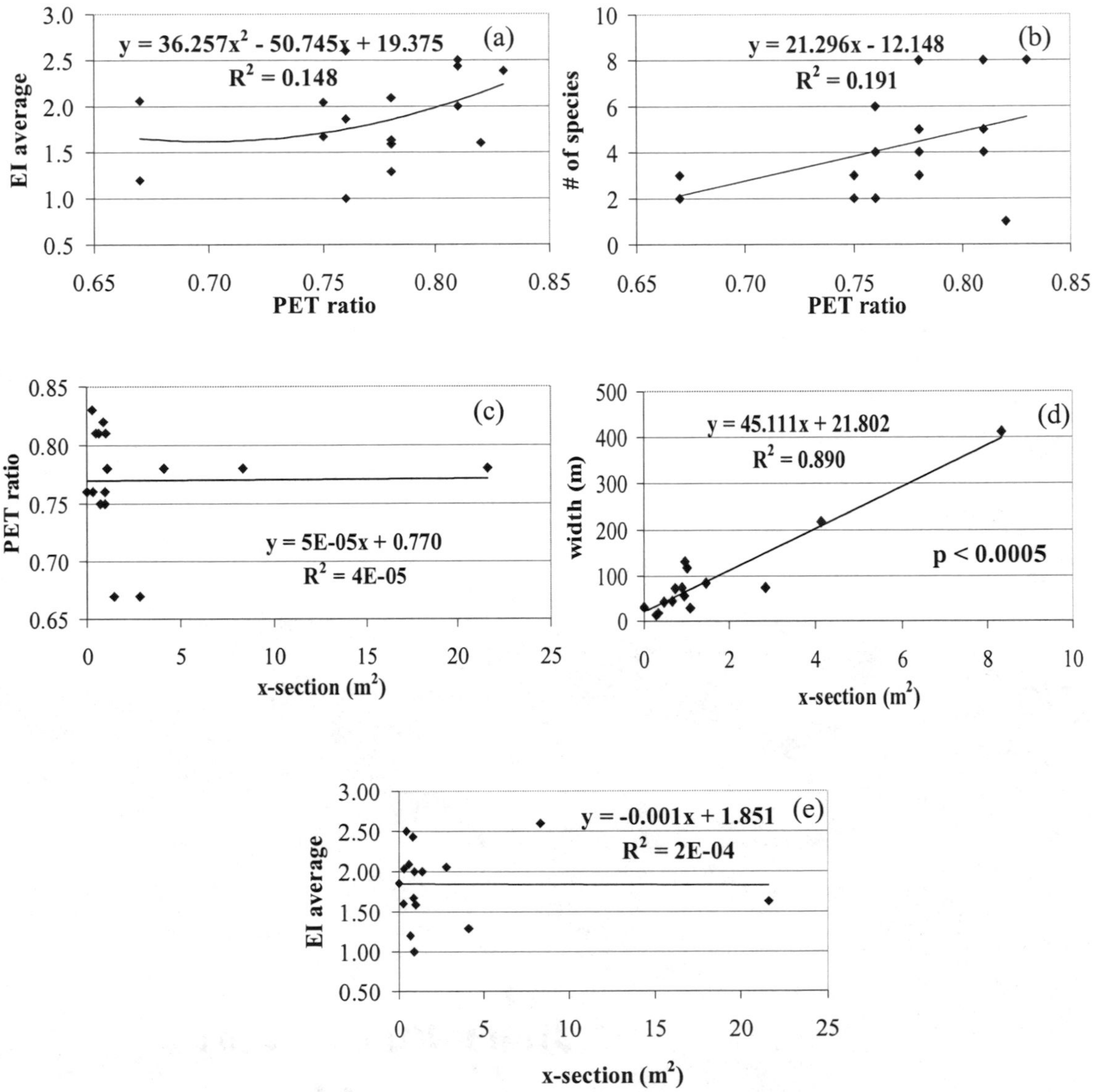

Figure 13. Two factors possibly influencing North Carolina floodplains: (a) ecological indices and PET ratio, (b) the number of prevalent woody species and PET ratio, (c) cross-sectional area and PET ratio, (d) wetland width and the cross-sectional area of the stream, and (e) ecological indices and cross-sectional area.

(Table 5, Appendix B).

Most sites in North Carolina had flood-prone widths (FPW) that were 100 percent wetland. Two sites had less than 100 percent: Otter Creek (85 %) and Phillipi Branch (97 %) (Table 4). Floodplains in North Carolina exhibited more primary and secondary wetland indicators than the central plain FPAs, even for PET ratios that were higher than several of the central plain sites. Consistently, more North Carolina floodplains had buttressed vegetation and water stained leaves. In contrast, the central plain sites exhibited more sediment and wrack deposition (Table 6). North Carolina exhibited a higher percentage of FPAs that featured depressional areas, and a lower gradient across FPWs that were capable of ponding water.

Stream Order

Central plain streams ranged in order from third to sixth with the majority of streams being fourth and fifth order. Stream order increased slightly with drainage basin area ($r^2 = 0.11$) (Figure 14a) and cross-sectional area increased with stream order ($r^2 = 0.42$) (Figure 14b). However, wetland width was not directly related to stream order ($r^2 = 0.02$) (Figure 14c). These streams also did not show an increase in the percentage of FPW that is wetland ($r^2 = 0.02$) with increasing stream order (Figure 14d). Furthermore, EI averages did not correlate with stream order ($r^2 = 0.00$) (Figure 14e) (Table 3).

Herbaceous vegetation showed no trend in response to stream order. However, trees did show a trend in response to stream order. *Ulmus rubra* (FAC) showed dominance on fourth order streams and some fifth order streams in drier areas. *Acer saccharinum* (FACW) showed dominance on fifth order streams and on some fourth and

Table 5. The factors influencing the occurrence of vegetation at the North Carolina study sites.

Site id.	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
PET ratio	0.67	0.67	0.75	0.75	0.76	0.76	0.76	0.78	0.78	0.78	0.78	0.81	0.81	0.81	0.82	0.83
Wetland width (m)	85	74	73	56	18	31	131	413	216	29	87	44	117	44	74	13
Percent wetland	100	100	100	100	100	100	100	100	100	96	84	100	100	100	100	100
Strahler order	2	2	1	1	1	1	1	3	4	2	4	1	2	1	2	1
# species	5	7	6	7	7	2	6	7	9	8	11	8	14	8	6	10
EI	2.06	1.43	1.67	2.04	1.86	1.00	2.60	1.29	1.52	1.63	2.09	2.00	2.50	2.25	1.50	2.24
Precipitation (mm)	1234	1234	1143	1143	1171	1171	1171	1136	1136	1185	1185	1190	1284	1284	1150	1163
Woody species	2	3	2	2	5	2	4	4	5	3	7	4	6	5	1	7
Drainage area (km^2)	3.09	13.74	1.40	3.27	0.17	0.46	3.55	42.11	59.21	1.84	127.49	0.92	5.68	1.31	6.54	0.44

Table 6. Primary and secondary wetland indicators for the central plain and North Carolina sites.
+ = presence of condition, -- = absence of condition.

Site number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Soil listed as hydric	--	--	--	--	--	+	--	+	+	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Buttressing	--	--	--	+	+	+	+	--	+	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	+	--	--	--
Sediment deposition	+	+	+	+	--	+	+	+	+	+	+	+	+	+	+	+	+	--	--	+	+	--	+	+	+	--	+	+	+
Water marks	+	+	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Saturated @ 12"	+	+	+	--	--	+	+	+	+	--	+	+	--	--	+	+	+	+	+	+	--	--	--	+	+	+	+	--	--
Ponded water	+	--	--	--	--	--	--	--	+	--	--	--	--	--	+	+	+	--	--	--	--	--	--	--	--	--	--	--	--
Wrack deposition	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Gleyed/ mottled	+	--	+	--	--	+	+	--	+	--	+	+	+	+	--	+	+	+	+	+	--	+	+	--	+	--	+	--	--
Stained leaves	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coated soil grains	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Streaking	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Site number	32	33	34	35	36	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Soil listed as hydric	--	--	--	--	--	+	--	--	--	--	--	--	--	+	+	+	--	--	--	--	--
Buttressing	--	--	--	--	--	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Sediment deposition	+	--	+	--	+	--	--	--	--	--	--	--	--	--	--	+	--	+	--	--	--
Water marks	--	--	--	--	--	--	+	--	--	--	--	+	+	+	--	+	--	--	--	--	--
Saturated @ 12"	--	--	--	--	--	+	+	+	+	+	+	+	+	+	+	--	+	+	+	+	--
Ponded water	--	--	--	--	--	--	+	+	+	--	--	--	+	+	+	--	+	+	+	+	+
Wrack deposition	+	+	+	+	+	--	--	--	+	--	--	--	+	--	--	+	--	--	--	--	--
Gleyed/ mottled	+	--	--	--	--	+	+	+	+	+	--	+	+	--	--	--	--	+	--	+	+
Stained leaves	--	--	--	--	--	--	--	+	+	--	+	+	+	+	+	+	+	--	--	--	--
Coated soil grains	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	+	--	--
Streaking	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	+	--	--	--

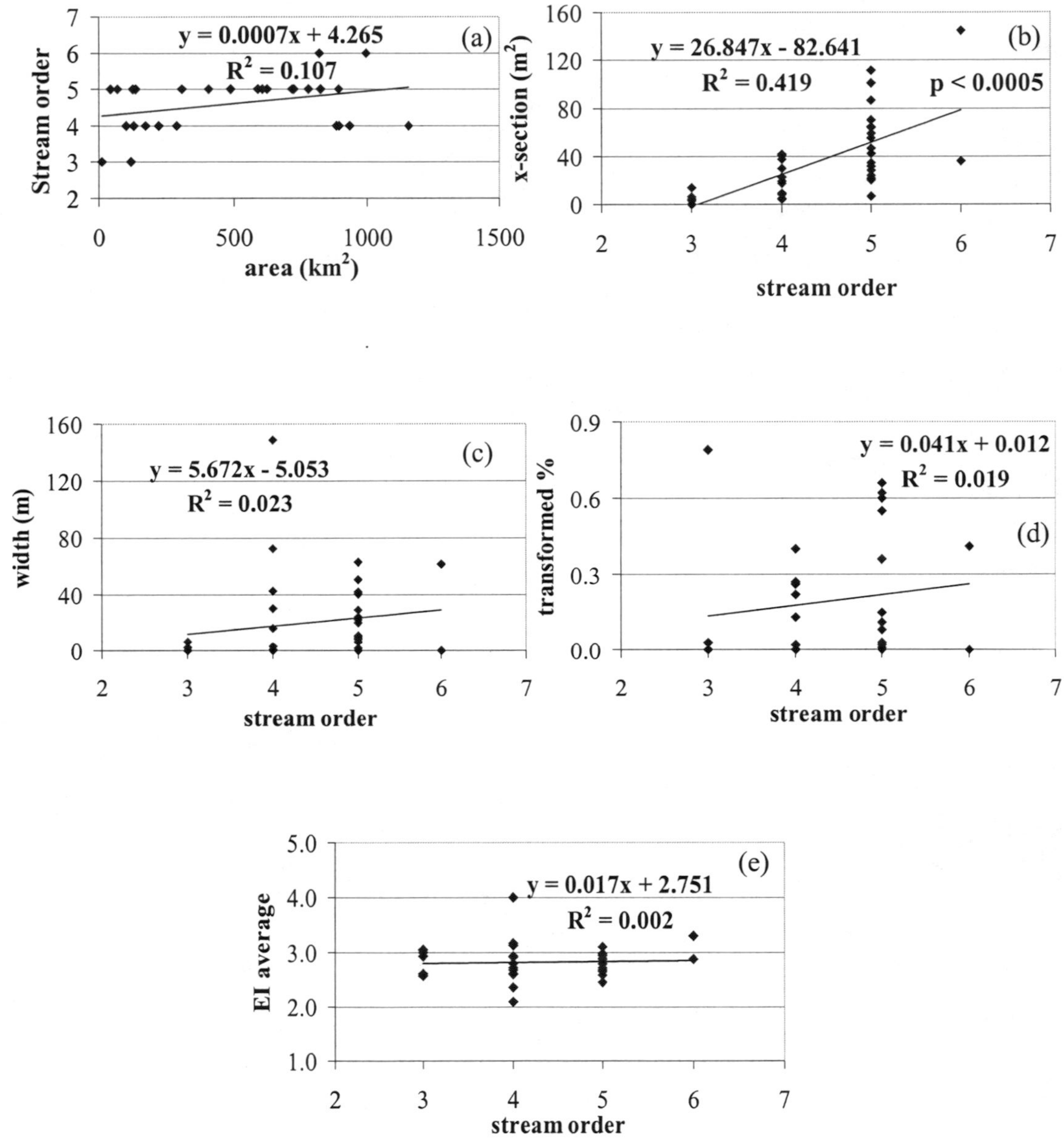

Figure 14. The relationship between stream order and five variables at central plain sites: (a) drainage basin area, (b) channel cross-sectional area, (c) wetland width, (d) the percent of the FPW that is wetland, and (e) the ecological indices.

third order streams in areas with lower PET ratios. In North Carolina *Taxodium distichum* (OBL) was only present on third and greater ordered streams (Appendix A).

The cross-sectional area of the studied streams ranged in the central plains from 2.8 m^2 to 144.5 m^2. In North Carolina the stream cross-sections ranged from 0.004 m^2 to 21.6 m^2. Central plain stream cross-sectional areas decreased in response to a rise in the PET ratio ($r^2 = 0.32$), while North Carolina streams did not (Figures 15a and 13c). In North Carolina and in the central plains streams, greater cross-sectional areas were associated with greater wetland widths (Table 7). With the removal of two outliers (sites 9 and 18) the r^2 rises to 0.70 at the central plain sites (Figure 15b). With the removal of Otter Creek (site K), the North Carolina r^2 rises to 0.89 (Figure 13d). This relationship does not exist between cross-sectional area and percent of FPW that is wetland at the central plain sites ($r^2 = 0.06$) (Figure 15c), or EI averages for the central plain ($r^2 = 0.00$) or North Carolina ($r^2 = 0.00$) (Figures 15d and 13e).

Drainage Basin Area

Drainage basin areas did not correlate with the percentage of the FPW that is wetland ($r^2 = 0.11$) (Figure 16a). EI averages showed slight increases with drainage basin area ($r^2 = 0.19$) (Figure 16b) (Tables 3 and 5). However, the EI average / drainage basin area comparison may be skewed due to the increase in gaged drainage basin areas with PET ratio ($r^2 = 0.24$) (Figure 16c). Gaged drainage basin size increased with PET ratio due to selection criteria utilizing USGS gaging stations that monitor mean daily discharge. Most streams that have no discharge for the majority of the year are not monitored for mean daily discharge.

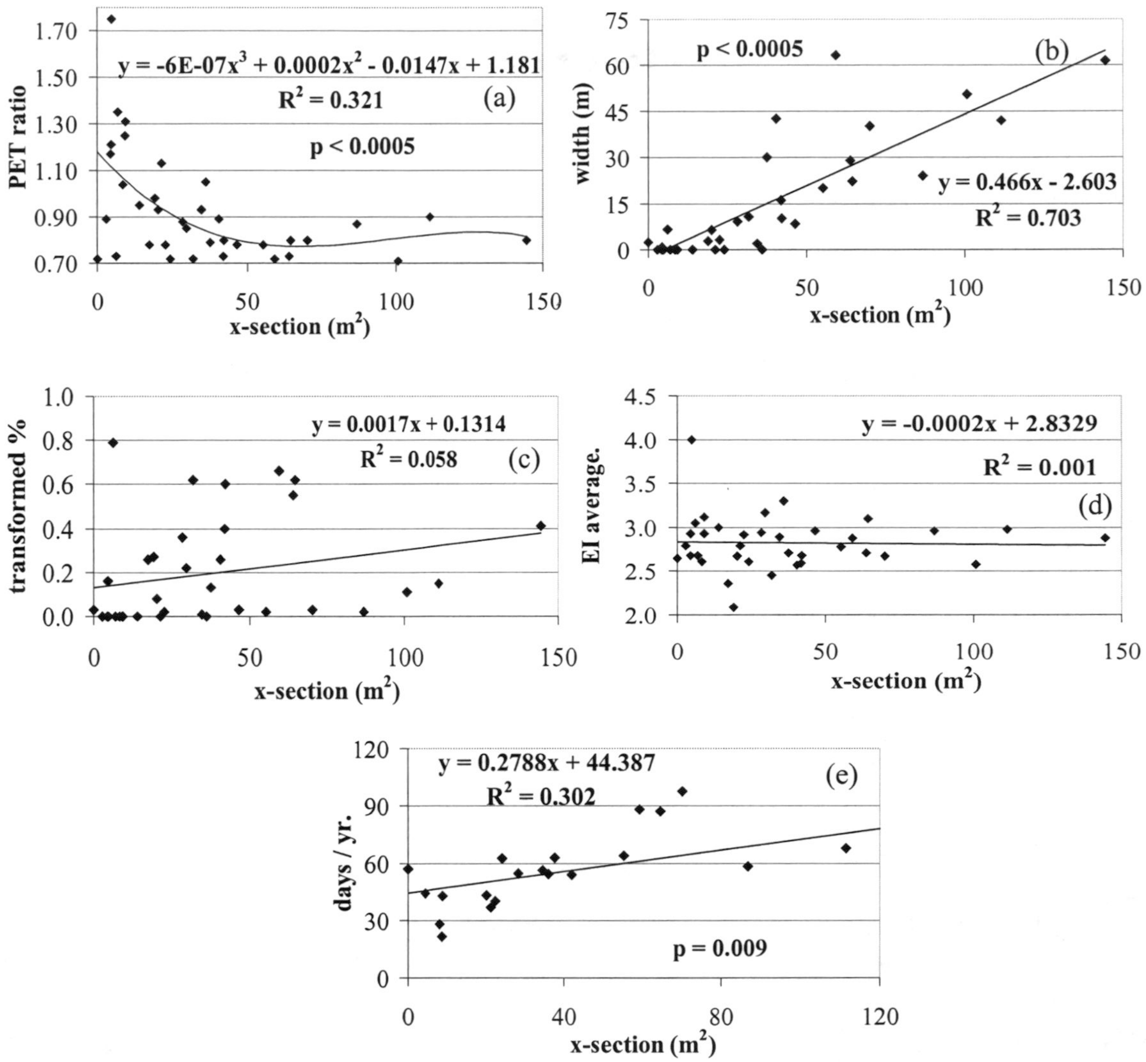

Figure 15. The relationship between cross-sectional area and five variables at the central plain sites: (a) the PET ratio, (b) wetland width, (c) the percent of the FPW that is wetland, (d) the ecological indices, and (e) the duration of flow exceeding average discharge.

Table 7. The geomorphic parameters of the central plain and North Carolina sites.
Qbkfl = bankfull discharge, n/a = not available.

Site number	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Drainage area (km^2)	n/a	487	606	119	69	136	n/a	221	128	n/a	44	715	287	624
Strahler order	5	5	5	3	5	5	3	4	4	5	4	5	4	5
Bankfull depth (m)	4.58	3.20	2.36	1.97	1.56	3.04	0.95	2.76	2.34	2.75	1.84	3.13	1.99	3.39
Bankfull width (m)	22.0	18.5	13.5	n/a	15.5	21.0	6.5	15.2	7.4	16.9	12.3	17.6	18.9	19.0
Cross-sectional area (m^2)	100.8	59.2	31.9	n/a	24.2	63.8	6.2	42.0	17.3	46.5	22.5	55.2	37.6	64.4
Flood-prone width (m)	459	81	15	81	19	47	7	38	550	280	156	1007	231	31
Qbkfl (m^3/s)	n/a	80	n/a	91	33	109	n/a	n/a	n/a	n/a	37	64	85	79

Site number	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Drainage area (km^2)	n/a	824	407	n/a	777	308	n/a	n/a	891	894	124	11	171	102
Strahler order	5	5	6	4	5	5	3	4	5	5	5	3	4	4
Bankfull depth (m)	3.24	4.12	5.16	2.56	3.77	2.61	0.39	3.09	3.69	2.38	3.01	1.58	2.18	1.11
Bankfull width (m)	13.0	17.0	28.0	11.6	23.0	10.9	7.3	13.1	30.2	8.5	11.5	8.9	8.8	7.6
Cross-sectional area (m^2)	42.1	70.0	144.5	29.7	86.7	28.4	2.8	40.5	111.4	20.2	34.6	14.1	19.1	8.4
Flood-prone width (m)	15	1340	143	330	1206	24	121	158	280	75	194	67	10	155
Qbkfl (m^3/s)	n/a	73	297	n/a	45	37	n/a	n/a	57	27	17	41	8	7

Site number	29	30	31	32	33	34	35	36
Drainage area (km^2)	995	723	n/a	932	1160	883	n/a	n/a
Strahler order	6	5	3	4	4	4	5	4
Bankfull depth (m)	3.34	1.32	0.87	0.86	1.39	0.96	0.75	0.94
Bankfull width (m)	10.8	16.2	5.0	5.2	6.6	9.6	9.1	5.1
Cross-sectional area (m^2)	36.1	21.4	4.4	4.5	9.2	9.2	6.8	4.8
Flood-prone width (m)	458	331	6	5	350	41	49	10
Qbkfl (m^3/s)	27	32	n/a	1	11	20	n/a	n/a

Table 7 cont'd. The geomorphic parameters of sites.

Site id.	A	B	C	D	E	F	G	H	I	J	K
Drainage area (km^2)	3.1	13.7	1.4	3.3	0.2	0.5	3.6	42.1	59.2	1.8	127.5
Strahler order	2	2	1	1	1	1	1	3	4	2	4
Bankfull depth (m)	0.44	0.59	0.21	0.34	0.17	0.02	0.31	1.12	0.47	0.35	2.00
Bankfull width (m)	3.3	4.8	3.5	2.8	1.9	0.2	3.1	7.5	8.8	3.1	10.8
Cross-sectional area (m^2)	1.5	2.8	0.7	1.0	0.3	0.004	1.0	8.3	4.1	1.1	21.6
Flood-prone width (m)	85	74	73	56	18	31	131	413	216	30	104

Site id.	L	M	N	O	P
Drainage area (km^2)	0.9	5.7	1.3	6.5	0.4
Strahler order	1	2	1	2	1
Bankfull depth (m)	0.44	0.45	0.48	0.39	0.22
Bankfull width (m)	1.5	2.2	1.0	2.3	1.3
Cross-sectional area (m^2)	0.7	1.0	0.5	0.9	0.3
Flood-prone width (m)	44	117	44	74	13

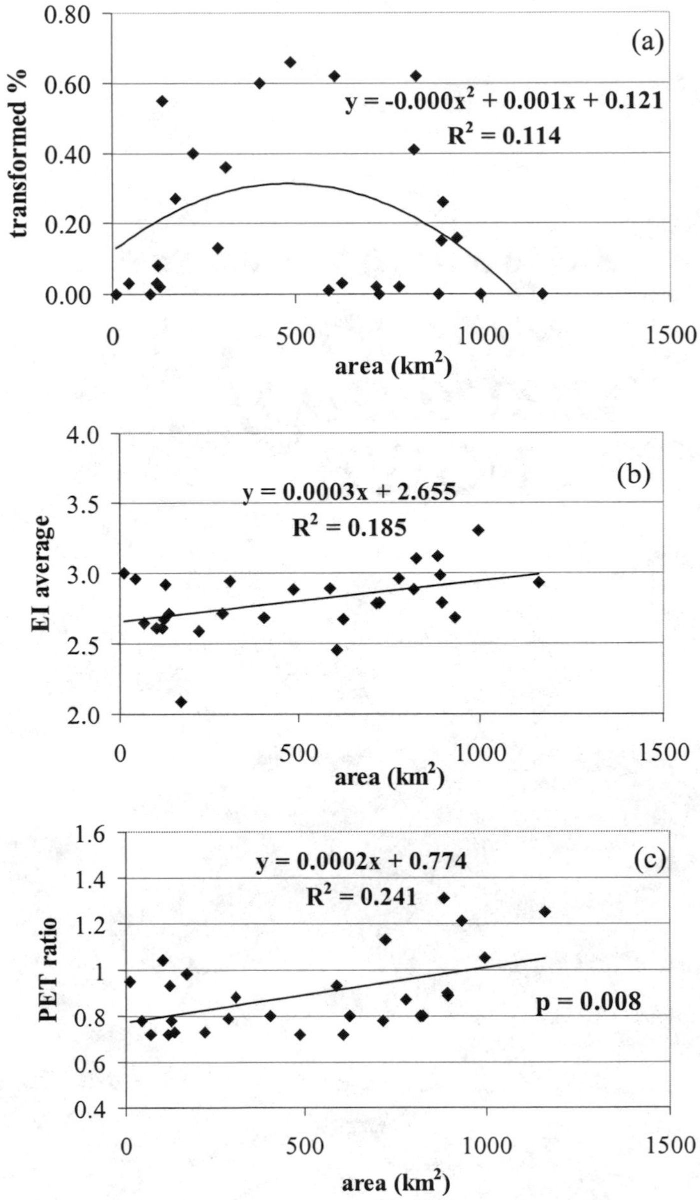

Figure 16. The relationship between the drainage basin area and three variables at the central plain sites: (a) the percent of the FPW that is wetland, (b) the EI average, and (c) PET ratio.

Soil

Soils ranged from clay to coarse sandy loam. The majority of soils along the central plain streams were clay based or had clay constituents. Soil color varied at several streams depending upon the location of sampling, wetland status, and geomorphic setting. Soil texture showed no relationship with the percentage of FPW that is wetland ($r^2 = 0.02$) (Figure 17a). Soil texture varied only slightly with the duration of overbank flow ($r^2 = 0.07$) (Figure 17b). Fine-grained soils were associated with a slightly longer duration of flooding than coarse-grained soils. Bankfull depth also varied slightly with soil texture ($r^2 = 0.15$) (Figure 17c). Fine-grained soils generally had steeper banks with greater bankfull depths than the coarse-grained soils (Table 7).

Overbank and Above Average Flow Duration

Most of the floodplains of the central plain streams studied were not geomorphically capable of ponding water in the area of study. This was due mainly to a lack of depressions and impoundments by natural levees in the floodplain. Most inundation was a result of direct, overbank flow from the stream. Those floodplains that were geomorphically capable of ponding water on the floodplain met wetland criteria for the majority of the ponded depression area. The average annual duration of overbank flow for central plain streams ranged from 0 to 4.2 days per year. Generally streams would not exceed bankfull discharge for several years and then, during a wet year, bankfull would be exceeded several times. During the time period in which analysis was done, bankfull discharge was exceeded several times on many streams in the central plains.

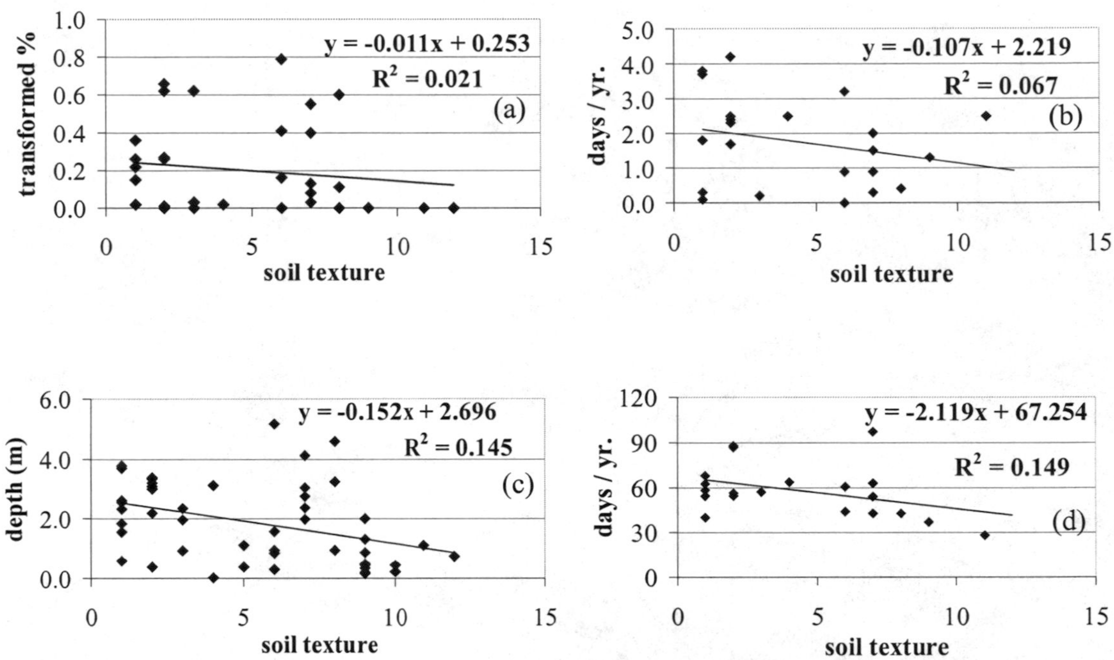

Figure 17. The relationship between soil texture and four variables at the central plain sites: (a) the percent of the FPW that is wetland, (b) duration of average annual overbank flow, (c) bankfull depth, and (d) the duration of above average discharge. 1 = clay, 2 = silty clay, 3 = sandy clay, 4 = silty clay loam, 5 = clay loam, 6 = silty loam, 7 = loam, 8 = sandy clay loam, 9 = sandy loam, 10 = loamy sand, 11 = medium sandy clay loam, 12 = coarse sandy loam.

The best correlations with flood duration for the central plain streams were drainage basin area ($r^2 = 0.14$) (Figure 18a) and stream order ($r^2 = 0.13$) (Figure 18b). For the 23 gaged sites, duration of overbank flow had no effect on the percent of the FPW that is wetland ($r^2 = 0.03$) (Figure 18c) or on the EI average ($r^2 = 0.01$) (Figure 18d) (Table 8).

Longer durations of flow exceeding average were associated with greater wetland width ($r^2 = 0.48$) (Figure 19a), cross-sectional area ($r^2 = 0.30$) (Figure 15e), and the percent of the FPW that is wetland ($r^2 = 0.29$) (Figure 19b). Longer durations of above average flow did not correlate with lower EI average ($r^2 = 0.00$) (Figure 19c). The duration of time that stream flow exceeded average responded linearly to increases in PET ratio ($r^2 = 0.41$) (Figure 11d). Greater durations were also associated with finer soil textures ($r^2 = 0.15$) (Figure 17d). Duration was not a function of drainage basin area ($r^2 = 0.04$) or of stream order ($r^2 = 0.02$) (Figure 19d and e).

Groundwater Contribution to Discharge

Average baseflow for the three streams with PET ratios less than 1.0 were as follows site 2 was 3.43 m^3/sec, site 12 was 3.44 m^3/sec, and site 16 was 5.72 m^3/sec (Figure 20a, b, and c). Average baseflow for the three streams with PET ratios greater than 1.0 were as follows: site 30 was 0.76 m^3/sec, site 33 was 0.03 m^3/sec, and site 34 was 0.65 m^3/sec (Figure 20d, e, and f). When normalized, sites 2 (7.04 m^3/sec/1000 km^2), 12 (4.81 m^3/sec/1000 km^2), and 16 (9.17 m^3/sec/1000 km^2) had greater average baseflow contribution than sites 30 (1.05 m^3/sec/1000 km^2), 33 (0.03 m^3/sec/1000 km^2), and 34 (0.74 m^3/sec/1000 km^2).

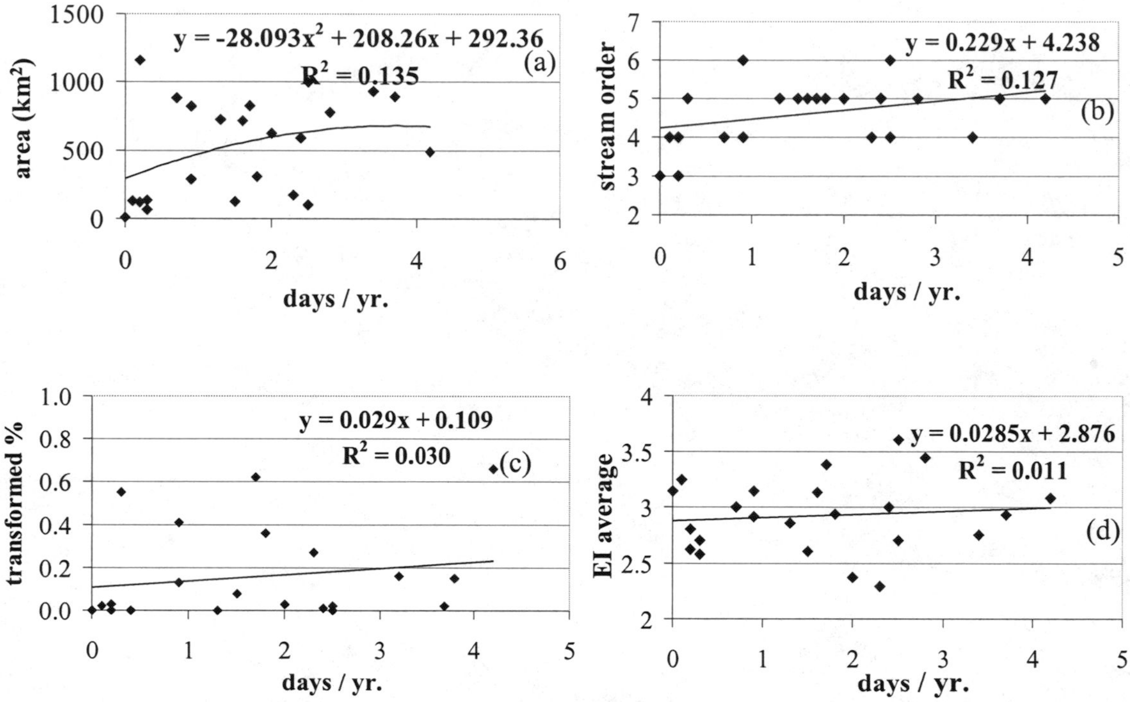

Figure 18. The relationship between average annual overbank flow duration and four variables at the central plain sites: (a) drainage basin area, (b) stream order, (c) the percent of the FPW that is wetland, and (d) the ecological indices.

Table 8. The possible factors influencing the average annual bankfull flow duration for the central plain sites. Qbkfl = bankfull discharge, bkfl fl duration = bankfull flow duration, soil codes: 1 = clay, 2 = silty clay, 3 = sandy clay, 4 = silty clay loam, 5 = clay loam, 6 = silty loam, 7 = loam, 8 = sandy clay loam, 9 = sandy loam, 10 = loamy sand, 11 = medium sandy clay loam, 12 = coarse sandy loam, n/a = not available.

Site number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
PET ratio	0.71	0.72	0.72	0.72	0.72	0.73	0.73	0.73	0.78	0.78	0.78	0.78	0.79	0.80	0.80	0.80	0.80	0.85
Strahler order	5	5	5	3	5	5	3	4	4	5	4	5	4	5	5	5	6	4
Drainage area (km^2)	n/a	487	606	119	68.9	136	n/a	221	128	n/a	44	715	287	624	n/a	824	407	n/a
Qbkfl (m^3/s)	n/a	80	n/a	91	33	109	n/a	n/a	n/a	n/a	37	64	85	79	n/a	73	297	n/a
Bkfl fl duration/yr	n/a	4.2	n/a	0.2	0.3	0.3	n/a	n/a	n/a	n/a	0.1	2.5	0.9	1.7	n/a	2.0	0.9	n/a
Soil code	8	2	3	3	1	7	6	7	1	7	1	4	7	2	8	7	6	1

Site number	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
PET ratio	0.87	0.88	0.89	0.89	0.90	0.93	0.93	0.95	0.98	1.04	1.05	1.13	1.17	1.21	1.25	1.31	1.35	1.75
Strahler order	5	5	3	4	5	5	5	3	4	4	6	5	3	4	4	4	5	4
Drainage area (km^2)	777	308	n/a	n/a	891	894	124	11	171	102	995	723	n/a	932	1160	883	n/a	n/a
Qbkfl (m^3/s)	45	37	n/a	n/a	57	27	17	41	8	7	27	32	n/a	1	11	20	n/a	n/a
Bkfl fl duration/yr	3.7	1.8	n/a	n/a	3.8	1.5	2.4	0.0	2.3	2.5	2.5	1.3	n/a	3.2	0.2	0.4	n/a	n/a
Soil code	1	1	2	2	1	7	2	6	2	11	2	9	9	6	n/a	8	12	3

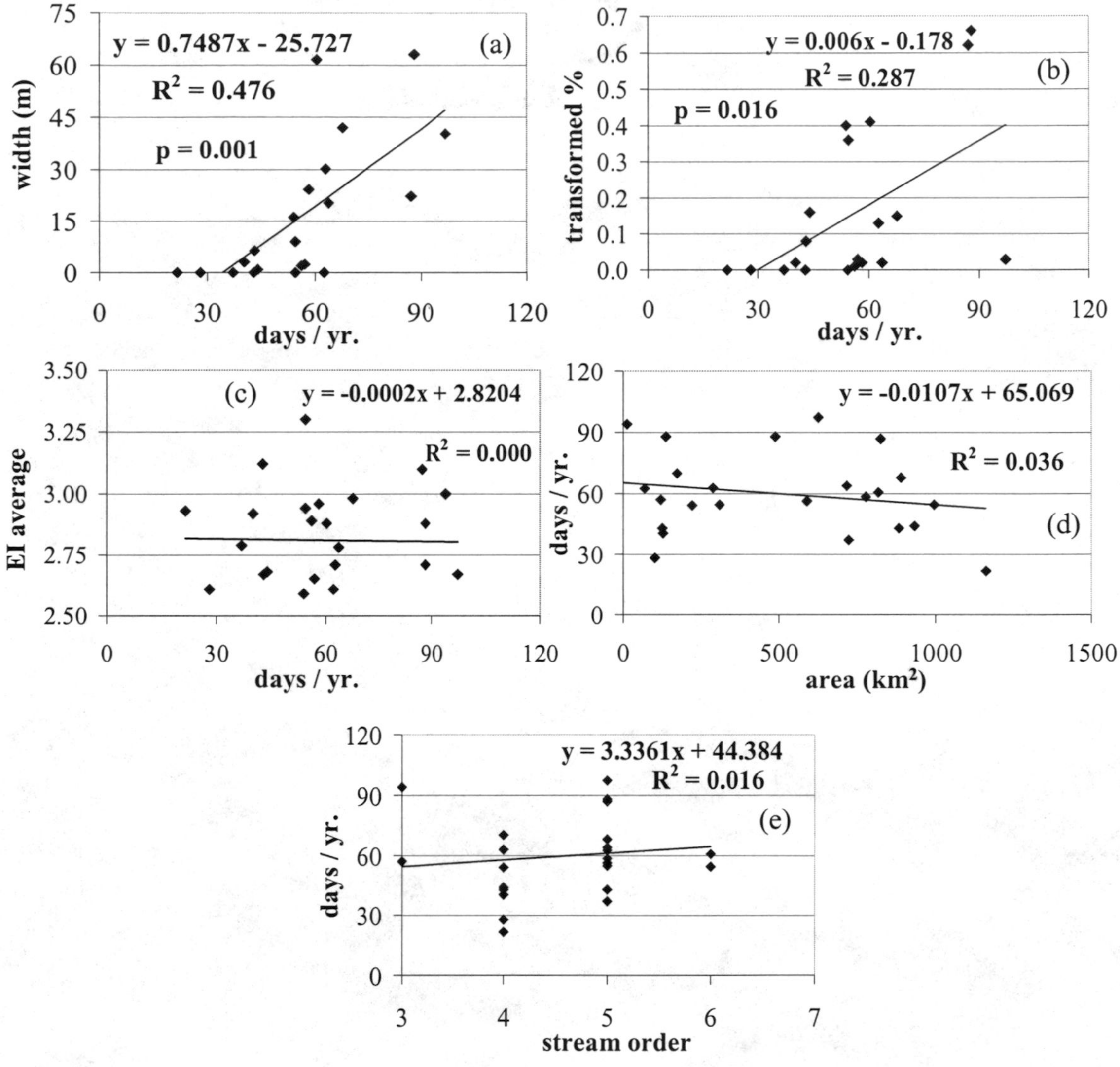

Figure 19. The relationship between the duration of flow exceeding average discharge and five variables at central plain sites: (a) wetland width, (b) the percent of the FPW that is wetland, (c) ecological indices, (d) drainage basin area, and (e) stream order.

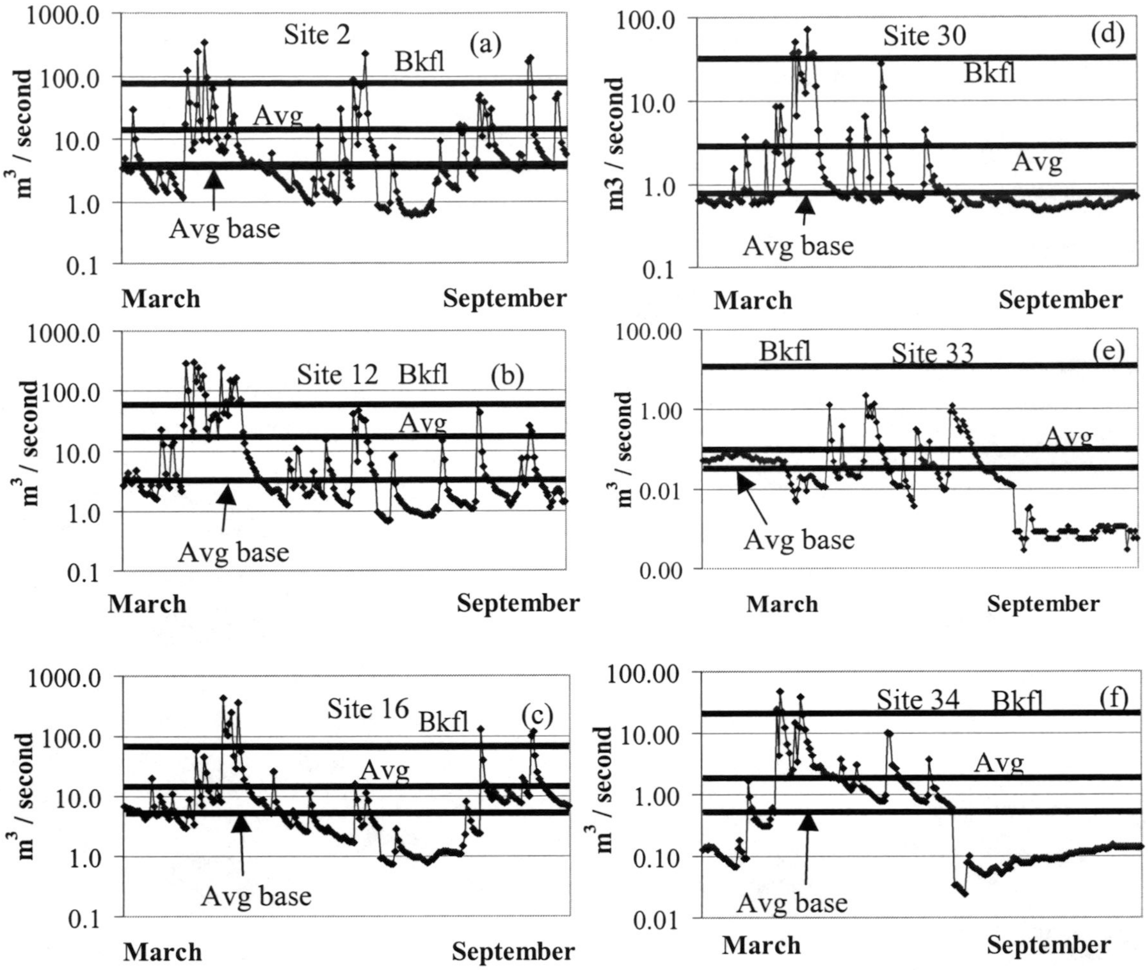

Figure 20. Hydrographs for selected sites from a synchronous time period from March - September 1993. Bkfl = bankfull discharge. Avg = average discharge. Avg base = average baseflow. Hydrographs a, b, and c have wetlands associated with them. Average baseflows were: (a) 3.43 m^3/sec, (b) 3.44 m^3/sec, and (c) 5.72 m^3/sec. Hydrographs d, e, and f did not have wetlands associated with them. Average baseflows were: (d) 0.76 m^3/sec, (e) 0.03 m^3/sec, and (f) 0.654 m^3/sec.

Discussion and Conclusions

The purpose of this study was to determine the controlling factors in the development and maintenance of riparian wetlands. Characterization was done by examining several factors that may influence the development and maintenance of riparian wetlands: stream order, drainage basin area, soil, and overbank flow duration. These factors were then compared with wetland and vegetation measurements and occurrences along a PET ratio gradient from humid to subhumid.

Maintenance of Wetlands

The greatest factor in determining the percentage of the FPW that is wetland was the PET ratio. Without augmentation of discharge, it would appear that there must be a surplus of precipitation over PET for wetlands to occupy a significant percentage of a floodplain. The majority of floodplains with a PET ratio below 0.98 had wetlands associated with them (Figure 21). This ratio appears to be the threshold for wetland occurrence along the studied streams. In order for wetlands to be maintained, the supply of water to floodplains must exceed the water demand of vegetation and the drainage caused by the presence of the stream channel. However, this supply does not appear to be solely driven by the PET ratio; other modifiers appear to be present. The presence of these modifiers is shown by the exponential decrease in the percent of the floodplain that is wetland as PET ratios increase (Figure 22a). There were large variations in the percentage of FPW consisting of wetland that are only partially explained by the other data collected through this study. One remaining possibility is the position of the groundwater table.

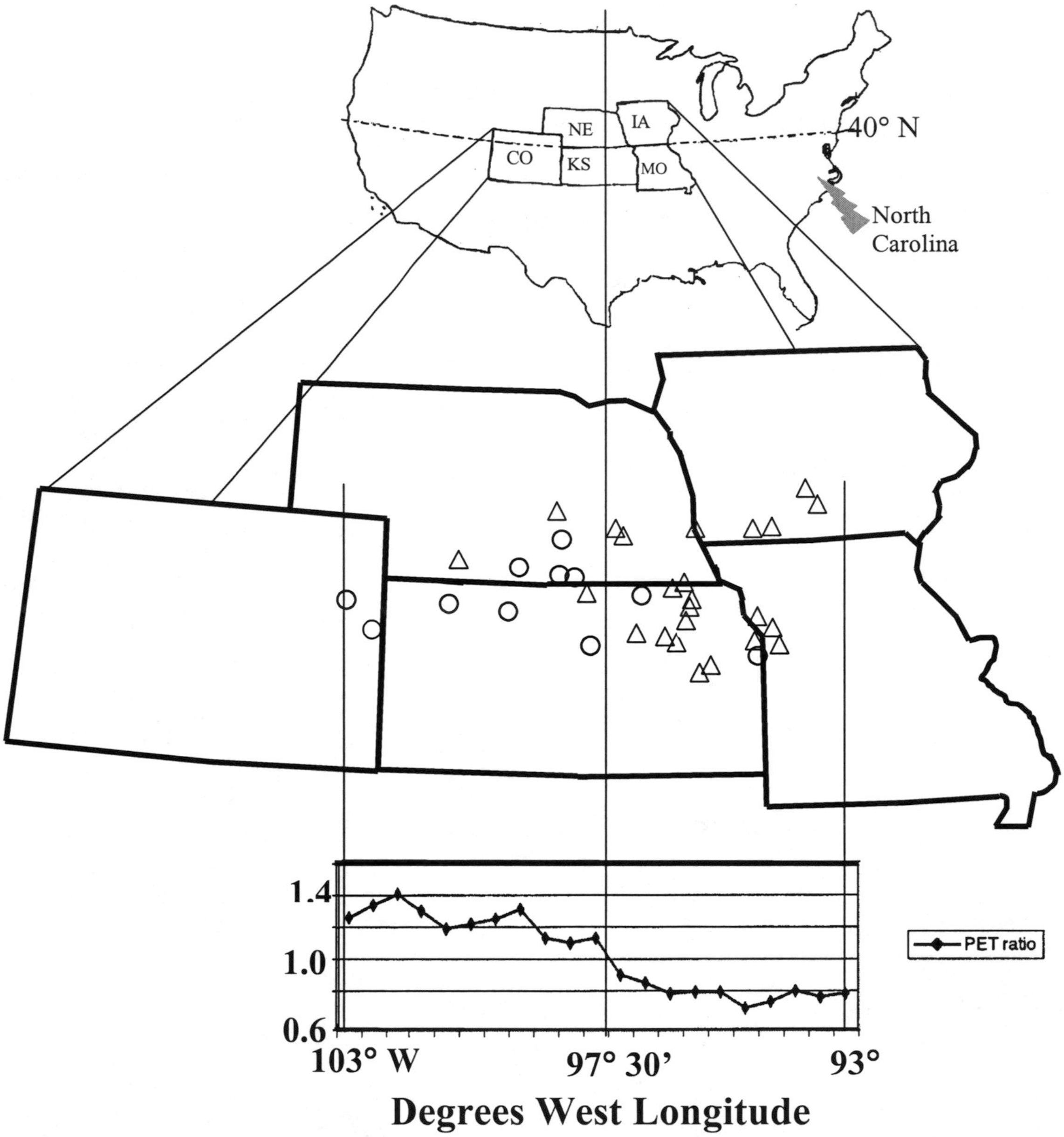

Figure 21. Distribution of sites with (triangles) and without (circles) wetlands.

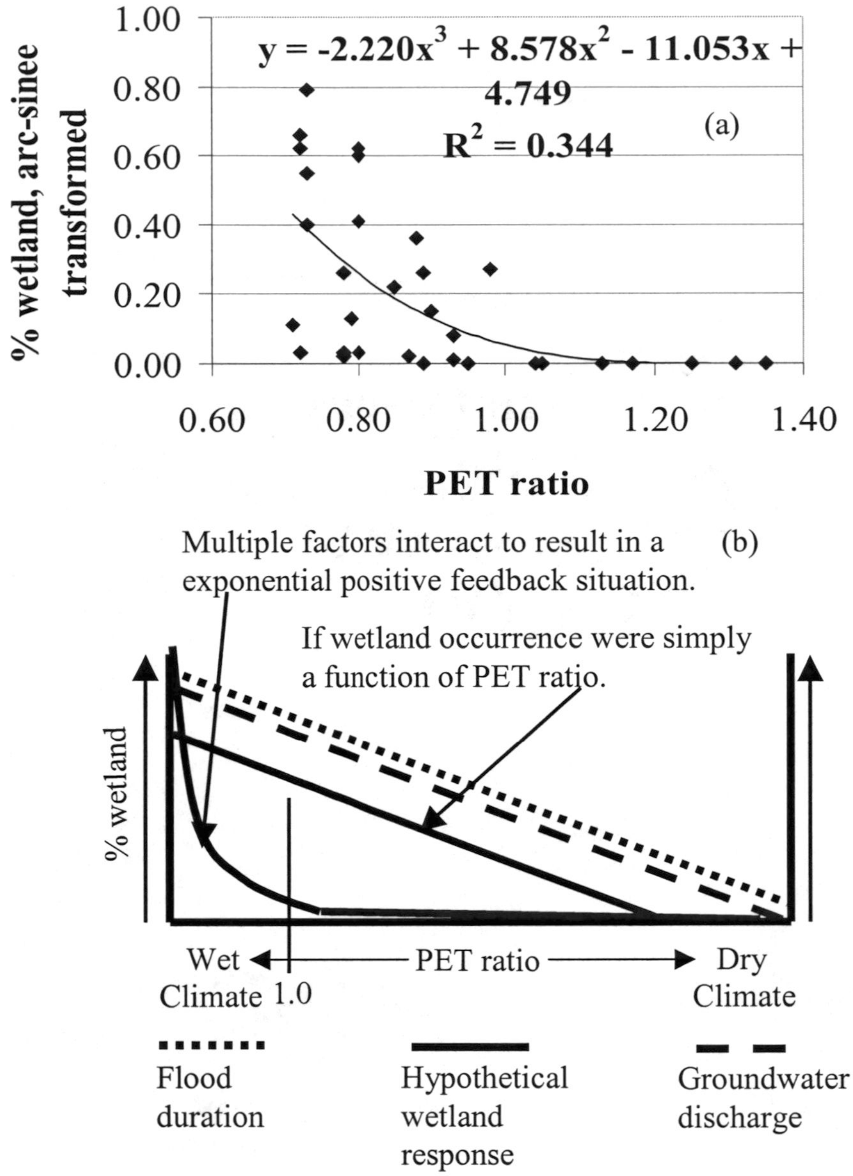

Figure 22. The exponential decrease in (a) the percentage of the FPW that is wetland as compared with (b) the conceptual model shows a similar relationship. As climate becomes drier, multiple hydrologic sources also decrease. As climates become wetter these factors interact in a positive feedback manner. The feedback situation may result in wetland extension beyond the FPW.

Groundwater inputs to stream channels were estimated for some sites in this study. Of the selected streams, streams with associated wetlands had higher baseflow discharges than those without. The increased durations of high baseflow and above average discharge are, in part, the result of high groundwater levels in the drainage basin. The more moist soil conditions could result in greater wetland widths along streams due to greater throughputs of water in the stream and the floodplain soils from groundwater discharge and bank storage.

Although precipitation is the ultimate source of water for the studied riparian systems, there appears to be differences in the delivery (timing, intensity, volume) of water between floodplains. North Carolina floodplains were consistently wetter than the central plain floodplains even at similar PET ratios. This would suggest a greater contribution of groundwater to the studied North Carolina floodplains. The wide variations in the percent of the FPW that is wetland, at the central plain sites, could also be attributed to variations in groundwater contributions. There is the possibility of a positive feedback situation between the groundwater flow originating from precipitation on uplands and streamflow resulting in stockpiling of groundwater in the floodplain.

During and following precipitation events, groundwater is recharged and streamflow is increased by overland flow and groundwater discharge. As the stormflow recedes, upstream variable source areas contribute groundwater discharge maintaining the baseflow of the stream (Hewlett 1961a, Hewlett 1961b). The greater the baseflow is (and thus the stream stage) the lower the hydraulic gradient is between the channel and the floodplain, resulting in slower groundwater discharge. This desynchronous drainage increases the duration of saturation in the floodplain at the point of study by decreasing the rate of drainage of the floodplain soils and backing up the flow of groundwater through the floodplain. Backed up groundwater flow results in a rise in the water table elevation in the floodplain (Figures 23 and 24). Backed up groundwater flow in an alluvial aquifer was shown to exist on Little Stony Creek, California in relation to increased reservoir stage (M.C. Rains, presentation at Society of Wetland Scientists annual meeting 1999). If the water table is high enough, then every addition of water not utilized by vegetation or drained by the stream channel would contribute directly to the water table elevation and could result in an exponential increase in the percentage of FPW until wetlands may even extend beyond the FPW, as in North Carolina.

In order for this situation to function, yearly precipitation on the uplands and floodplain must regularly exceed the ET of the vegetation and all other losses (agricultural and domestic wells and regional groundwater discharge). This excess must occur for a period of time during the growing season, sufficient to raise the groundwater table to the level that the FPW remains saturated within 30 cm of the surface for 14 days after the precipitation or overbank event. On the studied floodplains, the pattern of the percentage of the FPW that is wetland decreased exponentially as the PET ratio increased, indicative of multiple, decreasing water sources.

Greater channel depths did not negatively affect the occurrence of wetlands in North Carolina or in the central plains. In contrast, streams showed increased wetland width with greater channel cross-sections, regardless of drainage basin area, stream order or PET ratio. Natural channel cross-sections are formed by the discharges moving

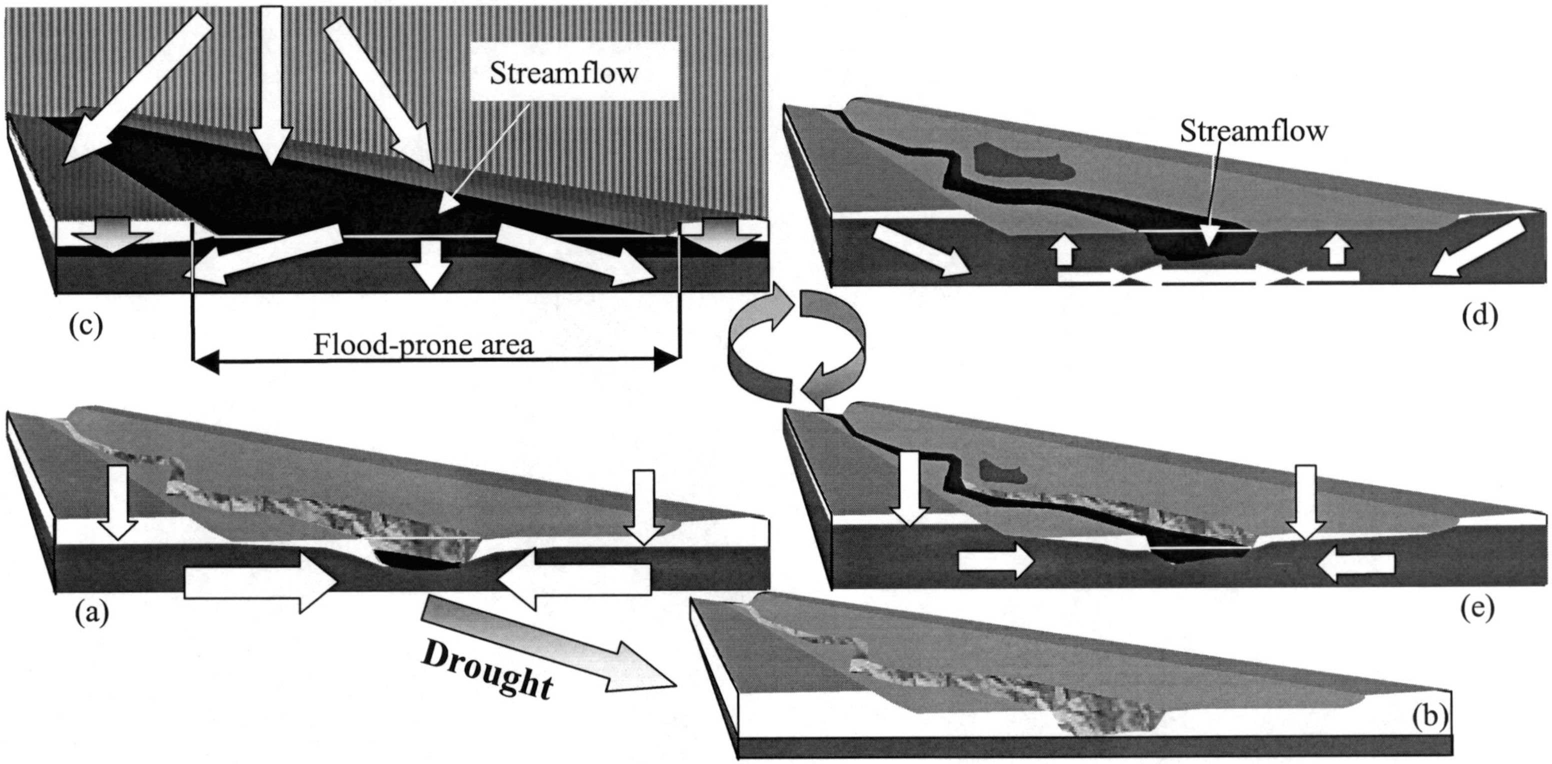

Figure 23. The cyclical pattern of rain, high streamflow, and groundwater discharge into the stream. This pattern is typical in humid region streams. (a) During baseflow conditions, streamflow is maintained by groundwater discharge. (b) If groundwater levels become low enough (drought), streamflow may become interrupted. (c) During storm events, streamflow and precipitation recharge the groundwater system. (d) The greater the upstream hydrologic sources the higher the stream stage resulting in decreased groundwater discharge and a saturated floodplain. (e) As stream stage decreases groundwater discharge increases, draining the floodplain. Higher PET ratios result in a shortened period of time between steps (c) and (a). This leads to a negative-feedback situation where the percentage of the FPW that is wetland decreases exponentially with watertable decreases until floodplains do not meet wetland criteria.

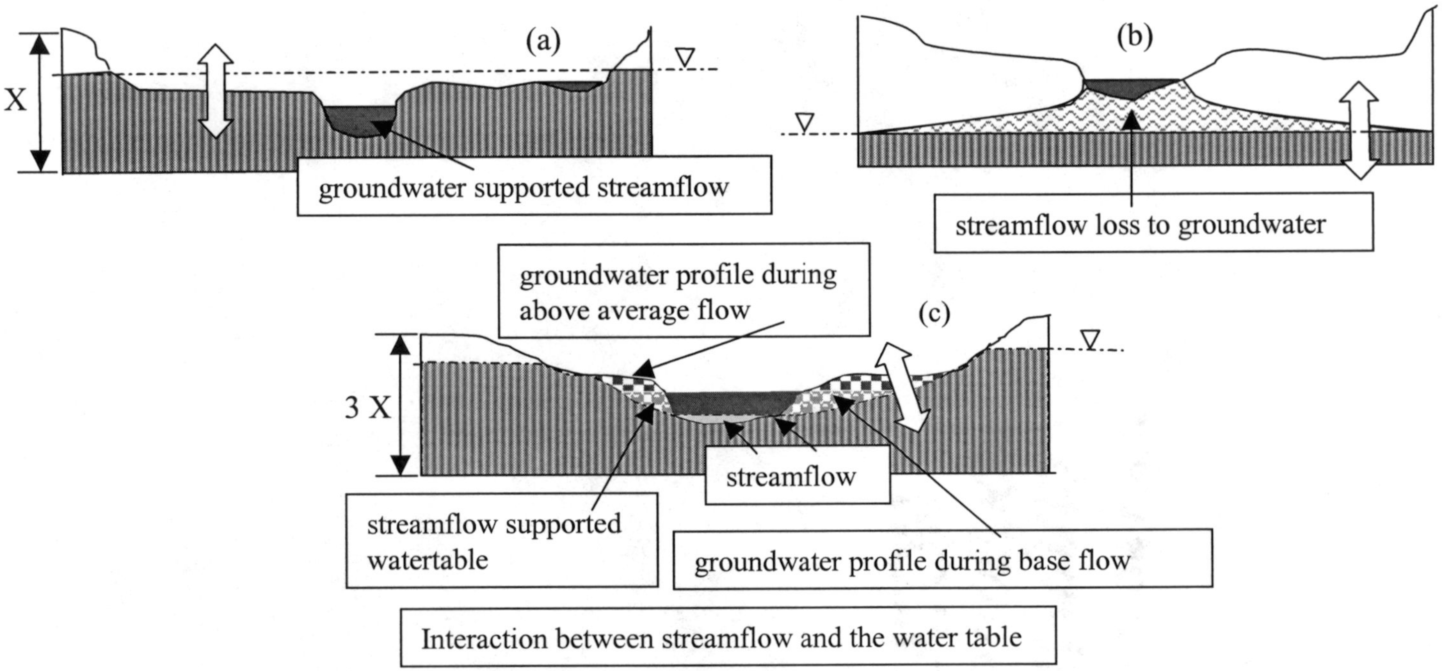

Figure 24. Cross-sections of streams contrasting hydrologic regimes of floodplains. (a) In regions where groundwater supports streamflow and floodplain hydrology, overbank flow is not necessary to maintain wetlands. (b) In regions where streamflow is lost to groundwater, wetlands can be maintained by supplemental sources (irrigation returnflow, streamflow from outside the region). (c) However, in humid regions where groundwater levels are normally too deep to support high percentages of the FPW as wetland, but high enough to support streamflow (high hydraulic gradient), there may be an interaction between streamflow and the water table that may support wetlands. There is a positive feedback interaction between groundwater levels and streamflow driven by climate. This is expressed as a exponential decrease in the percent of the FPW that is wetland as PET ratios increase. This interaction is a consequence of a reduced hydraulic gradient through the floodplain and an input of water from the stream into the groundwater table. This results in elevated groundwater levels in the floodplain, and thus greater percentages of the FPW as wetland. ∇ = water table level.

through them (Leopold et al. 1964, Knighton 1998). Although the presence of a deeper channel suggests that there may be more rapid drainage due to an increased hydraulic gradient, apparently this is not necessarily the case. Most of the channels that were deep tended to be perennial with greater average daily discharges of water in them, effectively reducing a possible hydraulic gradient that would otherwise augment floodplain drainage. Deeper channels also tended to be cut into fine-grained soils whose hydraulic conductivities are less than those of coarse-grained soils.

On North Carolina FPAs, with the exception of Otter Creek, there was a very strong correlation of wetland width with channel cross-section. Otter Creek is located on the steeper gradient of the south side of Tar River, resulting in a greater stream gradient when compared with other coastal plain streams. Otter Creek had wetlands comprising 85 percent of its FPW. This is indicative of the inability of the groundwater table to sustain wetlands for the entire FPW of this stream.

Interestingly the duration of overbank flow did not relate to the percentage of the FPW that is wetland. The lack of relation may have been because the difference between the smallest and the greatest duration (0.0 and 4.2 days, respectively) was not large enough to show the effect of overbank flow duration. The duration of overbank flow is probably conservative, given that in order for a day to be counted as an overbank flow day, daily discharge had to average greater than or equal to bankfull discharge. The use of average daily discharge probably underestimated overbank flow duration by 0.5 – 1 day per overbank event. Some short overbank events (less than 1 day), which probably exceeded bankfull, were not counted due to their low average daily discharge.

The analysis of the drainage basin area effects was biased by the original site selection, utilizing mean daily discharge records as a requirement for selection. Very few ephemeral streams are monitored for mean daily discharge, simply because they lack flow most of the time. In order for most streams to be monitored for mean daily discharge, they must be at least intermittent to perennial. As climate becomes drier (higher PET ratio), it takes larger watersheds to provide intermittent or perennial flow. Due to this lack of consistent flow in small sub-humid watersheds, the driest study sites had the largest watersheds. Comparable watershed areas on the wet end of the gradient created streams that were too deep, wide, and fast flowing for the methods used in this study. As a result of this, EI averages increased to drier conditions as drainage basins increased in area.

Vegetation

Precipitation had the largest effect on vegetation of the parameters examined. Drier climate resulted in lower groundwater levels, resulting in the contraction and eventual exclusion of the proportion of flood-prone width that was forested. As precipitation decreased, the number of non-graminoid species increased. Vegetation in FPAs changed from woody and forb dominated to those dominated by graminoids. This transition is at least partially influenced by current and historical agricultural / silvicultural practices. The majority of the central plains has historically been grazed and, in some areas, overgrazed by cattle (Donahue 1999). This grazing may have reduced the diversity of the FPA vegetation, especially on floodplains on the drier end of the gradient where grazing pressure may have eliminated or reduced forbs and woody plants.

Of note, the encroachment of agriculture into the FPW decreased the width of forested floodplain along some streams. This encroachment undoubtedly changed the outcome of the vegetation analysis through alteration in species composition and their distribution in the natural gradient from the streambank to the edge of the FPW. Encroachment by cropland reduced the species richness of vegetation for large portions of some FPAs. This encroachment has also changed the FPA average ecological index of vegetation, depending on the amount of area under cultivation. In addition to this, during the period of cultivation, the soils may be dry enough to allow some crops (all UPL species) to survive for at least their growing period, seriously influencing the interpretation of vegetation analysis during this period.

Neither the duration of average annual overbank flow nor the duration of above average discharge affected the distribution of woody vegetation. At the maximum observed overbank flow duration of 2.2 percent of the growing season, duration of inundation does not limit the distribution of woody vegetation (Bedinger 1979). The occurrence of two species that were affected by stream order (*Ulmus rubra* and *Acer saccharinum*) showed a greater sensitivity to stream discharge regimes than the duration of inundation. Woody species on the North Carolina floodplains showed greater sensitivity to PET ratio differences than the herbaceous species. Most annual herbaceous species respond to recent hydrologic regimes, whereas woody species respond to longer-term regimes due to their perennial life cycles.

Of the studied central plain floodplains and several others visited, very few had shrubs on them. The few that did were mainly *Ligustrum* spp. Cattle grazing may have had a negative impact on shrubs due to high seedling herbivory throughout the central plains. Saplings and tall herbaceous species have in many cases filled the niche of the shrub layer. The FPAs of many observed streams in the central plains are quite open after the herbaceous layer dies off during the winter.

Relative densities of vegetation would have been useful in the analysis of the vegetation data. However, time constraints precluded the collection of these data. This became evident as analysis was done and there were unanswered questions about the trends in vegetation dynamics over the climatic gradient. A prevalence index (weighted averages, Shannon Index, or Simpson Index) may have shown this better than the average EI.

If possible, the effect and occurrence of beaver damming action should be studied on a PET ratio gradient. This would lead to an understanding of the historic and current effects of beaver on wetland occurrence and stream stability.

Conclusions

- On the central plain sites the exponential trend in the percentage of the FPW that is wetland indicates a positive feedback situation between the groundwater system and streamflow.
- Greater discharges from upstream variable source areas, resulting in higher stream stages, decrease the hydraulic gradient through the floodplain. The reduction in hydraulic gradient increases the duration of saturation in the floodplain soils.

- Along North Carolina streams, high groundwater levels may maintain riparian wetlands.
- Precipitation was more important than PET ratio in determining woody species richness in the central plains.
- Drainage basin area, stream order, overbank flow duration, and soil texture did not significantly correlate with the maintenance or development of riverine wetlands on the central plain study sites.

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Appendix A. Floodplain Vegetation on the Central Plain Study Sites

Appendix A. Floodplain vegetation on the central plain study sites. + = prevalent, X = dominant, H = herb, V = vine, S = shrub, T = tree, n/a = not available. Note: some species are listed more than once with different wetland indicator status due to differing regional indicator status. Jaccard similarity calculated by comparison with the next higher PET ratio site (1 vs. 2, 2 vs. 3, etc).

	Site id.		1	2	3	4	5	6	7	8	9	10	11	12	13	14
	PET ratio		0.71	0.72	0.72	0.72	0.72	0.73	0.73	0.73	0.78	0.78	0.78	0.78	0.79	0.80
	Strahler order		5	5	5	3	5	5	3	4	4	5	4	5	4	5
	Jaccard similarity		0.56	0.45	0.55	0.63	0.74	0.67	0.54	0.69	0.57	0.50	0.69	0.76	0.67	0.56
	Drainage area (km^2)		n/a	487	606	119	69	136	n/a	221	128	n/a	44	715	287	624
Species	Indicator status															
Cannabis sativa	FACU-	H	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Agropyron smithii	FACU	H	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Amaranthus albus	FACU	H	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Ambrosia artemisiifolia	FACU	H	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Elymus canadensis	FACU	H	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Helianthus annuus	FACU	H	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Rudbeckia hirta	FACU	H	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Solidago nuttallii	FACU	H	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Solidago nuttallii	FACU+	H	--	--	--	--	--	--	--	--	--	--	+	--	--	--
Elymus canadensis	FAC -	H	--	--	--	+	--	--	+	+	--	--	--	--	--	--
Phytolacca americana	FAC -	H	--	--	+	--	--	--	+	--	--	+	+	--	--	--
Asclepias speciosa	FAC	H	--	--	--	--	--	--	--	--	--	--	+	+	--	--
Cannabis sativa	FAC	H	--	--	--	--	--	--	--	--	--	+	+	--	--	--
Commelina communis	FAC	H	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Elymus virginicus	FAC	H	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Panicum rigidulum	FAC	H	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Phytolacca americana	FAC	H	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Rhus toxicodendron	FAC	H	--	+	--	--	--	--	--	--	--	--	--	--	--	--
Verbesina alternifolia	FAC	H	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Hordeum jubatum	FAC +	H	--	--	--	--	--	--	--	--	--	+	--	--	--	--

Appendix A. Continued.

	Site id.		15	16	17	18	19	20	21	22	23	24	25	26	27	28
	PET ratio		0.80	0.80	0.80	0.85	0.87	0.88	0.89	0.89	0.90	0.93	0.93	0.95	0.98	1
	Strahler order		5	5	6	4	5	5	3	4	5	5	5	3	4	4
	Jaccard similarity		0.57	0.30	0.48	0.64	0.56	0.72	0.42	0.29	0.61	0.44	0.38	0.38	0.52	0.4
	Drainage area (km^2)		n/a	824	407	n/a	777	308	n/a	n/a	891	894	124	11	171	102
Species	Indicator status															
Cannabis sativa	FACU-	H	--	+	--	+	--	--	+	--	--	--	+	--	--	+
Agropyron smithii	FACU	H	--	--	--	--	--	--	--	--	--	--	--	X	--	--
Amaranthus albus	FACU	H	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Ambrosia artemisiifolia	FACU	H	+	--	--	--	--	X	--	+	--	--	+	--	--	--
Elymus canadensis	FACU	H	--	--	+	+	--	--	--	--	--	--	--	+	--	--
Helianthus annuus	FACU	H	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Rudbeckia hirta	FACU	H	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Solidago nuttallii	FACU	H	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Solidago nuttallii	FACU+	H	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Elymus canadensis	FAC -	H	+	--	--	--	--	--	--	--	--	--	--	--	--	--
Phytolacca americana	FAC -	H	+	--	--	--	--	--	--	--	--	--	--	--	--	--
Asclepias speciosa	FAC	H	--	--	--	--	--	--	--	--	--	--	--	--	+	+
Cannabis sativa	FAC	H	+	--	--	--	--	--	--	--	--	--	--	--	--	--
Commelina communis	FAC	H	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Elymus virginicus	FAC	H	--	--	--	--	--	+	+	--	+	X	--	--	--	--
Panicum rigidulum	FAC	H	--	+	--	--	--	--	--	--	--	--	+	+	--	--
Phytolacca americana	FAC	H	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Rhus toxicodendron	FAC	H	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Verbesina alternifolia	FAC	H	--	--	--	X	--	X	--	--	--	+	+	X	--	--
Hordeum jubatum	FAC +	H	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Appendix A. Continued.

	Site id.		29	30	31	32	33	34	35	36
	PET ratio		1.05	1.13	1.17	1.21	1.25	1.31	1.35	1.75
	Strahler order		6	5	3	4	4	4	5	4
	Jaccard similarity		0.58	0.55	0.38	0.67	0.75	0.27	0.20	←
	Drainage area (km^2)		995	723	n/a	932	1160	883	n/a	n/a
Species	Indicator status									
Cannabis sativa	FACU-	H	--	--	--	--	--	--	--	--
Agropyron smithii	FACU	H	--	--	--	--	--	--	--	X
Amaranthus albus	FACU	H	--	--	--	--	--	--	--	+
Ambrosia artemisiifolia	FACU	H	--	--	--	--	--	--	--	--
Elymus canadensis	FACU	H	--	--	--	--	--	--	--	--
Helianthus annuus	FACU	H	+	+	--	--	--	--	--	--
Rudbeckia hirta	FACU	H	--	--	--	--	--	--	+	--
Solidago nuttallii	FACU	H	--	--	--	--	--	--	--	--
Solidago nuttallii	FACU+	H	--	--	--	--	--	--	--	--
Elymus canadensis	FAC -	H	--	--	--	--	--	--	--	--
Phytolacca americana	FAC -	H	--	--	--	--	--	--	--	--
Asclepias speciosa	FAC	H	--	--	--	--	--	--	+	--
Cannabis sativa	FAC	H	--	--	--	--	--	--	--	--
Commelina communis	FAC	H	--	--	--	--	--	--	--	--
Elymus virginicus	FAC	H	+	--	--	+	+	+	--	--
Panicum rigidulum	FAC	H	--	--	--	--	--	--	--	--
Phytolacca americana	FAC	H	+	--	--	--	--	--	--	--
Rhus toxicodendron	FAC	H	--	--	+	--	--	--	--	--
Verbesina alternifolia	FAC	H	--	--	--	--	--	--	--	--
Hordeum jubatum	FAC +	H	--	--	--	--	--	--	--	--

Appendix A. Continued.

	Site id.		1	2	3	4	5	6	7	8	9	10	11	12	13	14
	PET ratio		0.71	0.72	0.72	0.72	0.72	0.73	0.73	0.73	0.78	0.78	0.78	0.78	0.79	0.80
	Strahler order		5	5	5	3	5	5	3	4	4	5	4	5	4	5
	Jaccard similarity		0.56	0.45	0.55	0.63	0.74	0.67	0.54	0.69	0.57	0.50	0.69	0.76	0.67	0.56
	Drainage area (km^2)		n/a	487	606	119	69	136	n/a	221	128	n/a	44	715	287	624
Species	Indicator status															
Rhus radicans	FAC +	H	+	+	--	+	+	--	--	--	--	+	+	--	+	--
Urtica gracilis	FAC +	H	X	+	X	+	X	X	+	+	X	+	+	+	+	--
Elymus virginicus	FACW-	H	--	--	--	--	--	--	--	--	--	--	+	+	+	--
Ipomoea lacunosa	FACW-	H	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Hordeum jubatum	FACW	H	--	--	+	--	--	--	--	--	--	--	--	--	--	--
Impatiens sp.	FACW	H	+	--	+	+	X	+	--	+	--	--	+	--	--	--
Ipomoea lacunosa	FACW	H	+	--	--	--	--	--	--	+	--	--	--	--	--	--
Laportea canadensis	FACW	H	+	X	+	--	--	+	+	X	+	X	--	--	X	+
Pilea pumila	FACW	H	--	X	+	+	--	X	+	+	+	+	--	--	--	--
Polyganum sp.	FACW	H	--	--	--	--	+	--	--	+	+	--	--	--	--	--
Urtica gracilis	FACW	H	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Verbesina alternifolia	FACW	H	--	--	--	+	--	--	--	+	--	--	--	--	--	--
Phalaris arundinacea	FACW+	H	+	--	+	--	--	+	--	+	+	--	X	+	--	--
Alisima plantago-aquatica	OBL	H	--	--	--	--	--	--	--	--	--	--	--	--	+	--
Boehmeria cylindrica	OBL	H	--	--	--	X	+	--	--	--	--	--	--	--	--	--
Calamagrostis canadensis	OBL	H	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Parthenocissus quinquefolia	FAC	V	--	+	--	--	--	--	+	--	--	--	--	--	--	--
Smilax rotundifolia	FAC	V	+	+	--	--	--	--	--	+	--	--	--	--	--	--
Smilax hispida	FAC	V	+	+	--	--	--	--	--	--	--	+	--	--	--	--

Appendix A. Continued.

	Site id.		15	16	17	18	19	20	21	22	23	24	25	26	27	28
	PET ratio		0.80	0.80	0.80	0.85	0.87	0.88	0.89	0.89	0.90	0.93	0.93	0.95	0.98	1
	Strahler order		5	5	6	4	5	5	3	4	5	5	5	3	4	4
	Jaccard similarity		0.57	0.30	0.48	0.64	0.56	0.72	0.42	0.29	0.61	0.44	0.38	0.38	0.52	0.4
	Drainage area (km^2)		n/a	824	407	n/a	777	308	n/a	n/a	891	894	124	11	171	102
Species	Indicator status															
Rhus radicans	FAC +	H	+	--	--	--	--	--	--	--	--	--	--	+	--	--
Urtica gracilis	FAC +	H	+	--	--	--	--	--	--	--	--	--	--	--	--	--
Elymus virginicus	FACW-	H	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Ipomoea lacunosa	FACW-	H	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Hordeum jubatum	FACW	H	--	--	--	--	--	--	+	--	--	--	--	--	+	--
Impatiens sp.	FACW	H	--	--	--	--	--	--	--	--	--	--	--	--	+	--
Ipomoea lacunosa	FACW	H	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Laportea canadensis	FACW	H	X	--	+	X	+	--	--	--	+	+	X	--	--	--
Pilea pumila	FACW	H	--	--	--	--	--	--	--	--	--	--	--	+	+	--
Polyganum sp.	FACW	H	--	--	--	--	--	--	--	--	--	--	--	+	--	--
Urtica gracilis	FACW	H	--	X	X	X	+	+	+	--	+	+	--	--	+	+
Verbesina alternifolia	FACW	H	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Phalaris arundinacea	FACW+	H	+	+	--	--	--	X	X	X	--	--	+	--	+	+
Alisima plantago-aquatica	OBL	H	+	--	--	--	--	--	--	--	--	--	--	--	--	--
Boehmeria cylindrica	OBL	H	--	--	--	--	--	--	--	--	--	--	+	+	X	--
Calamagrostis canadensis	OBL	H	--	--	--	--	--	--	--	--	--	--	--	--	--	+
Parthenocissus quinquefolia	FAC	V	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Smilax rotundifolia	FAC	V	--	--	--	--	+	--	--	--	+	+	--	--	--	--
Smilax hispida	FAC	V	--	--	--	--	--	--	--	--	+	--	--	--	--	--

Appendix A. Continued.

			29	30	31	32	33	34	35	36
	Site id.		29	30	31	32	33	34	35	36
	PET ratio		1.05	1.13	1.17	1.21	1.25	1.31	1.35	1.75
	Strahler order		6	5	3	4	4	4	5	4
	Jaccard similarity		0.58	0.55	0.38	0.67	0.75	0.27	0.20	←
	Drainage area (km^2)		995	723	n/a	932	1160	883	n/a	n/a
Species	Indicator status									
Rhus radicans	FAC +	H	+	+	+	--	--	--	--	--
Urtica gracilis	FAC +	H	--	--	--	--	--	--	--	--
Elymus virginicus	FACW-	H	--	--	--	--	--	--	--	--
Ipomoea lacunosa	FACW-	H	--	--	--	--	--	--	--	--
Hordeum jubatum	FACW	H	--	--	+	--	--	--	--	--
Impatiens sp.	FACW	H	--	+	--	--	--	--	--	--
Ipomoea lacunosa	FACW	H	--	--	--	--	--	--	--	--
Laportea canadensis	FACW	H	--	--	--	--	--	--	--	--
Pilea pumila	FACW	H	--	--	--	--	--	--	--	--
Polyganum sp.	FACW	H	--	+	--	--	--	--	--	--
Urtica gracilis	FACW	H	--	+	--	X	+	--	--	--
Verbesina alternifolia	FACW	H	--	--	--	--	--	--	--	--
Phalaris arundinacea	FACW+	H	--	X	--	--	--	--	--	--
Alisima plantago-aquatica	OBL	H	--	+	--	--	--	--	--	--
Boehmeria cylindrica	OBL	H	--	--	--	--	--	--	--	--
Calamagrostis canadensis	OBL	H	--	--	--	--	--	--	--	--
Parthenocissus quinquefolia	FAC	V	--	--	--	--	--	--	--	--
Smilax rotundifolia	FAC	V	--	--	--	--	--	--	--	--
Smilax hispida	FAC	V	--	--	--	--	--	--	--	--

Appendix A. Continued.

	Site id.		1	2	3	4	5	6	7	8	9	10	11	12	13	14
	PET ratio		0.71	0.72	0.72	0.72	0.72	0.73	0.73	0.73	0.78	0.78	0.78	0.78	0.79	0.80
	Strahler order		5	5	5	3	5	5	3	4	4	5	4	5	4	5
	Jaccard similarity		0.56	0.45	0.55	0.63	0.74	0.67	0.54	0.69	0.57	0.50	0.69	0.76	0.67	0.56
	Drainage area (km^2)		n/a	487	606	119	69	136	n/a	221	128	n/a	44	715	287	624
Species	Indicator status															
Aesculus glabra	FAC	S	--	--	--	--	--	+	+	--	--	+	--	--	--	--
Ligustrum sp.	FAC	S	--	--	--	+	+	--	+	--	--	--	--	--	--	--
Staphylea trifolia	FAC	S	--	+	--	--	--	--	+	--	--	--	--	--	--	--
Celtis occidentalis	FACU	T	--	--	--	--	--	--	--	--	--	--	--	--	--	+
Juglans nigra	FACU	T	+	--	--	+	+	+	+	+	--	+	+	--	+	--
Morus rubra	FACU	T	--	--	--	--	--	--	--	--	--	--	--	--	--	+
Quercus macrocarpa	FACU	T	--	+	--	--	+	+	+	+	--	+	+	--	+	--
Celtis occidentalis	FAC -	T	--	+	--	+	--	+	+	--	--	+	--	--	+	--
Morus rubra	FAC -	T	+	--	--	--	--	+	--	+	+	+	+	+	+	--
Quercus macrocarpa	FAC -	T	--	--	--	--	--	--	--	--	--	--	--	--	--	+
Acer negundo	FAC	T	--	--	--	--	--	--	--	--	--	--	--	--	--	+
Gleditsia triacanthos	FAC	T	--	--	--	--	--	--	--	--	--	--	+	+	--	--
Platanus occidentalis	FAC	T	--	+	+	X	+	--	+	--	--	+	--	--	+	--
Populus sargentii	FAC	T	--	+	--	+	+	+	+	+	--	+	--	+	--	--
Ulmus americanus	FAC	T	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Ulmus rubra	FAC	T	+	+	--	+	+	+	+	+	X	+	X	--	X	+
Populus sargentii	FAC+	T	--	--	--	--	--	--	--	--	--	--	--	--	--	+
Acer negundo	FACW-	T	+	X	+	+	+	X	+	+	+	+	--	--	+	--
Acer saccharinum	FACW	T	X	X	X	+	X	+	--	X	+	X	--	+	+	+
Platanus occidentalis	FACW	T	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Salix exigua	OBL	T	+	--	--	+	+	+	--	+	+	--	X	--	+	--
Salix rigida	OBL	T	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Appendix A. Continued.

	Site id.		15	16	17	18	19	20	21	22	23	24	25	26	27	28
	PET ratio		0.80	0.80	0.80	0.85	0.87	0.88	0.89	0.89	0.90	0.93	0.93	0.95	0.98	1
	Strahler order		5	5	6	4	5	5	3	4	5	5	5	3	4	4
	Jaccard similarity		0.57	0.30	0.48	0.64	0.56	0.72	0.42	0.29	0.61	0.44	0.38	0.38	0.52	0.4
	Drainage area (km^2)		n/a	824	407	n/a	777	308	n/a	n/a	891	894	124	11	171	102
Species	Indicator status															
Aesculus glabra	FAC	S	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Ligustrum sp.	FAC	S	--	--	+	--	--	--	+	--	--	--	--	+	--	+
Staphylea trifolia	FAC	S	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Celtis occidentalis	FACU	T	--	--	X	X	+	+	--	--	+	--	--	X	--	--
Juglans nigra	FACU	T	+	--	--	+	--	--	--	--	X	--	--	+	--	+
Morus rubra	FACU	T	--	+	--	+	+	+	+	--	+	--	+	--	--	--
Quercus macrocarpa	FACU	T	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Celtis occidentalis	FAC -	T	+	--	--	--	--	--	--	--	--	--	--	--	--	--
Morus rubra	FAC -	T	+	--	--	--	--	--	--	--	--	--	--	--	--	--
Quercus macrocarpa	FAC -	T	--	--	--	--	--	--	--	--	--	--	--	+	--	--
Acer negundo	FAC	T	--	+	+	--	+	--	+	--	+	--	--	--	--	--
Gleditsia triacanthos	FAC	T	--	--	+	+	--	--	--	--	--	--	--	--	--	X
Platanus occidentalis	FAC	T	+	--	--	--	--	--	--	--	--	--	--	--	--	--
Populus sargentii	FAC	T	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Ulmus americanus	FAC	T	--	+	--	--	--	--	--	--	--	--	--	--	--	--
Ulmus rubra	FAC	T	+	--	--	+	+	+	+	--	+	+	X	+	X	+
Populus sargentii	FAC+	T	--	--	--	+	+	+	+	--	+	X	--	--	--	+
Acer negundo	FACW-	T	+	--	--	--	--	--	--	--	--	--	--	--	--	--
Acer saccharinum	FACW	T	X	X	--	+	--	X	+	X	+	--	--	--	--	--
Platanus occidentalis	FACW	T	--	--	+	--	--	--	--	--	--	--	--	--	--	--
Salix exigua	OBL	T	+	+	--	--	--	--	--	--	--	--	--	--	--	X
Salix rigida	OBL	T	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Appendix A. Concluded.

	Site id.		29	30	31	32	33	34	35	36
	PET ratio		1.05	1.13	1.17	1.21	1.25	1.31	1.35	1.75
	Strahler order		6	5	3	4	4	4	5	4
	Jaccard similarity		0.58	0.55	0.38	0.67	0.75	0.27	0.20	←
	Drainage area (km^2)		995	723	n/a	932	1160	883	n/a	n/a
Species	Indicator status									
Aesculus glabra	FAC	S	--	--	--	--	--	--	--	--
Ligustrum sp.	FAC	S	--	+	+	--	--	+	--	--
Staphylea trifolia	FAC	S	--	--	--	--	--	--	--	--
Celtis occidentalis	FACU	T	--	+	--	--	+	+	--	--
Juglans nigra	FACU	T	+	+	+	--	--	--	--	--
Morus rubra	FACU	T	X	+	--	--	--	--	--	--
Quercus macrocarpa	FACU	T	--	--	--	--	--	--	--	--
Celtis occidentalis	FAC -	T	--	--	--	--	--	--	--	--
Morus rubra	FAC -	T	--	--	--	--	--	--	--	--
Quercus macrocarpa	FAC -	T	--	--	--	--	--	--	--	--
Acer negundo	FAC	T	--	+	+	--	--	--	--	--
Gleditsia triacanthos	FAC	T	--	--	--	--	--	X	--	--
Platanus occidentalis	FAC	T	--	--	--	--	--	--	--	--
Populus sargentii	FAC	T	--	--	--	--	--	--	--	--
Ulmus americanus	FAC	T	--	--	--	--	--	--	--	--
Ulmus rubra	FAC	T	+	X	+	X	--	+	--	--
Populus sargentii	FAC+	T	+	+	X	+	X	+	X	--
Acer negundo	FACW-	T	--	--	--	--	--	--	--	--
Acer saccharinum	FACW	T	--	--	--	--	--	--	--	--
Platanus occidentalis	FACW	T	--	--	--	--	--	--	--	--
Salix exigua	OBL	T	--	--	--	--	--	--	--	--
Salix rigida	OBL	T	--	--	--	--	--	--	+	--

Appendix B. Floodplain Vegetation on the North Carolina Study Sites

Appendix B. Floodplain vegetation on the North Carolina study sites. + = prevalent, T = tree, S = shrub, H = herb, F = fern -- = not prevalent.

	Site id.		A	B	C	D	E	F	G	H	I	J	K	L
	PET ratio		0.67	0.67	0.75	0.75	0.76	0.76	0.76	0.78	0.78	0.78	0.78	0.81
	Stream order		2	2	1	1	1	1	1	3	4	2	4	1
	Percent wetland		100	100	100	100	100	100	100	100	100	96	84	100
	Drainage area (km^2)		0.31	1.37	0.14	0.33	0.02	0.05	0.36	4.21	5.92	0.18	12.75	0.92
Species	Indicator status													
Acer saccharum	FACU-	T	--	--	--	--	--	--	+	--	--	--	--	--
Oxydendrum arboreum	FACU	T	--	--	--	--	--	--	--	--	--	--	--	--
Quercus alba	FACU	T	--	--	--	--	--	--	--	--	--	--	--	--
Ilex opaca	FAC-	T	+	--	--	+	+	--	--	--	--	--	+	+
Carpinus caroliniana	FAC	T	--	--	--	--	--	--	+	--	--	--	--	--
Liriodendron tulipifera	FAC	T	--	--	--	--	--	--	--	--	--	--	--	--
Pinus taeda	FAC	T	--	--	--	--	--	--	--	--	--	--	--	--
Liquidambar styraciflua	FAC+	T	--	--	--	--	--	--	--	--	+	--	+	+
Magnolia grandifolia	FAC+	T	--	--	--	--	+	--	--	--	--	--	--	--
Quercus mitchauxii	FACW-	T	--	--	--	--	--	--	+	--	--	--	--	--
Betula nigra	FACW	T	--	--	--	--	--	--	--	--	--	--	+	--
Magnolia virginiana	FACW+	T	--	--	--	--	--	--	--	--	--	--	--	--
Acer rubrum	OBL	T	+	+	--	+	+	--	--	+	+	+	+	--
Nyssa aquatica	OBL	T	--	+	+	--	+	+	--	+	+	+	+	+
Nyssa biflora	OBL	T	--	+	+	--	+	+	+	+	+	+	+	+
Taxodium distichum	OBL	T	--	--	--	--	--	--	--	+	+	--	+	--
Clethra alnifolia	FACW	S	--	--	--	+	+	--	--	--	--	--	--	--
Ligustrum sinense	FAC	S	--	--	--	--	--	--	--	--	--	--	+	--
Persea borbonea	FACW	S	--	--	--	--	--	--	--	--	--	--	--	--

Appendix B. Continued.

	Site id.		M	N	O	P
	PET ratio		0.81	0.81	0.82	0.83
	Stream order		2	1	2	1
	Percent wetland		100	100	100	100
	Drainage area (km^2)		0.57	0.13	0.65	0.04
Species	Indicator status					
Acer saccharum	FACU-	T	--	--	--	--
Oxydendrum arboreum	FACU	T	--	+	--	+
Quercus alba	FACU	T	--	--	--	+
Ilex opaca	FAC-	T	+	+	--	--
Carpinus caroliniana	FAC	T	--	--	--	--
Liriodendron tulipifera	FAC	T	+	--	--	--
Pinus taeda	FAC	T	+	--	--	+
Liquidambar styraciflua	FAC+	T	+	+	--	+
Magnolia grandifolia	FAC+	T	--	--	--	--
Quercus mitchauxii	FACW-	T	--	--	--	--
Betula nigra	FACW	T	--	--	--	--
Magnolia virginiana	FACW+	T	--	--	--	+
Acer rubrum	OBL	T	+	--	+	+
Nyssa aquatica	OBL	T	+	+	--	--
Nyssa biflora	OBL	T	--	+	--	+
Taxodium distichum	OBL	T	--	--	--	--
Clethra alnifolia	FACW	S	--	--	--	+
Ligustrum sinense	FAC	S	+	--	--	--
Persea borbonea	FACW	S	+	--	--	--

Appendix B. Continued.

	Site id.		A	B	C	D	E	F	G	H	I	J	K	L
	PET ratio		0.67	0.67	0.75	0.75	0.76	0.76	0.76	0.78	0.78	0.78	0.78	0.81
	Stream order		2	2	1	1	1	1	1	3	4	2	4	1
	Percent wetland		100	100	100	100	100	100	100	100	100	96	84	100
	Drainage area (km^2)		0.31	1.37	0.14	0.33	0.02	0.05	0.36	4.21	5.92	0.18	12.75	0.92
Species	Indicator status													
Phytolaca americana	FACU+	H	--	--	--	--	--	--	--	--	--	--	--	--
Eupatorium compositifolium	FAC-	H	--	--	--	--	--	--	--	--	--	--	--	--
Cypripedium acaule	FAC	H	--	--	--	+	--	--	--	--	--	--	--	--
Euphorbia heterophylla	FAC	H	--	--	--	--	--	--	--	--	--	+	--	--
Rhus radicans	FAC	H	+	+	+	--	--	--	--	--	--	--	+	--
Arundinaria gigantea	FACW	H	+	--	+	+	+	--	+	--	--	--	+	+
Boehmeria cylindrica	FACW	H	--	+	+	+	--	--	--	--	+	+	--	+
Impatiens sp.	FACW	H	--	+	--	--	--	--	--	--	--	--	--	--
Saururus cernuus	OBL	H	--	+	+	+	--	--	--	+	+	+	--	--
Smilax hispida	FAC	V	--	--	--	--	--	--	--	--	--	--	--	--
Smilax rotundifolia	FAC	V	--	--	--	--	--	--	+	+	+	+	+	+
Woodwardia aereolata	OBL	F	+	--	--	--	--	--	--	+	+	+	--	+

Appendix B. Concluded.

	Site id.		M	N	O	P
	PET ratio		0.81	0.81	0.82	0.83
	Stream order		2	1	2	1
	Percent wetland		100	100	100	100
	Drainage area (km^2)		0.57	0.13	0.65	0.04
Species	Indicator status					
Phytolaca americana	FACU+	H	+	--	--	--
Eupatorium compositifolium	FAC-	H	+	--	--	--
Cypripedium acaule	FAC	H	--	--	--	--
Euphorbia heterophylla	FAC	H	--	--	--	--
Rhus radicans	FAC	H	+	--	--	--
Arundinaria gigantea	FACW	H	+	+	+	+
Boehmeria cylindrica	FACW	H	--	--	--	--
Impatiens sp.	FACW	H	--	--	+	--
Saururus cernuus	OBL	H	--	--	+	--
Smilax hispida	FAC	V	+	--	--	--
Smilax rotundifolia	FAC	V	--	+	+	--
Woodwardia aereolata	OBL	F	+	+	+	+