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A raster-based GIS analysis of the cumulative impacts of humans and beaver on wetland area and types in the Chickahominy River watershed (Virginia, USA) from 1953 to 1994

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A thesis submitted in partial fulfillment of the requirements for the Environmental Studies track of the degree of Master of Interdisciplinary Studies at Virginia Commonwealth University

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Abstract

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Despite increased recognition of wetland functions and values, wetland loss and degradation continues in the United States. Digital wetlands and uplands coverages were analyzed to compare the cumulative impacts of humans and beaver (*Castor canadensis*) on wetland types in the Chickahominy River watershed (Virginia, USA) from 1953 to 1994. A vector-based approach was used for data manipulation, and a raster-based approach was chosen to analyze geographic change over time. Study findings indicated that anthropogenic activities were responsible for both wetland loss and gain in the watershed, and beavers substantially influenced shifting between wetland types. Wetland area increased 4% over 41 years.

The remainder of this manuscript has been prepared for submission to the peer-reviewed journal Wetlands, using the submittal format specified in the 'Instructions for Authors.'

INTRODUCTION

For hundreds of years, wetlands were considered wastelands by scientists, politicians, and the public (National Resource Council 1995, Perry and Vanderklein 1996). In fact, policies of the United States government encouraged dredging for navigation, dumping, draining, and filling of wetlands for agriculture or development (Maltby 1986, Mitsch and Gosselink 1986). For example, the Swamp Lands Acts of 1849, 1850, and 1860 promoted the drainage of wetlands in an attempt to protect public health (Dennison and Berry 1993).

As a result of the negative perception of wetlands, anthropogenic activities, combined with natural processes, have resulted in millions of hectares of wetland loss and degradation since settlement by European colonists. Approximately 53% of the nation's original wetlands disappeared between the 1780s and the 1980s (Dahl 1990). During the period 1950-1979, the average annual wetland loss exceeded 185,000 ha, with 87% due to agricultural conversion, 8% to urban development, and 5% to other development (Frayer et al. 1983, Dahl and Pyrell 1989).

In the past three decades, increased scientific study of wetland ecosystems led to an understanding of wetlands' beneficial ecological functions and, thus, to increased public acceptance and governmental protection of wetlands (Roberts and Lant 1988, Brinson 1993a, Smith et al. 1995, Reimold 1994, Perry and Vanderklein 1996). Although Dahl and Johnson (1991) reported that wetland loss slowed from the mid-1970s to the mid-1980s, other studies continued to document wetland degradation and loss throughout the country (Frayer et al. 1983, Peters 1989, Cashin et al. 1992, Brady and Flather 1994, Tiner et al. 1994). In the

Chesapeake Bay watershed, more than 15,000 ha of wetlands disappeared between 1982 and 1989, with most of the loss in Virginia. More than 9,700 ha, or 4%, of the wetlands in Virginia had been destroyed between 1982 and 1989 (Tiner et al. 1994, Chesapeake Bay Program 1997).

Located in topographic depressions, on slopes containing groundwater seeps or springs, or along shorelines of rivers, lakes, and coastal waters, wetlands exhibit characteristics of both terrestrial and aquatic ecosystems. Wetland habitats are transitional because the demarcation between wet and dry environments follows a continuum, with wetland boundaries expanding and contracting as a result of hydrologic changes in the adjacent landscape (Tiner 1988, Kent 1994, Perry and Vanderklein 1996). Correspondingly, wetlands differ according to source of water, direction of water flow, strength of water movement, topographic location within the surrounding landscape, dominant plant species, and regional climate (Hofstetter 1983, Brinson 1993a, Davis 1994, Chesapeake Bay Program 1997).

Because wetlands are transitional and diverse, more than 50 wetland definitions exist throughout the world (Dugan 1993). Furthermore, several classification schemes have been developed to delineate, inventory, and map wetland types (Shaw and Fredine 1956, Cowardin et al. 1979, Adamus et al. 1987, Hollands 1987, Brinson 1993a). The formal definition and classification scheme adopted by the U.S. Fish and Wildlife Service (FWS) in 1979 (Cowardin et al. 1979) is reflected in Section 404 of the Clean Water Act and is used in federal regulatory decision-making and to delineate wetlands for regulatory permits (Kent 1994). The FWS wetland definition and classification scheme is also used in the National Wetlands Inventory

Project to survey, classify, and map the nation's wetlands (Wilen and Tiner 1989). The FWS definition of wetlands is:

> "...lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. For purposes of this classification wetlands must have one or more of the following three attributes: 1) at least periodically, the land supports predominantly hydrophytes; 2) the substrate is predomininantly undrained hydric soil; and 3) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season of each year (Cowardin et al. 1979)."

Due to different physical, chemical, and biological attributes, wetlands perform ecological functions (or characteristic activities and processes) that can be classified into three categories: hydrologic, biogeochemical, and habitat and trophic support (National Resource Council 1995) (Table 1). Although basic ecological functions are common to most wetlands, wetland functions vary depending on wetland type (Brinson 1993, Richardson 1994, Trettin et al. 1994).

Wetland functions produce goods and services that have a corresponding social value (Brinson 1993a, Richardson 1994). For example, wetlands that store floodwater help to control flood damage in adjacent neighborhoods. Other social values derived from wetland functions include: hunting, fishing, timber production, assimilation of nutrients from wastewater or stormwater runoff, habitat for threatened and endangered species, nurseries for fish and shellfish, and economic benefits (Malanson 1993, Richardson 1994, Trettin et al. 1994). Several methods have been developed to assign economic value to the goods and services resulting from wetland functions (Odum 1978, Shabman and Batie 1988, Luzar and Gan 1991, Smith et al. 1995).

The societal values enhanced by wetland functions helped to provide the impetus for developing strategies to protect wetlands

(Wakefield 1982). Instead of promoting wetland loss, recent government policies now encourage research into and protection of wetlands with federal, state, and local laws (Dennison 1997). Other conservation efforts include acquisition and preservation of wetlands by government agencies or environmental groups, and using FWS conservation easements, under which the FWS pays farmers to conserve wetlands located on the farmers' property (Wakefield 1982, Pearson 1994).

Section 404 of the federal Clean Water Act, adopted in 1977, is the major regulatory program for protection of wetlands (Sifneos et al. 1992). The Clean Water Act provides jurisdictional authority to the U.S. Environmental Protection agency (EPA) and the U.S. Army Corps of Engineers (COE) to issue permits for dredge, fill, or other activities that would alter, impact, or destroy wetlands. Furthermore, because the federal government adopted a "no-net-loss" of wetlands policy, the COE applies guidelines to permit applications that require avoidance, minimization, and compensation of wetland impacts (Dennison 1997). The "Swampbuster" provisions of the 1985 Food Security Act also protect wetlands by denying agricultural loans, benefits, and payments to people who convert wetlands to agriculture.

In addition to federal governmental protection of wetlands, more than 25 states have laws that include wetland protection measures (Dennison and Berry 1993). In Virginia, the Chesapeake Bay Preservation Act protects wetlands through restricted development in designated preservation areas. Also, the Virginia Tidal Wetlands Act of 1972 requires permits for development in tidal wetlands.

Continued wetland loss and degradation after the adoption of the Clean Water Act has been explained both by failure to completely regulate ditching, draining and clearing of wetlands, and by inconsistent jurisdictional determinants of wetland delineation (Wakefield 1982, Tripp 1988).

Another growing concern about wetland loss is that cumulative loss of wetland function in a drainage basin may not be proportional to area lost (Johnston 1994). For example, wetland loss from watersheds containing 10 to 50% wetlands has had minimal effect on flood flow, whereas wetland loss in watersheds containing less than 10% wetlands substantially affected flood flow (Johnston et al. 1990).

Disturbance of surrounding upland habitats can also lead to wetland degradation through alteration of wetland hydrology and change in population dynamics of wetland species (Brinson 1993, Pearson 1994, Harbor 1994, Lemly 1997). Accordingly, changes in the biotic and abiotic processes in a watershed can influence the types and levels of functions performed by a wetland (Davis 1994).

Land use change due to agriculture and urban development increases impervious surface in a watershed through loss of vegetative cover and development of paved surfaces (Smith et al. 1993, Holland et al. 1995). Loss of vegetative cover can change stream flow patterns, lowering the water table and destroying wetlands (Swank et al. 1988, Pearson 1994). Increased impervious surface increases surface water runoff, flooding wetlands with stormwater during storm events and discharging less groundwater to wetlands during dry spells (Leopold 1968, Harbor 1994). Finally, land development affects the spatial extent and pattern of a landscape, resulting in fragmentation and loss of connectivity between native habitats, thus reducing accessibility for species that depend on wetland habitats (Brinson 1993, Pearson

1994). More research is needed to understand the cumulative, functional impacts of wetland loss (Brinson 1993, Hersperger 1994, Johnston 1994, Perry and Vanderklein 1996).

A possible amelioration to wetland loss and degradation in Virginia is increasing populations of beaver (*Castor canadensis*) (Johnston and Chance 1974). Beavers became extinct in Virginia in 1911 as a result of trapping (Blackwell 1949). In 1932, however, the Virginia Department of Game and Inland Fisheries reestablished beaver in some of its native range, and populations have increased to the point of becoming a nuisance to private property owners living in riparian corridors (McCall et al. 1996).

Beavers impact riparian zones by building dams to form ponds and build lodges (Naiman and Melillo 1984, Namian et al. 1986, Naiman et al. 1988, McCall et al. 1995, Brown et al. 1996). Beavers expand the saturated surface area of a riparian zone to increase habitat and food supply, and to protect the species from predators. As a result of increased saturation, wetlands develop. Beaver-created wetlands provide habitat for riparian birds and provide a pool of carbon and nutrients for ecological stability (Naiman 1988, Brown et al. 1996, McCall et al. 1996).

Despite the positive impacts of beavers on the landscape, beavers can also have negative effects by selectively harvesting trees to build dams. If the trees come from a forested wetland to create an emergent or open water wetland, the quality of wetland functions may diminish (E. Gilinsky, CES affiliation, personal communication). Furthermore, tree removal by Castor alters the community composition of a riparian forest, and the benefits of large trees in riparian ecosystems may be lost (Malanson 1993).

"Physical ecosystem engineering" refers to the physical modification, maintenance, or creation of habitats by organisms that may or may not remain as part of the engineered environment (Jones et al. 1997). Both beavers and humans are examples of ecosystem engineers (Jones et al. 1994). The effect of ecosystem engineers may be either positive or negative, and may directly or indirectly affect the habitats and resources available to other species (Callaway and Walker 1997).

Although the engineering of landscapes by beaver may have immediate negative impacts on trees or aquatic species--due to the conversion of a stream to a pond, Jones et al.(1997) argue that beaver dams result in a net increase in habitat types and resources available for other species over time. In other words, at a large temporal and spatial scale, beaver-modified landscapes become dynamic and enhance regional species richness.

Although both beavers and humans affect the status of wetland ecosystems, it is difficult to predict the ecological consequences of man or beaver as ecosystem engineers on the landscape. Because scientists are only beginning to study the ecological effects of ecosystem engineering, there is a growing need for more research comparing the impacts of both species.

The major objective of this study was to use a Geographic Information System (GIS) to evaluate and to compare the cumulative impacts to wetland ha and types from both man and beaver in the Chickahominy River watershed from 1953 to 1994. The research questions included: (1) What were the types of wetlands in 1953, and were they more likely to remain the same, convert to upland, or change to a different wetland type by 1994? (2) Which wetland types experienced the most change, and what explained the change between wetlands and uplands? (3) How did the composition of beaver-modified wetland types change from 1953 to 1994, and did beaver creation of wetlands help to offset anthropogenic activities?

The hypotheses were: (1) There was an overall (net) loss of wetlands due to anthropogenic activities in the Chickahominy River watershed from 1953 to 1994. (2) There was no (net) loss of wetlands in the watershed because the ha of wetlands that were lost to anthropogenic activities were offset by wetland gain from beaver activities.

METHODS

Site Description

The Chickahominy River watershed encompasses more than 110,000 ha in parts of Hanover County, Henrico County, New Kent County, James City County, Charles City County and the city of Richmond, Virginia. The watershed is located mostly within the Coastal Plain physiographic province, characterized by low-gradient black water streams. The headwaters of the river, located in the Piedmont physiographic province, lie northwest of Richmond and occupy the most highly urbanizing areas in the watershed. The population in the upper third of the basin has been growing steadily since the 1920s (Hupp et al. 1993). In the last 40 years, average population for the five counties in the watershed (plus the city of Richmond) has increased 155%. Population density, which is a measure of the degree of urbanization, increased from 46 people per km^2 in 1950 to 132 people per km^2 in 1990 (M. Garcia, Virginia Commonwealth University, personal communication). As the Chickahominy River nears the confluence with the James River, the concentration of development decreases and the land becomes rural residential, agricultural and forested. The Chickahominy River becomes tidal at Walkers Dam, and meanders through extensive and diverse wetlands as the river nears the mouth (Department of Conservation and Recreation 1990). Though the majority of land development is located near the headwaters of the river, the Chickahominy River watershed is located in the corridor between Norfolk and Richmond and will continue to be threatened with urban growth as these urban areas expand.

Data Sources

The source data for the study were created in response to an inter-agency agreement between the Chesapeake Bay Field Office (CBFO) of the FWS and the FWS National Wetlands Inventory Program (NWI) for the Northeast Region to conduct a mapping study of the Chickahominy River watershed. Sub-contracting for the NWI, the Natural Resources Assessment Group (NRAG), Department of Plant and Soil Sciences, of the University of Massachussetts produced detailed, digital maps of wetlands and deepwater habitats and upland land use/land cover for the entire Chickahominy River watershed for 1953 and 1994. Deepwater habitats are flooded lands, such as lakes or rivers, in which the surface water is permanent and deep (Cowardin et al. 1979).

Both 1953 and 1994 maps were created through stereoscopic interpretation of high-altitude aerial photographs acquired by the National Aerial Photograpy Program. NRAG prepared both the upland and wetland 1994 data layers from 1:40,000 scale color infrared positive transparencies. In addition, wetlands and deepwater habitats were updated, delineated and classified using original NWI digital and hardcopy data as a base. The 1953 data layers were created using a reverse trends analysis, which involved a comparison of 1:20,000 scale pan-chromatic black and white photographs of the watershed in 1953 with the aerial photographs of the watershed in 1994.

NRAG classified and delineated the wetlands and deepwater habitats according to the FWS classification system (Cowardin et al. 1979) and standard NWI mapping conventions (National Wetlands Inventory 1995). Beaver-modified or created wetlands were classified in the data through special modifiers in the classification system. For the upland land use and land cover classification, NRAG used a modification of the Anderson Level I/Level II system (Anderson et al. 1976).

The final vector-based digital coverages that NRAG created were used as the source data for this project. The four original coverages included general wetlands layers for both 1953 and 1994 and upland land use/land cover layers for 1953 and 1994. The projection for all of the coverages was UTM, meters, zone 18. County boundaries were obtained from U.S. Census TIGER line files, 1994.

Data Classification

Although the wetlands in the original data were classified into the most detailed level of the FWS classification hierarchy, the wetland types in this study were generalized to identify complexes of wetlands that share similar hydrologic, geomorphic, chemical or biological factors.

On the hierarchical scale, which employs 5 System names, 8 Subsystem names, 11 Class names, 28 Subclass names, and innumerable regionally developed Dominance Types, the wetlands in this study were re-classified into System, Subsystem, and Class (Appendix A). The wetlands were classified to the Class level to increase efficiency in data analysis and to identify general complexes of wetland ecosystem types. Furthermore, Class designations apply to average conditions over a period of years (Cowardin 1979). Only three of the five systems (and 13 wetland types) were present in the Chickahominy River watershed (Appendix B). The upland land use/land cover classification system (Anderson et al. 1976) that was used for the original data layers was modified and used for this study (Appendix C).

Data Manipulation

Instead of using the original vector-based coverages for data analysis, a raster-based approach was chosen to evaluate geographic change over time. The advantage of using GRID™, a raster-based geoprocessing package integrated with ARC/INFO™ GIS software, was that the watershed could be divided into discrete, uniform units called cells. Analysis was then possible over the entire watershed, so that change could be detected cell-by-cell from 1953 to 1994. Before analyzing the watershed using GRID, the four original vector coverages were imported into ARC/INFO for data manipulation.

Wetland and upland types were generalized and reclassified with a unique code by creating new fields in the polygon attribute tables (Appendix C). If the original classification included two classes (e.g. PAB/EM) for a wetland type, the wetland was re-classified with the first class listed. A unique code was given to all upland area in the wetland coverages, and to all wetland area in the upland coverages (Appendix C). To set the environment to make grid coverages for beaver-modified or created wetlands in 1953 and 1994, wetlands with beaver modifiers were selected out of the original classification and reclassified as either "beaver" or "not beaver" in the polygon attribute tables.

Before converting the polygon coverages into grid coverages, the grid cell size was determined. Because cell resolution affects the detail and accuracy of the analysis environment, a 10-meter cell size was chosen to include the smallest polygons from the input data (Environmental Systems Research Institute 1991).

After initial conversion of the upland and wetland coverages into grids, the wetland and upland grids did not align exactly. After determining that the (X,Y) coordinates of the vector coverages also did not match, a new polygon coverage was created to produce a slightly smaller map extent. The original (reclassified) coverages were then clipped to the size of the new map extent to ensure perfect alignment.

Using the clipped wetland and upland coverages, six grids were created based on the new classification fields in the polygon attribute tables. The grids included wetlands 1953, wetlands 1994, uplands 1953, uplands 1994, beaver 1953, and beaver 1994. The beaver grids were created by selecting the beaver classification in the PATs of the wetland coverages as the item to grid.

The wetland grids were overlaid on the upland grids for both 1953 and 1994 to determine if the wetlands and uplands were classified and aligned accurately in the same geographic locations. For example, the overlay determined whether the areas classified as wetlands in the upland grids were also classified as wetlands in the wetland grids. Because the results showed that more than 99% of the wetlands and uplands aligned accurately, two continuous grid coverages of upland and wetland types were created for 1953 and 1994, with wetland types selected as true in the order of precedence in overlapping areas (Appendix D). Merging the grids together enabled change analysis between wetland types and upland types. To prepare the beaver grids for analysis, new grid coverages were created to reflect both the wetland type and whether the type was beaver-modified or not.

Data Analysis

To calculate all changes in the wetland and upland types that occurred in the Chickahominy River watershed, the command COMBINE was used to derive a new grid from the overlay of the merged 1953 grid and the merged 1994 grid. The Value Attribute Table (VAT) of the new grid contained every change in the watershed in addition to a count of the number of cells representing that change. COMBINE was also used to calculate change in the beaver grids from 1953 to 1994.

The grids were imported into the Spatial Analyst extension of ArcView™ ver. 3.0a and analyzed using the Map Query function, Map Calculator, Tabulate Areas, and Summarize Zones functions of the analysis menu. Also, new coverages were created to represent areas of change both for wetlands and for the entire landscape. The county boundaries coverage was imported and summary statistics were created for each county in the watershed. The Spatial Analyst extension of ArcView was also used to create map layouts.

RESULTS

Between 1953 and 1994, 230 types of change (identified by any change in classification of upland type or wetland type) occurred in the Chickahominy River watershed, including changes within upland types and within wetland types in addition to changes between upland types and wetland types. The area of change in the 121,499-ha watershed was 34,609 ha, or 29% of the land. The area that remained unchanged was 86,890 ha, or 71% of the land (Appendix D). Most of the change occurred in New Kent, Henrico, and Hanover Counties, within the upper third of the watershed. Henrico County, the county that occupied the greatest area of land in the watershed, also experienced the greatest percentage (42%) of change (Table 2).

Of the 18,780 ha of wetlands in the watershed in 1953, 2,260 ha (12%) changed and 16,520 ha (88%) remained unchanged (Appendix D). Change in wetlands did not constitute one of the largest types of change in the watershed from 1953 to 1994(Table 3). The majority of wetland change in the watershed (99%) occurred in the Palustrine system, particularly in Palustrine forested wetlands (Table 4). In Charles City County, the county in the watershed that contained the greatest area of wetlands, 7% of the wetlands changed (Table 5). The highest percentage of wetland change occurred in Hanover County, the county that contained the fewest ha of wetlands in the watershed (excluding the city of Richmond).

Of the 2,260 ha of wetlands that changed from 1953 to 1994, 226 ha (10% of the change) were converted to uplands. The remainder of the wetland change (2,034 ha) was due to shifting between wetland types. Although 226 ha of wetlands were converted to upland between 1953 and

1994, 999 ha of wetlands were also gained in the watershed during the 41-year study period. Therefore, there was no net loss of wetlands in the watershed. Wetland area increased by 4%, from 18,780 ha in 1953 to 19,553 ha in 1994.

Of the wetlands that were lost to upland, more than twice as many ha were converted by anthropogenic activities than by natural succession (Fig. 1). Wetland gain occurred through the conversion of five upland land use/land cover types into wetlands (Fig. 2).

Of the 226 ha of wetlands that were converted to upland during the study period, 134 ha (60%) were Palustrine forested wetlands, 76 ha (34%) were Palustrine scrub shrub, and 16 ha (1%) were Palustrine emergent or Palustrine unconsolidated bottom wetlands. Although the Lacustrine system and the Riverine system experienced a net gain in wetlands from 1953 to 1994, the Palustrine system experienced a net loss of wetlands (Table 6). Wetland conversion to other wetland types occurred in classes of both Palustrine and Riverine systems, and no wetlands in the Lacustrine system were lost or changed from 1953 to 1994 (Table 7).

Of the 15,603 ha of Palustrine wetlands in 1953, 2,244 ha (14%) changed to either another wetland type or to upland by 1994. The Palustrine farmed wetland type disappeared in the watershed from 1953 to 1994, and was replaced with Palustrine forested wetlands. Two of the classes in the Palustrine system experienced strictly a gain in area. The Palustrine aquatic bed wetlands gained 4 ha from Palustrine forested wetlands, and the Palustrine unconsolidated shore wetlands gained 1 ha from upland forest. The remainder of the wetland classes in the Palustrine system experienced both gain and loss in area from

1953 to 1994, accounting for the majority of wetland change in the watershed (Figs. 3-6).

The only class of Lacustrine wetlands in 1953, Lacustrine limnetic unconsolidated bottom, gained 938 ha by 1994 (Fig. 7). Lacustrine littoral unconsolidated shore wetlands, which were not present in 1953, appeared in 1994 as a new wetland type (Fig. 8).

In the Riverine system, 16 ha (1%) of 2,697 ha in 1953 changed to either another wetland type or to upland by 1994. One of the Riverine classes, tidal Riverine emergent vegetation, experienced no gain or loss in area. The tidal Riverine unconsolidated bottom wetlands experienced both gain and loss in area (Fig. 9). The only change to the tidal Riverine unconsolidated shore wetlands was the loss of 14 ha to tidal Riverine unconsolidated bottom wetlands, and the only change to lower perennial Riverine unconsolidated bottom wetlands was a gain of 5 ha from Palustrine forested wetlands.

In 1953, 244 ha (1%) of the wetlands in the Chickahominy River watershed were beaver-modified (Appendix D). In 1994, beaver-modified wetlands increased 274% to 912 ha, or 5% of the wetlands (Appendix D). Although New Kent County experienced the greatest area increase in beaver-modified wetlands, Hanover County and Henrico County experienced the greatest percent increase in beaver-modified wetlands (Table 8).

Beavers converted 12 ha of upland (agricultural land and upland forest) into Palustrine emergent, Palustrine unconsolidated bottom, and Palustrine forested wetlands. The remaining 656 ha of newly modified beaver wetlands were created from Palustrine scrub shrub, Palustrine forested, and Palustrine emergent wetlands (Fig. 10). Beaver modification of existing wetlands resulted in 190 ha of no change in wetland type (except inhabitance by beaver), and resulted in 466 ha of wetlands changing to a different wetland type. Therefore, beavers contributed to 23% of the change between wetland types during the study period. Beavers were responsible for 1% of the 999 ha of upland conversion to wetland in the watershed. Beaver-modified Palustrine emergent and Palustrine scrub shrub wetlands experienced the greatest percent increase from 1953 to 1994 (Table 9).

DISCUSSION

The major objective of this study was to evaluate and to compare the cumulative impacts to wetland ha and types from both man and beaver in the Chickahominy River watershed from 1953 to 1994. Over the past 40 years, the average population of humans in the watershed increased substantially, particularly in the upper third of the basin where the headwaters are located (Hupp et al. 1993, M. Garcia, Virginia Commonwealth University, personal communication). Therefore, it was not surprising that 29% of the land in the watershed had changed, with the majority of the change located in the upper third of the basin.

The majority of the wetland change was also located in the upper third of the watershed. However, wetland change only constituted 7% of the overall change in the watershed. The overall increase in wetland area by 4% in the watershed was surprising due to inconsistency with other studies. From 1950-1979, the average annual wetland loss in the nation exceeded 185,000 ha per year (Frayer et al. 1983, Dahl and Pyrell 1989). Although Dahl and Johnson (1991) reported that wetland loss slowed from the mid-1970s to the mid-1980s, other studies documented continued wetland loss, even in Virginia (Frayer et al. 1983, Peters, 1989, Cashin et al. 1992, Brady and Flather 1994, Tiner et al. 1994, Chesapeake Bay Program 1997).

One explanation for the discrepancy of wetland loss between this study and other studies is that this study examined wetlands in 1994, which is more current than the ending date of the other studies. Although Tripp (1988) and Wakefield (1982) argued that continued wetland loss after the adoption of the Clean Water Act could be a result of inadequate or inconsistent enforcement of government regulations, another possibility is that wetland protection strategies, particularly in Virginia, are becoming more effective over time. Furthermore, the Virginia Tidal Wetlands Act of 1972 was protecting wetlands in Virginia before the adoption of the federal Clean Water Act of 1977. If time lag exists between the adoption of wetland protection efforts and actual protection of wetlands, Virginia may be experiencing positive results earlier than other states in the country.

Wetland mitigation, the replacement of wetland areas impacted by anthropogenic activity, offers another explanation for the increase in wetlands in the watershed. Following the adoption of the Clean Water Act, the EPA issued Guidelines that the COE must use to evaluate environmental impacts from proposed activities on wetlands. The Guidelines require that permit applicants take action to avoid, minimize, or mitigate for unavoidable wetland impacts (Dennison 1997). The EPA and the COE prefer wetland mitigation to occur on the site of the project, and want the area of wetlands created to at least equal the area of wetlands impacted by the project. Furthermore, the EPA and the COE prefer mitigation sites to be designed to replace lost wetland values with functionally equivalent wetland values, usually by replacing the impacted wetland with the same type of wetland.

Although wetland mitigation can provide a viable compensation for wetland loss (Wilson and Mitsch 1996), many ecologists believe there is a lack of knowledge on how to build a wetland properly (Roberts 1993). Functional replacement of wetland values can be ineffective, and vegetation planted on mitigation sites may take a long time to establish (Wilson and Mitsch 1996). Therefore, if wetland mitigation explains part of the offset of wetland loss in the Chickahominy establish (Wilson and Mitsch 1996). Therefore, if wetland mitigation explains part of the offset of wetland loss in the Chickahominy watershed, mitigation may also account for changes in wetland types from 1953 to 1994. For example, if a wetland mitigation site were designed to replace a forested wetland, the new wetland would appear as a scrub shrub wetland until mature vegetation was established.

The 944-ha increase in Lacustrine wetlands from 1953 to 1994 accounts for a large portion of wetland gain and shifting between wetland types in the watershed. Much of the wetland gain in the Lacustrine system is likely the result of the construction of two large reservoirs in the watershed during the 41-year study period. The 526-ha Diascund Reservoir was built in 1961, and the 403-ha Little Creek Reservoir was built in 1980. The majority of Lacustrine wetlands in 1994 were either Palustrine forested wetlands, upland forested land, or Palustrine scrub shrub wetlands in 1953. Evidence for the conversion of forest to build reservoirs can be seen during periods of low water (during summer months and when reservoirs are drained for dam maintenance) as tree stumps punctuate the reservoir bottom.

Although wetlands were most likely to remain unchanged from 1953 to 1994, wetland change was more likely to occur as a shift between wetland types (2,034 ha) than as a conversion to upland (226 ha). Most of the change in the 1953 wetlands (99%) occurred in the Palustrine system. In fact, all of the conversion of wetland to upland occurred in the Palustrine system. Although 161 ha of Palustrine scrub shrub matured into Palustrine forested wetlands, most of the change in the Palustrine system occurred through conversion of Palustrine forested vegetation to Palustrine scrub shrub or Palustrine emergent vegetation, or through conversion of Palustrine forest into ponds or lakes. Palustrine forested wetlands were also the most common wetland type to be converted into upland for anthropogenic development, including industrial, commercial and resort land uses. In addition to cutting down trees to build reservoirs and to develop land, loss of Palustrine forested wetlands in the Chickahmoniny River watershed may have also resulted from timber harvesting (Walbridge and Lockaby 1994, Chesapeake Bay Program 1997).

Loss of Palustrine forested wetlands could substantially affect the cumulative functions of wetlands in the Chickahmoniny River watershed. Two important biogeochemical functions of forested wetlands include: (1) nutrient and sediment removal from surface and ground water, and (2) export of organic carbon and associated nutrients downstream to aquatic ecosystems (Mitsch and Gosselink 1993, Walbridge and Lockaby 1994). Because forested wetlands serve important wetland functions, loss of forested wetlands may have a greater functional effect on the watershed than could be predicted by loss of area alone (Johnston 1994).

Unlike the Palustrine wetlands, only 1% of the Riverine wetlands changed from 1953 to 1994. Because most of the Riverine wetlands in the watershed were tidal, and because most of the tidal wetlands were located in the lower third of the basin, the Riverine wetlands likely remained the same because of the lack of development in the lower area of the watershed.

Although beaver modification of wetlands only accounted for 1% of wetland gain in the watershed, beaver impacts accounted for 23% of the change in wetland types from 1953 to 1994. Furthermore, beaver-modified occurred in Henrico and Hanover counties, where the majority of overall wetland loss also occurred. Therefore, although the second hypothesis for the study could not be supported because beaver wetland creation was not responsible for the "no net loss" of wetlands in the watershed, beavers may have a substantial impact on the watershed in the future if beaver populations continue to increase. Furthermore, a lag time may also exist between the establishment of beaver populations in a riparian area and the resultant development of wetlands.

Beaver-created wetlands have a positive effect on the landscape by providing habitat for riparian birds and providing carbon and nutrients for ecological stability (Naiman 1988, Brown et al. 1996, McCall et al. 1996). Furthermore, at large temporal scales, beaver-modified landscapes increase species richness (Callaway and Walker 1997). As populations of beavers continue to increase in the watershed, however, controversy surrounding the negative effects of beavers on property value will likely escalate (McCall et al. 1996, Kwon 1997). Possible solutions have been developed for managing beavers known to damage property, including: kill-trapping, live trapping, tree protection, water level control, and sterilization (Kwon 1997).

Summary

The results of the study indicate that neither hypothesis explains fully the impacts of man or beaver on the wetlands in the Chickahominy River watershed from 1953 to 1994. Although anthropogenic activities such as land development resulted in the majority of conversion of wetland to upland, anthropogenic activities may have also contributed to the offset of wetland loss in the watershed through wetland regulation, wetland mitigation, and the construction of large reservoirs.

Furthermore, because more than a quarter of the land coverage in the Chickahominy River watershed changed from 1953 to 1994, anthropogenic activities may also lead to indirect effects on wetland functions and values. Disturbance of upland habitats can lead to wetland degradation through alteration of wetland hydrology and change in population dynamics of wetland species (Brinson 1993, Pearson 1994, Harbor 1994, Lemly 1997). Furthermore, because land development can affect the spatial extent and pattern of a landscape, loss of connectivity between native habitats may reduce accessibility for species that depend on wetlands (Brinson 1993, Pearson 1994).

The results of this study demonstrate that research focusing exclusively on gain or loss of wetland area may not account for changes in the cumulative functions of wetlands in a landscape. Wetland functions vary depending on wetland type (Brinson 1993, Richardson 1994, Trettin et al. 1994), and the results of this study showed that 90% of the change in wetlands from 1953 to 1994 were a result of shifting between wetland types. Therefore, more research is needed to evaluate the functional consequences of change between wetland types. Furthermore, as beavers continue to play an increasingly important role as ecosystem engineers, research will be needed to study not only the area of wetlands beavers create, but to document the functional impact of beaver modification of various wetland types. Finally, because evaluation of wetland change over 40 years in this study used data from only the first year and last year of the time period, determination of exactly when wetland change occurred was not possible. Future studies might benefit from obtaining more data during shorter time increments.

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Table 1. Functions, related effects of functions, corresponding societal values, and relevant indicators of functions for wetlands

Function	Effects	Societal Value	Indicator
Hydrologic			
Short-term surface water storage	Reduced downstream flood peaks	Reduced damage from floodwaters	Presence of floodplain along river corridor
Long-term surface water storage	Maintenance of base flows, seasonal flow distribution	Maintenance of habitat during dry periods	Topographic relief on floodplain
Maintenance of high water table	Maintenance of hydrophytic community	Maintenance of biodiversity	Presence of hydrophytes
Biogeochemical			
Transformation, cycling of elements	Maintenance of nutrient stocks within wetland	Wood production	Tree growth
Retention, removal of dissolved substances	Reduced transport of nutrients downstream	Maintenance of water quality	Nutrient outflow lower than inflow

Table 1 continued

Function	Effects	Societal Value	Indicator
Accumulation of peat	Retention of nutrients, metals, other substances	Maintenance of water quality	Increase in depth of peat
Accumulation of inorganic sediments	Retention of sediments, some nutrients	Maintenance of water quality	Increase in depth of sediment
Habitat and Food Web Support			
Maintenance of characteristic plant communities	Food, nesting, cover for animals	Support for furbearers, waterfowl	Mature wetland vegetation
Maintenance of characteristic energy flow	Support for populations of vertebrates	Maintenance of biodiversity	High of density of vertebrates

[1]Source: National Research Council 1995

Table 2. Area (ha) of landscape change by county in the Chickahominy River watershed from 1953 to 1994

County	Ha no change	Ha change	Percent of county changed
Hanover	12,275	6,544	35
Henrico	17,247	12,733	42
New Kent	22,895	7,686	25
Charles City	19,201	4,668	20
James City	13,835	2,691	16
City of Richmond	1,437	287	17
Total	86,890	34,609	

Table 3. Largest area changes from 1953 to 1994 in the Chickahominy River watershed

Ha	1953 type	1994 type
5,216	Upland forested	Upland shrub scrub
4,323	Upland forested	Residential
3,069	Agriculture	Residential
2,315	Agriculture	Upland forested
1,649	Upland forested	Developed
1,496	Upland forested	Agriculture
1,284	Upland forested	Barren land
1,142	Upland forested	Herbaceous land
905	Herbaceous land	Residential
670	Herbaceous land	Upland forested

Table 4. Largest area changes in wetlands from 1953 to 1994 in the Chickahominy River watershed

Ha	1953 Wetland type	1994 Wetland type
565	Palustrine forested	Palustrine shrub scrub
530	Palustrine forested	Palustrine emergent
324	Palustrine forested	Lacustrine unconsolidated bottom
180	Palustrine forested	Palustrine unconsolidated bottom
161	Palustrine shrub scrub	Palustrine forested
101	Palustrine emergent	Lacustrine unconsolidated bottom
62	Palustrine shrub scrub	Palustrine emergent
55	Palustrine forested	Developed
37	Palustrine emergent	Palustrine forested
34	Palustrine scrub shrub	Industrial

Table 5. Area (ha) of wetland change by county in the Chickahominy River watershed from 1953 to 1994

County	Ha no change	Ha change	Percent change within county
Hanover	1,477	516	26
Henrico	3,058	480	14
New Kent	3,376	700	17
Charles City	5,001	392	7
James City	3,599	172	5
City of Richmond	9	0	0
Total	16,521	2260	

Table 6. Net area change in wetland systems from 1953 to 1994 in the Chickahominy River watershed

System	Ha in 1953	Ha in 1994	Percent gain or loss (+/-)
Lacustrine	480	1,424	+ 197
Riverine	2,697	2,708	+ 1
Palustrine	15,603	15,421	- 1
Total	18,780	19,553	

Table 7. Net area change in wetland classes from 1953 to 1994 in the Chickahmoniny River watershed (see Appendix C for wetland class definitions)

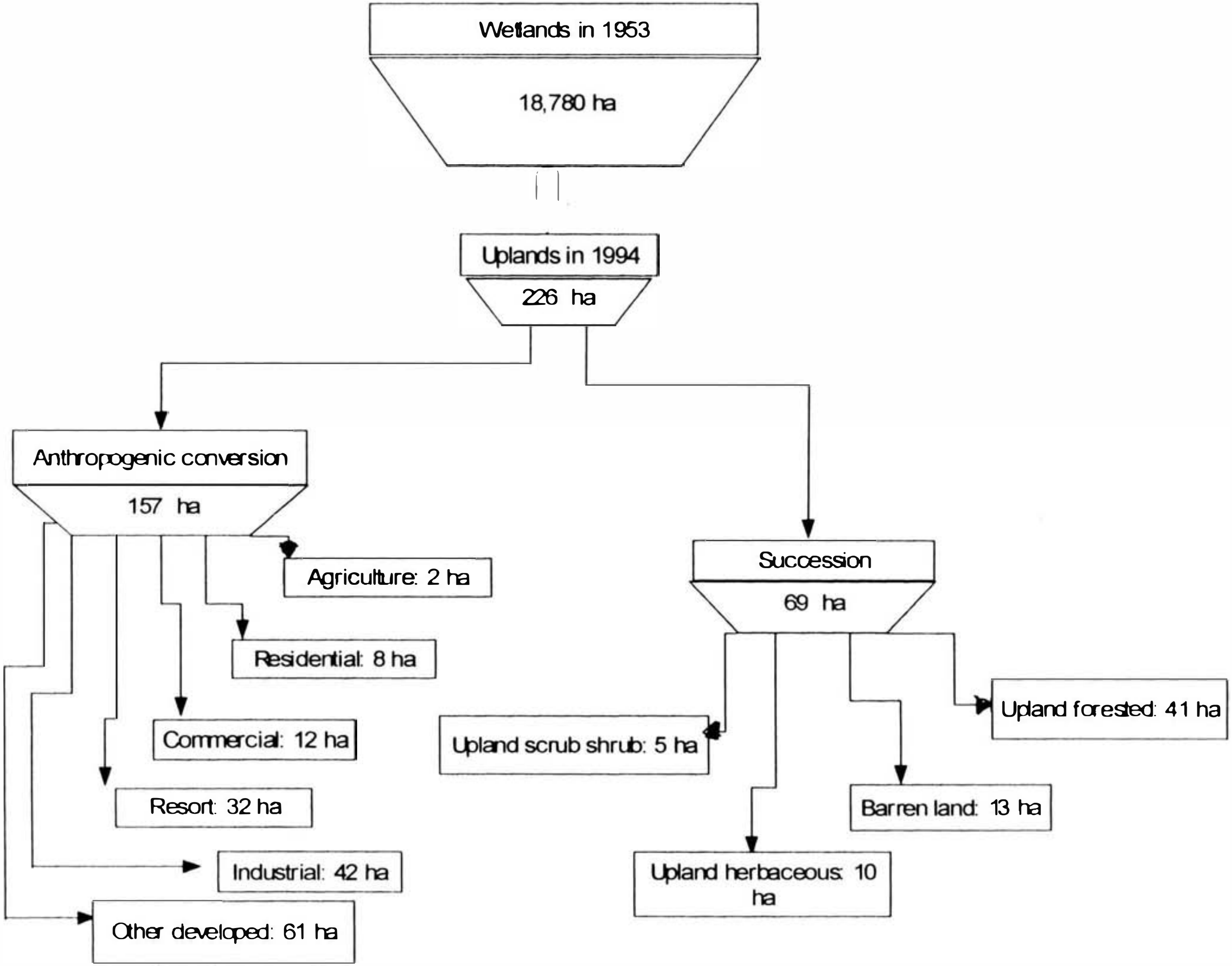
Class	Ha in 1953	Ha in 1994	Percent gain or loss (+/-)
L1UB	480	1,418	+ 195
L2US	0	6	--
PAB	10	14	+ 40
PEM	3,053	3,563	+ 17
PFO	11,175	9,817	- 12
PSS	1,053	1,367	+ 30
PUB	304	655	+ 115
PUS	3	4	+ 33
Pf	4	0	- 100
R1EM	28	28	0
R1UB	2,505	2,525	+ 1
R1US	97	83	- 14
R2UB	68	73	+ 7
Total	18,780	19,553	

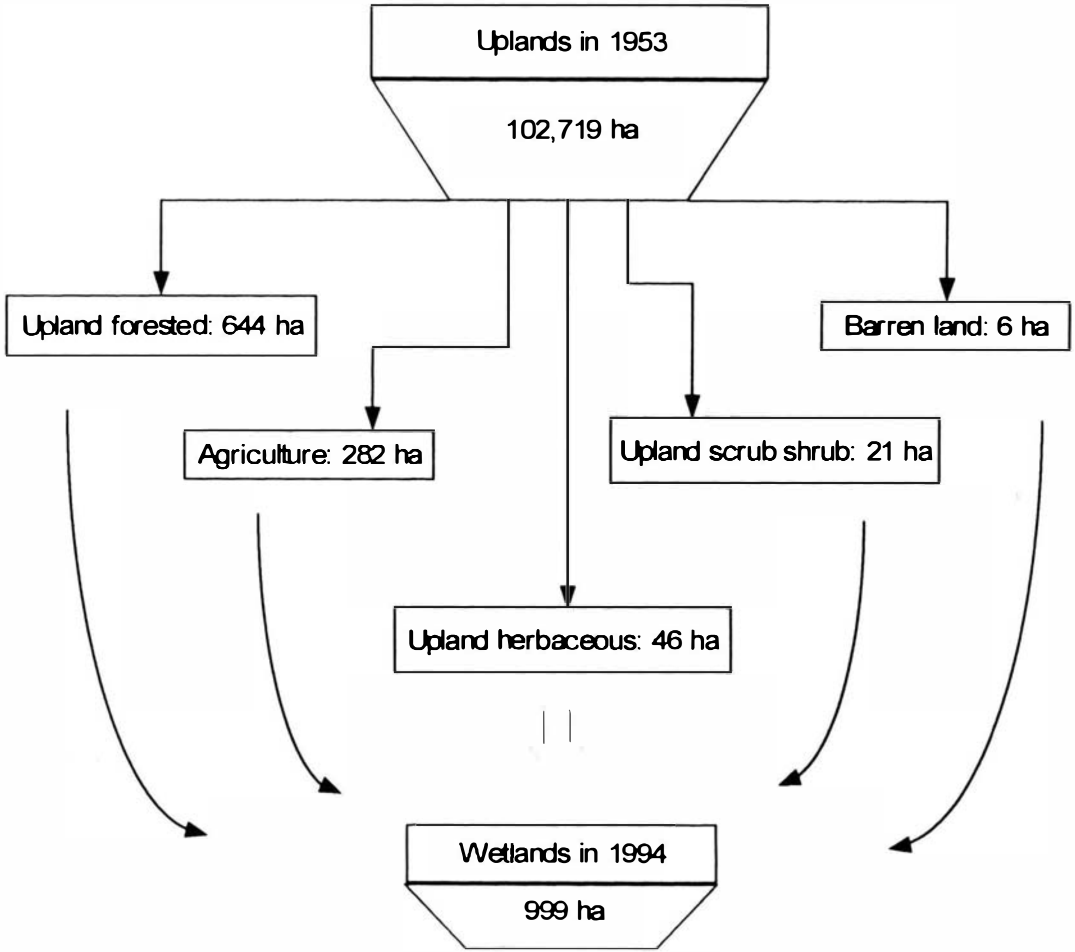
Table 8. Area of beaver wetlands by county in the Chickahominy River watershed from 1953 to 1994

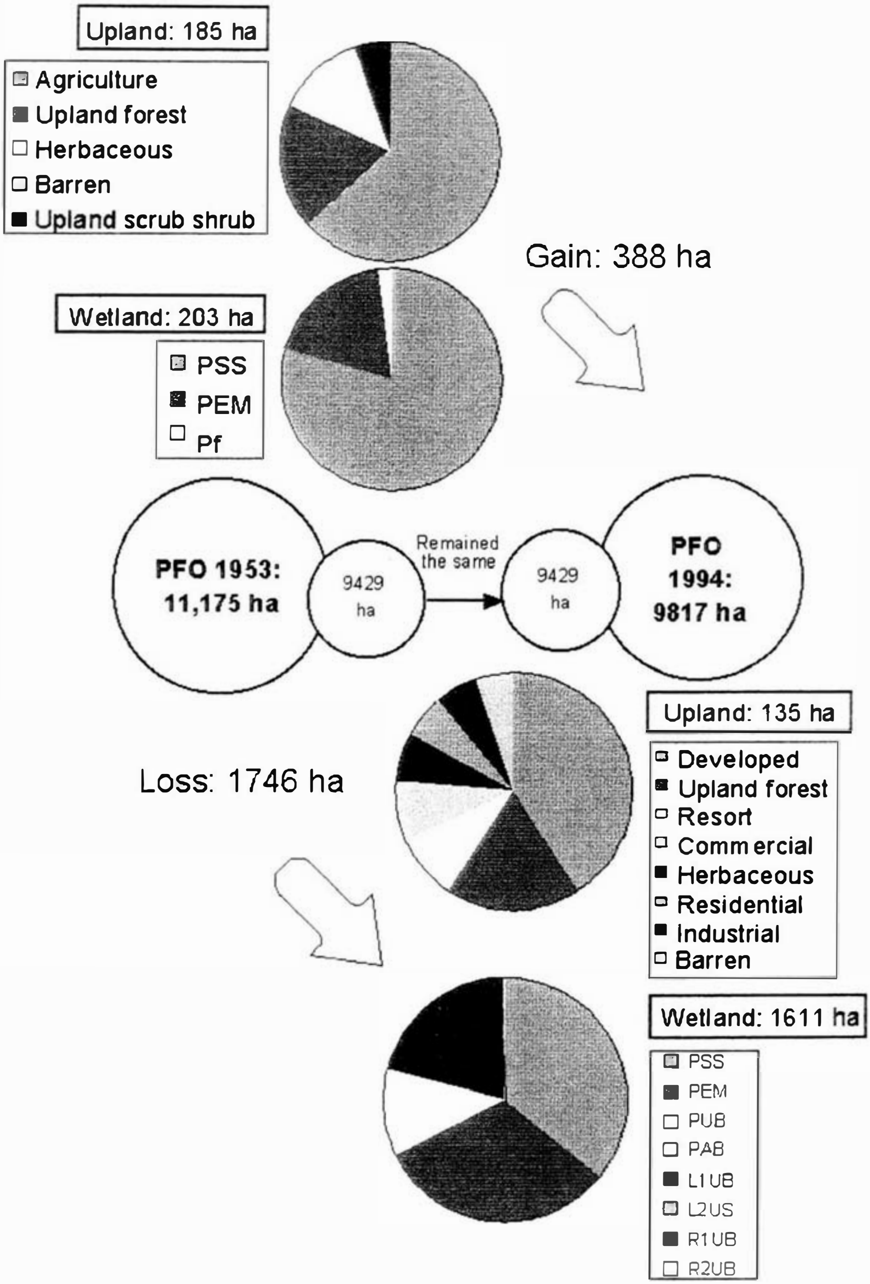
County	Ha in 1953	Ha in 1994	Percent change (+/-)
Hanover	14	118	+ 742
Henrico	4	27	+ 575
New Kent	85	375	+ 341
Charles City	110	280	+ 155
James City	31	112	+ 261
City of Richmond	0	0	--
Total	244	912	

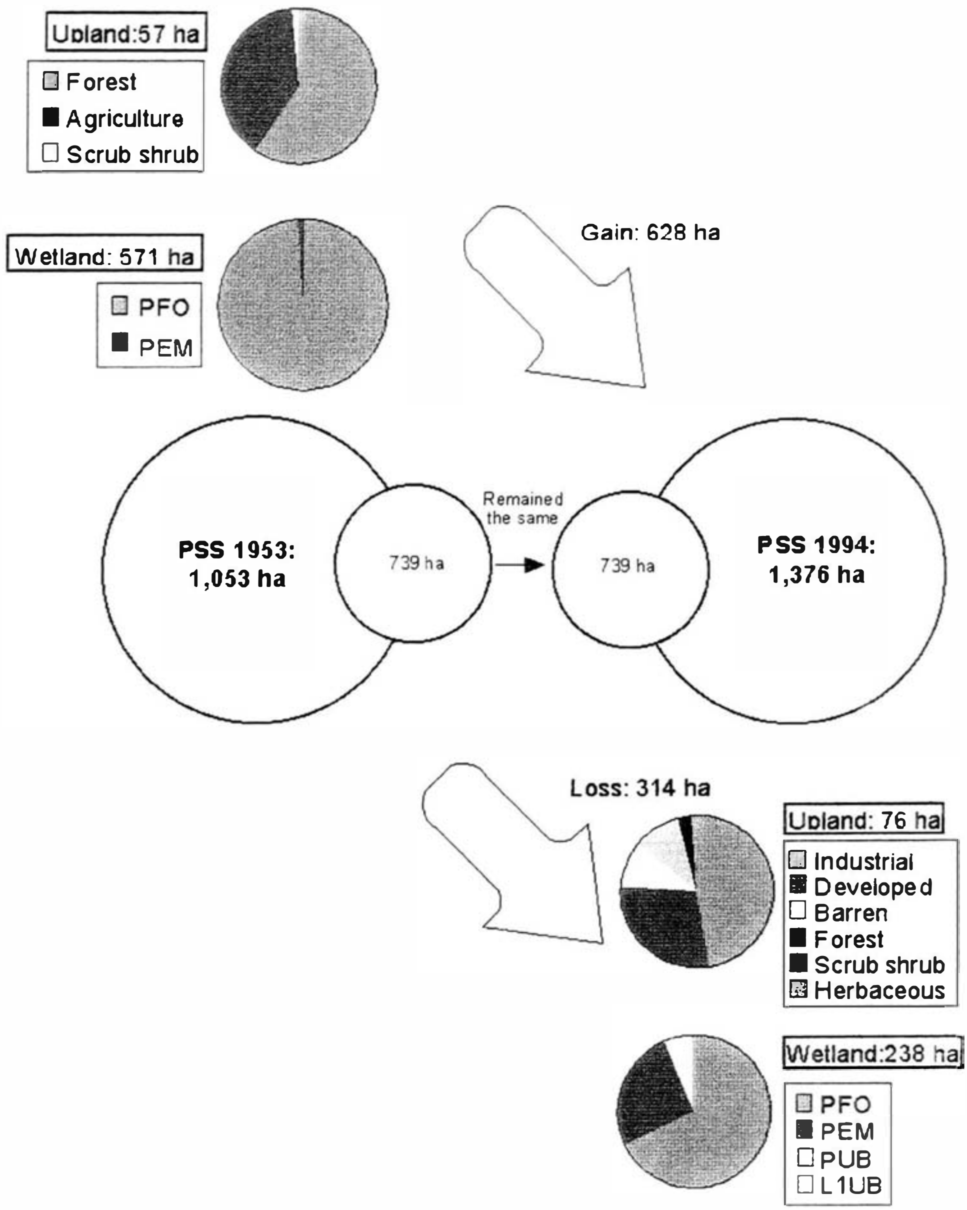
Table 9. Change in beaver-modified wetland types from 1953 to 1994 in the Chickahominy River watershed

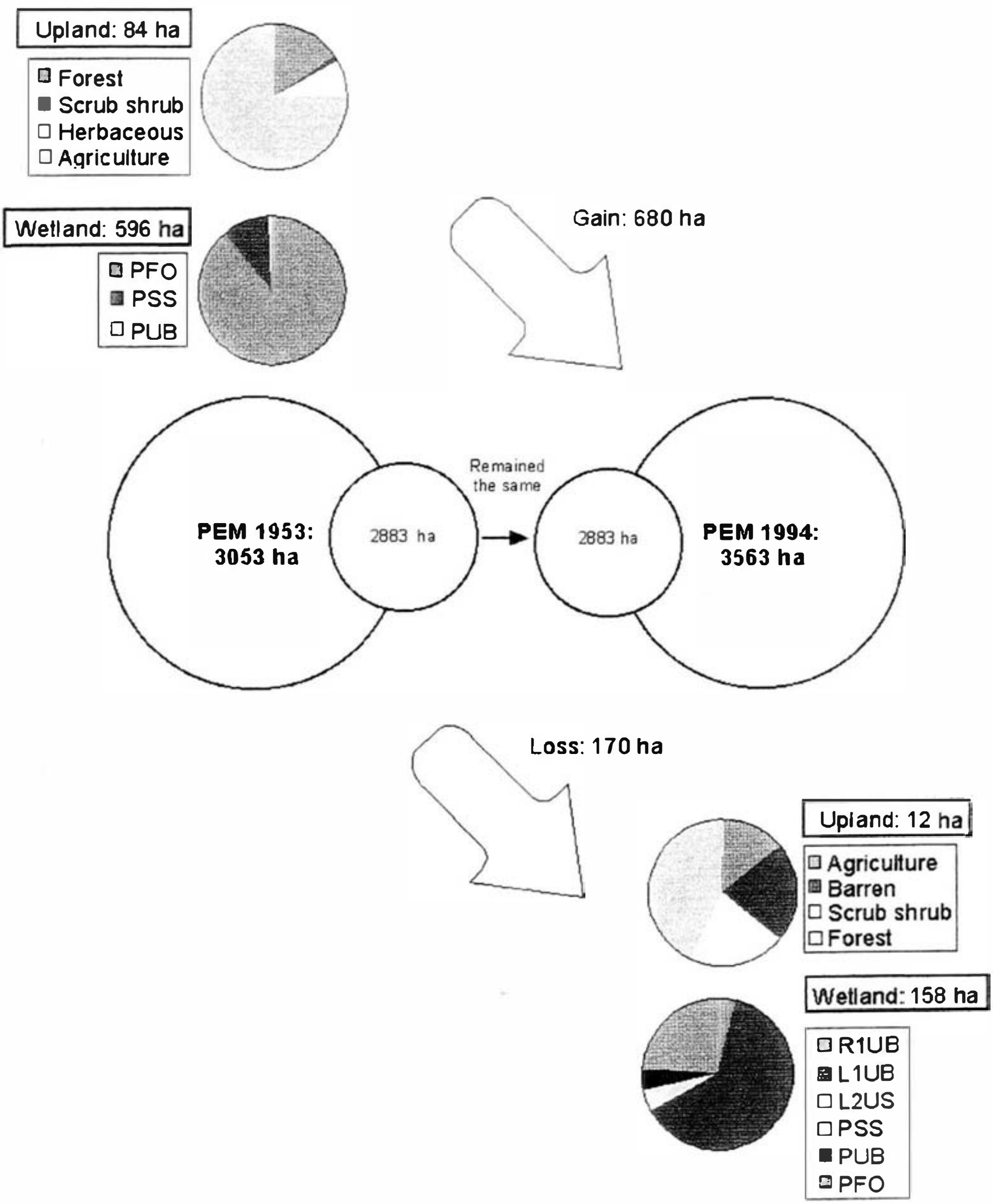
Wetland type	ha in 1953	ha in 1994	Percent increase
PAB	0	4	--
PSS	31	189	510
PEM	42	255	507
PUB	45	148	222
PFO	125	316	153
Total	244	912	

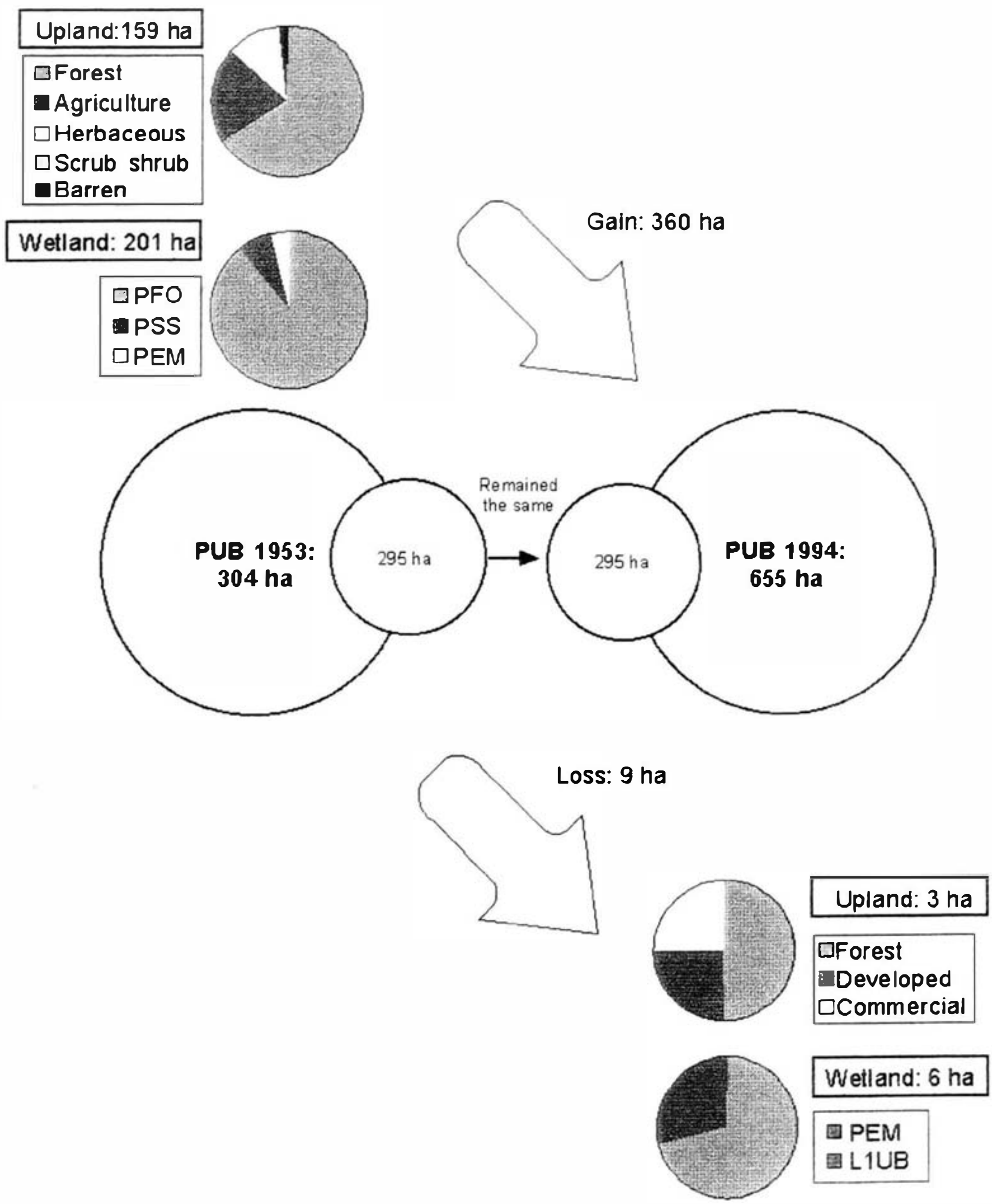

Wetlands in 1953
18,780 ha
Uplands in 1994
226 ha
Anthropogenic conversion
157 ha
Agriculture: 2 ha
Residential: 8 ha
Commercial: 12 ha
Resort: 32 ha
Industrial: 42 ha
Other developed: 61 ha
Succession
69 ha
Upland scrub shrub: 5 ha
Upland forested: 41 ha
Barren land: 13 ha
Upland herbaceous: 10 ha

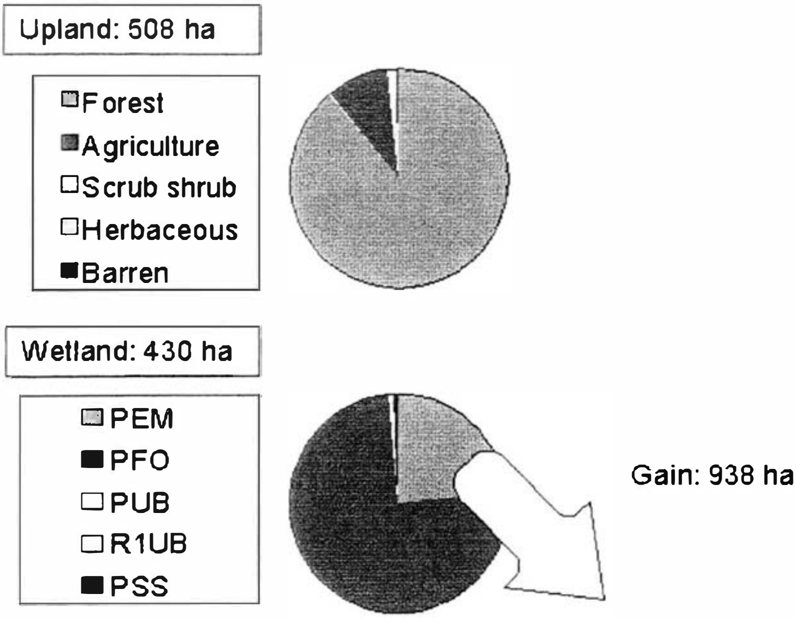

Uplands in 1953
102,719 ha
Upland forested: 644 ha
Agriculture: 282 ha
Upland herbaceous: 46 ha
Upland scrub shrub: 21 ha
Barren land: 6 ha
Wetlands in 1994
999 ha

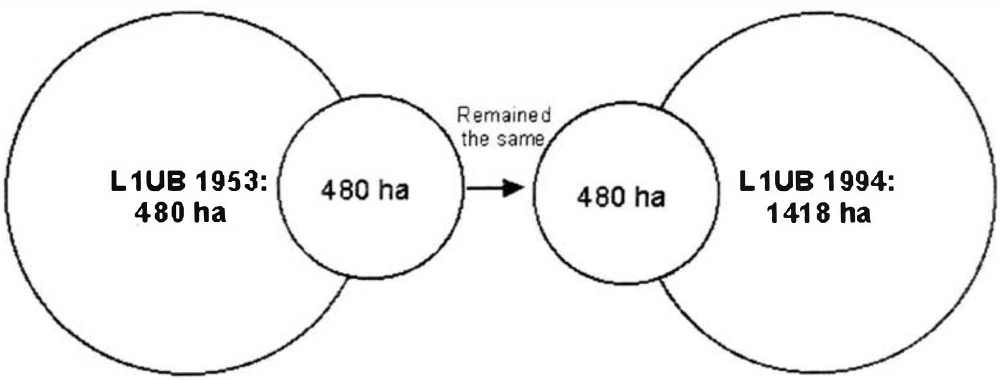

Upland: 185 ha
Agriculture
Upland forest
Herbaceous
Barren
Upland scrub shrub
Gain: 388 ha
Wetland: 203 ha
PSS
PEM
Pf
PFO 1953: 11,175 ha
9429 ha
Remained the same
9429 ha
PFO 1994: 9817 ha
Upland: 135 ha
Developed
Upland forest
Resort
Commercial
Herbaceous
Residential
Industrial
Barren
Loss: 1746 ha
Wetland: 1611 ha
PSS
PEM
PUB
PAB
L1UB
L2US
R1UB
R2UB

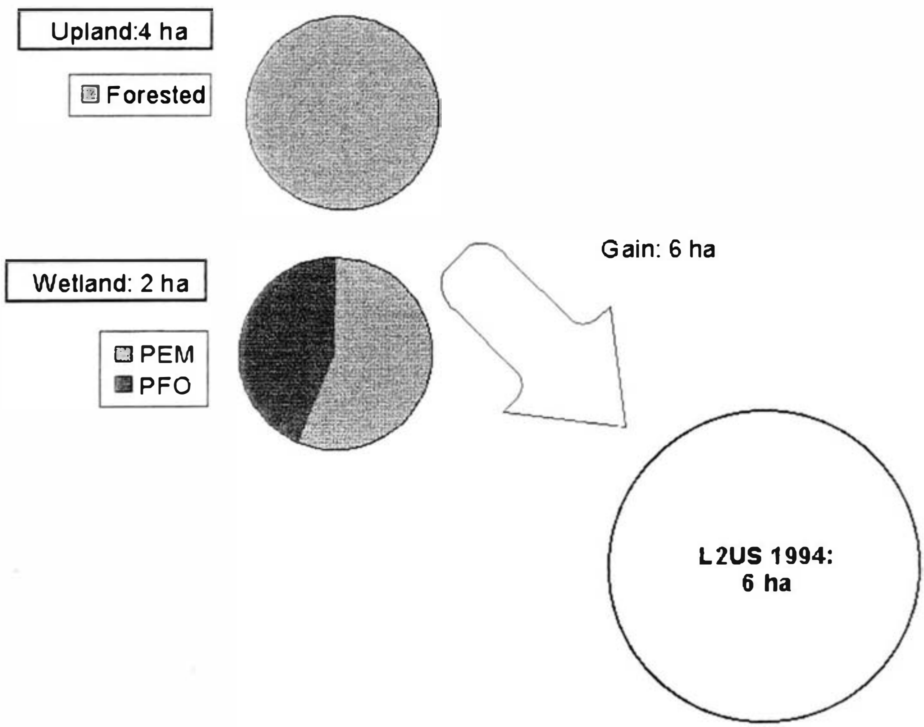

Upland:57 ha
Forest
Agriculture
Scrub shrub
Wetland: 571 ha
PFO
PEM
Gain: 628 ha
PSS 1953:
1,053 ha
739 ha
Remained the same
739 ha
PSS 1994:
1,376 ha
Loss: 314 ha
Upland: 76 ha
Industrial
Developed
Barren
Forest
Scrub shrub
Herbaceous
Wetland:238 ha
PFO
PEM
PUB
L1UB

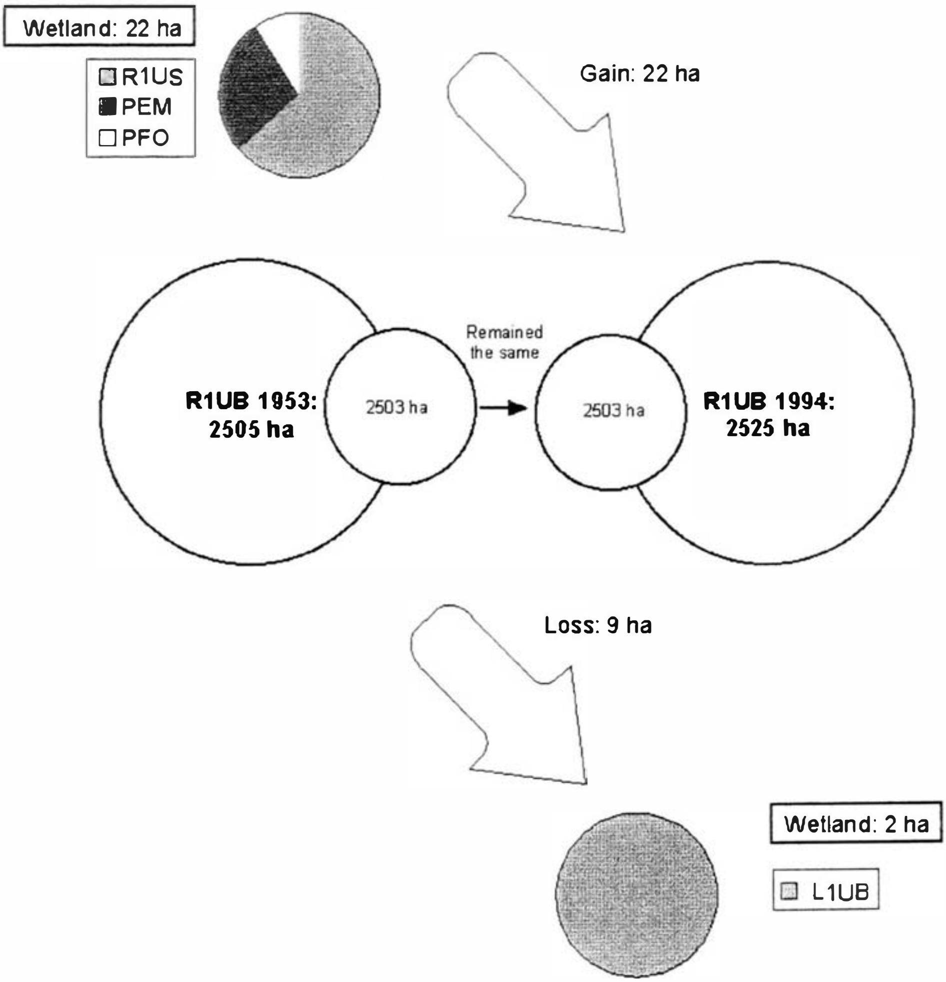

Upland: 84 ha
Forest
Scrub shrub
Herbaceous
Agriculture
Wetland: 596 ha
PFO
PSS
PUB
Gain: 680 ha
Remained the same
PEM 1953: 3053 ha
2883 ha
2883 ha
PEM 1994: 3563 ha
Loss: 170 ha
Upland: 12 ha
Agriculture
Barren
Scrub shrub
Forest
Wetland: 158 ha
R1UB
L1UB
L2US
PSS
PUB
PFO

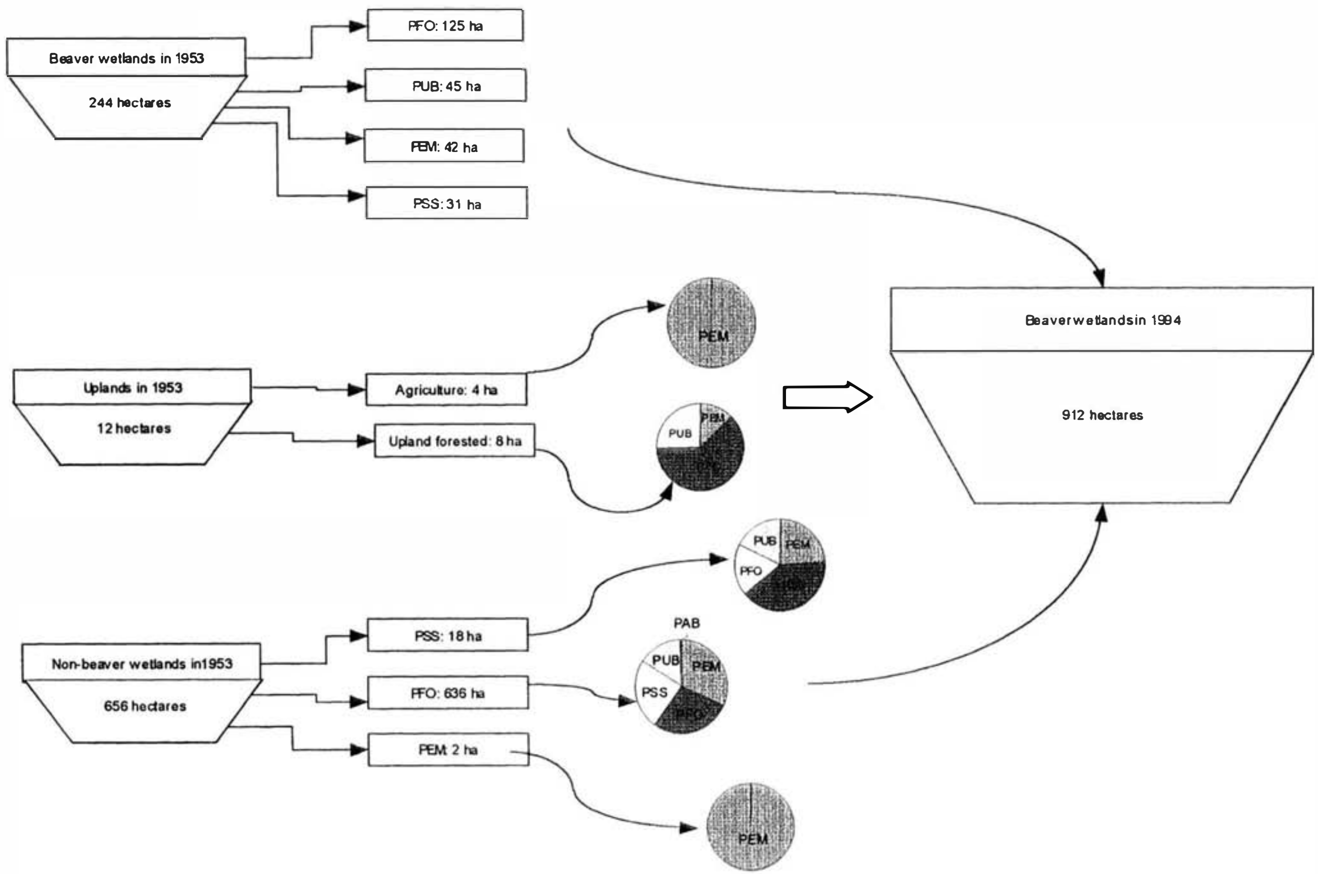

Upland:159 ha
Forest
Agriculture
Herbaceous
Scrub shrub
Barren
Wetland: 201 ha
PFO
PSS
PEM
Gain: 360 ha
PUB 1953: 304 ha
295 ha
Remained the same
295 ha
PUB 1994: 655 ha
Loss: 9 ha
Upland: 3 ha
Forest
Developed
Commercial
Wetland: 6 ha
PEM
L1UB


Upland: 508 ha
Forest
Agriculture
Scrub shrub
Herbaceous
Barren
Wetland: 430 ha
PEM
PFO
PUB
R1UB
PSS
Gain: 938 ha

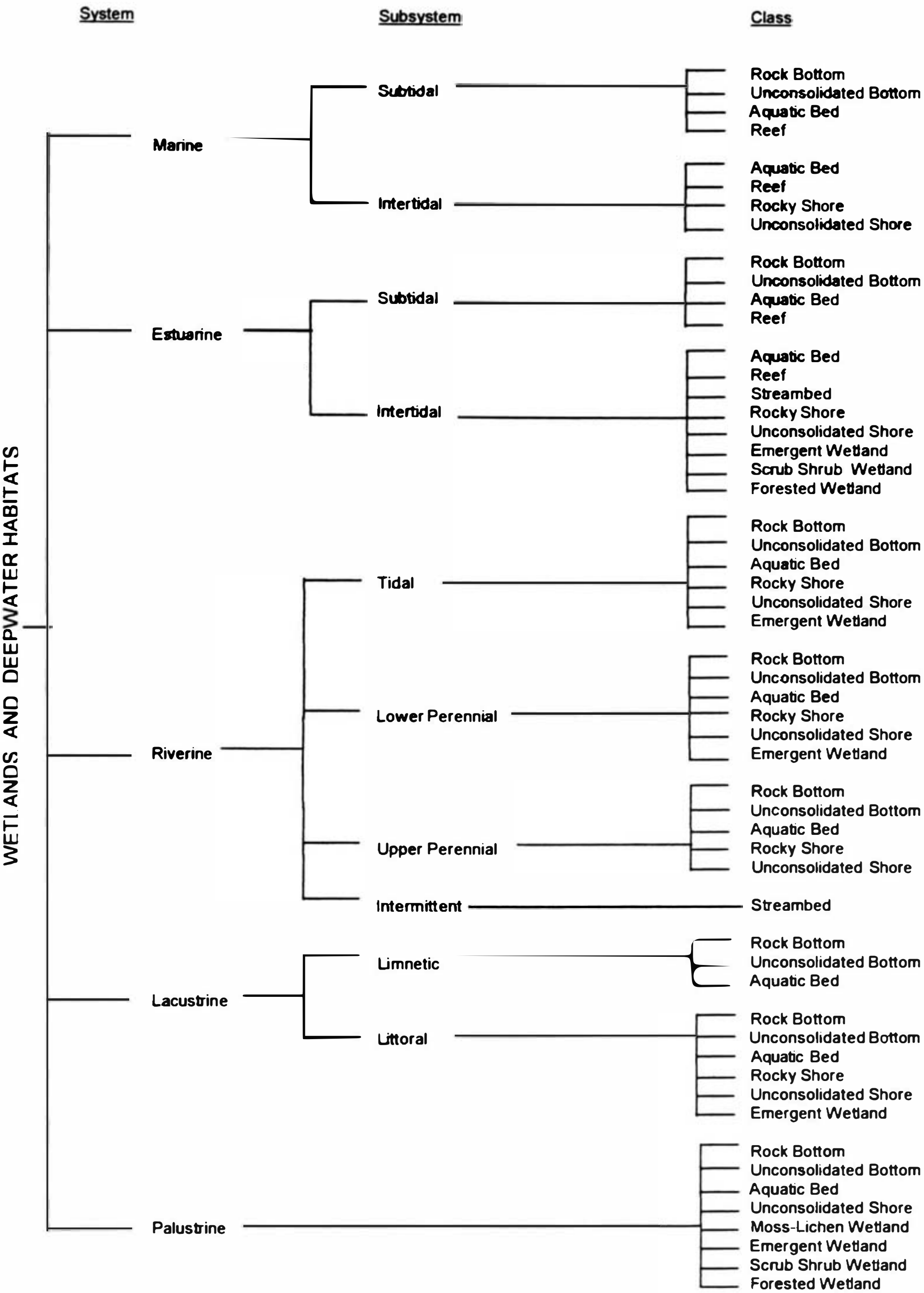

L1UB 1953:
480 ha
480 ha
Remained
the same
480 ha
L1UB 1994:
1418 ha


Upland:4 ha
Forested
Wetland: 2 ha
PEM
PFO
Gain: 6 ha
L2US 1994:
6 ha


Wetland: 22 ha
R1US
PEM
PFO
Gain: 22 ha
R1UB 1953:
2505 ha
2503 ha
Remained
the same
2503 ha
R1UB 1994:
2525 ha
Loss: 9 ha
Wetland: 2 ha
L1UB


Beaver wetlands in 1953
244 hectares
PFO: 125 ha
PUB: 45 ha
PEM: 42 ha
PSS: 31 ha
Uplands in 1953
12 hectares
Agriculture: 4 ha
Upland forested: 8 ha
PEM
PUB
PEM
Non-beaver wetlands in1953
656 hectares
PSS: 18 ha
PFO: 636 ha
PEM: 2 ha
PUB
PEM
PFO
PAB
PUB
PEM
PSS
PFO
PEM
Beaverwetlandsin 1994
912 hectares

Appendix A


System
Subsystem
Class
WETLANDS AND DEEPWATER HABITATS
Marine
Subtidal
Rock Bottom
Unconsolidated Bottom
Aquatic Bed
Reef
Intertidal
Aquatic Bed
Reef
Rocky Shore
Unconsolidated Shore
Estuarine
Subtidal
Rock Bottom
Unconsolidated Bottom
Aquatic Bed
Reef
Intertidal
Aquatic Bed
Reef
Streambed
Rocky Shore
Unconsolidated Shore
Emergent Wetland
Scrub Shrub Wetland
Forested Wetland
Riverine
Tidal
Rock Bottom
Unconsolidated Bottom
Aquatic Bed
Rocky Shore
Unconsolidated Shore
Emergent Wetland
Lower Perennial
Rock Bottom
Unconsolidated Bottom
Aquatic Bed
Rocky Shore
Unconsolidated Shore
Emergent Wetland
Upper Perennial
Rock Bottom
Unconsolidated Bottom
Aquatic Bed
Rocky Shore
Unconsolidated Shore
Intermittent
Streambed
Lacustrine
Limnetic
Rock Bottom
Unconsolidated Bottom
Aquatic Bed
Littoral
Rock Bottom
Unconsolidated Bottom
Aquatic Bed
Rocky Shore
Unconsolidated Shore
Emergent Wetland
Palustrine
Rock Bottom
Unconsolidated Bottom
Aquatic Bed
Unconsolidated Shore
Moss-Lichen Wetland
Emergent Wetland
Scrub Shrub Wetland
Forested Wetland

Appendix B. Wetland Types in the Chickahominy River watershed, Virginia

Subsystem	Class	Description
Lacustrine System: tidal or non-tidal wetlands situated in a topographic depression or dammed river channel, maintaining less than 30% vegetative cover and exceeding 8 ha		
Limnetic	Unconsolidated bottom	deepwater habitats, including lakes and reservoirs
Littoral	Unconsolidated shore	wetland habitats, including lake and reservoir shorelines
Palustrine System: non-tidal wetlands dominated by trees, shrubs, persistent emergents, or emergent mosses or lichens		
N/A	Aquatic bed	dominated by plants that grow on or below the surface of the water
N/A	Emergent	erect, rooted, herbaceous plants, excluding mosses and lichens
N/A	Forested	characterized by woody vegetation that is 6 m or taller
N/A	Scrub shrub	characterized by woody vegetation that is less than 6 m
N/A	Unconsolidated bottom	ponds

Appendix B cont. Wetland Types in the Chickahominy River watershed, Virginia

Subsystem	Class	Description
Palustrine system cont.		
N/A	Unconsolidated shore	pond shoreline
N/A	Farmed	farmed wetland
Riverine System: wetlands and deepwater habitats defined by channels--bounded on the landward side by wetland, upland, or channel bank--that transport flowing water		
Tidal	Emergent	erect, rooted, herbaceous plants in low-gradient, tidal environment
Tidal	Unconsolidated bottom	at least 25% cover of particles smaller than stones and vegetative cover less than 30% in low-gradient, tidal environment
Tidal	Unconsolidated shore	75% unconsolidated particles smaller than stones and vegetative cover less than 30% in tidal environment
Lower perennial	Unconsolidated bottom	at least 25% cover of particles smaller than stones and vegetative cover less than 30% low-gradient, non-tidal environment

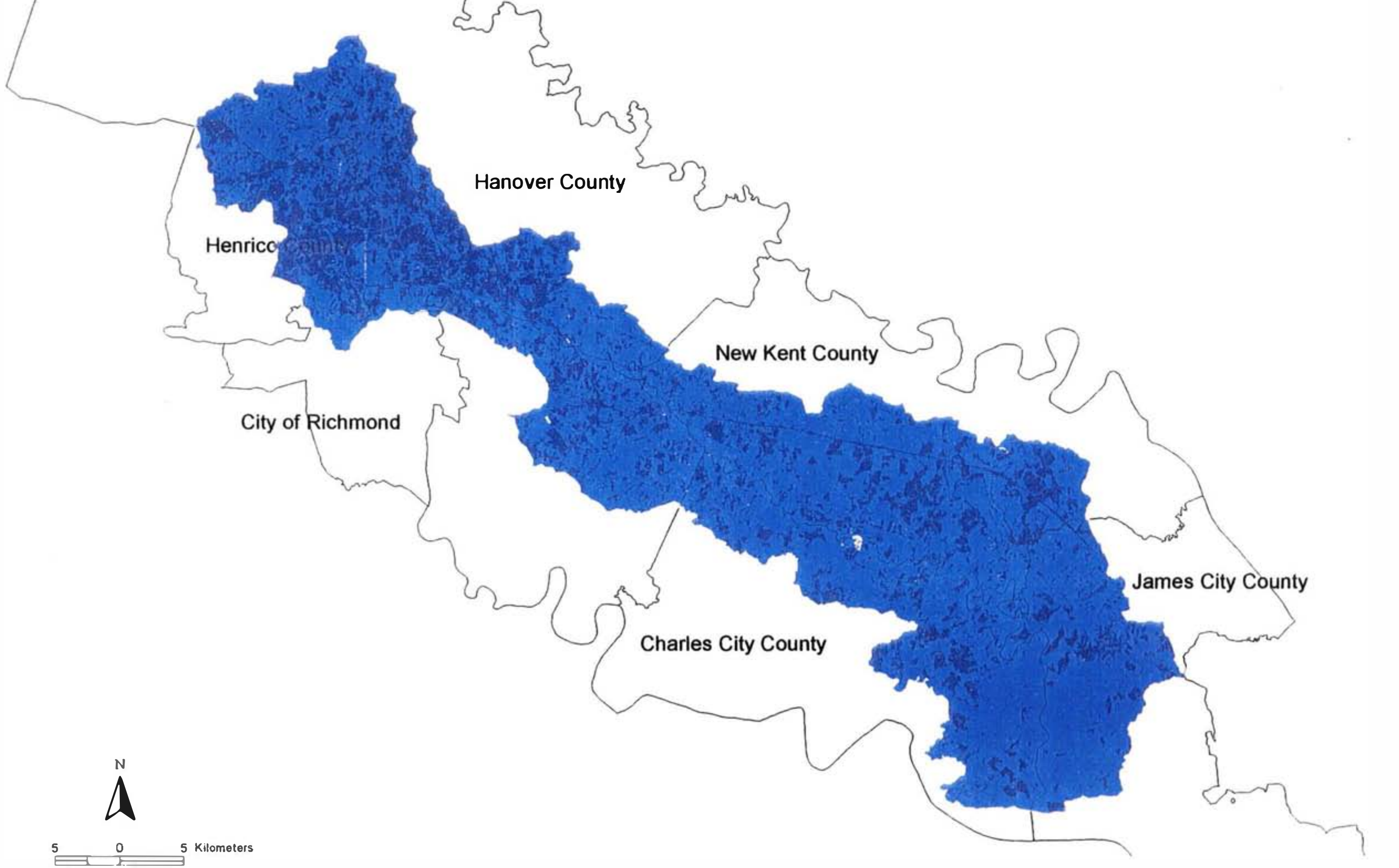
Appendix C. Code and Classification for Wetland and Upland Types in the Chickahominy River watershed, Virginia

Code	Classification	Description
Wetland types		
1	L1UB	Lacustrine limnetic unconsolidated bottom
2	L2US	Lacustrine littoral unconsolidated shore
3	PAB	Palustrine aquatic bed
4	PEM	Palustrine emergent
5	PFO	Palustrine forested
6	PSS	Palustrine scrub shrub
7	PUB	Palustrine unconsolidated bottom
8	PUS	Palustrine unconsolidated shore
9	Pf	Palustrine farmed
10	R1EM	Tidal riverine emergent vegetation
11	R1UB	Tidal riverine unconsolidated bottom
12	R1US	Tidal riverine unconsolidated shore
13	R2UB	Lower perennial riverine unconsolidated bottom
98	U	Upland in wetland coverages
Upland types		
14	UFO	Upland forested
15	USS	Upland scrub shrub
16	UHE	Upland herbaceous
17	BAR	Barren land
18	AGR	Agriculture
19	RES	Residential

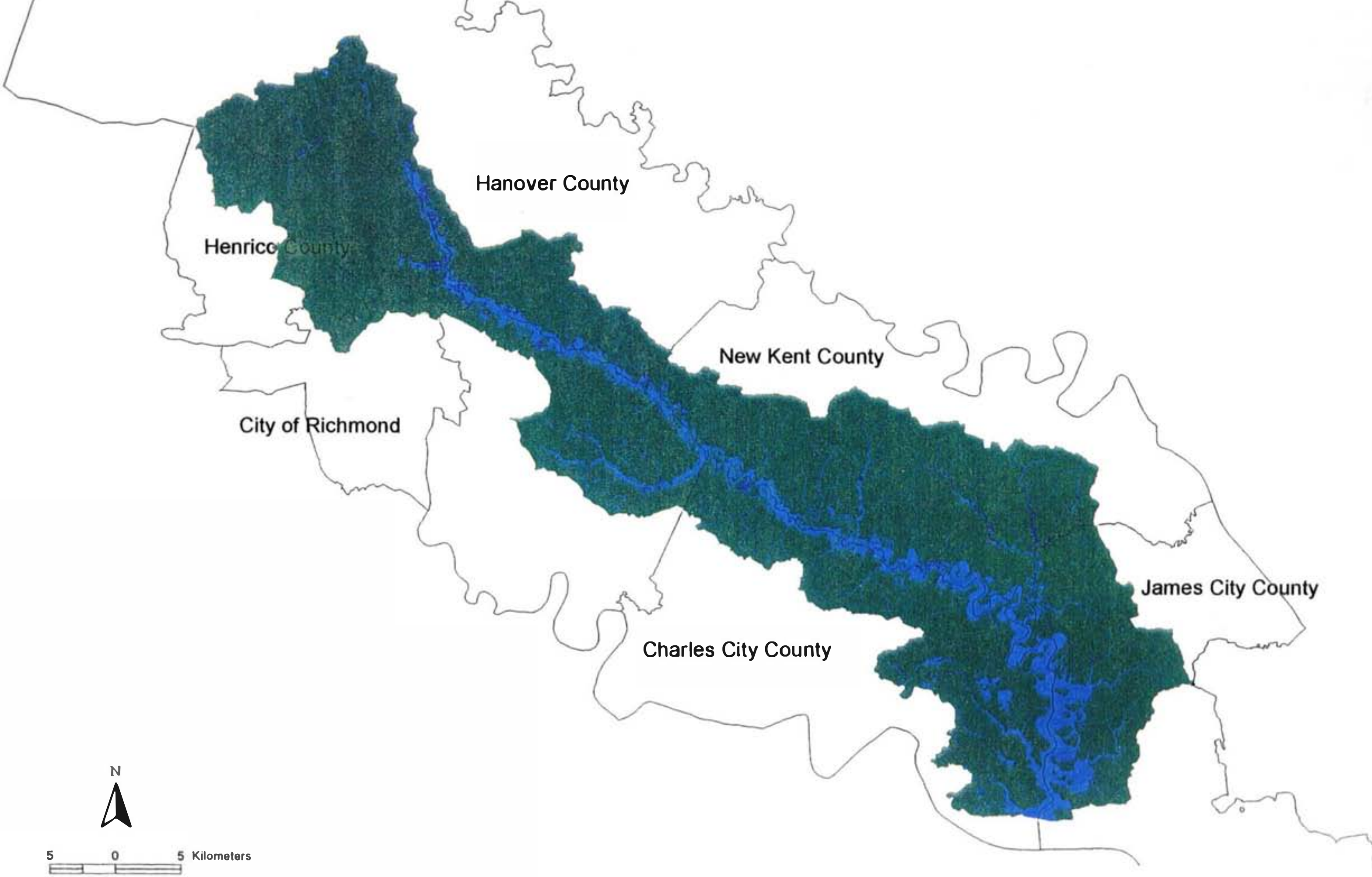
Appendix C cont. Code and Classification for Wetland and Upland Types in the Chickahominy River watershed, Virginia

Code	Classification	Description
Upland types cont.		
20	COM	Commercial
21	IND	Industrial
22	DEV	Developed land (airports, junkyards, landfills, transportation corridors, power substations, public buildings and structures)
23	RESO	Resort complexes with golf courses and related land uses
99	W	Wetland in the upland coverages

Appendix D

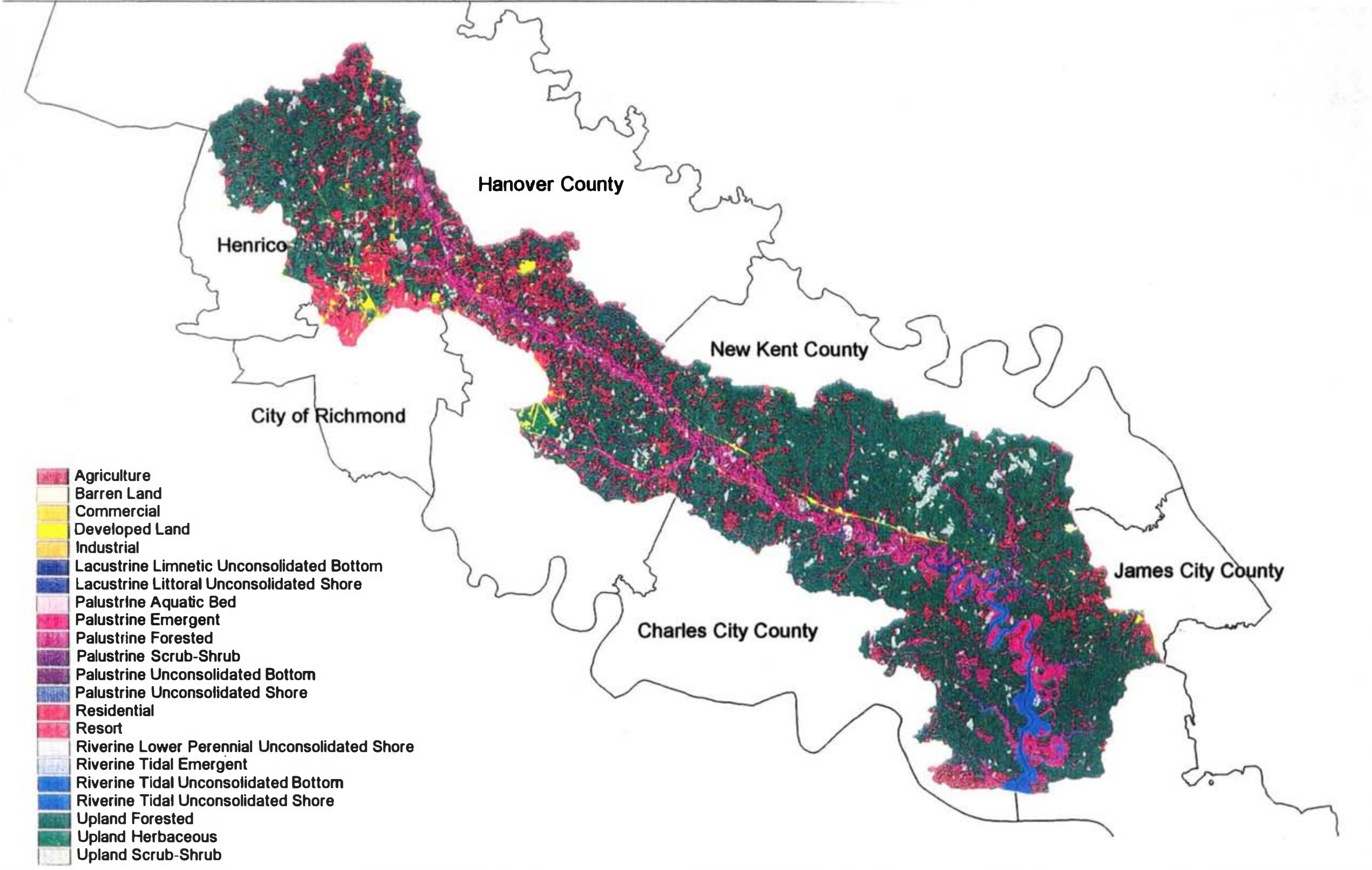


Change in landscape from 1953 to 1994 in the Chickahominy River watershed, Virginia



Change in wetlands from 1953 to 1994 in the Chickahominy River watershed, Virginia

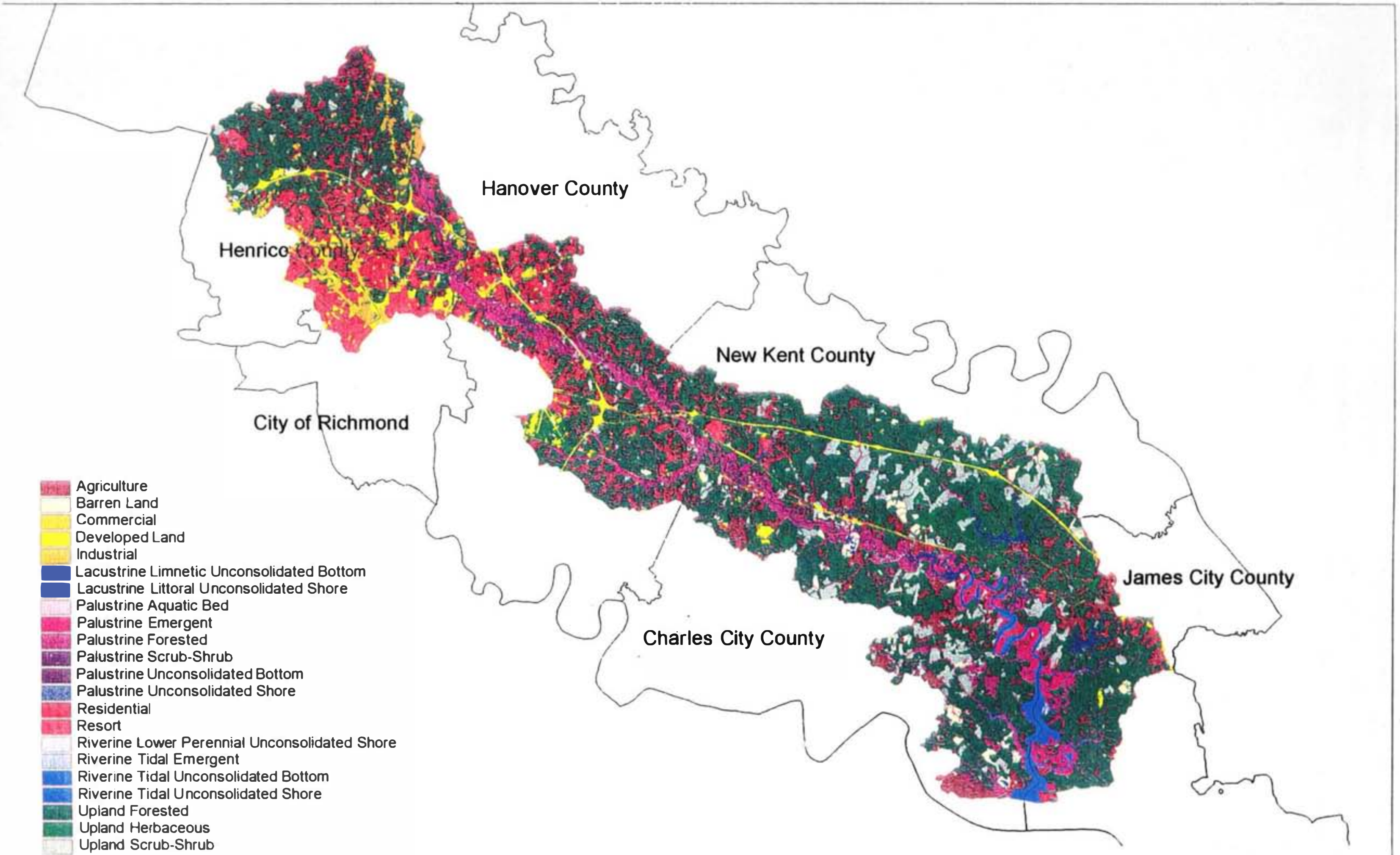
No Change
Change
Upland in 53



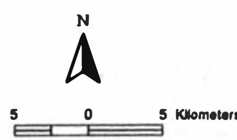
Wetland and Upland types in the Chickahominy River watershed, 1953

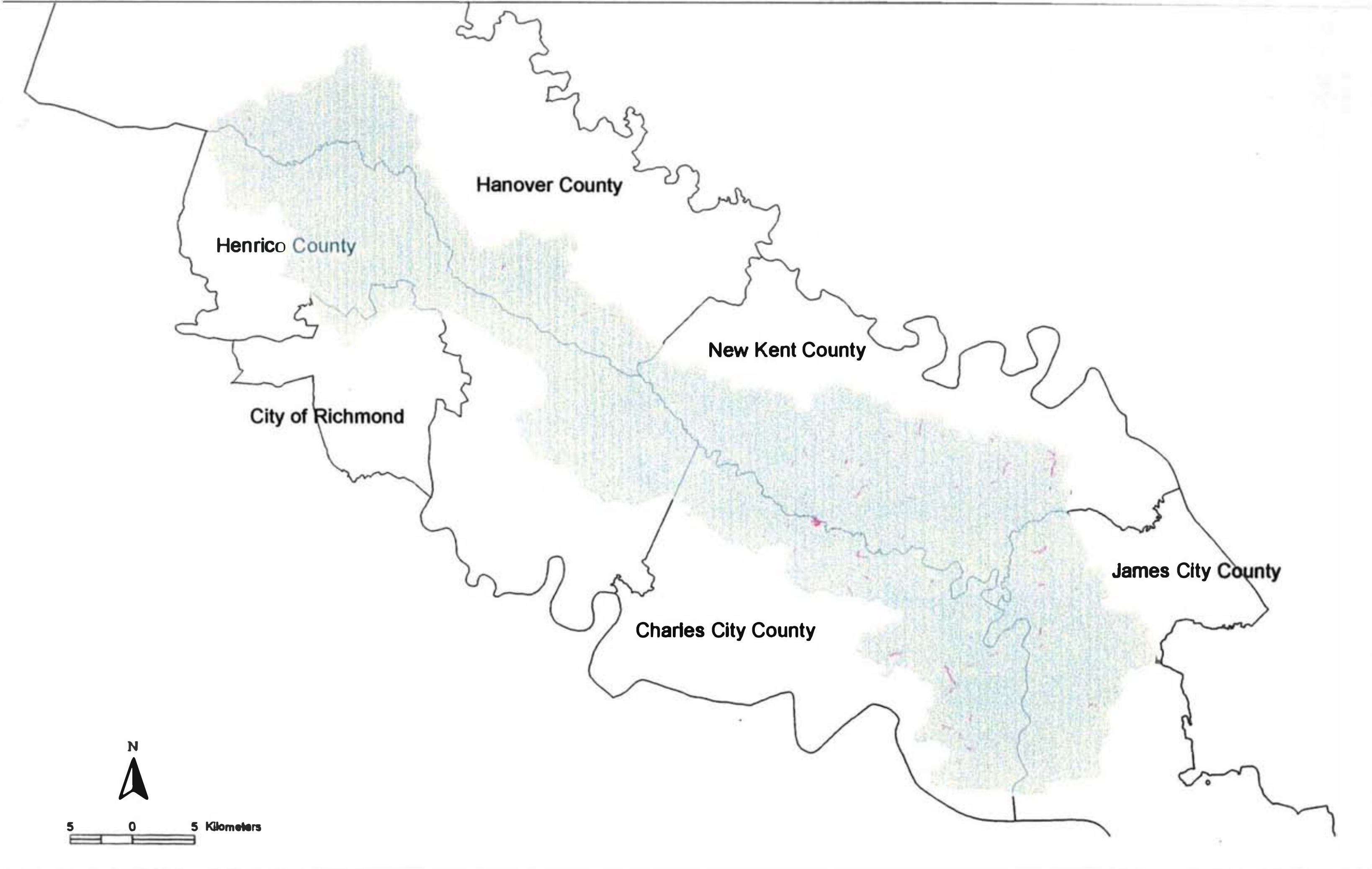
N

5 0 5 Kilometers

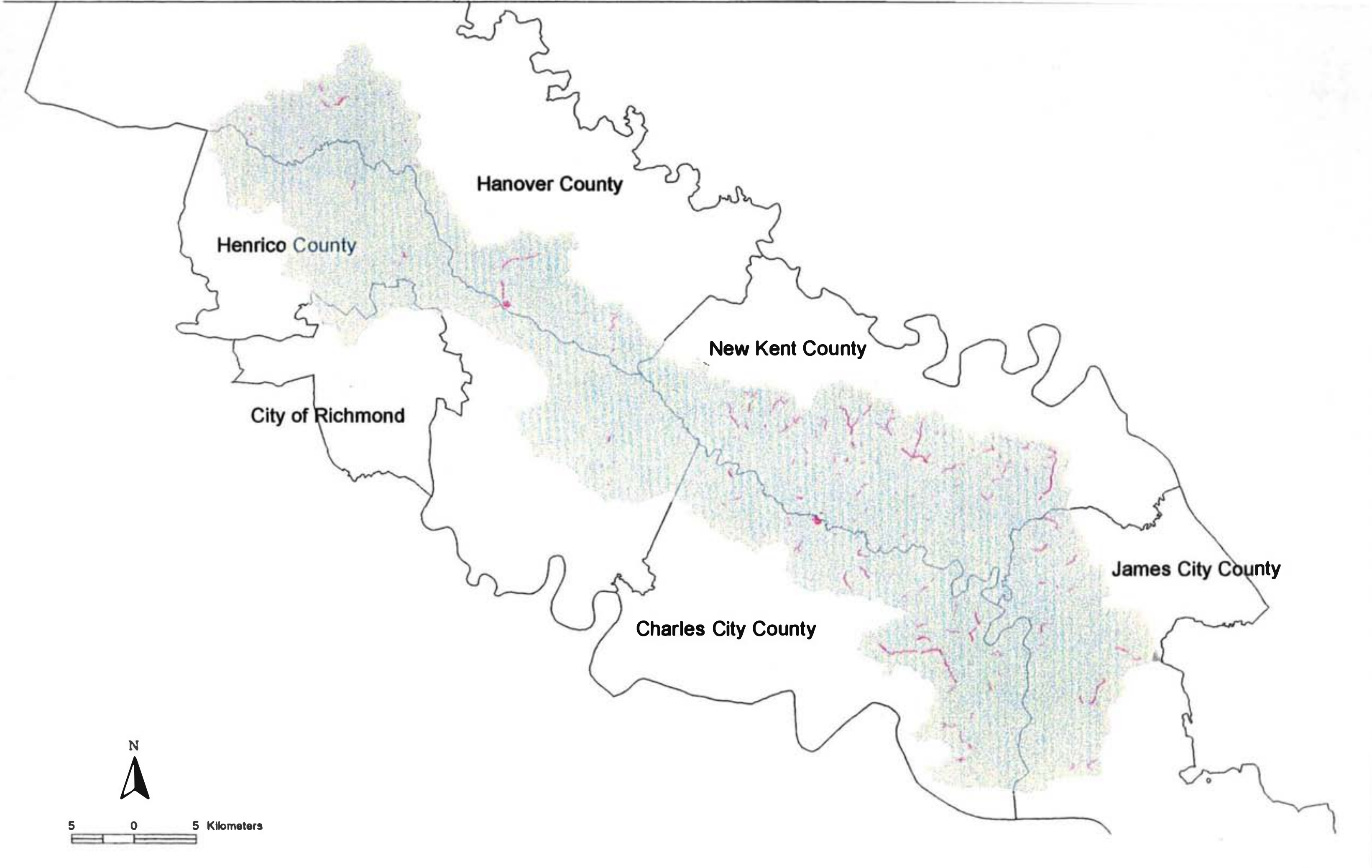


Wetland and Upland types in the Chickahominy River watershed, 1994





Beaver-modified wetlands in the Chickahominy River watershed, 1953



Beaver-modified wetlands in the Chickahominy River watershed, 1994

Beaver-modified
Not beaver-modified

Vita

[redacted]