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Colonial impacts to wetlands in Lebanon, Connecticut

Robert M. Thorson
Department of Geology and Geophysics and Department of Anthropology, University of Connecticut, Storrs, Connecticut 06269-2045
Andrew G. Harris and Sandra L. Harris*
Department of Geology and Geophysics, University of Connecticut, Storrs, Connecticut 06269-2045
Robert Gradie III
Department of Anthropology, University of Connecticut, Storrs, Connecticut 06269-2176
M. W. Lefor
Department of Geography, University of Connecticut, Storrs, Connecticut 06269-2148

ABSTRACT

The expansion and contraction of the agricultural economy in Lebanon, Connecticut, a seventeenth century New England colonial village, was associated first with conversion of "wilderness" to a pastoral landscape, and later with nearly wholescale reforestation. Freshwater wetlands throughout the area were strongly impacted by this discrete pulse of landscape disturbance, but the response of each wetland to local and upstream land use was site specific. The individualistic nature of wetland responses can be understood only by treating the drainage basin as a linked physical system that integrates geomorphic processes in a downstream direction.

Our study is based on the historical geography of 61 wetlands within a very small watershed (Susquetonscut Brook; 14 km^2), on the stratigraphy of 18 widely distributed sites (as interpreted from conventional geomorphic, lithologic, radiocarbon, and pollen techniques), and on numerical modeling of historic flood discharges. Our results indicate that (1) presettlement wetlands were strongly impacted either directly or indirectly by English land-use practices; (2) the hydrogeologic setting of each wetland was responsible for either mitigating or amplifying these impacts at downstream sites; (3) the pulse of disturbance from the colonial period (1695–1787) continues to govern the modern sediment budget, flood regime, and riparian habitat of wetlands and watercourses throughout the area; (4) wetland impacts from Native American populations were not significant enough to be detected by our study; and (5) although many swamps were drained by the colonists, these wetland losses were more than offset by the amount of wetlands created.

*Present address: U.S. Geological Survey, Water Resources Division, Marlboro, Massachusetts 01752.

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INTRODUCTION

Widespread public support for wetlands protection derives from the general perception that wetlands are ancient, pristine, stable ecosystems of high intrinsic value. This is clearly not the case for many freshwater wetlands in the glaciated uplands of southern New England, a setting that was dramatically impacted by a wave of European agricultural technology that passed over the landscape like a storm beginning in the late seventeenth century and culminating shortly after the American Revolution. A tangible, quantifiable record of serious wetland impacts resulting from this ecological transition (or catastrophe) lies within the sediments of swamps and floodplains throughout this reforested region.

Wetland regulation is arguably the most contentious environmental issue in the United States with respect to the conflict between public and private property rights (National Research Council, NRC; 1995). Hence, the identification and delineation of wetland ecosystems must follow explicitly standardized legal procedures. Specifically, the recent NRC guidelines for wetland regulation (1) make no provision for the *origin* of wetlands, (2) require the identification of sites that have been *recently altered* by anthropogenic or natural events, and (3) allow wetlands on *agricultural* lands to be treated differently. These guidelines make sense when the alterations are very recent and are self-evident. But when wetland impacts have been naturally mitigated for centuries, and when abandoned, but reforested, agricultural land is not considered, the convenient assumptions underlying the regulatory process break down.

The investigation of historically impacted wetlands also has scientific merit because it provides a framework for evaluating landscape response to disturbance within the context of human ecology (Naveh and Leiberman, 1990; Worster, 1990; Chase, 1995). Most hydrogeologists who investigate wetlands understand that the impacts at any site were influenced by the integrated effects of all upstream sites, and that linkages between sites, however obscure, influence the differentiation of natural changes from anthropogenic ones. This watershed-scale perspective, however, is seldom applied in routine wetland investigations, especially in other disciplines, owing to the complexity of the issues involved (Phillips, 1992).

Our investigation lessens the problems of a watershed-scale approach by (1) focusing on a high concentration of wetlands in a very small area, (2) selecting a reforested agricultural area in which historic settlement occurred as a discrete pulse, and (3) selecting a watershed in a physiographic setting that would amplify, rather than attenuate, flood response in a downstream direction. Our study area is a small (14 km^2) watershed at the headwaters of Susquetonscut Brook in the highlands of east-central Connecticut (Fig. 1). During the middle of the eighteenth century, the entire watershed was agricultural land within the colonial town of Lebanon, a small geographic area adjacent to, and governed by, a municipal Town Center (Fig. 1). Lebanon's land-use history, which begins in 1692 (Figs. 2–4), documents the agricultural conversion of the upland soils, the regulation of

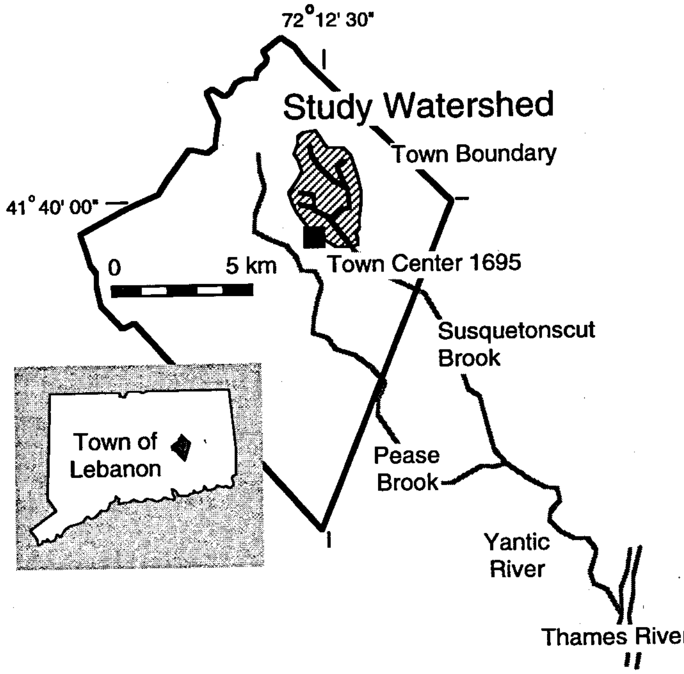

Figure 1. Location of study watershed area (hachured) within the headwaters of Susquetonscut Brook, in the town of Lebanon. Watershed is enlarged as Figures 2, 3, 5, and 9.

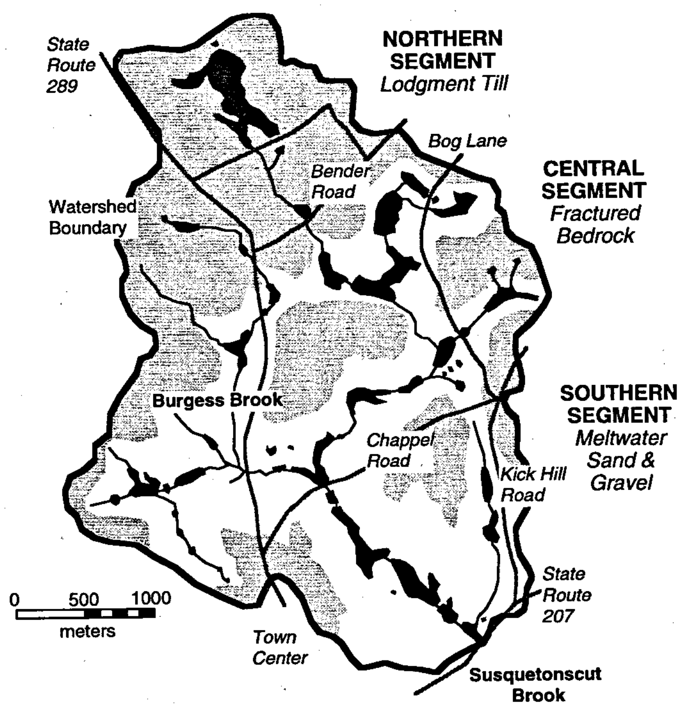

Figure 2. General setting of the study area showing stream network, roads, physiographic sections, and localities mentioned in the text. Boundaries between physiographic segments trend northeast-southwest parallel to the strike of the bedrock. Wetlands examined in this study (black) are shown. Areas above 122 m (400 ft) elevation are shaded. Dominant aquifers are listed for each segment.

streamflow for hydropower, the use of floodplains for grazing, deliberate wetland drainage, mining of wetlands for bog iron, the local extinction of beaver, and the construction of roads and bridges. The watershed had a variety of wetlands present at the time of settlement that attracted use as drained cropland and water-supply reservoirs. The outlet of Susquetonscut Brook was tightly constricted by artificial fill associated with a highway bridge built before 1720; this facilitated our treatment of the watershed as a closed physical system with a low sediment delivery ratio. Our results are broadly applicable because the rural-suburban character of the town and its large percentage of second-growth (or third-growth) forest are typical for southern New England.

This review is a case study addressing the physical evidence for hitherto unrecognized human impacts on the riparian wetlands in Susquetonscut Brook. We began with a field traverse of the stream network to identify, locate, and describe human influences on the channels and adjacent slopes. Next, we used aerial photographs to map all wetlands within the watershed and to classify them according to land-use history, rather than by traditional methods. Our main objective, however, was to reconstruct the recent development of the wetland system at the watershed scale by using sedimentary evidence from cores and natural exposures, and by hydrologic modeling of former conditions.

Our results demonstrate that (1) hidden human impacts to the wetland system were pervasive and ubiquitous, (2) stratigraphic evidence for the predicted effects of land-use changes is indeed present, and (3) that modern conditions continue to be influenced by the colonial deforestation that began more than three centuries ago. There is nothing "pristine" left in the scenic rural wetlands of Lebanon.

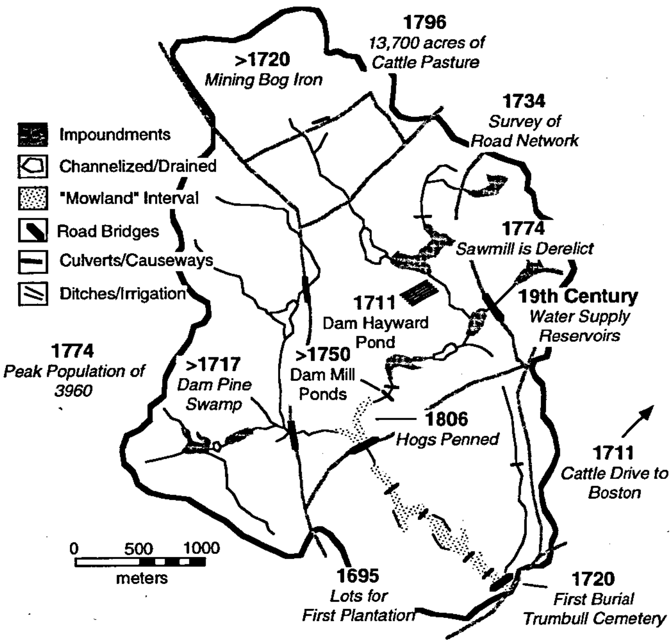

Figure 3. Map showing location of anthropogenic changes to the drainage network. Evidence from primary historic accounts (tax, deed, etc.) in boldface and listed by date; > symbol indicates structure in place before the date shown. Evidence from ground reconnaissance shown symbolically. Impoundments (dark gray) are located in central section where gradients are high. "Channelized" indicates rerouting of the main channel. Stone concentrations interpreted as former causeways are particularly abundant along the main stem.

BACKGROUND

The sedimentary record

The ecological transformations that swept New England during the seventeenth and eighteenth centuries were recognized in their time (Deane, 1790) but were infrequently documented and are poorly understood, especially in quantitative terms. Ecological impacts on the presettlement flora, fauna, and indigenous peoples are known reasonably well because these were subjects of scientific interest to colonial writers. Anecdotal descriptions of transient changes in soils and hydrology are also available because these phenomena were vital to the agricultural economy (Cronon, 1983). But historic documents are inadequate to assess the "naturalness" of our present landscape in areas where historic structures (farmsteads, enclosures, dams for water supply) are not readily apparent (Thorson and Harris, 1991). At what scale of resolution (Urban et al., 1987) is the landscape the same, or different, from precolonial times?

The invasive nature of colonial agricultural technology, its broad geographic application, and its intensification through time ensured that permanent changes in the soils and streams of southern New England occurred before original conditions could be adequately documented. The limited depth of prehistoric archaeological sites on slopes above wetlands, the dearth of presettlement soils (Hill et al., 1980), and the ubiquitous gridwork of stone walls demonstrates that upland soils were pervasively disturbed. Strata from wetlands, however, can be reliable indicators of land-use changes because they are sites of net deposition, and therefore act as recorders of changes in the flux of nutrients, sedimentary particles, and pollen grains (Bormann et al., 1974; Carter, 1986; Phillips, 1989). Thus, presettlement conditions at the landscape scale, the baseline from which environmental "alteration" must be measured, require field investigations of sedimentary strata within small freshwater wetlands.

Previous studies of wetland impact in New England have relied on a range of techniques. Pollen records confirm the known changes in watershed vegetation associated with land clearing, agricultural use, and abandonment to pasture and forest cover (Brugam, 1978; Kelso and Beaudry, 1987) and demonstrate that Native American populations had little impact on vegetation beyond the larger estuaries and floodplains (McAndrews, 1988). Engineering studies indicate that sediment transport at the Atlantic scale (Meade, 1982) was relatively insensitive to deforestation. The elevated sedimentation rates in New England lakes during historic time (Webb and Webb, 1988) tell us almost nothing about landscape change at the scale of farms, villages, and

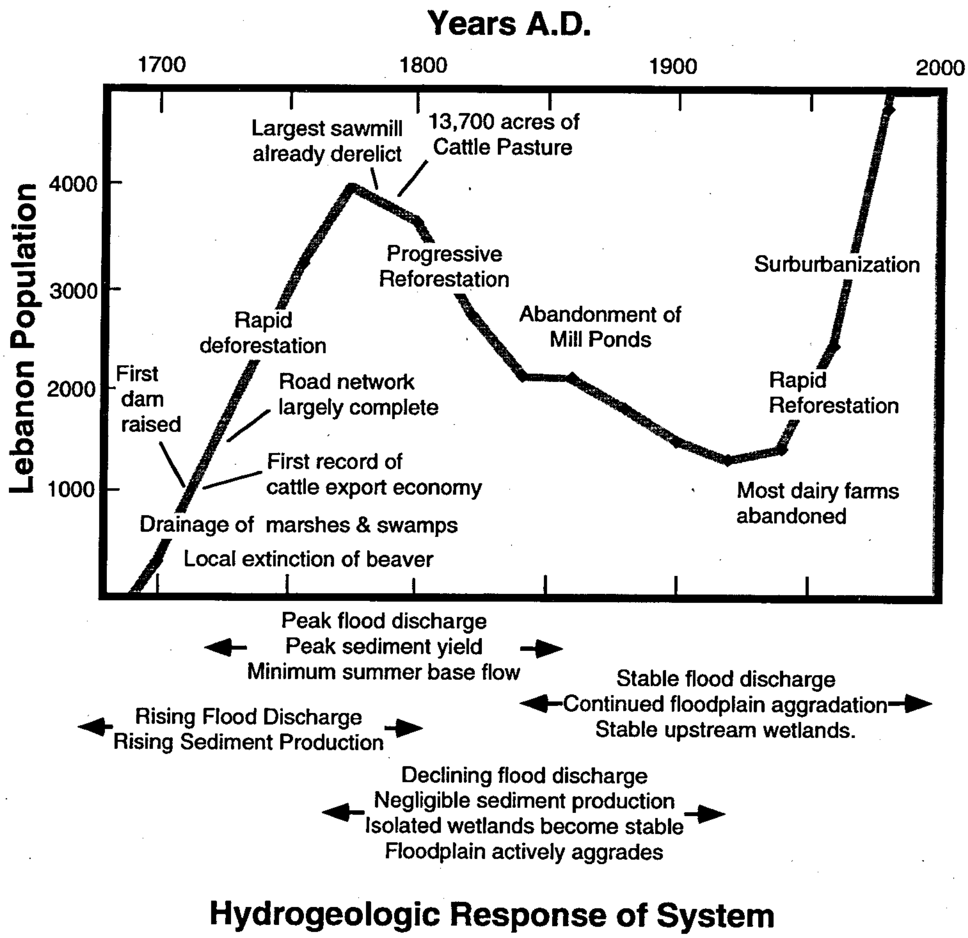

Figure 4. Graph illustrates changes in population of Lebanon from official census data (Milne, 1986). Specific historic events (lines) and general land use activities are superimposed on the population curve. Blocks of text beneath graph describe general hydrogeologic response to human activities, with arrows indicating general time range of response.

towns. The poor correlation between modern agricultural activities and sediment yield of larger New England streams (Gordon, 1979; Toney, 1987) belies the dramatic relationship between these variables in smaller drainages.

Our conclusion that small headwater wetlands in southern New England are the most (rather than the least) impacted by human disturbance is counterintuitive to the general perception that these remote wetland areas largely escaped the imprint of human hands (Adamus, 1983). Ironically, strict regulations are now mandated in the same watersheds that were once mined for ore, clear-cut of forest, mired by livestock, and dammed for hydropower. But unlike the obvious global effects of mining and agriculture in more arid landscapes (Hooke, 1994; Turner, 1990) the best record of equivalent landscape changes in New England lies buried beneath our protected wetlands.

The study area

Susquetonscut Brook is one of two major tributaries that meet to form the Yantic River near Norwich in southeastern Connecticut, a drainage network created by differential erosion of high-grade metamorphic rocks during Tertiary time (Denny, 1982). Our study area constitutes the northernmost 14 km^2 of the Susquetonscut Brook drainage (Fig. 2), centered on 41°40′00″ N; 72°12′30″W. The watershed is approximately 5 km long, 4 km wide, and lies about 8 km south of the nearest city, Willimantic, Connecticut. The western third of our study area is drained by Burgess Brook; the eastern two-thirds by an unnamed stream. These tributaries merge just north of Chappel Road to form a single channel, here referred to as the main stem. Surface soils are sandy loams and stony sandy loams classified as dystrochrepts and udorthents (Cunningham and Ciolkosz, 1984), which reflect moderate to weak horizonification under acidic postglacial conditions. A discontinuous mantle of loamy topsoil above the till created by late-glacial eolian deposition (Thorson and Schile, 1995) and Holocene biomantle production (Johnson, 1990) is responsible for most of the suspended sediment transported to the streams.

The watershed consists of three physiographic segments, each covering about one-third of the area and each containing highlands above 122 m elevation (400 ft). In the *Northern Segment*, elevations reach approximately 152 m (500 ft) and are underlain by sandy glacial till of low permeability with moderate local relief (Clebnik, 1980). A perched water table often occurs in shallow depressions. Local summits are glacially streamlined hills with broad, till-covered summits, and were ideal sites for upland colonial agriculture. In the *Central Segment*, watershed relief reaches a maximum; streams occupy bouldery ravines at about 90–100 m deep as they cross through a belt of resistant rock, and hill summits project above 182 m (600 ft) elevation. Ground water availability is dominated by flow within fractured rock. In the *Southern Segment*, a well-developed modern floodplain lies terraced below a broad, gravely valley fill deposited by meltwater deltas and streams during glacier recession about 17,000 years ago. The most transmissive aquifers occur within these glacial sedimentary basins, insuring persistent wetness throughout the year. These meltwater deposits are, in turn, flanked by till-covered drumlinoid slopes rising to 134 m (440 ft) elevation, which recharge the stratified drift aquifer.

Vegetation in the study area is classified as the Appalachian Oak Forest Section of the Eastern Deciduous Forest (Bailey, 1978), and consists of areas reforested after abandonment of farms. Dominant trees include oak, maple, hickory, ash, hemlock, and white pine; chestnut was prominent prior to the outbreak of chestnut blight in the early twentieth century. The modern climate is temperate, with a mean precipitation of about 1,200 mm distributed evenly throughout the year (Ruffner, 1985), although the year-to-year variability of rainfall is high. Proximity to the Atlantic Ocean moderates extreme variations in temperature and is responsible for high-intensity precipitation events associated with strong frontal activity and hurricanes. Major hurricane floods occurred in 1927, 1938, and 1955, with storm precipitation exceeding 125 mm in a three-day period (Patton, 1988). The water budget is dominated by infiltration and evapotranspiration during the winter and summer months, respectively (Thomas et al., 1967).

The regional pollen stratigraphy and climatic modeling experiments (Webb et al., 1993) demonstrate that peak post-glacial warmth was delayed until sometime between 9,000 and 6,000 B.P., owing to the persistent effects of the Laurentide Ice Sheet. Slightly cooler and moister conditions characterized the last several millennia (Davis, 1983). Historic climate records begin in 1742 (Landsburg, 1967). In the most general terms, average conditions for the period 1780–1840 were colder, drier, and more variable than present; the period 1840–1890 was colder, wetter, and more variable than present; and the period 1890–1990 has shown a broad trend towards warmer, drier, and more stable conditions.

Land-use history

The abundance of Native American names and the presence of late Woodland and contact-period artifacts indicate that the town of Lebanon was occupied by Mohegan peoples before being "transferred" to a collective of colonists in 1692. The town was named by John Fitch, who, noting the majestic cedars within local swamps, compared the area to that of the Holy Land (Milne, 1986). Ironically, what is now the village green (listed on the National Register of Historic Places), was once a perched swamp, the draining of which may have been the first serious impact to a local wetland. Another early historical impact took place at the largest wetland in the study area, which was mined for bog iron between the late 1720s and early 1730s.

The narrow, original house lots dating to 1695 fronted on the town common and extended eastward, downslope across the floodplain of Susquetonscut Brook, between Chappel Road and Route 207 (Figs. 2 and 3). The pattern of stone walls, collapsed bridge abutments, and ditches runs perpendicular to the brook and indicates that individual landowners each maintained his own causeway across the marsh. An early deed describes "mowlands" in the floodplain of Susquetonscut Brook, suggesting that at least part of the floodplain was being used (and artificially drained) at this time. Government surveys indicate that the present network of roads and villages was established before 1734.

The population of Lebanon grew from about 350 inhabitants at the time of settlement to a premodern peak of nearly 3,960 inhabitants (including 116 slaves) in 1774 (Fig. 4). Colonial population growth was fueled by an export agricultural economy that accelerated in the decades before and during the American Revolution. For example, cattle drives to Boston occurred as early as 1711, and the tax list for 1796 describes 13,700 acres as cattle pasture, nearly all of which has since been reforested. Evidence for early and intense deforestation is found in a 1774 deed referring to the largest saw mill in the area as "old" (generally meaning derelict). A second deed in 1806 indicates the commercial penning of hogs, which implies that forest clearing may have been essentially complete. After its peak, the population of Lebanon declined steadily throughout the nineteenth and early twentieth centuries, rising again only after the automobile provided convenient access to nearby cities.

The widespread occurrence of mills, reservoirs, and irrigation ditches demonstrates the degree to which water was regulated in the basin during colonial times. Specific historical descriptions are available for six of the eight artificial impoundments in the basin. Associated with these ponds were at least six industrial enterprises, including a grinding shop, a grist mill, a saw mill, a cider press, a distillery, and a shop of undetermined function. The historic accounts of these structures and reconnaissance archaeological investigations indicate that industrial development of the Brook reached its peak between 1775 and 1825. Additionally, cattle watering would have required many artificial ponds in this rocky and generally well-drained hill country.

The earliest evidence for the deliberate management of water is a 1711 deed for Hayward Pond, which was impounded by a "nine-foot" stone-faced earthen dam to power a grist mill that operated through the end of the nineteenth century. Pine Swamp (Fig. 3) was impounded by 1717. Two dams were raised near the head of the steep ravine between Hayward Pond and Chanski Basin sometime before 1750 (Sawmill Pond, Fig. 3). Two other nineteenth-century dams (Manning Pond and Unnamed Dam) are located directly above Hayward Pond, and probably were used to regulate streamflow to it as part of an integrated water-management scheme. Two more dams, both located below Hayward Pond, were discovered in field surveys.

Irrigation ditches and structures are also sporadically mentioned in written accounts, and were observed during our reconnaissance. The upper dam along the main stem and the dam above Hayward Pond have been reinforced and continue to function as unregulated stock ponds. Most of the other dams are partly collapsed, but still retain ponds.

CRONON'S HYPOTHESIS

William Cronon (1983, p. 122–124; Table 1) summarized historical accounts from the eighteenth and nineteenth centuries regarding how colonial land-use practices impacted the hydrologic regimes in New England. Based on his analysis, the earliest hydrologic changes in colonial Lebanon would have been associated with the local extinction of beavers (*Castor canadensis*), whose persistent presence in southern New England for the past 12,000 years (Kaye, 1962) was an important component of the fluvial system (Naiman and Johnson, 1988). Breaching of beaver dams, which may have been abandoned as early as 1640, would have released sediment from storage, and their dams could no longer have attenuated flood peaks.

Historical accounts also indicate that removal of the forest canopy in Susquetonscut Brook would have increased both the frequency and magnitude of floods, and would have greatly elevated the flux of suspended sediment from the upland landscape. Enhanced flooding would have been a direct consequence of many factors, chief among them being the decreased permeability associated with the deeply frozen and compacted soils of cultivated and pastured areas, and with the enhanced rate of spring snowmelt in exposed areas. The effect of deforestation on the ground-water budget of wetlands in Susquetonscut Brook, however, would have been case-specific. In some cases, the reduced infiltration responsible for enhanced flooding would have caused a reduction in ground-water recharge, leading to greater drying of soils and the loss of wetlands. Elsewhere, decreased evapotranspiration losses resulting from deforestation led to greater aquifer recharge and higher base-flow discharge to wetlands.

These historically based accounts of change are consistent with the results of modern empirical studies based on deforestation experiments (Hornbeck et al., 1970), flood discharge (U.S. Army Corps of Engineers, 1981) and water budget (Miller and Focazzio, 1988) models, regression analyses of watershed response to known changes (Pickup, 1988), case studies of wetland impacts (O'Brien, 1977), and by stratigraphic records (Jacobsen and Coleman, 1986).

The consistency between historical and empirical approaches suggests that the hydrologic impacts of the colonial land-use changes on wetlands in Susquetonscut Brook can be considered as a single broad hypothesis. Specific predictions from Cronon's hypothesis include the following.

1. Land clearing, grazing, and cultivation would have

TABLE 1. EXPECTED HYDROLOGIC IMPACTS OF COLONIAL LAND USE CHANGES*

Purpose	Specific Action	Local Impacts	Downstream Discharge: Total Runoff	Downstream Discharge: Base Flow	Downstream Discharge: Peak Flood	Sediment Load: Direct	Sediment Load: Indirect	Relative Importance
Transportation	Roads, trails	Drainage occlusion	+	–	+/–	–	+	Low
Hydropower	Mills, dams, sluiceways	Reservoir storage. Local rise in water table	+	+	–	–	–	High
Drainage	Ditching, channelization	Local sediment production. Peat decomposition	0	–	+	+	+	Low
Food Production	Tillage, pasture	Sediment production. Decreased infiltration. Ground freezing	+	–	+	+++	+	Medium
Property Division	Stone walls/fencing	Drainage occlusion. Sediment retention	+	–	+/–	–	–	Low
Forestry/Clearing	Clearing	Sediment mobilization. Limited infiltration	+	+	++	++	+	Very high
Trapping	Beaver extinction	Sediment source from abandoned dams	–	–	–	++	+/–	Medium

*Qualitative relative estimate for the significance of selected impacts on selected parameters. Major increase = +++; moderate increase = ++; slight increase = +, decrease = –, or no effect = 0.

increased both total discharge and base flow, owing to increased runoff from bare soils and decreased evapotranspiration from denuded watersheds, respectively.

2. Sediment transport would have increased due to erosion of exposed upland soils, and to enlargement of channel banks in response to increased flood flows.

3. The subsequent construction of mill dams during the late eighteenth and early nineteenth century would have attenuated and desynchronized peak flood flows by mass storage in reservoirs, and simultaneously increased the permanent storage of sediment in reservoirs and ponds.

4. Expansion of the transportation network (roads, cartways, causeways, and trails) and the construction of fences and stone walls would have created site-specific occlusions of the drainage network, leading to enhanced retention of sediment on the upstream sides, causing wetter conditions, the enhanced growth of obligate hydrophytes, and additional retention of sediment.

5. Ditching and channelization of streams would have contributed to the release of sediments from storage through the effects of increased stream power, and through the aerobic decomposition of organic soils in situ by bacterial respiration.

These specific predictions can be tested by comparing them with the actual changes at wetland sites as reconstructed from stratigraphic records in a range of hydrogeologic settings.

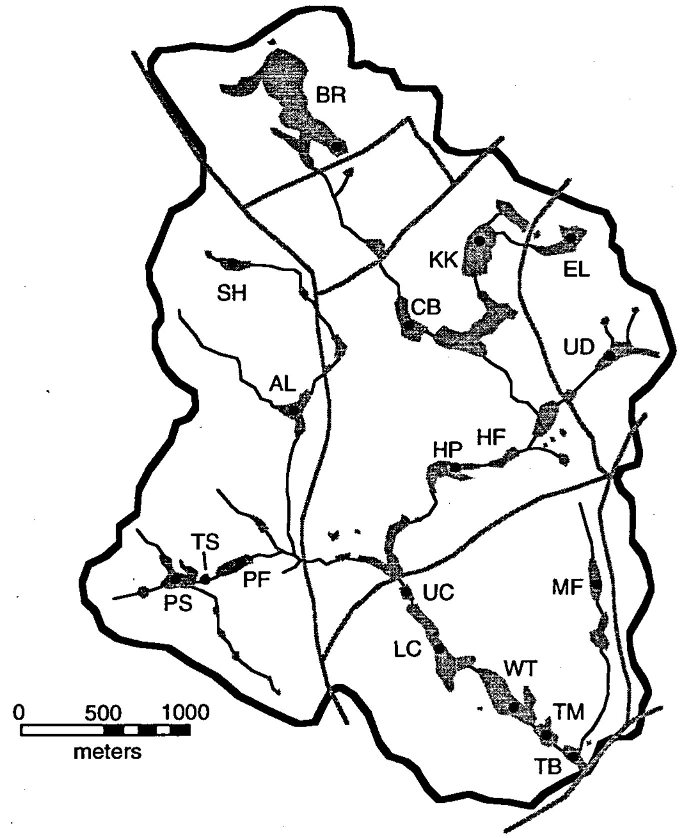

Figure 5. Map showing wetlands investigated in this study. Full names for abbreviations and wetland characteristics are given in Table 3. Large black dots show locations of natural exposure, sediment cores, or transects of cores for stratigraphic interpretation that are summarized in this report (additional details are given in Thorson, 1992).

METHODS

Mapping and classification

To map the wetlands in the watershed we used aerial photographic stereo pairs from the spring of 1986 at an approximate contact scale of 1:12,000. By simultaneously examining wetland boundaries from the National Wetlands Inventory of the Willimantic Quadrangle (Metzler and Tiner, 1992) and the aerial photographs, we developed an operational definition of a wetland for mapping purposes (a flat landform where the photographic tone contrasted strongly with the adjacent terrain and where prolonged wetness was consistent with geomorphic setting and field observations). Our population of wetlands ($n = 61$) is based strictly on the interpretation and field checking of the aerial photographs against the ground distribution of hydric soils (Tiner and Veneman, 1989), and includes all sites that were large enough to map at a scale of 1:12,000. We included all sites linked by the drainage network but excluded recently excavated farm ponds on the upland. Although the lower floodplain of Susquetonscut Brook is continuous along the main channel, we subdivided it into four sedimentary basins (wetlands) between constrictions, all of which were partly human in origin (Fig. 5; Tables 2–4). The spatial density of wetlands examined (4.4 per km^2) was sufficient to characterize the watershed qualitatively, and is representative of terrain throughout eastern Connecticut.

The classification system used by the National Wetland Inventory (Cowardin et al., 1979) was inappropriate because every wetland in our study area belonged to the same subclass (Broad-leaved Scrub-shrub Palustrine Wetlands; Fig. 4). A classification based on surficial geology (Clebnik, 1980) and soils type (U.S. Soil Conservation Service, 1983) failed because the mapped units were independent of wetland stratigraphy. A hydrological classification of wetlands (Gosselink and Turner, 1978) required surface-water data that was unavailable. The most consistent and meaningful classification that we could devise was based on apparent land use (Table 2).

We obtained quantitative data for each wetland and its upstream watershed (Table 3) in order to examine the relationship between wetland response to geomorphic setting. Data on wetland elevation and stream gradient were obtained from the U.S. Geological Survey topographic map of the Willimantic Quadrangle (7.5′ series scale 1:24,000). Parameters associated with the geomorphic setting of each wetland including wetland area, the length of stream channel draining directly into the wetland without an intervening wetland, and the number of known occlusions upstream of a wetland were obtained from aerial photographs.

TABLE 2. LAND-USE CLASSIFICATION OF WETLANDS*

Category	Subtype	Operational Definition	Number	Percent
Intentionally Created	Dams	Marshes, swamps, and remnants of open water impounded by unmaintained stone-faced and earth-fill dams	8	13
Intentionally Created	Ponds	Ponds upstream from artificial constriction; generally stock ponds	18	30
Intentionally Created	Quarries	Marsh and open-water within active or abandoned quarries as of March 22, 1986. Does not include small excavations and swimming pools in residential areas	5	8
Unintentionally Created	Occlusion	Swamps upstream of historic structure such as abandoned roads, walls, and cattle fords	20	33
Apparently "Natural" Wetlands	Constriction	Wetland upstream from constriction for which no evidence of a historic structure is present	7	11
Apparently "Natural" Wetlands	Other	Meets operational definition of wetland but none of the criteria above	3	5
Total			61	100

*Field-checked from 1986 aerial photographs at 1:12,000 scale.

Field reconnaissance and sampling

To examine the wetlands mapped from aerial photographs, we walked approximately half of the length of the stream network. We paid particular attention to intentional changes in the drainage network such as channelization and causeway construction, and to the structure, storage capacity, and spillway mechanisms of all historic impoundments.

To investigate the more subtle historic impacts on our population of 61 wetlands, we selected a sample of 18 sites for field study (Fig. 5; Table 4). We did not follow an objective, statistical sampling strategy. Instead, we chose sites based on the constraints of road access, permission to work on private property, and the presence of a thick sedimentary record, while simultaneously attempting to balance the broadest geographic distribution and variety in hydrogeologic settings. Although our sample (n = 18) was qualitatively selected and is biased toward sites with a thick sedimentary record, we believe that it is broadly representative of all large (> 1 ha) wetlands in the watershed. Almost all of the wetlands investigated were unnamed; thus we gave each an informal local name and a two-letter code (Table 4).

Field investigation

Field mapping of sites was based on soil morphology. Sedimentary records were obtained from natural exposures, centrally located cores in small wetlands, or traverses of multiple cores across larger wetlands. We selected sites from natural exposures (n = 5) as representative of streambanks in the vicinity. In most of the wetlands, we used a stainless steel probe to determine the depth to the underlying glacial substrate, and thus, the overall configuration of the wetland sediments. For areas underlain by more than a meter of sediment we used a 5-cm-diameter device to extract short cores in order to examine near-surface variability in composition. At sites where the near-surface deposits were similar over a broad area (n = 13), we estimated where the sediments would be thickest, and extracted a single piston core to the maximum depth of penetration. Routine procedures for measurement and for estimating sediment compaction were used. In wetlands having substantial variability in subsurface stratigraphy (n = 5), we used a transect of two or more cores taken from a surveyed baseline. Unit thickness was measured to the nearest centimeter, although variations in the height of the ground surface and in compaction errors introduce an uncertainty of several centimeters into all measurements. All cores were field wrapped in plastic, aluminum foil, and PVC pipe for transport. We attempted to obtain a core from two of the larger wetlands (Hayward Pond, Sawmill Pond), but could not extract the near-surface sediments because of their high water content.

Laboratory procedures

Qualitative observations on sedimentary texture, grain size and shape, compaction, bulk density, organic content, and degree of decomposition (indicated by the proportion and selective preservation of plant fibers and the color and texture of the matrix) were made for each lithologic unit following conventional procedures (Aaby, 1986). Measured data include moist Munsell color, the size of large particles, bed thickness, bed orientation, and the location of intrastratal lenses. Organic content was measured using loss on ignition. Munsell colors were recorded but are reported here without numerical coding. Pollen samples were taken above and below all lithological contacts and at regular intervals within thick units, usually at 10-cm intervals. Samples were extracted, prepared, counted, and plotted using the procedures outlined by Faegri and Iversen (1975). At least 200 grains were counted for each sample. Macrofossils were identified using standard taxonomic keys and a reference collection.

We obtained chronological control from 10 radiocarbon dates, 34 biostratigraphic horizons, and 15 instances where the historic disturbance horizon could be identified. Although the wave of colonial settlement in the watershed was diachronic (1695–1774), we assign a uniform age of 250 yrs. B.P. to the set-

TABLE 3. FIELD AND MAP DATA FOR SAMPLE OF WETLANDS IN STUDY AREA*

Identification Code	Local Name	Data Source	Number of Stratigraphic Sections	Selected Parameters: Wetland Elevation (m)	Wetland Area (ha)	Upstream Gradient (m/km)
AL	Alice's Swamp	Core	1	105	3	62
BR	Bender Road	Core	1	160	12	26
CB	Chanski's Basin	Bank	2	114	3	25
UC	Chapel Hill, Upper	Bank	2	79	8	20
LC	Chapel Hill, Lower	Transect	5	78	8	20
EL	Ellis Pond	Core	1	114	3	109
HF	Hayward Floodplain	Bank	1	na	1	na
HP	Hayward Pond	Test core	0	na	2	na
KK	Kalmon Kurcnik's	Core	1	114	7	199
MF	Manning Floodplain	Transect	2	102	2	78
PS	Pine Swamp	Core	1	99	3	62
PF	Pogmore Floodplain	Transect	2	96	1	101
TS	Typha Swamp	Core	1	98	0	119
SH	Sweet Hill	Core	1	168	1	37
TB	Trumbull Bridge	Core	1	75	7	16
TM	Trumbull Marsh	Core	1	76	7	17
UD	Unnamed Dam	Core	1	111	3	132
WT	Wet Transit	Transect	3	76	7	17

*Map data from U.S.G.S. Willimantic Quadrangle, scale 1:24,000.

tlement horizon for the purposes of rate calculations. Radiocarbon samples consisted of hand-picked wood obtained from wet-sieved peat, and were obtained above or below lithological core breaks. All dates were given standard counts following routine laboratory pretreatment procedures, and are reported in radiocarbon years before present (1950) based on a half life of 5,568 years. Biostratigraphic dates were assigned through comparison of pollen diagrams for each wetland with the well-established regional pollen stratigraphy (Deevey, 1939; Davis, 1969; Gadreau and Webb, 1985) and are supported by the available radiocarbon and macrofossil evidence. The arbitrary error assigned to each presettlement biostratigraphic date (± 500 yr) includes both our vertical sampling resolution and the chronological error inherent in the regional pollen record; this error is not included in estimated rates for sediment accumulation.

Stratigraphic interpretations

Biostratigraphic dates follow the zonation and dates of Davis (1969) and Gaudreu and Webb (1985; Fig. 6). The most easily recognized biostratigraphic horizon is the pine/oak transition (Zone B/C-1 boundary) dating to approximately 8,500 ^{14}C B.P. Next in order of prominence is the C3a–C3b zone boundary, which marks the arrival of the Europeans (Brugam, 1978) and is consistently expressed as an increase in ragweed and grass pollen and a decrease in tree pollen. An abrupt first occurrence of chestnut pollen to a level of about 10 % of the total pollen count marks the local arrival of chestnut at about 2,000 B.P. The chestnut rise coincides with an increase in the abundance of hickory pollen (5,000 B.P.) in most cores from Susquetonscut Brook, indicating a negligible background sedimentation rate during this interval. The transition between a spruce-fir assemblage and the pine-dominated assemblage in our cores is correlated with the Zone A–Zone B pollen zone boundary at about 10,000 B.P. We assign a date of 12,000 B.P. to the transition between a sedge/herb/heath pollen assemblage to one dominated by spruce (Zone T–Zone A).

We interpreted wetland prehistory based largely on first-order, macroscopic, sedimentary evidence (Fig. 7). Bedded strata consisting largely of inorganic grains indicate slackwater sedimentation from turbid streams, generally under lacustrine conditions. Aquatic (limnic) peats are fine grained, detrital, and frequently contain the seeds of aquatic taxa. Matted (interwoven) fibrous peats with a dominance of cryptogam and monocot tissue and a dearth of wood often coincide with times of high mineral sedimentation, and indicate accumulation in unforested marshes. Variations in the ratio between organic and inorganic content is a function of the availability of sediment from the upstream watershed.

Peat accumulation in swamps is indicated by autochthonous humified peats with abundant wood, especially in situ roots. Thoroughly decomposed horizons (Saprists) with a high mineral content in woody peat sequences indicate net decomposition of peat, an interpretation often supported by a hiatus in bracketing dates. Topstratum (overbank) sedimentation is indicated by bioturbated mineral horizons occasionally interbedded with peaty lenses. Coarse-grained topstratum deposits often exhibit cross-stratification, basal scouring, and load structures, indicating rapid

TABLE 4. QUALITATIVE DESCRIPTION OF WETLANDS IN STUDY WATERSHED*

Wetland Code	New London County Soil Map†	National Wetlands Inventory§	Surfical Geology**	Land-Use Subtype‡	Stratigraphic/ Hydrogeologic Setting‡
AL	Adrian Muck	P-SS-1	Stratified drift	Other	Tributary confluence
BR	Ridgebury e.f.s.l.	P-SS-1	Till	Occulsion	Artifical occlusion
CB	Adrian Muck	P-SS-1	Stratified drift	Occlusion	Drained
UC	Rippowam	P-SS-1	Stratified drift	Constriction	Main flood plain
LC	Rippowam f.s.l.	P-SS-1	Stratified drift	Occlusion	Main flood plain
EL	Adrian Muck	P-SS-1	Bedrock	Occlusion	Bedrock basin
HF	Ridgebury e.f.s.l.	P-SS-1	Stratified drift	Occlusion	Drained
HP	Ridgebury e.f.s.l.	P-SS-1	Stratified drift	Dam	Upland stream
KK	Ridgebury e.f.s.l.	P-SS-1	Bedrock	Occlusion	Artifical occlusion
MF	Ridgebury e.f.s.l.	P-SS-1	Till	Occlusion	Upland stream
PS	Ridgebury e.f.s.l.	P-SS-1	Stratified drift	Occlusion	Tributary confluence
PF	Ridgebury e.f.s.l.	P-SS-1	Bedrock	Dam	Bedrock basin
TS	Canton vsfsl	P-SS-1	Stratified drift	Dam	Upland stream
SH	Rippowam f.s.l.	P-SS-1	Till	Occlusion	Upland stream
TB	Rippowam f.s.l.	P-SS-1	Stratified drift	Occlusion	Main flood plain
TM	Carlise Muck	P-SS-1	Stratified drift	Occlusion	Main flood plain
UD	Carlise Muck	P-SS-1	Till	Dam	Bedrock basin
WT	Rippowam f.s.l.	P-SS-1	Stratified drift	Occlusion	Main flood plain

*Soil texture abbreviations are: e.f.s.l. = extremely stony fine sandy loam; f.s.l. = fine sandy loam; P-SS-1 = subclass Palustrine shrub-Scrub broadleaved.
†Soil Conservation Service, 1983.
§Cowardin et al., 1979.
**Clebnik, 1980.
‡This report.

deposition by current traction on a soft floodplain surface. Immature floodplain soils (Aquents) are recognized by their blocky structure, incipient mottling, root casts, and surface relief. The specific identification of plant macrofossils, diatom frustules, and pollen also aided in identification of these environments.

Flood discharge modeling

Quantitative estimates for how deforestation and dam impoundment affected peak flood discharge were obtained using HEC-1, a widely used flood discharge model developed by the U.S. Army Corps of Engineers (1981; Table 5). For the purposes of this report, we modeled the peak flood discharge at the Lower Chapel Road wetland that would have been produced by a storm with a one-year recurrence interval from unfrozen soil. To implement the model, we divided the 14 km^2 watershed into 26 subbasins, each of which yielded runoff, based on soil properties and average slope (Harris, 1993). Discharges from each subbasin were then summed and routed in a downstream direction at a rate controlled by the hydraulic configuration of the channel in each reach (roughness, size, gradient, etc.).

We directly calibrated the model to Susquetonscut Brook for a series of storms using weather data from USGS stations, map data for present land use and reservoir geometry, and field measurements of storm discharge and lag time from a gauging station installed near the Lower Chappel Road wetland. We calibrated the model by iteratively changing the land-use input parameters until they yielded the observed storm discharges. We then inverted the model to retrodict peak discharge, total discharge, and ground-water recharge for two separate historic land-use scenarios. Our presettlement scenario assumes no reservoirs and complete forest cover; it does not take into account the effect of beavers, which have been reintroduced into the watershed, the effects of which are already included in model calibration. Our "developed" scenarios are based on unpublished data from nearby Worcester County, Massachussetts (John Larkin, Research Director, Sturbridge Village, Inc., written communication, 1993), which suggests that two thirds (67%) of the terrain was "improved" (10% tillage and 57% pasture) with the remaining third (33%) being woodlot, outcrop, and other uses. We could not model active human management of stormflows, hence the impoundments modulate flood discharges based solely on their preabandonment shapes and spillway cross sections.

RESULTS

Deliberate channel alterations

The only site-specific, historically documented changes in the stream network within Susquetonscut Brook are short reaches of the channel that have been submerged by extant water-supply reservoirs (Hayward Pond, Sawmill Pond, Pine Swamp, Unnamed Dam). During our field studies, however, we discovered that deliberate changes to the stream network are nearly

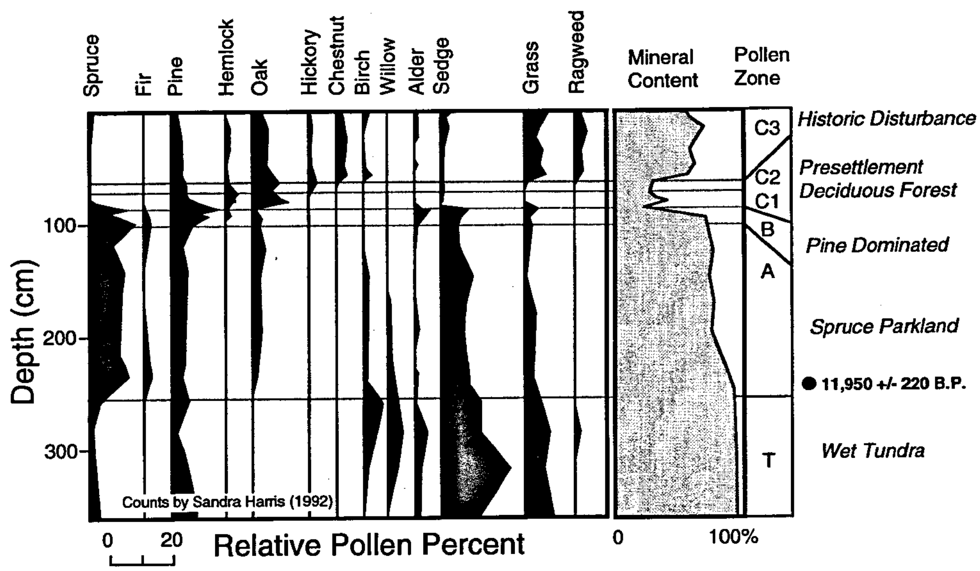

Figure 6. Representative pollen diagram for the study area from the Pogmore Floodplain site. Pollen abundance (black), mineral content (shaded), and pollen zonation (Davis, 1969) are given. Approximate boundary dates for biostratigraphic zones are T/A = 12,000; A/B = 10,000; B/C1 = 8,500; C2/C3 = 250 B.P. Core stratigraphy is given in Figure 7.

ubiquitous and have taken many forms. Most modifications appear subtle in the field, owing to secondary growth of forest, burial beneath alluvium, and turbation by tree blowdowns; in many cases, attributing human cause to channel change was based solely on anomalously large boulders or channel widths.

We did not do an archaeological inventory of these deliberate modifications but noted them when discovered (Fig. 3). Among the many changes that we observed were (1) draining of the main stem by ditching and diking of the meadows between the Kalmon Kurcnik and Ellis wetlands, (2) straightening of the stream by channelization (excavation and bank-armoring) of the main stem in the Hayward Floodplain wetland, and of the tributary to the south of Pine Swamp, (3) excavation of irrigation channels below Sawmill Pond, (4) drainage of Alice's Swamp and Pine Swamp by deepening of the channel, (5) drainage of riparian meadows by ditches parallel to the Lower Chappel road wetland, and (6) a variety of anomalous stone concentrations across the channel, which can be easily mistaken for bouldery, natural riffles in many cases.

The channel-crossing stone concentrations are particularly abundant, occur in a variety of forms, and are clearly artificial. Where they occur in ravines between reservoirs (Sawmill Pond, Hayward Pond) and mills we interpret them as check dams (designed to reduce peak stream power during floods). Where two or more of the stones remain fitted together along the channel margin (Trumbull Bridge, Trumbull Marsh, Lower Chappel Road, Hayward Pond, Bender Road), we interpreted them as abutments for wooden bridges; where unfitted we interpret them as crude fords (or foundations for private wooden bridges) when the stones were simply heaped into the channel. When the stones extended into swamps, rather than channels, we interpreted them as primitive causeways for livestock.

Every wetland that we examined had a stone concentration of one form or another at its constricted outlet that could be, but often probably is not, of human origin. Proving such an assertion is complicated by the construction activities of beavers, which have recently been re-introduced and which have incorporated stone slabs up to 10 kg into their dams.

Flood retrodictions

Results from HEC-1 modeling indicate that peak discharges (mean annual flood) during the time of maximum colonial development were twice as high as the undisturbed, base-line scenario (Table 5), despite the mitigating influence of the reservoirs and check dams. Most of the increase results from enhanced overland flow on deforested, compacted soils. Modern flows are actually lower than those of the undisturbed condition, owing to the continued presence of abandoned dams, which attenuate peak flows through the effect of reservoir storage. First-order infiltration to the ground-water table (assumed to be the reciprocal of storm runoff) would have been substantially lower during colonial times, suggesting that upland streams would probably have been drier at peak agricultural expansion, more than two centuries ago. This interpretation is supported by the increased development of local ponds during the nineteenth century.

Watershed-scale effects

We used conventional regression and correlation techniques to investigate the quantitative relationships between wetland and watershed characteristics (Table 3; wetland elevation, wetland area, stream gradient, watershed area) but were unable to find any meaningful correlations. Apparently, the distribution and

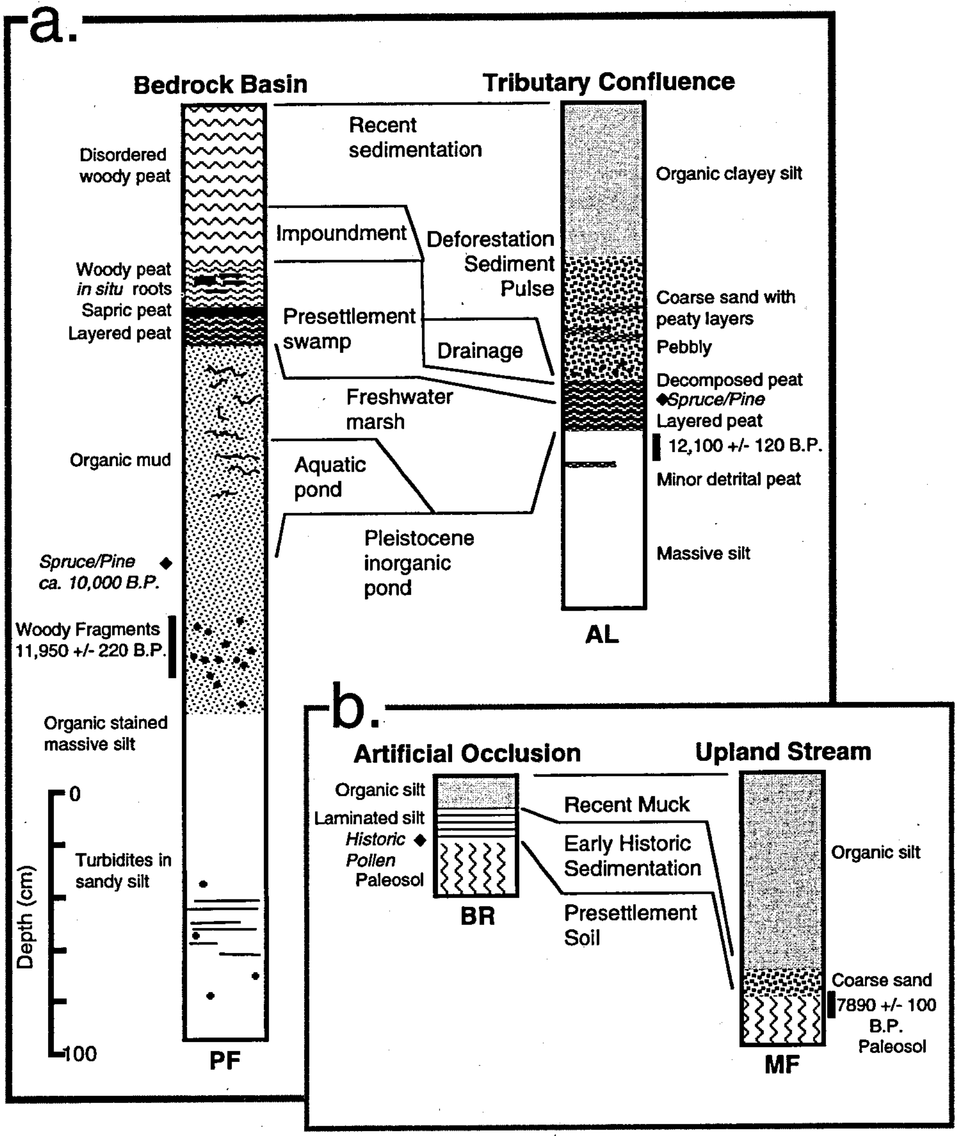

Figure 7. Measured stratigraphic sections of type wetlands for four hydrogeologic settings as discussed in text. Descriptions, radiocarbon dates (solid bar), and pollen dates (diamond) are listed on outside of columns. Interpretations and correlation lines are presented between columns. a, Longer, more continuous records of Pogmore Floodplain (PF; on left) and Alice's Swamp (AL; on right); b, Shorter, simpler records of Bender Road (BR; on left) and Manning Floodplain (MF; on right).

configuration of wetlands in Susquetonscut Brook are not governed by simple hydrologic, topographic, or hypsometric relationships. Instead, wetland characteristics represent site-specific, individualistic responses to local geology and anthropogenic impact.

The only wetland characteristics found to be highly correlated were those obtained from the stratigraphic analysis described below. Our results demonstrate that the flux of mineral sediment to wetlands was initially high prior to about 8,000 B.P., but diminished to negligible rates prior to European settlement. Since settlement, the average sedimentation rate increased several orders of magnitude at almost all sites (Fig. 8). Geologic age is thus associated with sedimentation rate, regardless of hydrogeologic setting. The modern wetlands of Susquetonscut Brook are overloaded with sediment.

Our land-use classification of wetlands provides an additional semiquantitative measure of landscape change (Table 2). Eighty-four percent of the wetlands in the study area watershed of Susquetonscut Brook appear to have been modified by human action, and more than half were either created or deliberately changed in some way prior to the federal management of wetlands. The largest single land-use category of wetlands appears to be wetlands inadvertently created upstream from drainage occlusions.

TABLE 5. PREDICTED STREAM DISCHARGES FROM CALIBRATED MODEL (HEC-1)*

Scenario	Land Use			Rainfall	Peak Flood		Storm Runoff	
	Forest (%)	Improved (%)	Reservoirs (n)	(mm)	(m^3/sec)	(% modern)	(mm)	(% modern)
Before 1692	100	0	0	69	7	118	14	74
Maximum Development 1754–1825	33	67	6	69	12	211	30	158
Modern, 1930–1996	78	22	6	69	6	100	19	100

*Based on 1-year storm recurrence. Improved land is 10% tillage, 57% pasture for developed scenario, 3% tillage, 19% pasture for modern scenario.

Wetland stratigraphy

The stratigraphy of 18 wetlands in Susquetonscut Brook is known with enough detail (Thorson, 1992) so that we can establish the geologic origin of each and document how colonial land use altered the environment from its presettlement condition (Figs. 7, 8). Each wetland responded to human impact in an individualistic manner. However, qualitative similarities in the pattern of stratigraphic change were clearly related to the hydrogeologic setting in which the wetland was located. Such similarities provided a basis for classifying each of the 18 wetlands studied into one of six categories. In turn, this permitted us to restrict the need for detailed description to only six sites (Appendix 1). Stratigraphic records for the remaining 12 wetlands are summarized as Table 6 and Figures 7 and 9. Our taxonomic approach underscores the importance of hydrogeologic setting in controlling wetland impact and provides a conceptual framework for integrating effects in a downstream direction.

Upland streams. These wetlands (Manning Floodplain, Sweet Hill) occur as expanded reaches of small, ephemeral streams at high elevations near the edges of the watershed and always occur immediately above constrictions. The till-covered slopes above these wetlands are sites of net erosion and are locally devoid of Holocene topsoil. The stratigraphy of these wetlands is dominated by an abrupt pulse of traction-deposited agricultural sediment (bedload sand and fine gravel) that overlies a well-defined presettlement horizon. Presettlement deposits in these settings are largely absent, and are instead represented by incipient poorly drained soils, now preserved beneath the bioturbated historic valley fills.

Entrapment of sediment from disturbed agricultural soils at drainage occlusions created the upland stream wetlands. The steep gradients and poorly drained soils of their watersheds, together with the potential for their use as pasture, is consistent with the sedimentary evidence.

Bedrock basins. Pogmore Floodplain, Ellis, and Unnamed Dam are examples of the bedrock basin wetlands that occur near the headwaters of the drainage network within the rugged, central physiographic segment. They lie within an east-west–trending belt of near-surface, heavily fractured bedrock where the stony meltout till is highly permeable and where the local relief exceeds 100 m. Each wetland parallels a prominent fracture zone in the local bedrock and is a zone of ground-water discharge from the fractured bedrock aquifer. Additionally, each wetland has a narrow outlet.

The bedrock basin wetlands have been sites of net organic deposition for all of postglacial time, and the sediments are dominated by limnic and marsh peats containing negligible watershed-derived (allogenic) mineral sediment. Prior to settlement, all of these sites were wooded swamps characterized by conditions of slow peat accumulation. Historic impacts to the three basins were similar, and are dominated by an abrupt rise in the water table to ponded conditions accompanied by strong siltation from topsoil erosion in their small steep watersheds. The abrupt rise in the water table at all sites is clearly shown by the drowning of woody peats, and was almost certainly caused by the raising of small dams at their outlets. The observation that these wetlands contained, but were not overwhelmed by, topsoil loss is consistent

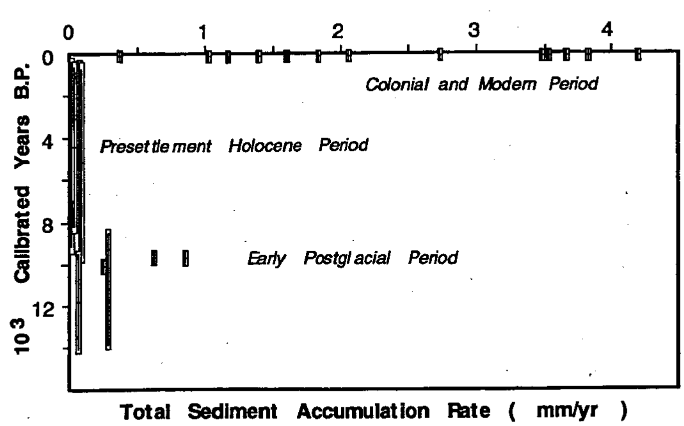

Figure 8. Plot showing changes in average sedimentation rate through time in wetlands from Susquetonscut Brook. All estimates are based on the compaction-corrected thickness between intervals dated by biostratigraphy and radiocarbon. All rates are subject to large uncertainties.

TABLE 6. SUMMARY OF HISTORIC CHANGES BASED ON STRATIGRAPHIC RECORDS*

Wetland Basin Code	Locality	Depositional Environment at Different Times: Presettlement Condition	Early Historic Changes	Recent Trends
UC	Upper Chappel Road	Unknown	Channel erosion. Pulse of coarse TSS followed by organic TSS	Reduced deposition of coarse TSS
TB	Trumbull Bridge	Unknown	Channel erosion? Bridge occludes drainage. Marsh deposits	Reduced deposition of coarse TSS
LC	Lower Chappel Road	Marshy flood plain. Slow peat accumulation	Pulse of coarse TSS followed by organic TSS	Second pulse of coarse TSS
WT	Wet Transit	Marshy flood plain. Hiatus in Holocene peat accumulation	Pulse of coarse TSS. Deliberate ditching. Soil?	Reduced deposition of coarse TSS
TM	Trumbull Marsh	Marsh; Hiatus in Holocene peat	Pulse of coarse TSS. Deliberate ditching. Soil?	Second pulse of coarse TSS
PS	Pine Swamp	Stable wooded swamp	Deliberate drainage. Impounded to aquatic pond. Siltation	Collapse of dam. Reverted to wooded swamp
AL	Alice's Wetland	Stable wooded swamp	Deliberate drainage. Strong pulse of coarse TSS	Continued TSS, but finer grained and at reduced rates
TS	Typha Swamp	Stable wooded swamp	Impounded to aquatic pond. Siltation	Siltation
EL	Ellis Wetland	Peat accumulation in wooded swamp	Impounded to aquatic pond. Limited siltation	No change
PF	Pogmore Floodplain	Peat accumulation in wooded swamp	Impounded to aquatic pond. Strong siltation	Reduced siltation. Collapse of dam, reverted to wooded swamp
UD	Unnamed Dam	Peat accumulation in shallow aquatic pond	Siltation. Impounded to deeper aquatic pond. Limited siltation	Reduced siltation
MF	Manning Floodplain	Seasonally wet bottomland. Incipient soil development	Strong pulse of coarse TSS	Continued TSS, but finer grained and at reduced rates
SH	Sweet Hill	Seasonally wet bottomland. Incipient soil development	Impounded to inorganic pond. Rapidly filled with slopewash	Unknown. Deliberate drainage?
BR	Bender Road	Seasonally wet slope. Incipient soil development	Occluded to shallow inorganic pond. Slopewash deposition	Reverted to wooded swamp
KK	Kalmon Kursnik's	Unknown	Occluded to shallow muddy pond. Siltation?	Deliberate drainage to wooded swamp
CB	Chanski's Basin	Forested levee of stream in basin	Strong pulse of coarse TSS	Continued TSS, but finer grained and at reduced rates
HF	Hayward Floodplain	Sinuous sand/gravel channel	Channelization to single straight channel	Well-drained soil above ditch
HP	Hayward Pond	Stream channel?	Impounded to aquatic pond. Strong siltation	Reduced siltation

*Event history is based on field stratigraphy of each site, independent of written records. TSS is an abbreviation for topstratum sedimentation. All events are listed in relative sequence.

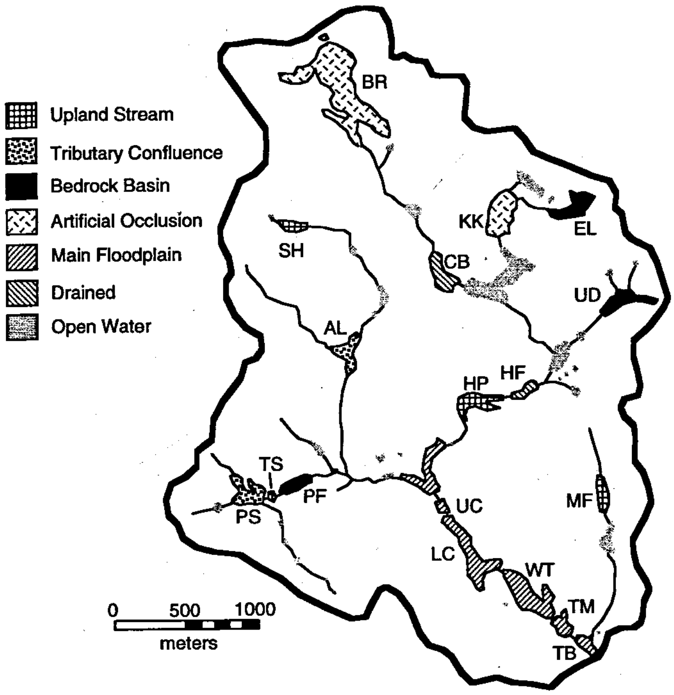

Figure 9. Classification of wetlands in study area based on stratigraphic response to colonial impact, which was governed by the hydrogeologic setting (boxes) at individual sites. Areas above 122 m (400 ft) are shaded. Refer to text for explanation. Full names for abbreviations and wetland characteristics are given in Table 3.

with the poor agricultural potential of the stony soils in their watersheds and the resistance of these soils to erosion. There seems to have been no attempt to drain or ditch these wetlands because their bedrock outlets were impossible to excavate with available technology and because the steep hydraulic gradients and high fracture permeability around their edges created numerous springs.

Tributary confluences. Located at the confluences of first-order tributaries, these wetlands (Pine Swamp, *Typha* Swamp, Alice's Swamp) occur where perennial stream flow often reaches its upstream limit in response to decreased channel gradient and increased catchment area. Such sites are often small sedimentary basins underlain by fine-grained glaciolacustrine sediment capable of supporting a perched water table. The stratigraphy of these settings consists of a pulse of bioturbated alluvium containing historic pollen overlying a thin, degraded, oxidized peat dominated by pollen of tundra and boreal taxa, in one case radiocarbon-dated to over 12,000 B.P. In two of the swamps (Pine Swamp, *Typha* Swamp), the unconformity between the Pleistocene peat and historic alluvium was buried by younger aquatic peats caused by subsequent impoundment.

The decomposition of the peat and absence of Holocene sediments beneath a thick historic fill almost certainly indicates the intentional drainage of presettlement swamps for colonial tillage and hayfields. Impoundment of these sites would have led to the preservation of woody peats, as was the case for the deposits of bedrock basins. Our interpretation is supported by the proximity of the basins to the early road network, by the flat expanse of land that would have become available upon drainage, and to the anomalous channel geometry (steep banks) of the outlet streams. The sequence of initial drainage followed by later impoundment is also consistent with the early historic priority for meadows and mowlands followed by a later priority associated with stock watering and hydropower development (Gradie and Poirier, 1991).

Main floodplains. The riparian wetlands of the main floodplains (Upper Chappel Road, Lower Chappel Road, Trumbull Bridge, Wet Transit, Trumbull Marsh) are restricted to the perennial main stem of Susquetonscut Brook below Hayward Pond. Like wetlands at upland confluences, these sites are underlain by glacial meltwater sediment, but it is much more coarsely grained, and forms part of an abandoned system of kame terraces paralleling the valley wall. Ground-water recharge from the flanking till slopes discharges along the edge of the modern floodplain by seepages from these productive aquifers.

In all cases, the stratigraphy of these sites is dominated by vertically accreted mineral sediments associated with frequent overbank flows. Presettlement conditions at these sites are typified by a thin horizon of humified marshy peat lying above early postglacial alluvium and Holocene topstratum sediments. Reconnaissance observations of the main stem between Chappel Road and Route 207 (notably the absence of a modern organic topsoil and the presence of levees along the stream bank) indicate the net vertical accretion of topstratum sediments along much of the modern floodplain. This accretion appears to be particularly rapid at the Lower Chappel Road wetland, where the gravely channel bed is locally aggraded, where levees are most prominent, and where basal radiocarbon dates postdate nuclear testing. Rates of vertical accretion appear much slower between Chappel Road and Hayward Pond.

Evidence for a pause in topstratum accumulation associated with agricultural activity followed later by renewed topstratum accumulation is present at most sites (Fig. 10). The antiquity of the radiocarbon date for the humified presettlement peat lying immediately beneath the historic topstratum sediments suggests that the site was drained prior to its burial by mineral sediment derived from upstream reaches.

Artificial occlusions. Occlusion of the stream immediately downstream from the site formed these wetlands (Bender Road and Kurcnik's), which are of postsettlement age. The pulse of pond sedimentation at the Bender Road wetland—laminated silts of historic age grading into organic muck—indicates that topsoil erosion from disturbed soils coincided with wetland creation: presettlement conditions at this site were a poorly drained forested soil at the base of a slope. The same stratigraphic sequence is preserved in Kurcnik's wetland, but the historic age of the occlusion could not be confirmed because our cores did not penetrate to presettlement sediments. Evidence for historic ditching and artificial fill is especially prominent along the north-eastern margin of this wetland.

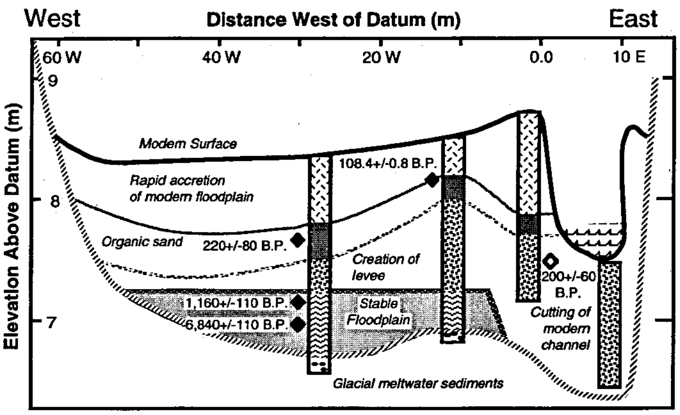

Figure 10. Cross-section across the main stem below Chappel Road (LC wetland) based on ground observations and four cores. Interpretations shown by correlation lines. Height and shape of the presettlement floodplain shown by shaded area. Radiocarbon dates from Thorson (1992) and Harris (1993).

DISCUSSION

Most wetland investigations attempt to examine human impacts in either time or space. We have attempted to integrate both approaches by focusing on a very small watershed and by drawing conclusions from qualitative wetland histories. Although we have demonstrated that human impacts to the wetlands in Susquetonscut Brook were pervasive and that wetland response was governed by hydrogeologic setting, the dates at which most of the events occurred, the rates at which wetlands responded, and the specific mechanisms responsible for wetland interaction remain elusive. In this context, the value of our review lies not so much with its scientific rigor but in its research strategy.

The pace of landscape change prior to disturbance by European land-use practices was negligible in human terms. The rate of sediment influx for the preceding 8,000 years, even in the most efficient of sediment traps, was not measurably higher than the influx of airborne dust from the continental interior. An explanation for the limited transfer of sediment within the watershed under "natural" conditions is not well understood, but the persistence of beavers, the negligible impact of indigenous inhabitants, and the insensitivity of the forest to broad changes in climate, wildfires, pathology, and severe storms are probably important.

With the arrival of the colonists, however, came a rapidly applied, large-scale, drastic alteration of land use, cultivation practices, water management, and animal husbandry, collectively the most disruptive landscape event since the melting of the Pleistocene glaciers 17,000 years earlier. The abandonment of farms throughout the study area did not bring the wetlands back to their presettlement conditions because the modern flood regime and mechanisms of sediment transfer remain permanently altered by previous soil erosion and by the construction of a now-derelict water management infrastructure, most of which is now overlooked.

More specifically, the nature of historic impacts to wetlands depended principally on their hydrogeologic settings. In streams near the headwaters of the watershed, especially below till-covered slopes, sediment mobilized by erosion of deforested slopes was trapped in the first available tributary confluence or occluded site, where it buried the former valley bottom. Colonial impacts at these sites were immediate, long lasting, and typical of the responses of headwater streams to agricultural conversion elsewhere in the eastern United States (Costa 1975; Trimble, 1981). Most of this sediment, which entered the system as a single pulse during the eighteenth century, remains stored high in the watershed, where it is now being intermittently entrained and mobilized down-valley.

In lowland swamps underlain by permeable sand and gravel aquifers, a similar pulse of agriculturally produced sediment took place *after* an interval of peat decomposition. Because the regional water table has likely risen slightly within the last few thousand years (Webb et al., 1993; Thorson and Webb, 1991), this decomposition probably resulted from deliberate drainage of swamps prior to denudation of the upstream watersheds. This geological interpretation is consistent with eighteenth century advice for draining swamps (Eliot, 1760), and with our observations of drainage ditches. Peat decomposition also may have been accentuated by the diminished ground-water recharge associated with deforested slopes. The absence of decomposition horizons in bedrock-rimmed basins probably results from the prohibitive cost of drainage.

The broad sediment-covered floodplain of Susquetonscut Brook is essentially a modern landform. Its present instability—rapid topstratum deposition, strong bank erosion, and thalweg aggradation—are governed by changes set in motion three centuries ago. In the constricted reaches just south of Chappel Road (Upper Chappel Road), the presettlement channel was first enlarged by lateral bank erosion, and later infilled by gravelly lateral bars. In expanded reaches to the south (Fig. 10), coarse-grained overbank strata deposited by floods with no prehistoric counterparts underlie more than a meter of historic alluvium. Ironically, overbank sedimentation is so fast that it precludes pedogenesis and peat accumulation, even though much of the watershed has been reforested for more than a century. The thickness (110–130 cm) and shape of topstratum deposits along the main stem are similar to those reported for postsettlement alluvium elsewhere in the unglaciated eastern United States (Knox, 1977; Trimble, 1970; Jacobson and Coleman, 1986; Scully and Arnold, 1981). The observed changes in channels size are consistent with disturbed rivers at a variety of scales (Kesel et al., 1992).

The disproportionately large floods of the historic period noted along the Connecticut (Jahns, 1947) and Housatonic (Patton, 1988) Rivers have been attributed to the enhanced runoff of deforested landscapes. This effect appears to have been accentuated in the smaller drainage of Susquetonscut Brook and is consistent with the results of our HEC-1 runoff models. The width of the channel along the main stem has remained nearly constant in many areas (as indicated by the pattern of stone walls, bridge abutments, inset terraces, and large second-growth trees), and significant downcutting has not occurred (bouldery channel lag horizons are common). Thus, the historic accumulation of leveed topstratum deposits probably represents both the need to pass larger storm discharges (either a higher mean annual flood or modal dominant discharge) and the availability of loamy sand from bank erosion of upland sites.

The very low sediment delivery ratio from the watershed and the continuous existence of a reservoir in Hayward Pond (since 1711) indicates that the sediment responsible for aggradation of the main stem came from channel erosion between Hayward Pond and Chapel Hill Road. This interpretation is supported by field observations from this reach. Topstratum deposits above historic soils are proportionately thinner (20–40 cm); the channel has a more rectangular cross section; and the frequency of unstable banks is higher. Additional sediment is being contributed from Burgess Brook because the modern channel is now downcut below a gravely terrace of historic age. Despite the clear evidence that sediment mobility was enhanced during the historic period, most of the sediment produced by colonial disturbance remains in upstream storage, and the total yield of agricultural sediments to the Yantic and Shetucket Rivers has been relatively small. Channel erosion is the main source of sediment. Point-source management of sediment "pollution" at upland sites seems to have little influence at downstream sites.

Historic documents indicate that peak rates of deforestation occurred early (ca. 1720–1754), prior to the intensive period of water regulation that peaked between 1775 and 1825. These relations suggest that an early phase of enhanced flooding caused by deforestation should have been followed by a period when peak discharges along the main stem were reduced by intentional water management. Abandonment and partial destruction of the hydropower infrastructure would then be followed by a return to the preimpoundement, deforested, flood regime.

The organic and agriculturally modified central part of the topstratum sequence may represent a time of reduced flood discharges associated with the period of intensive water management. This change may have been superimposed upon a reduction in mineral sediment production caused by abandonment of farms, as suggested by the reduced siltation rates in upland cores, and by deforestation experiments (Boormann et al., 1974). However, any anthropogenic changes would have been superimposed on natural climatic variation. Alternatively, a decrease in critical stream power during channel-forming floods may have led to aggradation of the bed, which in turn, may have forced an increase in the rate of topstratum sedimentation.

The trend toward increased wetness during the transition from base-line to historic conditions in Lebanon is consistent with the historic accounts, suggesting that lowland areas became wetter while the adjacent terrain simultaneously became drier (Marsh, 1869). These effects would have been amplified by the generally colder conditions of the eighteenth century. Thus, the unwanted growth of wetlands at occlusions would have occurred simultaneously with the increasing need to create artificial reservoirs for hydropower regulation (Gradie and Poirier, 1991), irrigation, and stock watering. At the same time, the increase in wetland cover caused by impoundments, occlusions, and sediment erosion would have increased runoff-generating area during storms, and contributed to the observed increase in bankfull discharge. Finally, we cannot rule out the possibility that peak flood discharges during historic time were associated with the catastrophic failure of earthen dams now completely collapsed or were associated with exceptionally severe storms that went unrecorded.

The landscape position, land-use history, and stratigraphy of the Susquetonscut wetlands lead us to a view of past changes that are in conflict with frequently assumed notions of landscape stability and orderly progress to a land-cover end point (Egler, 1977). Glaciation, as a land-reshaping pulse, led to a period of dynamic instability during which the soils and streams readjusted for thousands of years, then stabilized. The subsequent pulse of landscape instability caused by European settlement mimicked that of the late-glacial recovery period, a pulse from the which the physical landscape is still recovering. Meaningful regulation of contemporary wetlands in Susquetonscut Brook must therefore be predicated on viewing these environmental "resources" as evolving representatives of a changing landscape, not on viewing them as ancient, pristine ecosystems.

CONCLUSION

Stratigraphic and geomorphic evidence can be used to document historic human impacts to wetlands in Lebanon, Connecticut. A variety of wetlands were present prior to colonial settlement, but they were fewer in number, smaller in area, much more stable, and less encumbered with sediment than those we vigilantly try to protect today. Modern riparian wetlands on the floodplain of Susquetonscut Brook are still adjusting to a pulse of change initiated more than three centuries ago.

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APPENDIX 1. DETAILED STRATIGRAPHY OF WETLAND LOCALITIES USED AS TYPE EXAMPLES FOR DIFFERENT HYDROGEOLOGIC SETTINGS

Hydrogeologic Setting: Bedrock Basin
Example Wetland: Pogmore Floodplain (PF)
Site Description: The modern stream meanders through a swampy forested bottomland below Pleistocene terrace scarps. At the wetland

coring site the channel has negligible gradient and occupies a channel no more than 2-m-wide cut into organic strata. Fifty meters down valley, however, it flows rapidly over stony artificial fill interpreted here as the collapsed remnants of an unreported earthen dam.

Stratigraphy: Prior to about 12,000 B.P., the site was undergoing rapid sedimentation within a watershed dominated by tundra vegetation (Figs. 6 and 7). The transition to boreal forested conditions at a depth of about 2.5 m is indicated by the arrival of spruce in both the pollen and macrofossil records. Evidence for a mosaic of habitats at this time is indicated by the presence of horsetail, violet, water lily, and pond weed in the macrofossils.

An upward decrease in the concentration and continuity of mineral strata, and an increase in the abundance of hydrophytic local pollen indicate that the Pogmore Floodplain wetland changed from a sediment-laden boreal marsh to a stable organic pond as the watershed became progressively mantled and stabilized with coniferous forest. The spread of pine forest shown in the pollen records (Zone B; ca. 11,000–8,500 B.P.) marks an abrupt transition from a silty boreal marsh to a wooded swamp. A highly decomposed (sapric peat) layer, dating from between 8,500 ^{14}C B.P. and the arrival of hickory pollen about 5,000 B.P., represents peat decomposition under intermittently aerated (drier) conditions during peak warmth of the mid-Holocene (Webb et al., 1993). Strata above the residual layer (also in situ layered woody peats) indicate the return to slow peat accumulation under wetter conditions of the last few thousand years.

The top unit, a highly turbated sediment-rich organic muck, abruptly overlies decomposed woody peat. The sharp lithologic transition coincides with the settlement pollen horizon, which is clearly marked by the increase in ragweed, grass, and chestnut pollen, but not with the lower limits of rootlets, mottling, or evidence for water-table fluctuation. Hence, the abrupt lithologic transition represents a sedimentary event, rather than a change in bulk density associated with autocompaction (George, 1975). The base of the postsettlement unit occurs just above a concentrated zone of light-colored fibrous tissue that intrudes the youngest presettlement peats, and which we interpret as the in situ roots and rhizomes of woody vegetation that are dead, but not completely decomposed. Collectively, these features indicate that the postsettlement stratum was caused by an abrupt transition to ponded conditions at a time of strong siltation. This interpretation is supported by the presence of the collapsed primitive dam downstream and with historic evidence for water use at upstream sites.

Hydrogeologic Setting: Upland stream
Example Wetland: Manning Floodplain (MF)
Site Description: The core was extracted about 20 m west of a small intermittent stream channel, and upstream from a forest-covered stony occlusion of unknown origin. Based on multiple test cores that exhibited an eastward-thickening stratum of recent mineral sediment, the coring site was located near the distal margin of a broad levee of loamy overbank sand. Prolonged seasonal inundation of the coring site during spring flooding is indicated by the absence of a surface soil.

Stratigraphy: The bulk of our sediment core (80 cm) contains a thoroughly bioturbated black mineral silt with a characteristic postsettlement pollen spectrum. This amorphous silt grades downward to a coarse, granule-bearing sand with an erosional basal contact.

This fining-upward sequence of historic sediment overlies a black fine sandy loam containing oxidized mottles, root casts, decomposed wood fragments, and a characteristic pedogenic crumb structure. These features are collectively interpreted as the A horizon of an incipient paleosol (aquent), the development of which was inhibited by poor drainage. A bulk radiocarbon date for the horizon of 7,890 ± 100 B.P. confirms the antiquity and stability of this small floodplain prior to settlement.

Hydrogeologic Setting: Tributary confluence
Example Wetland: Alice's Swamp
Site Description: The site is a small, flat lowland at the confluence of two unnamed tributaries of Burgess Brook, upstream of a bedrock ravine. The core from Alice's Swamp was taken about 40 m north of the tributary confluence, midway between the bordering streams. It is dominated by a thick sequence of modern alluvium.

Stratigraphy: The radiocarbon date of 12,100 ± 120 B.P. was obtained on detrital twigs within silty lacustrine strata at depth of 1.3 m, indicating that the wetland is the site of a sediment-filled Pleistocene pond. A strongly humified, herbaceous peat just above the radiocarbon sample consists almost entirely of monocot tissue, is devoid of mineral sediment coarser than silt, and contains a pollen spectrum dominated by spruce, pine, and sedges predating the arrival of deciduous forest. This unit indicates that the pond was replaced by a small freshwater marsh as sediment influx from the watershed diminished.

Lying with sharp unconformity above the freshwater marsh deposits is a graded sequence of coarse mineral detritus nearly 50 cm thick of postsettlement age. The unit is pebbly near its base, but grades upward into an interbedded sequence containing lenses of sandy silt, detrital organic fragments, and organic horizons, all of which contain a historic pollen assemblage. The uppermost 50 cm of this sequence is dominated by sandy silt, and extends upward to the modern surface of the swamp, which is periodically inundated by storm flow.

The abrupt and sustained reversal from conditions of a slackwater, freshwater marsh to conditions of rapid mineral sedimentation resulted from deforestation and erosion of upland soils during the colonial period, followed by sediment transport to the site by strong flood flows. The absence of wood and deciduous pollen within the youngest presettlement peat and its strongly humified character suggest that Alice's Swamp was a site of net peat decomposition prior to the influx of historic sediment. The aeration and decomposition of this decomposed, peaty soil is likely to have resulted from deliberate drainage of the swamp.

Hydrogeologic Setting: Main floodplain
Example Wetland: Lower Chappel Road (LC)
Site Description: This site spans the full width of the floodplain of Susquetonscut Brook near the upstream end of an expanded reach below Chappel Road. The stratigraphy was investigated by excavations along the stream bank supplemented by four cores taken in a transect perpendicular to the main channel (Fig. 10).

Stratigraphy: At the base of each core are current-bedded fluvial deposits associated with channel bed and bar deposition overlain by mineral overbank strata; this unit of inorganic strata was deposited during late glacial downcutting of the former glaciofluvial plain.

Overlying these late glacial deposits is a relatively uniform mantle of Holocene floodplain sediments dominated by interbedded silt and reddish brown herbaceous peats containing detrital wood fragments, discrete interbeds of medium sand, and no postsettlement pollen. Radiocarbon dates from near the top of this sequence at Lower Chappel Road are late Holocene in age (1,160 ± 110 to 220 ± 80 B.P.), whereas a similar sample from Trumbull Marsh, just downstream, yielded a mid-Holocene date of 6,480 ± 110 B.P. The limited thickness of sediment accumulation, the presettlement ages, and the composition of floodplain strata indicate that the long-term Holocene history of Susquetonscut Brook was characterized by negligible sediment transport in a marshy, seasonally inundated floodplain only rarely affected by severe floods.

Overlying the Holocene floodplain is a thick sequence of mineral-rich sediments deposited by overbank flows containing both coarse sand as well as detrital wood dating at 200 ± 60 B.P. Although highly variable from site to site, this topstratum sequence at Lower Chappel Road consists of an early coarse-grained phase followed by a finer grained, bioturbated interval. This organic deposit is devoid of sand horizons, and contains exotic pebbles, incipient soil structure, and rootlet mottling, all features suggestive of an agricultural soil. Above the organic interval the third topstratum unit, coarser grained, extends upward to the modern surface and is still undergoing rapid deposition. A radiocarbon date of 108.4 ± 0.8 B.P. from the base of this deposit indicates the modern alluvium postdates nuclear weapons testing in the mid-twentieth century.

Hydrogeologic Setting: Artificial occlusion
Example Wetland: Bender Road (BR)
Site Description: This site has the largest area and highest elevation of any wetland in the watershed. It is a contiguous swamp consisting of many coalesced perched basins above the upland till. At its southern limit, it drains southward across an eighteenth century road through a collapsed nineteenth-century stone culvert.
Stratigraphy: The saturated, bioturbated muck beneath much of the surface of the swamp near its southern limit overlies an unoxidized laminated sandy silt of lacustrine origin that contains historic pollen. These historic lacustrine deposits lie sharply above an incipient paleosol similar to that at the Manning Floodplain wetland. These relationships indicate that the southern part of this large wetland was converted to a localized pond when southerly drainage from the basin was impeded by road construction.

Hydrogeologic Setting: Drained wetlands
Example Wetland: Hayward Floodplain (HF)
Site Description: This broad terrace above a channelized stream has a distinct distal edge where it impinges on the flanking valley.
Stratigraphy: The surface is overlain by a thick, organic-rich loamy soil. It formerly was a stream floodplain, but no longer receives sediments owing to its elevated position above the channelized stream, and perhaps to upstream impoundments.

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