Vegetation and Stream Survey
Lower Makefield Township
Bucks County, Pennsylvania

Report No. 78-50

Division of Limnology and Ecology
Academy of Natural Sciences of Philadelphia
19th and the Parkway Philadelphia, Pa. 19103

December 1, 1978

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I. INTRODUCTION

The general purpose of this report is to provide a partial natural resource inventory for Lower Makefield Township which can be used in effecting responsible decisions for guiding township growth in the future. Given township budgetary constraints, the Academy of Natural Sciences of Philadelphia deemed it impossible to prepare a complete resource inventory for the township, expecially one that provided precise and useful data for decision making. In reviewing a list of resource inventory needs of the township with Mr. Steven Wharton of Lower Makefield, the Academy selected for detailed study several key elements. These include terrestrial vegetation, wetland vegetation, biological and chemical quality of surface water, and soils. The results of these selected resource studies are presented in this report along with a series of five mylar maps of the township (scale of 1"=800'). One map delineates drainage basins of the township, one is to be used in the preparation of a soils map, one depicts vegetation assemblages in the township, and the two additional maps are provided for future use by the township.

The Academy engaged Andropogon Associates to prepare the terrestrial vegetation map and report. Soils mapping, which is ongoing, is being done by Mr. Steven Wharton of the township. Dr. Alfred E. Schuyler, Department of Botany of the Academy of Natural Sciences of Philadelphia, conducted the wetland study. All other work was done by members of the Division of Limnology and Ecology of the Academy; these included Robert R. Grant (algae), Jay W. Richardson, Jr. (insects) and Dr. Stephen L. Friant (chemist). Lynne Berseth (environmental planner/aquatic biologist) was project leader of the study.

The individual resource elements (except soils) are presented as separate chapters of this report. Within each of these chapters, conclusions and recommendations are presented which relate to the specific resource elements investigated.

II. FOREST VEGETATION OF LOWER MAKEFIELD TOWNSHIP

Andropogon Associates

Ecological Planning & Design
490 Shawmont Avenue   Philadelphia PA 19128

FOREST VEGETATION OF LOWER MAKEFIELD TOWNSHIP

Vegetation map and report
submitted to

The Academy of Natural Sciences
19th and the Parkway
Philadelphia PA 19103

Prepared by

Andropogon Associates
Ecological Planning & Design
490 Shawmont Avenue
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15 November 1978

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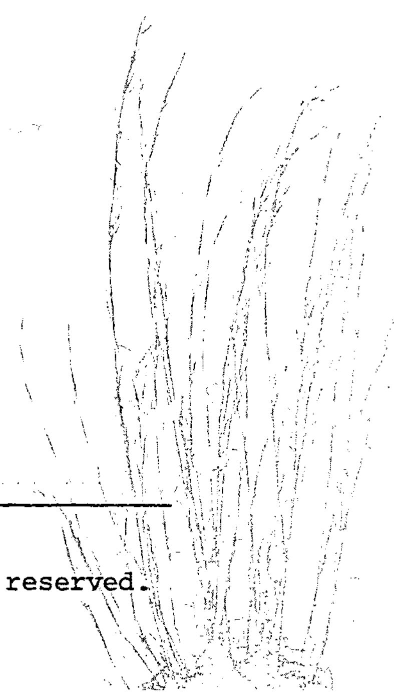

AN OVERVIEW

The forest vegetation of Lower Makefield Township is the product of centuries of man's intervention upon a once entirely forested landscape. Repeated cutting for timber and clearance for agricultural use and development have both altered the composition of the forests and reduced their extent. At present, the forest vegetation which remains in the Township is confined primarily to wet and poorly drained soils, steep slopes, and along stream and river corridors.

The Township is located in two major physiographic provinces, the Piedmont and the Inner Coastal Plain. The northern two-thirds of the Township (approximately north of the Reading Railroad line) is situated in the Triassic Lowlands of the Piedmont, and is comprised primarily of sedimentary rock (sandstone, shale, argillite, and conglomerate) of the Stockton and, to a lesser extent, the Lockatong Formations. The landform pattern presents smooth, round-topped hills separated by wide valleys. Surface drainage is generally good, but internal drainage ranges from good to poor. Nearly all the Township's best agricultural soils overlie the Stockton Formation, where the forest vegetation is confined to streambanks, steep slopes, and isolated woodlots.

The southern one-third of the Township (approximately south of the Reading Railroad line) is situated in the transition zone between the Piedmont and the Inner Coastal Plain. Parallel bands of Baltimore Gneiss and Chickies Quartzite of the Piedmont run along the southern boundary of the Township, defining the approximate fall-line zone. These harder metamorphic, sedimentary rocks present steeper slopes and occasional exposed outcrops. Drainage is poorer and the soil is generally not suited to agriculture, all of which has resulted in larger areas of forest remaining in this part of the Township, including the most significant and extensive forest tract -- the "Five Mile Woods".

To the south of the gneiss and quartzite, and in the eastern portions of the lower one-third of the Township, occur unconsolidated and deeply weathered sands and gravels of the Pennsauken Formation of the Inner Coastal Plain. The soils are sandier at the surface, although subsurface drainage is often poor. Though the forest was cleared and the land used for agriculture, these soils are less suitable for farming than those underlain by the Stockton Formation. This probably resulted in the earlier abandonment of farming, though subsequent suburban development maintained the reduced extent of forest, confined largely to areas of poor drainage.

The eastern boundary of the Township occurs at the Delaware River. Adjacent to the river runs a band of Wisconsin and Recent unconsolidated sand and gravel deposits on river terraces. The floodplain forest has been gradually cut and narrowed over time and, for much of the river, remains only as a narrow band at the water's edge and as isolated stands on the undeveloped portions of the floodplain. Similar disturbance has occurred along most of the streambanks. Since many of the forest species of this area will tolerate wetter conditions, a distinctive floodplain forest did not develop except where alluvial deposition was more extensive.

The patterns of land-use history in Lower Makefield Township have determined the patterns of native vegetation. The extensive forests of beech and mixed oak and chestnut were cleared for agriculture in all but the marginal areas. The remaining woodlands continued to be cut for timber. Gradual suburbanization later occurred on the soils less suited to farming. More recent development has occurred not only on the better agricultural soils, but in remnant forest areas as well. If continued, this intrusion of development onto poorly drained soils, steeper slopes, and small drainage channels will exact a high toll in future environmental costs and, if uncontrolled, could lead to the effective elimination of forests within the Township boundaries.

NATIVE VEGETATION OF LOWER MAKEFIELD TOWNSHIP

Before colonization, the Township was entirely forested. The better drained, upland sites probably supported a forest of mixed oaks and chestnut (since virtually eliminated by the chestnut blight). The more mesic uplands as well as the lowlands were probably nearly pure beech, with occasional and local swamps of red maple and tupelo. The alluvial floodplains along the Delaware and some of the larger streams supported a more diverse forest type, which included sycamore, elm, walnut, and silver maple, as well as species from the surrounding forests. The distinctions between Piedmont and Coastal Plain forest types were probably much less distinct than at the present time. At present, no old, mature forests remain, so virtually all the forests are successional, that is to say they are all undergoing various stages of development where species predominance and composition are changing fairly dramatically over time. It is in the successional forests of the southern portion of the Township where a distinctive Coastal Plain forest has developed. Many of the understory shrubs and herbs of the Coastal Plain occur in these younger forests. Sweetgum, a tree of very limited occurrence in the Piedmont, is very abundant on old agricultural land and the recently disturbed land in the south. Most of these more southern species, however, become much less abundant as the forest develops over time. The many successional stages seen in the Township accounts for much of its vegetative diversity. Past land use has produced a native vegetation which, though disturbed, is potentially richer in character than the pre-Colonial, nearly uniform forest cover. Careful vegetation management and controls could maintain the present rural image as well as reasonable expanses of open space.

The forest types of the Township have been described in four major groups:

1 *UPLAND FORESTS*

These forest types occur on slightly drier and better drained upland soils and the forests of these areas are probably tending to mixed oak over time. Only very limited distinctions between Coastal Plain and Piedmont types were observed, although this may be due to the very reduced amount of habitat still in forest.

UPLAND FOREST TYPES

1 Black locust
2 Oak/hickory

2 *MESIC UPLAND AND LOWLAND FORESTS*

These forest types generally occur on more mesic and more poorly drained uplands and lowlands. Over time these forests are probably tending to nearly pure beech, although no extensive stands of truly mature forest were observed. Fairly dramatic differences in vegetation in the Coastal Plain versus the Piedmont are apparent in the earlier successional types of this forest group.

MESIC UPLAND AND LOWLAND FOREST TYPES

3 Sweetgum/red maple
4 Red maple/ash/tulip poplar
5 Oak/sweetgum/red maple
6 Oak/red maple/ash/tulip poplar
7 Oak/hickory/beech

3 *FLOODPLAIN FORESTS*

These forest types occur on alluvial floodplain soils. This forest is very reduced in extent and variable in character. Although some successional changes were apparent, the developmental trends of these forests are still unclear.

FLOODPLAIN FOREST TYPES

8 Silver maple/black walnut/sycamore
9 Ash/red maple/elm
10 Red maple/white oak/pin oak
11 Silver maple/red birch
12 Silver maple/sycamore/elm

4 *SWAMPS*

These forest types occur on very poorly drained, wet depressions and are more extensive in the southern portions of the Township. Sweetgum occurs in the younger, southern swamps and distinguishes them from the swamps of the north.

SWAMP FOREST TYPES

13 Sweetgum
14 Red maple/tupelo

MAPPING METHODS

The forest vegetation of the Township was mapped from black-and-white stereo pairs of aerial photography (1"=2,000' scale) as well as ground reconnaissance. Areas of uniform character were delineated from the photography and the vegetation type and habitat type of each area was determined by examination in the field.

Because only relic pieces of forest remain in the Township, primarily because of past land uses, virtually all the forests show a distinct edge, usually of early successional and/or disturbance species, such as black cherry, sassafras, tulip poplar, catalpa, locust, etc. Although this edge effect is felt beyond the immediate forest margin, it is not so overwhelming in the interior as at the immediate edge. For the purposes of vegetation mapping, these edges were ignored and the forest interior type was mapped.

VEGETATION TYPES

UPLAND FORESTS

The forest species native to this region appear to be able to grow on a wide variety of soil types and topographic conditions, provided that adequate moisture is available (though some species are eliminated by excessive moisture). Virtually all the soils in the Township retain a good deal of moisture and, therefore, no sharp contrasts occur in the vegetation as land forms vary. Rather, certain species are favored in the slightly drier areas and others in the slightly damper and more poorly drained soils. These natural, subtle variations in vegetation have been emphasized by man's use of the land.

On the slightly drier and better drained soils of the uplands, mixed oaks and chestnut were probably once predominant, although subsequent developments have favored the oaks as well as tulip poplar and hickories. Today, representatives of these upland forests are loosely confined to a few small sites on the ridgetops and steep sideslopes in the northern and central portions of the Township.

The black locust forest type (*1*) occurs in dense, nearly monospecific stands of black locust, commonly appearing as one of the earliest stages of forest succession. Certainly, other early phases may also occur, but none were apparent locally and the abundance of oldfield and hedgerows has assured an available seed source for black locust. There are also almost certainly intermediate stages in the development of the mature mixed oak forest, but such types were not observed within the Township. Black locust, however, was also observed occupying several sites where there had been disturbance of the soil beyond the surface layers effected by the plow.

The oak/hickory forest type (*2*) is a layered forest composed primarily of mixed oaks and hickories, although oaks are predominant and a variety of other species are present in much less abundance. The flowering dogwood is the most common understory tree, and is especially dense at edges and in more open areas. Less commonly occuring shrubs include viburnums and spicebush. Where not seriously disturbed, the ground layer is quite rich, supporting a variety of ephemeral herbs and vines. This forest type was observed in a young condition as well as fairly mature, although no truly mature areas occurred. Tree saplings in the understory were approximately the same as those species in the canopy, and these forests can be expected to remain similar in composition in the near future. Over time, however, if left undisturbed and the canopy continues to close, it is likely that species composition will alter in the larger tracts of forest. The oaks probably will still be abundant, but sugar maple, red maple, and white ash are likely to increase, and the hickories and tulip poplar likely to decrease. Maple-leaf viburnum should continue to be abundant, though small trees and shrubs are likely to be more confined to edges and more open forest areas.

Differences between the Coastal Plain and Piedmont expressions of this forest type were difficult to observe, as there is almost none of this forest remaining in the southern portion of the Township. It is probable that tree species predominance was and would be similar, although some distinctions in the shrub layer might be expected.

MESIC UPLAND AND LOWLAND FORESTS

The natural environment of Lower Makefield is well suited to forest growth. No truly severe stresses are encountered and the growing conditions are generally mesic throughout. However, in some areas, soil conditions and/or topography have produced slightly wetter soils, usually with poorer drainage, which are somewhat less conducive to agricultural use. In the past, these forest types were probably nearly pure beech, with a predominant understory of maple-leaf viburnum. The transition from the mixed oak type was likely in the past and is today a gradual one. Although no extensive tracts of pure beech remain today, the most mature forest found in these areas support mixed oaks and hickories, as well as abundant beech. The predominance of young beech in the understory, coupled with limited oak and almost no hickory reproduction, give evidence to the trend to develop into beech forest. Because these areas are less suited to agriculture, the forests are more extensive and these forest types are the best represented within the Township. Although not seriously farmed, these areas were heavily and often repeatedly logged, so a variety of successional stages of forest development are apparent.

Much of this more mesic habitat occurs on the gneiss and schist of the lower portion of the Township in the transition zone to the Inner Coastal Plain physiographic province. Although many of the common tree species are similar, sweetgum is notably apparent in this area as well as a wide variety of shrubs typical of these southern habitats of the Coastal Plain. Because the successional forests are often younger and more open in character, shrub growth is favored. Moreover, earlier devastating fires have since been largely controlled, further favoring shrub development. Many of these shrubs are typical of the Coastal Plain and in the successional areas of the southern portions of the Township a true Coastal Plain forest can be seen. This is especially important since much of the Inner Coastal Plain forest in the region has been destroyed, making these habitats more unique and important locally than they might otherwise be. These differences in forest type, however, tend to become less distinct as the forest matures and closes, presenting conditions inhospitable to many of the Coastal Plain shrubs and herbaceous plants as well as to the sweetgum, which is generally restricted to younger landscapes.

Five major forest types of this group are represented in Lower Makefield Township. The two earlier phases of successional development are represented by different types in the Piedmont and Coastal Plain transition zone. The later successional stage occurring in the Township is generally similar in the north and south and is already showing a blurring of distinction between the vegetation of the physiographic provinces, although some limited shrub and ground layer differences persist. Although, as cited earlier, no extensive areas of pure beech occur, this is the likely trend of forest development in these areas, barring future severe disturbance.

The sweetgum/red maple forest type (*3*) is the earliest successional woodland apparent in the Coastal Plain influence area and is distinguished by the abundance of sweetgum, a species which barely occurs at all north of the Reading Railroad line. The sweetgum often occurs in dense monospecific and even-aged stands, though the older woodlands more frequently show a higher incidence of red maple as well. The sweetgum appears unable to reproduce as the forest closes and sweetgum reproduction is generally confined to sprouts in more open sections of the woodland. Shrub growth is often dense at edges and in openings, and it is here that dramatic differences between the northern and southern portions of the Township can be seen. Sweet pepperbush and highbush blueberry are the most common understory shrubs and are typical of the Coastal Plain, although spicebush, a prevalent shrub of the Piedmont, also occurs. Yellow birch, black cherry, and tupelo occur occasionally, and, like the shrubs, favor openings and edges. A variety of ferns and wet woodland herbs occur in the ground layer as well as clubmosses (ground pine and ground cedar). The parallel young successional forest type of the northern Piedmont sections of the Township is red maple/ash/tulip poplar (*4*). The associated, but occasional, tree species are also tupelo, yellow birch, and black cherry, while spicebush is the most prevalent shrub. Sweetgum, sweet pepperbush, and highbush blueberry are notably absent. The most frequent presentation of this forest is of dense, nearly even-aged red maple and ash, occurring among larger and older tulip poplars, with a locally dense understory of spicebush. Wet woodland herbs, ferns, and vines occur in the ground layer and Jewelweed is especially abundant.

The next phase of forest development in the Inner Coastal Plain transition zone after sweetgum/red maple appears to be the oak/sweetgum/red maple forest type (*5*). Sweetgum is gradually being eliminated from the forest at this time, and it appears unable to reproduce under the closed canopy conditions. The larger existing sweetgum, however, persist, while red maple reproduction is reduced. The most notable distinction, however, is the appearance of abundant oaks and occasional hickories, occurring in all layers of the forest, though none are as old as the earlier occurring tree species. Red, white, and black oak are abundant; however, where the soils are wetter, white oak is favored and pin oak appears. Yellow birch is common in gaps and tupelo is occasional in wetter areas. Some pignut hickory and beech are seen in the understory among abundant oak saplings. Sweet pepperbush is still common in the understory, though less so than in the earlier forest stage, and occasional swamp azalea (typical of the Coastal Plain) and arrowwood (typical of both Piedmont and Coastal Plain environments) occur. The ferns, club-mosses, and wet woodland herbs are still apparent, though less extensively developed.

In the northern Piedmont sections of the Township, succeeding the red maple/ash/tulip poplar type is the oak/red maple/ash/tulip poplar forest (*6*). As in the south, the appearance of abundant oaks and hickories distinguishes this stage of succession. Though ash and red maple persist, their reproduction is somewhat limited and the tulip poplar now is confined to a few relic and aged individuals, and is not likely to reappear except where new forest openings or gaps occur. Yellow birch is present, but confined as in the south to local areas where the canopy is more open. The red and black oaks are abundant, though scarlet and chestnut oak appear on the slightly drier soils and pin and white oak seem to favor the wetter soils. Shagbark and pignut hickory and beech are evident in the understory. The similarities in forest development between the north and the south of the Township are more apparent at this stage, though some shrub and small tree distinctions remain. Flowering dogwood is still the most common understory tree, though ironwood is also present. Spicebush and arrowwood occur as the predominant shrubs. Wet woodland herbs comprise the bulk of the ground layer where disturbance is slight.

As forest development and maturation continues, the distinctions between the Coastal Plain and the Piedmont become much less distinct. The third major stage of succession is similar both in the north and south in the oak/hickory/beech forest (*7*). This is the most mature forest type occurring in the Township and though layered is more open and park-like in character in the understory, with the canopy closed and shade quite dense.

This type is best distinguished by the substantial appearance of beech, which is the only species seen reproducing freely, primarily vegetatively from root sprouts. The oaks and hickories from earlier stages persist, though reproduction is curtailed. Occasional mockernut and red hickory, however, are occurring. The understory is sparse and comprises primarily beech saplings and maple-leaf viburnum, which is commonly associated with beech in both Piedmont and Inner Coastal Plain landscapes. Witchhazel occurs occasionally and mayapple is developing in the ground layer, an herb more typical of the Piedmont than the Coastal Plain. The abundant shrubs of the earlier stages no longer occur and the distinctive Coastal Plain shrubs of the south have disappeared, along with the sweetgum,in the older, darker forests. The landscape is more uniform in character and species diversity is similarly reduced. The eventual transition to nearly pure beech can be surmised, but nowhere within the Township is this latter forest type extensively developed. If left undisturbed, however, the beech will predominate, and cast a dense shade and occupy the root zone so fully as to inhibit invasion by other species. At this point, the formerly dynamic quality of these forests will be replaced by very gradual, almost imperceptible, change.

FLOODPLAIN FORESTS

Many of the species of the upland and lowland forests of Lower Makefield will tolerate conditions of periodic flooding as well as a fairly wide range of drainage conditions, and as such can and do grow under floodplain conditions. Many of the streams of the Township were probably not distinguished by floodplain forest of notably different character from the surrounding woodlands. However, where disturbance is recent, the early successional stages often distinguish floodplain succession from succession of the nearby forests. Similarly, where extensive alluvial deposition has occurred, some species distinctions seem to persist.

In the southern portions of the Township, no truly distinctive floodplains were observed, in part because on the gneiss and schist very little alluvial deposition occurs, and because the Inner Coastal Plain streams have been virtually cleared in the course of development. Where the southern streams support forest, it is generally similar in character to adjacent woodlands.

Three floodplain forest types were observed in the Piedmont sections of the Township. The silver maple/black walnut/sycamore forest type (*8*) generally occurs along narrow, steeper stream corridors and appears to be an earlier successional phase. The silver maple occurs in bands almost at the water's edge in fairly dense stands, while the walnut is confined to monospecific groves, occurring occasionally. Isolated, individual sycamores appear throughout the length of the forest, usually at the water's edge. Occasionally, black cherry, red oak, and scarlet oak occur. Shrub growth is limited, and spicebush often fills gaps in the canopy. Vine growth is often rampant, especially at edges and is predominantly grape and poison ivy. Jewelweed is the most common herbaceous plant.

This floodplain forest type appears to be succeeded by the ash/red maple/elm forest (*9*). Both green and white ash are abundant. Red maple appears to have replaced the silver maple, and individual American elms occur frequently. Pin and scarlet oak and slippery elm occur occasionally. Shrub growth is still very limited, although spicebush and arrowwood occur in pockets. The forest is quite dense and appears not to change dramatically, though the scarlet oak may increase somewhat over time. It is possible that these floodplains may be too wet for the development of beech.

The red maple/white ash/pin oak floodplain forest (*10*) occurs on somewhat shallower stream corridors and is typified by a distinct favoring of certain species, i.e., red maple, white oak, and pin oak, from the surrounding forest, rather than the appearance of species such as sycamore, which are generally restricted to the floodplain. Similarly, on the somewhat wetter lowlands, the same three species were found locally off the floodplains. In the southern portions of the Township, a similar favoring of wetter species appears as sweetgum, white oak, and pin oak on the wetter lowlands. These areas are unlikely to change much over time, except for a gradual reduction in pin oak. Here too conditions are probably too wet for beech.

The floodplain of the Delaware River has been substantially cleared and only a very reduced amount of distinctive floodplain forest occurs. For the most part, the remaining forest near the river is not distinguished from the mesic upland and lowland forest types. A major exception to this is a large tract of silver maple/red birch forest (*11*) which occurs on a high flat river terrace. The area has been severely disturbed in the past and its development may not be typical of such terraces. The silver maple and red birch occur in dense even-aged stands, although recently it appears that the silver maple has overtopped the birch, which is locally failing. Future development of this area is unclear and may be affected by the rampant growth of alien species which occur on the tract.

The remaining floodplain forest along the Delaware occurs in the narrow, restricted bands at the water's edge. The forest type is silver maple/sycamore/elm (*12*), although a wide variety of other species occur as well. Though the river serves as a major transportation corridor, it also serves as a corridor for extensive plant migration and naturalization, and many species including a number of non-native plants persist along its banks. Silver maple, sycamore, and American elm occur throughout the forest, although other species observed include red maple, box elder, slippery elm, catalpa, princess tree, basswood, ailanthus, green ash and white ash. Shrub and herbaceous growth is quite restricted, though abundant vines occur in gaps, including grape, poison ivy, bittersweet, and honeysuckle. Although many of these species are successional in character, this narrow band of forest is likely to continue to support such diversity since disturbance in various forms frequently occurs.

SWAMPS

The areas occupied by swamps in Lower Makefield are very limited in extent and probably have not supported any past agricultural use, though cutting for timber and past forest fires have made an impact and no great old swamps occur. These areas are usually wet depressions which are extremely poorly drained, with standing water often apparent at the surface. Some limited peat development has occurred and sphagnum moss is often abundant in the ground layer. The predominant species of these swamps are red maple, tupelo, and, in the south, sweetgum. These swamps also appear to be too wet for the development of other tree species from adjacent habitats. Often the interior of the depression is too wet for substantial tree growth and the vegetation is at present confined to occasional wetland shrubs and wetland herbaceous plants.

In the southern portions of the Township, where the Coastal Plain influence is apparent, sweetgum is frequently the major tree of early swamp development. Over time, however, if the habitat is undisturbed, sweetgum is likely to give way to red maple and tupelo, the predominant species of the more northern swamps. Because of the severe stresses of these environments, tree species are more limited than elsewhere and nearly monospecific stands of trees were frequently observed. Moreover, the stands are usually nearly even-aged and do not show the abundance of the species in all ages and sizes characteristic of the more upland soils.

The sweetgum swamp (*13*) is confined to a single location in the south of the Township where the Coastal Plain influence is very visible in younger landscapes. The sweetgum is nearly monospecific and even-aged. A variety of shrubs concentrate at the wetter areas and at the edges of the wetland, with many typical of the Coastal Plain, including arrowwood, highbush blueberry, sweet pepperbush, swamp azalea, fetterbush, and maleberry. Herbaceous growth includes cattail, sedges, and water purslane, among others.

The red maple/tupelo swamp (*14*) occurs to a very limited extent. Red maple and tupelo are the major tree species. In the northern swamp, arrowwood forms a dense understory where there are trees and the open interior supports alders, shrub dogwoods, and swamp loosestrife. In the southern swamp, the shrub and herbaceous growth is similar to that of the sweetgum swamp.

WOODY OLDFIELDS

Although not truly forest, the major well-developed woody oldfields were also mapped for the Township. In a Township so disturbed over time as Lower Makefield, these oldfields represent an important reservoir of native species and provide additional excellent wildlife habitat, complementing the forested open space. Species diversity is rich in these oldfields, particularly the shrubs.

A clear division occurs between those fields designated woody oldfield (WOF), which are likely to develop into forest types of the upland and lowland varieties (types 1 thru 7) and the wet woody olfields (WWOF), which will probably develop as swamps (types 13, 14). Because these fields represent early stages of succession, the distinctions between the northern Piedmont and southern Coastal Plain fields are very sharp, particularly in the shrub and ground layers. Similarly, sweetgum is the major tree species in the oldfields of the southern portion of the Township.

The woody oldfields (WOF) support a variety of tree species, typically including crabapples, apples, red cedar, black locust, sassafras, and cherries, with sweetgum found in the south. Tree seedlings and saplings of later forest types also occur, such as oaks, hickories, ashes, maples, and tulip poplar. In the north, the associated shrubs include bush dogwoods, arrowwood, and sumac, while bayberry, chokeberry, highbush blueberry, blackhaw, and shrub dogwoods are typical of the south. The ground layer supports a variety of agricultural grasses as well as little bluestem, a native grass common on abandonned agricultural land. In the southern oldfields, however, haircap moss, ground pine, and ground cedar also occur in the ground layer.

The wet woody oldfields generally support the same species which occur in the swamps, except that tree growth is younger and less dense.

DISTURBANCE CLASSIFICATIONS

All the native forest vegetation in Lower Makefield has been disturbed either by past agricultural use and/or logging. There is no forest which does not show the impact of past intervention by man. In some areas, however, the native forests are developing well, while in others natural succession has been arrested by the successful invasion of non-native weedy plants, such as Japanese honeysuckle.

For each of the areas mapped in the Township, a disturbance classification of low, moderate, or severe has been given to indicate the health and stability of the native plants in the stand.

In those areas designated as low disturbance, good reproduction of native species of the canopy, understory, and ground layers, as described in the forest types, is in evidence. In those areas designated as moderate disturbance, reproduction of native plants is reduced, but still apparent. In general in these areas, tree reproduction is good, shrub reproduction impaired, and the ground layer is nearly replaced by alien weeds. Although the natural succession has been slowed down, the native forest is still holding its own. In areas designated as severe disturbance, reproduction of native plants is severely curtailed and the invasion of non-native plants is likely to continue, at the expense of the native species. Usually, disturbance is in evidence in all layers of the forest and a further decline of native populations can be expected in the near future.

Although disturbance in the past radically altered the face of the landscape, converting forest to farmland, the potential of the landscape to support native forest was not substantially effected. The vigor and diversity of many of the oldfields on abandonned agricultural lands attest to this resilience. The upper soil horizons, although impacted by erosion, were usually not summarily removed. Today, however, the nature of disturbance, though not so widespread, is potentially more severe in the long run. Topsoil is completely removed and subsoil exposed. Although still local in occurrence, successional areas colonized almost completely by alien species, in particular ailanthus, appear to be increasing, along with many weedy herbaceous plants typical of urban vacant lots. Species diversity is comparatively low and the native plants poorly represented. Continued disturbance of this kind poses a real threat to the native species. The Norway maple, for example,. can be very invasive in local woodlands, reproducing in shade, casting a particularly deep shade, and creating strongly alleleopathic conditions in the soil which sharply inhibit native plant reproduction. Where past disturbance frequently just reverted the landscape to an earlier stage of native succession, recent stresses distinctly urban in character and more lasting are apparent. Concurrently, the seed sources for non-native plants are increasing in range and abundance, further favoring their appearance even in areas not so dramatically disturbed.

Those areas classified as severely disturbed are obviously more susceptible to future disturbance, while at the same time those areas of low disturbance are well worth protecting. In the long run, however, adequate protection of the native forest types will require not only measures to ensure open space, but management techniques which in the event of disturbance can foster native rather than non-native growth.

FORESTS OF SPECIAL CHARACTER

Forests of special character are designated with an asterisk on the vegetation map. Although this designation is certainly somewhat subjective, the forests indicated generally support vegetation most typical of the area. Disturbance is usually low and species diversity high. These areas merit a high priority for protection and/or acquisition.

CONCLUSIONS AND RECOMMENDATIONS

Lower Makefield Township is undergoing a transformation from an agricultural landscape to a suburban one. In the eighteenth and nineteenth centuries, the once extensive forests of the area were cleared and logged, but the relic forests and hedgerows retained good representation of the native species and forest types of the area. However, the more recent impacts of suburbanization are potentially far more devastating to the native vegetation. At the present time, many of the Township's forests are threatened by proposed developments and extensive tracts are up for sale.

Although some developers appear to have attempted to save forest trees, most have been severely damaged in the course of construction and will likely die within a few years. Understory, shrub, and ground layer growth is entirely removed and the forest habitat preempted.

If natural habitat, particularly forest preservation, is desired, the Township will have to act very quickly to reverse or radically modify recent development trends. Once development has occurred, it is virtually impossible to reestablish a forest resource on a site. Similarly, good agricultural soils are lost as a resource once built upon. At the same time, growth can and should be accommodated. The native landscapes have enormous amenity value for residents as well as being valuable to wildlife and of use in protecting water resources. The benefits of good planning should be felt by all within the Township.

We recommend, on the basis of our study of the Township's vegetation, that the following measures be undertaken. And it should be reemphasized that *time is of critical importance.*

1 *The Township must clarify its goals and objectives concerning the natural landscape. A truly comprehensive representation of native landscapes will require different solutions than a piecemeal approach. If wildlife is determined to be valuable, many of the successional landscapes and their management become a concern. Once it is determined what the Township wishes to do, appropriate*

methods for realizing these goals can be undertaken. The decision to acquire the "Five Mile Woods" is an excellent first step toward preserving and protecting a significant natural resource. At the same time, it should be noted that many of the Township's forest types are not represented in this acquisition.

2 *A comprehensive open space plan, which best serves the long-range community goals formulated by the above, must also be determined. Because vegetation effects drainage conditions and because resources and land are limited, it is suggested that the open space plan be coordinated with water resource protection and management planning.*

3 *Methods must be designed to ensure the physical reality of the goals and open space plan. This will likely involve many solutions, including direct acquisition, regulatory ordinances, revision of zoning codes, increased public awareness, and vegetation management.*

4 *The development of a comprehensive vegetation management plan would aid significantly in reducing the impacts on the native landscape normally associated with suburban development as well as provide for sound and economical management of open space. Much of the vegetation in the Township is already showing stress and the alien landscape is rapidly increasing its range. Alteration of some construction methods, replanting with selected native plants, and a minimum amount of maintenance could aid immeasurably in retaining the natural landscape and wildlife habitat, despite continued growth. Moreover, the landscape potential of native plant associations used for the appropriate environmental conditions is great, but presently vastly underrealized.*

The vegetation management program can be applied at the level of larger open space, new development, and down to the level of roadside management and individual homes which, through increased public awareness and the offering of good alternative solutions, can bring the natural landscape back into the fabric of the entire Township.

"Some natural resources have no price tag, no marketability, and no assessed valuation, yet they provide the very character of a community which draws people to settle there -- and these people, through poor land use planning, may destroy the very amenities they sought to live among." -- Sean Reily

"We abuse the land because we regard it as a commodity belonging to us. When we see the land as a community to which we belong, we may begin to use it with love and respect. There is no other way for land to survive the impact of mechanized man." -- Aldo Leopold

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SPECIES LIST

Common name	*Botanical name*
Ailanthus	*Ailanthus altissima*
Alder	*Alnus* spp.
Apple	*Malus* spp.
Arrowwood	*Viburnum dentatum*
Ash	*Fraxinus* spp.
Ash, green	*Fraxinus pennsylvanica*
Ash, white	*Fraxinus americana*
Azalea, swamp	*Rhododendron viscosum*
Basswood	*Tilia americana*
Bayberry	*Myrica* spp.
Beech	*Fagus grandifolia*
Birch, red	*Betula nigra*
Birch, yellow	*Betula lutea*
Bittersweet	*Celastrus scandens, C. orbiculata*
Blackhaw	*Viburnum prunifolium*
Blueberry, highbush	*Vaccinium corymbosum*
Bluestem, little	*Andropogon scoparius*
Box-elder	*Acer negundo*
Catalpa	*Catalpa bignonioides*
Cattail	*Typha latifolia*
Cedar, red	*Juniperus virginiana*
Cherry, black	*Prunus serotina*
Chestnut, American	*Castanea dentata*
Chokeberry	*Pyrus arbutifolia*
Club moss	*Lycopodium* spp.
Crabapple	*Malus* spp.
Dogwood, shrub	*Cornus amomum, C. stolonifera, C. paniculata*
Dogwood, flowering	*Cornus florida*
Elm	*Ulmus* spp.
Elm, American	*Ulmus americana*
Elm, slippery	*Ulmus rubra*
Fetterbush	*Leucothoe racemosa*
Grape	*Vitis* spp.
Ground cedar	*Lycopodium complanatum*
Ground pine	*Lycopodium obscurum*
Hickory	*Carya* spp.
Hickory, red	*Carya ovalis*
Hickory, shagbark	*Carya ovata*
Honeysuckle, Japanese	*Lonicera japonica*
Ironwood	*Carpinus caroliniana*
Jewelweed	*Impatiens palida, I. capensis*
Locust, black	*Robinia pseudoacacia*
Loosestrife, swamp	*Lythrum salicaria*
Maleberry	*Lyonia ligustrina*
Maple	*Acer* spp.
Maple, Norway	*Acer platanoides*
Maple, red	*Acer rubrum*
Maple, silver	*Acer saccharinum*
Maple, sugar	*Acer saccharum*
Mayapple	*Podophyllum peltatum*

Common name	*Botanical name*
Mockernut	*Carya tomentosa*
Moss, haircap	*Polytrichum* spp.
Moss, sphagnum	*Sphagnum* spp.
Oak, black	*Quercus velutina*
Oak, chestnut	*Quercus prinus*
Oak, pin	*Quercus palustris*
Oak, red	*Quercus rubra*
Oak, scarlet	*Quercus coccinea*
Oak, white	*Quercus alba*
Pepperbush, sweet	*Clethra alnifolia*
Pignut	*Carya glabra*
Pinxter flower	*Rhododendron nudiflorum*
Poison ivy	*Rhus radicans*
Princess tree	*Paulownia tomentosa*
Sassafras	*Sassafra albidum*
Sedge	*Carex* spp.
Spicebush	*Lindera benzoin*
Spikerush	*Eleocharis* spp.
Sumac	*Rhus typhina, R. glabra, R. copallina*
Sweetgum	*Liquidambar styraciflua*
Sycamore	*Platanus occidentalis*
Tulip poplar	*Liriodendron tulipifera*
Tupelo	*Nyssa sylvatica*
Viburnum	*Viburnum* spp.
Viburnum, maple-leaf	*Virburnum acerifolium*
Walnut, black	*Juglans nigra*
Water purslane	*Ludwigia* spp.
Witchhazel	*Hamamelis virginiana*

III. REPORT ON THE FLORA OF WETLANDS AND POORLY DRAINED WOODS OF LOWER MAKEFIELD TOWNSHIP, BUCKS COUNTY, PENNSYLVANIA

INTRODUCTION

During September and October 1978, six and one half days were spent evaluating the flora of wetlands and poorly drained woods of Lower Makefield Township, Bucks County, Pennsylvania. Particular attention was given to Five Mile Woods because it is the last extensive Coastal Plain forest of its kind left in Pennsylvania. An additional day was spent obtaining data from museum specimens and the literature in order to document the extent to which the flora has been altered by man's activity during the past 50 years.

METHODS

Two days were spent recording the kinds of plants found in wetlands at the following scattered sites in Lower Makefield Township: (1) along Dyers Creek about 3.8-4 km northwest of Yardley, (2) along Core Creek about 4.5-5 km west-northwest of Yardley, (3) along Buck Creek about 2.8 km west of Yardley, (4) along Brock Creek about 2 km south-southwest of Yardley, (5) along Brock Creek about 0.4 km southeast of Roelofs, (6) headwaters of Queen Anne Creek and adjacent area in Five Mile Woods about 1.4-2.7 km southeast of Roelofs, and (7) wetlands along the Pennsylvania Canal from the southern borough boundary to about 5.2 km southeast of yardley.

Two and one half days were spent in Five Mile Woods recording the kinds of plants growing in poorly drained conditions as well as in wetlands. In addition, woody plants over 1.5-m tall were counted in two transects 1.8-m wide and 230-m long (Table III-1). The transects were located 75-m north and 75-m south of Big Oak Road and ran in an east-west direction.

One day was spent obtaining information from herbarium specimens at the Academy of Natural sciences and *The Flora of Bucks County* (Benner, 1932) about the past distribution of Coastal Plain plants in Lower Makefield Township.

Voucher specimens of wetland plants and plants of Five Mile Woods were collected and deposited in the herbarium of the Academy of Natural Sciences of Philadelphia.

RESULTS

Three general categories of wetland may be recognized in Lower Makefield Township: (1) Forested Wetland, (2) Herbaceous Wetland, and (3) Stream Channels.

[1]Michael E. Kachur and Frank W. Acker were field assistants.

Forested Wetland

This wetland category is generally dominated by *Acer rubrum* (red maple) along with *Liquidambar styraciflua* (sweet gum) in some areas. However, these trees are not restricted to wetland and the shrubby and herbaceous understory are better indicators of wetland conditions. Such plant assemblages include *Alnus serrulata* (alder), *Sambucus canadensis* (elder), *Impatiens capensis* (jewelweed), *Onoclea sensibilis* (sensitive fern), *Symplocarpus foetidus* (skunk cabbage), *Cinna arundinacea* (wood reedgrass), *Chelone glabra* (turtlehead), and *Boehmeria cylindrica* (bog hemp). Some of these species also occurred in non-wooded habitats where they (e.g., *Impatiens capensis*) often grew in drier conditions that would not be classified as wetland.

Herbaceous Wetland

In areas not dominated by trees, assemblages of the following species were reliable indicators of wetland: *Typha latifolia* (cattail), *Sparganium americanum* (bur reed), *Sagittaria latifolia* (arrowhead), *Alisma subcordatum* (water plantain), *Polygonum hydropiperoides* (mild water pepper), *Polygonum punctatum* (water smartweed), *Leersia oryzoides* (rice cutgrass), *Lycopus uniflorus* (water horehound), *Ludwigia palustris* (water purslane), *Carex lupulina* (sedge), and *Carex comosa* (sedge). In the wetland area southeast of Yardley along the Pennsylvania Canal, water was present for long enough periods of time to allow for the growth of such submergent species as *Ceratophyllum echinatum* (coontail) and *Potamogeton pusillus* (pondweed). Some species such as *Lythrum salicaria* (purple loosestrife), which often dominate herbaceous wetland, may also grow in drier conditions that would not be classified as wetland.

Stream Channels

With the exception of the stream along the Pennsylvania Canal southeast of Yardley, stream channels are mostly devoid of extensive aquatic vegetation. However, in Five Mile Woods, two species of water starwort (*Callitriche heterophylla* and *C. stagnalis*) occur abundantly in small shallow pools of Queen Anne Creek. These species also grow at other sites but are much less abundant. In non-wooded areas, *Ludwigia palustris* (water purslane) sometimes is locally abundant and *Elodea nuttallii* (waterweed) is occasionally found.

Data from herbarium specimens and *The Flora of Bucks County* (Benner, 1932) reveal that numerous Coastal Plain species grew on poorly drained moist or wet substrates south and southeast of Yardley during the past 50 years. Time did not permit an extensive search for these previously reported species (listed in Table III-2) but judging from the amount of development in the area, it is probable that as many as 20 of them no longer grow in Lower Makefield Township. A similar, but less extensive group of Coastal Plain species have also been reported from Five Mile Woods and vicinity (Table III-3). Many of these species can still be found but at least four of them (indicated on table) could not be located in the fall of 1978.

DISCUSSION

Pennsylvania's limited Coastal Plain has been considerably altered by urban and suburban development during the past 50 years. In Lower Makefield Township it is possible that about 25 species of Coastal Plain plants have been extirpated, including six species that are now considered so rare as to be threatened with extinction from Pennsylvania (Wherry, 1976). Five Mile Woods is the last extensive Coastal Plain forest in Pennsylvania and thus deserves special consideration. It is located on a narrow zone of bedrock formations (Greenman, 1955) between the Coastal Plain and the Piedmont Plateau. Its location on such restricted transitional bedrock formations makes it of special interest ecologically for comparative studies with forests located on the Coastal Plain and Piedmont Plateau.

In addition to its unique Coastal Plain flora, Five Mile Woods also contains a large amount of forested wetland and a small area of boggy, herbaceous wetland. These wetlands are important ecologically for their water holding capacity, sediment retention, pollutant filtration, nutrient recycling, effect on increasing oxygen content of the water, and habitats they provide for wildlife.

The most extensive wetland in Lower Makefield Township occurs along the east side of the Pennsylvania Canal from the Yardley borough boundary to Ferry Road. This area is one of the most aesthetically appealing along the canal to hikers. The proximity of it to densely populated areas and to the Delaware River makes its wetland roles (e.g., water holding capacity, sediment retention, pollutant filtration, and nutrient recycling) very important. Reducing or eliminating such a wetland would have a negative ecological impact on the Delaware River.

Many of the small forested wetlands in Lower Makefield Township also have important ecological roles. Allowing such areas to be developed will increase the amount of water in stream channels and contribute to an increase in turbidity.

Fewer sediments will be retained by the wetlands and increased stream flow will erode more sediment from stream banks. Small areas of herbaceous wetland, even that in the ditches of Interstate 95, have a similar ecological role.

Some of the rare Coastal Plain plants mentioned in this report grow in moist open areas or at least in areas where tree density is low. These plants can grow to some extent in places where man has altered the environment by logging or farming but can not grow in areas that have been bulldozed, filled in, or heavily landscaped.

RECOMMENDATIONS

The following recommendations are made for wetlands and poorly drained Coastal Plain woods in Lower Makefield Township:

1. Preserve Five Mile Woods because of its botanical uniqueness and for the wetlands it contains. Periodically monitor the woods to determine the condition of its flora. If changes occur in the flora it would be important to determine if these changes are related to succession, increases in adventive weeds, different water conditions, etc.

2. Delineate and protect the extensive wetland southeast of Yardley along the east side of the Pennsylvania Canal because of its ecological and aesthetic importance. A careful delineation of the wetland boundary, based on assemblages of wetland plants, is needed now before conditions are altered by encroaching development.

3. Devise a simple method for delineating wetland boundaries for all wetlands of the township according to assemblages of plant species. Record the location of wetlands and periodically monitor them to determine condition of the flora.

4. Continually monitor changes in the flora of the township by periodic field checks. For example, verification of the extirpation of 25 species of Coastal Plain plants from the township would yield quantitative data concerning the current status of the township's flora.

5. Encourage developers to consider alternatives to procedures that would have detrimental impacts on the township's flora. Developers can devise methods that will allow more of our native flora to be preserved instead of eliminated.

LITERATURE CITED

Benner, W.M. 1932. The Flora of Bucks County, Pennsylvania. Published by the author, Philadelphia.

Greenman, D.W. 1955. Ground Water Resources of Bucks County, Pennsylvania. Pennsylvania Geological Survey, 4th Ser., Bull. W11.

Wherry, E.T. 1976. Rare Plants of Southeastern Pennsylvania. Bartonia 44:22-26.

Table III-1. Woody plants over 1.5 meters tall found in Five Mile Woods, Lower Makefield Township, Sept.-Oct. 1978.

Transect 1 (North of Big Oak Road)

Taxon	Number of Plants
Acer rubrum L.	34
Liquidambar styraciflua L.	28
Fagus grandifolia Ehrh.	13
Betula lenta L.	9
Quercus rubra L.	8
Liriodendron tulipifera L.	5
Quercus alba L.	4
Fraxinus americana L.	3
Carya ovata (Mill.) Koch	2
Ulmus americana L.	2
Sassafras albidum (Nutt.) Nees	2
Populus tremuloides Michx.	1
Total Trees	111
Viburnum dentatum L.	39
Lindera benzoin (L.) Blume	9
Vaccinium corymbosum L.	6
Smilax sp.	1
Clethra alnifolia L.	1
Rhododendron viscosum (L.) Torr.	1
Pyrus sp.	1
Total Shrubs	58
Total Plants	169

Table III-1 (continued). Woody plants over 1.5 meters tall found in Five Mile Woods, Lower Makefield Township, Sept.-Oct. 1978.

Transect 2 (South of Big Oak Road)

Taxon	Number of Plants
Fagus grandiflora Ehrh.	20
Acer rubrum L.	18
Liquidambar styraciflua L.	10
Betula lenta L.	9
Quercus rubra L.	7
Carya ovata (Mill.) Koch	6
Liriodendron tulipifera L.	6
Nyssa sylvatica Marsh.	3
Quercus alba L.	1
Fraxinus americana L.	1
Prunus serotina Ehrh.	1
Total Trees	82
Lindera benzoin (L.) Blume	25
Viburnum dentatum L.	22
Vaccinium corymbosum L.	9
Clethra alnifolia L.	1
Viburnum acerifolium L.	1
Hamamelis virginiana L.	1
Prunus virginiana L.	1
Total Shrubs	60
Total Plants	142

Table III-2. Rare Coastal Plain plants reported from the south and southeast of Yardley, Pa. during the past 50 years.

Taxon	Status in Bucks County (Benner, 1932)
Arisaema pusillum	Damp woods and thickets; rare
Aster radula	Low woods; rare
Bartonia paniculata	Moist sandy soil, Coastal Plain; rare and local
Bartonia virginica	Moist sandy soil of woods, occasional on Coastal Plain; rare elsewhere
Calamagrostis cinnoides	Moist thickets; rare
Carex folliculata	Wet woods and swamps; locally abundant on the Coastal Plain, unknown elsewhere in the County
Eupatorium pilosum	Moist soil of the Coastal Plain; rare
Eupatorium pubescens	Dry or sandy soil; rare
Gentiana saponaria	Moist or wet soil in lower end; locally abundant
Gerardia purpurea	Moist sandy soil; common on the Coastal Plain, rare or absent elsewhere
Habenaria ciliaris	Boggy woods and thickets; rare
Illex laevigata	Swamps, wet woods and thickets of the Coastal Plain; not frequent
Ilex opaca	Moist woods and thickets; rare
Leucothoe racemosa	Swamps, moist thickets and banks; common on the Coastal Plain, rare elsewhere
Lilium superbum	Low rich soil of the Coastal Plain; locally abundant
Liquidambar styraciflua	Low rich soil of the Coastal Plain where it is frequent

Table III-2 (continued). Rare Coastal Plain plants reported from the south and southeast of Yardley, Pa. during the past 50 years.

Taxon	Status in Bucks County (Benner 1932)
Lobelia nuttallii	Moist soil on the Coastal Plain; locally abundant
Lygodium palmatum	Low woods and thickets; rare
Lyonia mariana	Moist sandy soil; occasional in lower end
Magnolia virginiana	Swamps; locally abundant on the Coastal Plain
Myrica heterophylla	not listed from Bucks County
Oxypolis rigidior	Swampy places in lower districts; occasional
Panicum longifolium	Moist sandy soil on the Coastal Plain where it is frequent
Panicum meridionale	Moist sandy woods or open grounds; rare
Phoradendron flavescens	On *Nyssa sylvatica* branches; very rare
Polygala cruciata	Low sandy soil of the Coastal Plain; rare
Quercus phellos	Moist sandy soil of the Coastal Plain where it is rather frequent
Rhexia virginica	Wet sandy soil; locally abundant on Coastal Plain, rare elsewhere
Rhododendron viscosum	Swampy ground; frequent on Coastal Plain rare elsewhere
Solidago uliginosa	Swampy ground on Coastal Plain; infrequent
Viburnum cassinoides	Swampy woods [three localities cited]

Table III-2 (continued). Rare Coastal Plain plants reported from the south and southeast of Yardley, Pa. during the past 50 years.

Taxon	Status in Bucks County (Benner, 1932)
Viburnum nudum	Swampy ground on the Coastal Plain; occasional
Viola primulifolia	Moist woods meadows and swamps; frequent on the Coastal Plain, occasional elsewhere
Woodwardia areolata	Wet woods in Coastal Plain district; more common than preceding [*Woodwardia virginica*]

Table III-3. Rare Coastal Plain plants reported from Five Mile Woods and vicinity, Lower Makefield Township, during the past 50 years. Species indicated by asterisk were not found in the Academy's fall 1978 survey.

Taxon	Status in Bucks County (Benner, 1932)
Arisaema pusillum	Damp woods and thickets; rare
Bartonia paniculata	Moist sandy soil of Coastal Plain; rare and local
Bartonia virginica	Moist sandy soil of woods; occasional on Coastal Plain; rare elsewhere
Calamagrostis cinnoides	Moist thickets; rare
Clethra alnifolia	Wet soil; common on the Coastal Plain, rare elsewhere
**Euonymus americanus*	Low woods and thickets; rare
Eupatorium pilosum	Moist soil of the Coastal Plain; rare
Gentiana saponaria	Moist or wet soil in lower end; locally abundant
Gerardia purpurea	Moist sandy soil; common on the Coastal Plain, rare or absent elsewhere
Leucothoe racemosa	Swamps, moist thickets and banks; common on Coastal Plain, rare elsewhere
Lilium superbum	Low rich soil of the Coastal Plain; locally abundant
Liquidambar styraciflua	Low rich soil of the Coastal Plain where it is frequent
**Lyonia mariana*	Moist sandy soil; occasional in lower end
Myrica pensylvanica	Sterile soil on Coastal Plain; rare

Table III-3 (continued). Rare Coastal Plain plants reported from Five Mile Woods and vicinity, Lower Makefield Township, during the past 50 years. Species indicated by asterisk were not found in the Academy's fall 1978 survey.

Taxon	Status in Bucks County (Benner, 1932)
Panicum longifolium	Moist sandy soil on the Coastal Plain where it is frequent
* *Panicum meridionale*	Moist sandy woods or open grounds; rare
Rhexia virginica	Wet sandy soil; locally abundant on the Coastal Plain, rare elsewhere
Rhododendron viscosum	Swampy ground; frequent on Coastal Plain, rare elsewhere
* *Viola primulifolia*	Moist woods, meadows, and swamps; frequent on the Coastal Plain, occasional elsewhere

IV. BIOLOGICAL STREAM SURVEY

INTRODUCTION

During late summer, 1978 (August 31 and September 6 and 7), a biological stream survey was conducted at several sampling stations along the major streams occuring within Lower Makefield Township. These streams included: Dyers, Buck, Core, Silver and Brock Creeks, and Rock Run. The purpose of the survey was to evaluate the overall water quality conditions and relative health of the individual stream ecosystems. In addition to providing a baseline condition of the stream systems against which to measure disturbances or improvements to water quality, the biological survey can be used to some extent to examine the source and/or cause of disturbances. The composition of the flora and fauna coupled with water chemistry data reflects stream disturbances. Therefore, by examining the data it is possible to evaluate the probable cause and relative extent of the water quality problem. To accomplish this it is important to examine the biota and chemistry in a more detailed manner and on a more frequent basis than that described here. Nevertheless, an attempt is made to identify any obvious sources of pollution to the stream system.

During the course of its work in the eastern and southern U.S., the Academy has observed the characteristics of disturbed aquatic communities. Together with the scientific literature, these observations indicate that in ecologically comparable reaches of rivers and streams not adversely affected by pollution, the numbers of species present are similar. In addition, in the absence of disturbance the populations of the different species tend to be small to moderate; no single organism occurs in disproportionately large numbers, dominating the flora or fauna. The biota typically includes representatives from many taxonomic groups, and from all the levels of the food chain. In a healthy situation the genera and species present should be largely predictable, given the geographical location and the type of stream and habitat.

The first effect of pollution is usually to change the relative sizes of populations of various species. Some organisms are known to be especially sensitive to particular types of pollution. Populations of those species which are relatively sensitive to the pollutant, or whose habitats are destroyed by it, become smaller. Relatively tolerant species may experience population increases as the environment becomes more favorable to them or as inter-specific competition lessens with the decline in numbers of more sensitive organisms. More serious or more prolonged pollution continues or accelerates the process, so that a shift in species composition occurs, with some species disappearing while others become more numerous. Severe pollution usually produces a situation in which the number of different species is greatly reduced and/or the population size of pollution-tolerant species is greatly increased. In some types of toxic pollution the populations of all species present are depressed.

High diversity, no disproportions in numbers, the presence of sensitive as well as tolerant organisms, and a complex food web are all attributes of balanced, stable aquatic communities. Because even subtle departures from these conditions frequently result from environmental disturbances, a biological river survey is a sensitive tool for evaluating ecological health.

During the stream survey, a three-person survey team evaluated the condition of the algae, insect and fish community at many of the stream stations indicated in Figure IV-1. The approximate locations of these stations are as follows:

1A - Core Creek at Woodside Road
1C - Core Creek at Lindenhurst Road
2A - Dyers Creek near Mt. Eyre Road
2B - Dyers Creek at River Road
3A - Buck Creek at Houston Road
3B - Buck Creek at West Afton Avenue
4A - Brock Creek at Oxford Valley Road
4B - Brock Creek at Edgewood Road
4C - Brock Creek at West Afton Avenue
5A - Silver Creek at Edgewood Road
6A - Rock Run at Big Oak - Makefield Road

Sampling for fish was done on August 31 and insect and algae sampling was conducted on September 6 and 7. During sampling, habitats throughout at least one riffle pool sequence at each station were examined.

In order to obtain the maximum amount of data with limited time and personnel, cursory survey work was concentrated in areas containing the greatest proportion of species. Shallow water habitats were worked intensively, with rocks, logs and debris being examined for insects, other invertebrates and algae. Mud and sand from shallow water were sifted to obtain worms, molluscs and insect larvae. Mud flats were examined for algal mats and snails. Rocks were removed from riffles and systematically searched for families partial to fast water habitats, including mayflies, caddisflies, stoneflies and hellgrammites. Beds of aquatic plants and root tangles were worked with a dip net to obtain beetles, damselflies and other organisms that favor such habitats. Accumulations of leaves and trash in backwaters were collected and placed in a white pan so that dragonflies, midge larvae, leeches, etc. could be easily picked out. Field observations were continued at each station until the investigators had obtained sufficient data to characterize the condition of the stream.

ALGAE AND AQUATIC VASCULAR PLANTS

Introduction

Algae and aquatic vascular plants are important components of riverine ecosystems. Using solar energy, they transform inorganic carbon from their environment into organic matter that forms the base of the aquatic food web. In this process of photosynthesis, oxygen is produced as a byproduct. The maintenance of a healthy aquatic flora is essential to insure efficient functioning of the aquatic ecosystem by providing food and oxygen while at the same time purifying the water.

Algae and aquatic vacular plants can be used as indicators of ecological conditions in natural and altered environments. Benthic algae growing on persistent substrates at a given site can be presumed to reflect the consequences of the prevailing water quality. The study of the composition of benthic algal communities in terms of species present and the sizes of their populations reveals pertinent information on the health and ecological characteristics of the environment in which they are living.

Methods and Procedures

A detailed examination of each habitat was made in the field in order to determine the common algae present at the various sampling stations. In addition to the field determinations, some specimens were returned to the Academy laboratories for taxonomic determination by appropriate specialists; Dr. Francis Drouet (blue-green algae), Ms. Noma Ann Roberts (diatoms) and Mr. Michael Kachur (vascular plants).

Results

Table IV-1 presents species occurrence records at the individual stations. The algal flora was generally similar in the six streams. Diatoms were the most abundant algal group, followed in rank by green algae and blue-green algae. Overall algal growth was moderate in amount, which is the expected condition in small, tributary streams. Aquatic vascular plants were present in Core, Buck, Brock and Silver Creeks, but they were nowhere abundant. The only plant species observed was a water-starwort (*Callitriche* sp.), except in Brock Creek where a few colonies of an aquatic moss were seen.

Every one of the eight stations examined showed brown mats of diatom streamers covering many of the submerged rocks. These mats were all similar in appearance, but to determine specific species occurence, samples were taken at three different stations and random counts of 100 cells were made at the Academy on uncleaned material from each. The results were almost identical and showed that the diatom population was heavily dominated by a single species. *Melosira varians* occupied 89% of the material examined from Core Creek (Station 1C) and 86% of the material examined from Brock Creek (Station 4C) and Silver Creek (Station 5A).

Scattered colonies of green algae were observed at each station except 2B and 4C. The only widespread genera were *Spirogyra* and *Cladophora*. Blue-green algae were not recorded from Stations 1A, 1C and 3A; were rare at Stations 4A, 5A and 6A; and were locally common at Stations 2B and 4C. The blue-green algal colonies were almost exclusively *Microcoleus*.

Conclusions

The results of the benthic stream studies indicate that Core Creek was in the best condition of the six streams. Buck and Brock Creeks were less healthy than Core Creek. Both Silver Creek and Rock Run showed evidence of pollution at the study stations. Dyer Creek represented an intermediate condition between the former and the latter pairs of streams.

The pollution indicated in Silver Creek and Rock Run could have been due to excessive nutrient enrichment, suspended sediment loading, possible discharge of toxic materials or some combination of these. All the streams studied showed evidence of nutrient enrichment and siltation levels that were higher than would be expected in undisturbed watersheds. These problems are associated with non-point source loading within the township.

Enhancement of these watersheds depends primarily on controlling non-point source influences. No unique resources were found among the benthic flora.

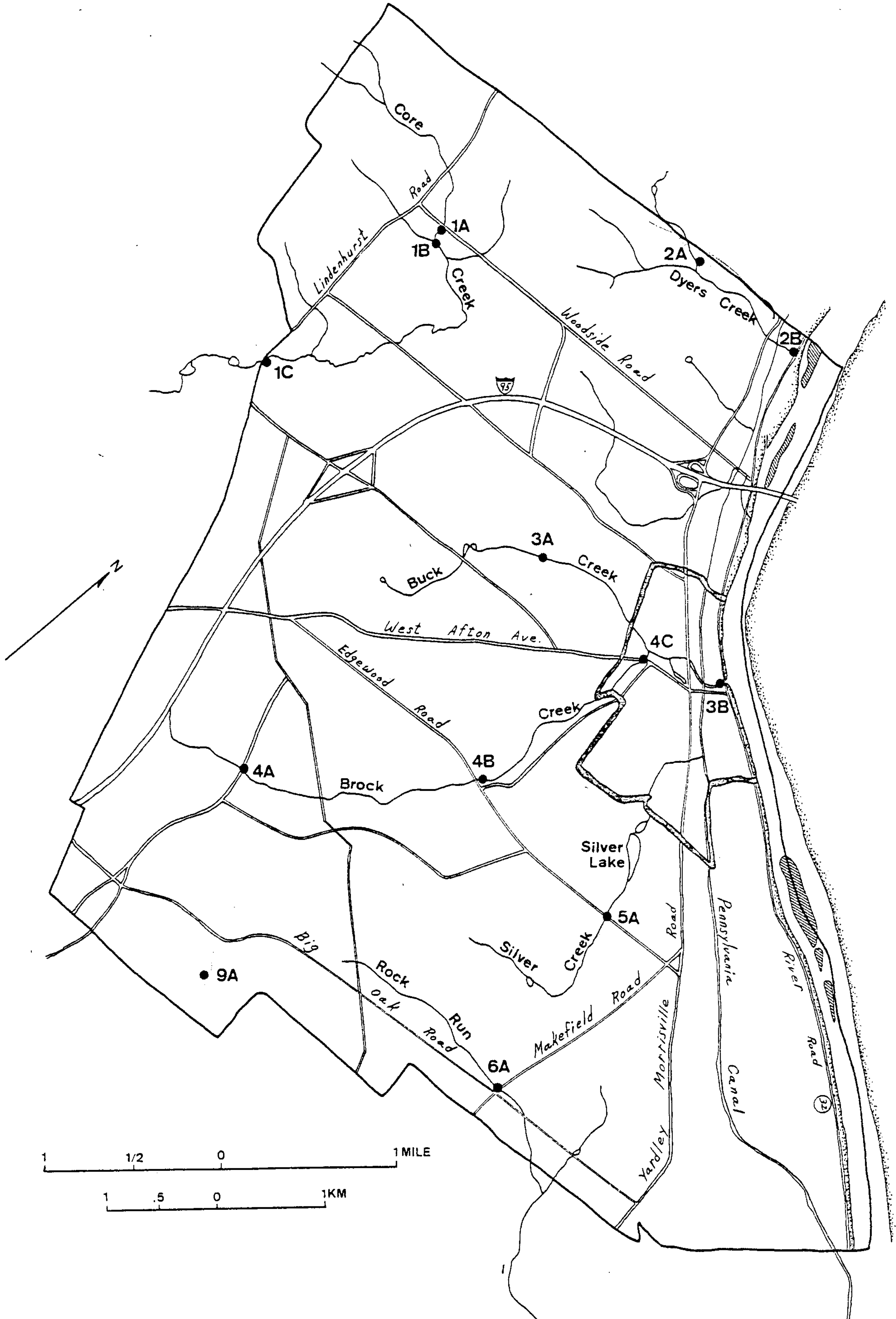

Figure IV-1. Sampling stations used in biological and chemical surveys.

Table IV-1. Species list of common algae and aquatic vascular plants occurring in streams in Lower Makefield Township, September 6-7, 1978. See Figure IV-1 for station locations.

Taxon	Stations 1A	1C	2B	3A	4A	4C	5A	6A
Green Algae (Chlorophyceae)								
Cladophora sp.	X	X	-	-	X	-	X	-
Spirogyra sp.	X	-	-	X	X	-	-	X
Oedogonium sp.	-	-	-	-	X	-	-	-
Hydrodictyon reticulatum (L.) Lagerh.	-	X	-	-	-	-	-	-
Tetraspora gelatinosa (Vauch.) Desv.	-	-	-	X	-	-	-	-
Stigeoclonium lubricum (Dillw.) Kütz.	-	-	-	-	-	-	X	-
Blue-Green Algae (Myxophyceae)								
Microcoleus vaginatus (Vauch.) Gom.	-	-	X	-	X	X	X	X
Schizothrix rubella Gom.	-	-	-	-	-	-	X	-
Microcoleus lyngbyaceus (Kütz) Crouan	-	-	X	-	-	-	-	X
Diatoms (Bacillariophyceae)								
Melosira varians C.A. Ag.	X	X	X	X	X	X	X	X
Synedra ulna (Nitz.) Ehr.	-	-	-	-	-	-	X	-
Navicula rhynchocephala v. *germainii* (Wallace) Patr.	-	X	-	-	-	X	-	-
Vascular Plants								
Callitriche sp.	-	X	-	X	-	-	X	-
Fontinalis sp.	-	-	-	-	X	-	-	-

INSECTS

Introduction

Aquatic insects are extremely diverse, both in species and in choices of habitat. Because of their tolerance of a wide range of environmental conditions, their relatively sedentary nature, and, for many species, the length of their aquatic life stages before they emerge as adults, they are important to the study of riverine ecosystems. Species composition and sizes of aquatic insect populations are often reliable qualitative indicators of the ecological conditions in a river system.

Methods and Procedures

Because of the diversity of habitat, behavior and form exhibited by insects, examination of all potentially productive habitats and substrates was performed at each study location. During this survey, the insect fauna was collected at each of the stations by hand, and with dip nets. Usually specimens collected in this manner are either preserved in the field or transported to the laboratory alive, where special methods necessary for preservation are completed. However for economic reasons, no specimens were retained by the Academy during this study.

Results

A cursory study of the insect fauna of six streams in Lower Makefield Township, which included Core, Dyers, Brock, Buck, Silver and Rock Run Creeks, indicates that varying degrees of enrichment exist within each of the streams studied. The streams were of two types, those that were located in a rural setting such as Core Creek and portions of Brock Creek and those located in urbanized areas such as Dyer, Buck, Silver, Rock Run and the lower portion of Brock Creek. Table IV-2 presents common species occurrence records for each stream station.

Core Creek, a small, moderately-healthy stream flowing through woodlots and pastures, was typical of a rural stream. This stream, and presumably other streams like it in the township, suffers principally from siltation, lack of shade and the input of fertilizers washed in from farmlands through which it flows. The insect fauna of this stream consisted mainly of moderately-tolerant species of caddisflies, mayflies and damselflies. Other species also common were the aquatic beetles, midge larvae, and the common water strider. In general, the fauna was characterized by a moderately-diverse community with those species most tolerant of high nutrient conditions dominating the community. Other non-insect invertebrates also indicates moderate enrichment such as the large population of flatworms found in Core Creek. It is well known that this particular organism expands its population under the influence of increased enrichment.

A variety of stream conditions ranging from semi-healthy to moderately polluted were seen in those streams within the urbanized area. Perhaps the healthiest streams in this category are Buck Creek (3A) and the lower segment of Brock Creek (4C). Both streams flow through residential areas where they undoubtably receive nutrients washed in from lawns, gardens and other sources. In addition to moderately-high nutrient conditions, both streams showed evidence of siltation. This was particularly true in the case of Brock Creek, where much of the bottom substrate was composed of shifting sand and silt. This sediment appears to originate from several sources including unstable stream banks, construction, agricultural runoff and storm drains. Despite enrichment and sedimentation, both streams contained moderately healthy insect communities. These communities were dominated by the net spinning caddisfly, *Hydropsyche* spp. and the heptageniid mayfly, *Stenonema* spp. These species were exceedingly common in both streams. Other species that were found to be fairly numerous included elmid and psephenid beetles, the common water strider and midge larvae. The presence of flatworms and blue-green algae in Brock Creek but not in Buck Creek indicates that Buck Creek is in slightly better condition than Brock Creek.

Dyers Creek, also flowing through some residential areas, represented an intermediate condition between the semi-healthy Brock and Buck Creeks and the polluted condition of Silver and Rock Run Creeks. Essentially, Dyers Creek was heavily enriched and showed signs of siltation. The insect fauna, however, was basically similar to that found in Brock Creek with net spinning caddisflies, mayflies and beetles dominating the community in terms of numbers of individuals. The non-insect invertebrates were more revealing than insects regarding the condition of this creek. Unusually large populations of a freshwater sponge, flatworms, bryozoa and the river snail, *Physa* sp., in addition to the presence of blue-green algae, clearly indicated that substantial nutrients are present. It is likely that if present conditions persist or further degradation takes place, the insect fauna will decline in overall diversity.

Silver Creek and Rock Run Creek were in the poorest condition of any of the streams studied. The insect fauna in Rock Run was non-existent, except for the common water strider, *Geris* sp., which is actually quite independent of water quality since they utilize atmospheric oxygen rather than dissolved oxygen in the water. The cause (or causes) of the polluted condition of Rock Run was not clear. However, the presence of growths of both green and blue-green algae and large populations of flatworms suggest that the pollutant is excessive nutrients, probably inorganic as well as organic in form. During the previous week this station was noted as being excessively muddy, which would suggest that suspended sediment is also a problem for this creek. It is also possible that during dry periods there is insufficient water to support an aquatic insect community. Silver Creek was in only slightly better condition than Rock Run. The only insects found were the caddisflies, the common water strider and midge larvae. More sensitive species such as dragon- and damselflies, mayflies and beetles had completely disappeared. In addition to the poor insect fauna, the presence of blue-green algae, a sewage fungus (*Sphaerotilus* sp.) and flatworms attest to the polluted nature of this stream. The source of the pollution was not clear but it is probably multiple, such as organic waste and runoff from lawns, orchards, farmland and roadways. In addition, a citizen of the township reported that a neighbor regularly sprays his shade trees with pesticides and it is possible that, in part, the poor condition of the insect fauna may be due to wash-in of these pesticides.

Conclusions

The results of the cursory study of six streams in Lower Makefield Township indicate that to varying degrees each stream exhibits the effects of increased enrichment and/or siltation. The sources of enrichment and siltation were not defined during the study, however, it is likely that they are multiple. Among the most obvious would be runoff from farmland, development sites, parking lots, roadways, orchards, lawns and gardens. In addition, toxic pollutants in the form of pesticides used in agriculture as well as in residential areas to control insect pests may find their way into the streams via surface runoff, thus contributing to the degraded conditions. The effect of these pollutants varied from only moderately affecting the insect community, as in Buck Creek, to virtual elimination of the fauna, as in Rock Run Creek. The severity of pollution in these creeks is evident when one considers the overall diversity of insect species. In a normal piedmont stream 70 to 100 or more species are usually found, while in the streams studied in Lower Makefield Township it is likely that not more than 50 or 60 species were present in any one stream.

Table IV-2. Insect species recovered at individual survey Stations on six streams in Lower Makefield Township, September 1978. See Figure IV-1 for station locations.

	Core Cr 1A	Core Cr 1C	Dyers Cr 2B	Brock Cr 4A+4C	Buck Cr 3A	Silver Cr 5A	Rock Run 6A
Phylum Arthropoda							
Class Insecta							
Group Paleoptilota							
Order Odonata							
Suborder Zygoptera							
Family Agrionidae							
Calopteryx sp.	X	X	X	X	X	-	-
Family Coenagrionidae							
Enallagma sp.	X	-	-	-	-	-	-
Suborder Anisoptera							
Family Aeshnidae							
Boyeria sp.	-	-	-	-	X	-	-
Order Ephemeroptera							
Family Baetidae							
Baetis spp.	X	X	X	X	X	-	-
Family Heptageniidae							
Stenacron spp.	X	X	X	X	X	-	-
Stenonema spp.	X	X	X	X	X	-	-
Group Neoptilota							
Order Plecoptera	-	-	-	-	-	-	-
Order Hemiptera							
Suborder Heteroptera							
Family Gerridae							
Gerris spp.	X	X	X	X	X	X	X
Order Neuroptera							
Family: Sialidae							
Sialis sp.	X	-	-	-	-	-	-
Order Teichoptera							
Family Limnephilidae							
Neophylax sp.	-	-	X	-	-	-	-
Family Hydrosychidae							
Hydropsyche spp.	X	X	X	X	X	X	-
Cheumatopsyche spp.	X	X	X	X	X	X	-
Order Coleoptera							
Family Elmidae							
Elmis spp.	X	X	X	X	X	-	-
Family Psephenidae							
Psephenus spp.	X	X	X	X	X	-	-
Order Lepidoptera	-	-	-	-	-	-	-
Order Diptera							
Suborder Nematocera							
Family Chironomidae	X	X	X	X	X	X	-

FISHES

Introduction

Ten locations on 6 creeks in Lower Makefield Township were sampled on August 31, 1978 for fish. This brief survey was intended to give an indication of species composition of the streams and to locate unusual communities or species of fish present. Habitat and water quality were observed to determine the presence of man-induced influences and how they may have affected the fish populations.

Methods

Fish were collected with a 10x4-ft. seine made of ¼ in mesh. A pool and a riffle at each study location were seined. Generally, one haul at each habitat type was taken, although empty hauls were repeated. In no way were the collections intended to be quantitative or comparable among sampling sites.

Many of the fish collected were preserved in formalin and returned to the Academy of Natural Sciences in Philadelphia for identification. Species that were collected in large numbers were noted and returned to the stream.

Notes were taken on the condition of each stream at the sampling sites; again, these were general impressions and not quantitative measurements. Factors such as water clarity, depth, substrate type, cover, bank stability, and pool:riffle ratios were considered.

Stations sampled were the same as the water chemistry stations (Fig. IV-1).

Results and Discussion

Approximately 14 species of fish were collected from the six creeks sampled (Table IV-3). The streams were classified according to physical characteristics into 3 groups: small, natural; small, disturbed; and medium, disturbed.

Generally, the small, natural streams were characterized by clear, shallow water, stable banks, and the presence of riffles and pools. Although the watershed as a whole was not evaluated for each creek, if the banks immediately around the sampling site were not cultivated or domesticated, the stream was classified as "natural". Stations 1A+1B, 1C, 2A, and 3A fall into this group. These streams yielded few species and were dominated by creek chubs and blacknose dace. Tessellated darter, pumpkinseed, and white sucker were the only other species observed or collected at these stations.

The small, disturbed streams exhibited signs of either terrain disturbance, domesticated banks (lawns, for example), and/or turbid water. The water was similar in depth and flow to the small, natural streams. Stations 2B, 4A, 4B, 5A, and 6A were classified in this group of small, disturbed streams. Station 6A was the poorest in fish habitat, with no substantial riffles observed at the sample site, little cover, and high turbidity. Although Stations 4A and 4B were considered "disturbed", they yielded a fish fauna similar to the undisturbed streams. The other stations yielded some additional species, mainly shiners and sunfishes (Table IV-3). Creek chubs and blacknose dace, the dominant species in the previous group, were absent in collections from Stations 2B and 6A.

Station 3B is the only station which fit into neither of the two previous groups. It is a considerably larger stream than those observed at the other sites; silty, with trash and a disturbed substrate. For those reasons it was classified as medium, disturbed. No fish were collected in the riffles and the pool species were mainly cyprinids (Table IV-3). This station may be influenced by the Delaware River as the species collected are typical of a big river drainage in the area and the station is quite close to the river. Station 2B, which was also dominated by cyprinids, indicates a similar influence from the Delaware.

It is clear from this brief survey that none of the streams contains any unique or unusual fish species or hold much promise as a sport fishery. Generally, they are too small to support a substantial biomass. Although the differences in water and habitat quality noted above are exerting some influence on fish populations, e.g., the shift away from creek chub and blacknose dace as conditions deteriorate, other factors should be considered. The proximity of the Delaware River is responsible for some changes, as would be expected. Natural variability is expected from site to site, even in undisturbed watersheds. However, the disturbed streams are certain to be less desirable both aesthetically and in terms of native fish faunas. The most extremely disturbed stream, Rock Creek at Station 6A, serves as the best example of a damaged system.

Conclusions

Although the streams in the township are not large enough to support a sport fishery, they should be preserved as much as possible as integral components of a well-balanced, desirable ecosystem. The mouths of the streams at the Delaware River may also be used by several species of fish in the Delaware River for spawning. To maintain stream populations as well as the potential value of these streams to Delaware River fishes, water quality should be preserved in the undisturbed streams and improved in the disturbed streams.

Similarly, land management practices should be directed towards the maintenance of natural bank vegetation for stability and as fish habitat.

Table IV-3. Species and numbers of fish collected at each sampling station on six creeks in Lower Makefield Township, August 1978. See Figure IV-1 for sampling site locations.

	Core 1A + 1B	1C	Dyers 2A	2B	Buck 3A	3B	Brock 4A	4B	Silver 5A	Rock 6A
Silvery minnow (*Hybognathus nuchalis*)						3				
River chub (*Nocomis micropogon*)						4				
Golden shiner (*Notemigonus crysoleucas*)						3				
Common shiner (*Notropis cornutus*)				5		1			1	
Spottail shiner (*N. hudsonius*)						2				
Spotfin shiner (*N. spilopterus*)				3						
Blacknose dace (*Rhinichthys atratulus*)	2		5*		1		1	4	3	
Longnose dace (*R. cataractae*)				1						
Creek chub (*Semotilus atromaculatus*)	5	3*	3*		1		4	5*	6	
White sucker (*Catostomus commersoni*)					4			1		1
Unidentified Sunfishes (*Lepomis* spp.)									6	
Pumpkinseed (*L. gibbosus*)		1							1	1
Black crappie (*Pomoxis nigromaculatus*)						1				
Tessellated darter (*Etheostoma olmstedi*)	X+							3		

*Several returned to the stream

+Sight observation

V. SURFACE WATER CHEMISTRY

INTRODUCTION

Water samples for chemical analysis were collected on August 31, 1978 at station locations along creeks in the Lower Makefield Township (see Fig. IV-1 for station locations). The following physical-chemical constituents were measured: dissolved oxygen, pH, temperature, nitrate, nitrite, ammonia and total phosphorus. These parameters were selected because they have direct effects on stream biota and because they are affected to a great extent by urbanization.

Data derived from these analyses indicate something about the probable cause and relative extent of surface water quality problems in the township. In order to be more definitive about stream water quality and the causes of disturbances, a more detailed chemical sampling program would be required. Nevertheless, this study is an important first step in seeking to understand existing surface water quality conditions in the township.

METHODS

Measurements of dissolved oxygen and temperature were made using a YSI #57 meter and a Corning 601A portable meter was used to measure pH. Stream flow, which is used to calculate discharge, was measured with a Marsh McBirney Inc. #201 Flow Meter. Water samples, collected in polyethylene containers, were frozen and removed to the laboratory for all other analyses.

Ammonia Determination

Ammonia nitrogen concentrations were obtained by the Direct Nesslerization Method (Standard Methods, 1975, 418B, pp. 412-415) as modified and adapted for the Bausch and Lomb Spectronic mini-20 spectrophotometer. Ammonia sample concentrations were evaluated from a laboratory-prepared standard curve.

Nitrite Determination

The nitrite nitrogen concentration is determined through the formation of a reddish purple azo dye (Standard Methods, 1975, 420, pp. 434-436) as modified and adapted for the Bausch and Lomb Spectronic mini-20 spectrophotometer (Baush and Lomb Water Technology Manual #33-10-15-10030). Nitrite sample concentrations were evaluated from a laboratory-prepared standard curve.

Nitrate Determination

Nitrate nitrogen concentrations were determined by the Cadmium Reduction Method (Standard Methods, 1975, 419C, pp. 423-427) as modified and adapted for the Baush and Lomb Spectronic mini-20 spectrophotometer (Baush and Lomb Water Technology, Manual #33-10-15-10030). Nitrate is quantitatively reduced to nitrite by batch mixing with amalgamated cadmium filings. The nitrite produced is determined by diazotizing with sulfanilamide and coupling with N- (1-naphthyl)-ethylenediamine to form a reddish purple azo dye. Nitrate sample concentrations were evaluated from a laboratory-prepared standard curve.

Total Phosphorus

Total phosphorus concentrations were determined by the Technicon Autoanalyzer System AAII and the Block Digestion BD-40 employing persulfate digestion (Standard Methods, 1975, 425C-III, pp. 476). Phosphorus was determined by the Ascorbic Acid Method (Standard Methods, 1975, 425F, pp. 481-483) where ammonium molybdate and potassium antimonyl tartrate react with orthophosphate to form a heteropoly acid-phosphomolybdic acid that is reduced to the intensely colored molybdenum blue by ascorbic acid. Phosphorus sample concentrations were evaluated from a laboratory-prepared standard curve.

RESULTS AND DISCUSSION

Table V-1 presents chemistry data from water samples collected at individual station locations. Stream discharge measurements are also included in this table.

It is important to emphasize that a rainfall directly preceeded stream sampling and this could have affected the concentration of many of the chemical constituents measured in the study. Earlier in the day on August 31 there had been a rainfall of .42 inches (recorded at Trenton Airport). On August 28 there had been another rainfall of 2.20 inches (also recorded at the Trenton Airport). Because these rainfalls increased runoff, the quantity of potential pollutants from non-point sources would be expected to be higher immediately after the storm events. Therefore, runoff related pollutants, including sediment from construction sites, fertilizer and manure associated with agriculture, and highway-and residential-related pollutants, would be expected to be major contributing factors in affecting the water quality observed in the township streams during the Academy's August study. Increased runoff would also serve to increase stream velocities and discharge and could also act to resuspend nutrient-laden sediments in the stream. Dissolved oxygen might be improved under such conditions, and phosphorus concentrations would be expected to be greater.

Dissolved Oxygen

Dissolved oxygen concentrations were well above 7 mg/l at all stations except at Station 4B (Brock Creek at Edgewood Road) where the concentration was 6.7 mg/l. The reason for this slightly lower value is not clear. In any case, this level of dissolved oxygen is more than sufficient for supporting aquatic life in the stream. Data collected by the Bucks County Division of Natural Resources in October, 1970 at Buck and Brock Creeks also showed high dissolved oxygen concentrations at all stations (including the area near the Academy's Station 4B).

pH and Temperature

In the six streams sampled, pH ranged from 6.8 to 7.3. This range is considered normal for piedmont streams and does not present any difficulty for aquatic life. Temperature ranged from 21°C to 24°C. Generally speaking, those reaches having vegetative cover overhanging the stream exhibited lower temperatures than those reaches more exposed to sunlight. This is particularly apparent in the Core Creek area. Station 1A is located in a wooded stream corridor and Station 1C in an open pasture. There was a 2°C difference between these stations. Station 9A, which is located on Queen Anne Creek in the Five Mile Woods, exhibited a temperature of 23°C, which was intermediate within the temperature range recorded in streams during this study. Because the stream was located in a wooded area, a lower temperature might have been expected but it is thought that ground water infiltration into this "wet area" introduced warmer temperatures from the environs to the creek. The temperature range observed in Lower Makefield Township streams is well within the tolerance range for the fish found there.

Nitrogen

Nitrogen values (especially nitrate and ammonia) were elevated at most of the stream stations sampled in Lower Makefield Township. There are no apparent point sources of nitrogen in the township. The major man-induced sources of nitrogen in Lower Makefield Township would be expected to be urban runoff, septic tank and cesspool leachate, and agricultural runoff, including fertilizer and livestock wastes. Because these sources arise from diffuse sources (nonpoint) they are difficult to control.

Nitrogen levels can also be affected by a number of natural processes and sources including rainfall, geological formations, soils, and decomposition of vegetation and animal matter (particularly important in wetland areas).

The actual species of nitrogen, (ammonia) (NH_4^+), nitrite (NO_2^-), nitrate (NO_3^-), and complex organic forms is controlled by a number of chemical, physical and biological factors. Normally ammonia undergoes rapid oxidation and is stepwise converted to nitrite (NO_2) and nitrate (NO_3) in the stream setting. For this reason, nitrate is usually the predominant species in streams (except when reducing conditions are present). Likewise, unless there is a fairly recent or nearby source, the concentration of ammonia should be fairly low in streams.

While all forms of nitrogen can be transported by runoff, nitrate also has the ability to leach through soils with relative ease. Ammonia, however, is usually adsorbed on soil particles and is less likely to leach unless adsorption sites on soil particles become saturated.

Concern over nitrogen concentrations stems from the fact that nitrogen is an important nutrient for aquatic plants. Excessive amounts can contribute to nuisance algal bloom conditions, especially where streams enter lakes or ponds. The U.S.G.S. (1967) reported that the quantities of nitrate present in surface waters are generally less than 1.10 mg/l NO_3-N. Chu (1942) reported that a range of NO_3-N concentrations of 0.77-3.74 mg/l was optimal for algal growth. When present in extremely high concentrations ammonia can be toxic to aquatic life.

As indicated, nitrogen levels were elevated at stream stations throughout the township. Nitrate concentrations (as N) ranged from 0.5 to 5.2 mg/l, nitrite concentrations (as N) ranged from 0.03 to 0.11 mg/l and ammonia (as N) ranged from 0.1 to 0.40 mg/l. In the Core Creek area agricultural runoff is probably a prime factor affecting nitrogen concentration, especially at Station 1C, located on a farm, where the nitrate concentration was approximately eight times that recorded in the wooded corridor of that stream at Woodside Road (1A). It is also possible that Station 1C is influenced by activities of the Grey Nuns of the Sacred Heart College. For the Core Creek stations, 1A had the highest nitrite and ammonia concentration and this might suggest a nearby source, such as septic tanks or cesspools in that vicinity of the stream.

Along Dyers Creek, Station 2B exhibited higher ammonia levels (0.25 mg/l). Again, this might be related to septic tank leachate.

The highest nitrate and nitrite values for all streams in the township occurred along Buck Creek; nitrate concentrations of 5.2 mg/l and 4.8 mg/l were measured at Stations 3A and 3B, respectively. Septic tank leachate from upstream areas and urban storm runoff are probably important in affecting these concentrations. Ammonia levels of 0.20 and 0.25 mg/l were measured at these stations; these levels are thought to be relatively high.

Brock Creek (Stations 4A and 4B) exhibited much reduced nitrate and nitrite values but had some of the highest ammonia concentrations measured in the township. Station 4B which is probably influenced by septic tank drainage and agricultural runoff had a value of 0.40 mg/l, and Station 4A, farther downstream, had a value of 0.35 mg/l.

For Silver Creek (Station 5A), nitrate, nitrite and ammonia concentrations were 7.6 mg/l, 0.03 mg/l and 0.20 mg/l, respectively. Although these values were not the highest recorded, they were considered high, especially in light of the fact that this creek drains to Silver Lake where algal blooms are most likely to occur. Urban runoff from this largely residential area is thought to be a major factor affecting these nitrogen concentrations.

Rock Run (Station 6A) showed one of the highest ammonia values (0.40 mg/l). Urban runoff would be highly suspect in this stream corridor.

Queen Anne Creek (Station 9A) also showed a high ammonia level (0.40 mg/l). The reason for this is not altogether clear, but it could be related to the abundance of decaying humic material throughout this area of the Five-Mile Woods. Nitrate and nitrite were not particularly high.

Phosphorus

Phosphorus can originate from diverse sources. In Lower Makefield, the most probable sources would include runoff of phosphorus-laden silts and sediments from construction sites, fertilizer and manure, and septic tanks. Leakage and/or exfiltration from sewer lines could also be an important source.

Because phosphorus is a nonconservative element, it undergoes a number of changes in receiving waters. It can be assimilated biologically, removed physically by precipitation reactions with other ions or sorbed on particulate matter. Essentially, these mechanisms provide a means for temporary removal and storage of phosphorus within the stream; ultimately, phosphorus is released and is gradually transported downstream. The rate and amount of phosphorus uptake and release is dependent upon many factors including velocity, which can affect the resuspension of phosphorus-laden sediment; the presence of cations, expecially calcium and iron which form insoluable precipitates with phosphorus; channel morphology; and biotic assimilation.

Mackenthum (1968) recommended that to help prevent algal blooms, the concentration of total phosphorus should not exceed 0.10 mg/l in flowing waters or 0.05 mg/l where streams enter lakes or resevoirs. Chu (1942) reported significant increases in growth of different algal species in culture with such concentrations. Even concentrations of inorganic phosphorus of 0.01 mg/l can contribute to excessive growths of algae (Curry and Wilson, 1955). The concentrations presented here are intended to serve as guidelines only, since algal blooms do not always occur with elevated phosphorus concentrations. A number of other chemical, physical and biological factors also play a role in promoting algal growth.

The concentrations of total phosphorus determined in the stream water samples from Lower Makefield Township are not particularly troublesome except for Stations 2B (0.10 mg/l), 3B (0.18 mg/l), 3A (0.12 mg/l) and 6A (0.19 mg/l). Most of these areas are residential and subsequently urban runoff, including sediment from construction sites, would be suspect sources in these areas. Phosphorus contributions from Buck and Brock Creeks can potentially affect algal populations in Lake Afton in the Borough of Yardley. For this reason the concentrations determined in Buck Creek pose a definite threat to that lake system. The Bucks County Division of Natural Resources reported elevated values for Buck Creek, Brock Creek and Lake Afton in their studies in 1970.

Discharge

Table V-1 also presents discharge information. These reported measurements are not considered to be very accurate, but they can be used to make a rough comparison of stream flow at the different stations for this time of the year.

Although organisms living within the stream respond to the concentration of various chemical constituents, these concentrations provide little data on comparative differences in loading over space and time. The concentration of any substance in a stream is a function of the amount of that substance and the dilution factor (quantity of water). For this reason, it is valuable to provide data on the dilution factor so that comparisons in the amounts of a substance can be made between stations and over time. For example, under low flow conditions, the concentrations of a substance such as phosphorus might be greater than in the spring when flow is greater but the contribution of phosphorus might be similar at both times.

The following formula should be used to compare relative changes in loading:

$$PPD = (mg/l)(cfs \times 0.646317)(8.34)$$

where PPD = pounds per day
mg/l= concentration of constituent
cfs = cubic feet per second = stream discharge
0.646317 and 8.34 = correction factors for conversion from one unit to another.

CONCLUSIONS AND RECOMMENDATIONS

The concentrations of total phosphorus and nitrogen (as nitrate, nitrite and ammonia) are high and these concentrations affect the aquatic biology of the streams in the township.

A substantial amount of nutrient material (nitrogen and phosphorus) is considered to be derived from nonpoint sources, including residential and agricultural areas.

Septic tanks appear to pose problems in stream quality, and this should be investigated further. Additionally, faulty sewer lines could be a factor in affecting nutrient concentrations in the streams.

Along all streams there is evidence of sedimentation and channel enlargement. This is caused by excessive stormwater runoff and/or sediment and silt erosion from the landscape.

Storm runoff and associated nonpoint source pollutants appear to be major water quality problems in the township. Because pollutants originate from diffuse sources they are difficult to control. A stormwater management program which serves to decrease runoff to streams would be an important factor in improving surface water quality in the township.

In order to more closely examine the existing water quality condition of the township streams and determine causes for degradation, a more extensive investigation should be conducted.

Table V-1. Chemical-physical data sampling from water samples collected at Station on six Lower Makefield Township streams, August 31, 1978. Station locations are depicted in Figure IV-1.

Station	Stream Discharge (cfs)	Dissolved Oxygen (mg/1)	pH	Temperature (°C)	Nitrate (N mg/1)	Nitrite (N mg/1)	Ammonia (NH_3) (N mg/1)	Total Phosphorus (P mg/1)
1A	9.5	8.0	7.3	21.0	0.50	0.40	0.30	<0.02
1B	-	-	-	-	1.20	0.03	0.10	<0.02
1C	11	8.4	-	23.0	3.8	0.03	0.10	0.06
2A	-	8.0	7.3	21.0	2.5	0.04	0.10	0.04
2B	3.0	8.5	6.8	23.0	1.4	0.05	0.25	0.10
3A	44	8.0	7.1	22.0	5.2	0.10	0.20	0.12
3B	262	8.8	7.0	21.0	4.8	0.11	0.25	0.18
4A	25	8.8	7.2	23.5	1.2	0.03	0.35	<0.02
4B	26	6.7	7.1	23.5	2.9	0.04	0.40	<0.02
5A	17	8.5	7.0	23.0	3.6	0.03	0.20	<0.02
6A	16	7.7	-	24.0	1.2	0.03	0.40	0.19
9A	14	9.2	6.9	22.8	1.0	0.03	0.40	<0.02

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VI. RECOMMENDATIONS FOR STREAM MANAGEMENT

In order to effectively implement these recommendations concerning stream management in Lower Makefield Township, it is essential that the basic characteristics of aquatic ecosystems are well understood. For this reason, Appendix A (prepared by Ruth Patrick, Robert R. Grant, Jay W. Richardson and Robin Vannote), which is presented with this chapter, explains in a simple manner the biological and chemical characteristics of stream ecosystems. The principles explained therein apply to practically every stream system, including those of Lower Makefield Township. In this larger context, and based upon apparent problems observed during the Academy's stream surveys, several specific management recommendations were developed.

The principal problems with the streams in Lower Makefield Township are:

1. There is an indication that existing septic tanks, cesspools or sewer lines are not functioning correctly. This results in the addition of nutrients to township streams. Problems with the specific systems should be investigated further and steps taken to ameliorate any serious problems. (This is not to say that septic systems should necessarily be replaced with sewer lines.)

2. Stormwater runoff appears to have a major impact on the individual stream environments within the township. The minimum in-stream effects resulting from runoff include sedimentation, erosion of stream banks, and the addition of nutrients, toxic substances, and other pollutant materials.

In a discussion of the effects of erosion and sedimentation, the Academy of Natural Sciences of Philadelphia (ANSP, 1973) stated:

> Erosion and sediment transport may be manifested by increased turbidity of the water or the increase of deposition of sediments within the channel.
>
> A sediment load may result from unstable stream banks which develop after the banks are snagged or vegetation is removed. Under such conditions the roots of the plants no longer hold the soil material in place and they slump into the stream. This slumped material may either remain along the edges of the stream or may form unconsolidated or consolidated berms within the stream channel itself. Some of the finer particles of this material are carried down and increase the turbidity of the water. Such conditions particularly occur after storms.

Turbidity may also be produced by the eroding of the stream bed. In the dredging and shortening of the stream, sometimes a slope or gradient greater than that which is characteristic of the stream develops. Such an increase in slope causes the stream to degrade upstream and aggrade downstream. The resultant sediment load is transported downstream, and in river areas of low velocities, unstable berms or silt bars are formed within the channel proper.....

....the silt load entering often carries with it nutrients such as ammonia and phosphates, and thus the nutrient balance and/or concentration is often changed within the stream due to the introduction of a silt load. This change in nutrients will affect the kinds of algal species and their productivity. Furthermore, it should be pointed out that colloids including those found in silt, often adsorb onto their surfaces heavy metals and thus take them out of solution. Thus a stream containing silt and receiving a pollutant containing heavy metals may not be as toxic to aquatic life as one in which silt is not present.

The assimilation and mineralization of organic wastes by bacteria and subsequent oxidation may be slowed if sufficient oxygen is not produced by algae. In silt-laden streams it often takes a much longer time for the stream to recover from an organic load than is the case if the stream was clear.

Many organisms within a stream are filter feeders, and thus if there is a heavy silt load in the water their feeding apparati become clogged with silt and they are not able to live. Other organisms such as fish are adversely affected by too heavy a silt load in the water due to the abrasion of gill tissue. The gills of fish living in heavily silted waters often have their epithelial cells badly distended or in some cases destroyed. Thus the ability of oxygen to be transferred from the water to the blood of the fish is greatly impaired. This clogging of the oxygen exchange apparatus also occurs in insects and as a result these organisms are quickly eliminated. Mayflies are one of the most sensitive organisms to increased silt load. Species of caddisflies, which are filter feeders, are also a very sensitive group to high silt loads. Blackfly larvae and other filter feeders can likewise be affected.

The effects of a sediment load in the stream on the structure of the ecosystem and upon individual organisms are various. It is well known that turbidity cuts down the depth to which light penetrates in a stream. Since light is necessary for photosynthesis, turbidity may limit the zone in which algae can live and reproduce. Because algae form one of the most important food bases and, in some cases, <u>the</u> most important food base of stream organisms, anything that cuts down the productivity of the algae will tend to reduce the overall productivity of the ecosystem.

The suspended solids load which settles out on the bed of the stream tends to homogenize the stream bed. It is the diversity or roughness of the stream bed that is greatly reduced when the crevices between rocks are filled up and covered over with silt so that the surface of the bed of the river is composed of sediments of similar-sized particles. Under these conditions the flow is usually faster and not diverse in pattern. This homogeneity of substrates and pattern of flow greatly reduces the habitats for species occupancy.

Many organisms, particularly fish, often deposit their eggs in redds, constructed on gravel shoals or in clean sand at the lower end of a pool or in riffles. This is particularly true in high-gradient streams. The water that filters through the sand carries with it oxygen which makes this area an ideal habitat for the hatching of eggs and the young larvae. If a silt load is introduced into the stream these suspended particles often settle out between the sand and gravel particles and fill the interstitial spaces. As a result water with its oxygen cannot penetrate these areas and the sand becomes unfit as a breeding ground. The silt may also settle out and suffocate eggs and larvae.

In order to minimize the amount of runoff entering streams from the landscape, a stormwater mamagement plan which emphasizes problems within and solutions specific to the individual sub-watershed basins should be devised for the township. Natural resource constraints should be the key to this stormwater plan.

To help prevent nutrient additions associated with runoff, the township might consider the following means of control.

In agricultural areas, livestock could be prevented from having unlimited access to streams. In addition to potentially providing manure additions to the stream, cattle are highly disruptive of stream banks where they have access. Fencing could be used to prevent unlimited stream access.

A buffer strip (50 to 100 feet wide) consisting of natural vegetation (not lawn) could be provided along both sides of the stream. This strip would help deter runoff and nutrient additions from agricultural, roadside and residential areas.

3. The third major problem involving the Lower Makefield Township streams relates to natural streamside vegetation. In many areas, including Stations 6A, 5A, 4A, 3B, and 1C, the streams are devoid of natural streamside vegetation. The importance of streamside vegetation was summarized by ANSP (1973):

> The trees which grow close to or on the banks of a stream contribute considerable amounts of leaves or other detritus to the stream, and their roots provide protected habitats. Since organisms have detrital food preferences, the removal of trees or shift in species may substantially alter the base of the food web and total productivity of the ecosystem.
>
> The undercut root systems of trees often provide cover for fish and are a favored retreat during periods of high summer temperatures.
>
> Eliminating trees from the immediate bank of the stream has several effects upon the aquatic life. Over-arching branches of trees produce a variable light pattern and thus increase the diversity of habitat within the stream. It is well known that various species of aquatic life prefer different light intensities. Secondly, the over-arching tree branches shade the streams in summer and thus greatly reduce the peak temperatures that develop in the streams during hot weather periods. It is well recognized that many organisms such as trout cannot live in water that is warm (over 75°F) during the summer months.
>
> There are other values of bank-side trees. One is the fact that tree leaves and the organisms such as insects that live or feed on leaves fall into the stream and thus provide a detrital base for the aquatic life. Detritus has been shown to be one of the most important food bases for the food webs

> in forest streams. Since this streamside vegetation typically is composed of many species, it offers a variety of different types of detritus as a food source. Man often replants these banks with one species or does not replant them, and as a result this detrital food source is reduced as to variety and amount. This streamside vegetation also tends to hold the banks of the stream in place and thus its elimination may have severe consequences on the stability of the banks.

An effort should be made to maintain natural streamside vegetation. Natural species rather than adventive ones should be encouraged. A 50 to 100 foot strip of such natural vegetation should be maintained on both sides of the stream.

Another important aspect of the water quality problem of streams within the township relates to the general condition of vegetative cover throughout the township. There are relatively few natural hardwood stands remaining in the township. In addition to having special intrinsic values, maintenance of these hardwood forests is important to stream quality as well. A discussion of this point is quoted below (ANSP, 1973):

> It has been pointed out by Bormann and Leopold that the cutting down of the forest greatly increases the erosion of sediments into a stream. The work of Wark and Keller pointed out that cutting down the forest will increase the suspended load about 8 times. They also found that increasing the amount of land in row crops will increase the sediment loads entering the stream. Thus it is quite evident that the removing of the flood plain forests and the subsequent development of the flood plain in urbanization or agriculture inevitably contributes to a continual increase in siltation...The clear cutting of bottom hardwoods may increase the nutrients and sediment concentrations in the streams. Other studies (cited above) have shown that runoff from cleared forest land is higher in nutrients than from non-cleared land. This is due to the lack of absorption by micro-organisms and plant growth and to the increase in nitrogen fixing bacteria in the soil of the cleared areas. Various studies (cited above) have shown that clear cutting the forest increases erosion and the sediments entering a stream.

One other factor which is important to note is that streams reflect the land use conditions within their watershed regardless of how large or small the drainage system.

Problems which exist within the smaller stream basins of Lower Makefield eventually affect the receiving waters of the larger drainage system of the Delaware River. Additionally, streams such as Rock Run and Core Creek, which originate in Lower Makefield but flow out into other political jurisdictions, are particularly vulnerable to disturbances along their course to the Delaware River. Efforts should be made by each township to preserve and enhance the quality of any streams flowing through their boundaries. Without this awareness and committtment there is little hope for enhancing the quality of the larger drainage net work of the Delaware River system.

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Appendix VI-A

General Characteristics of Aquatic Ecosystems in: ANSP. Report on Channel Modifications submitted to the Council on Environmental Quality. Pages 196-203. 1973.

In order to understand the effects of watershed use upon the stream we must know what the characteristics of aquatic ecosystems are and how they function. Essentially, aquatic ecosystems are quite similar to terrestrial systems; that is, the basis of their food web is plants and detritus. In the terrestrial world these plants are mainly grass, shrubs, and trees, and the detritus consists of leaves and other plant parts, and also detritus produced by animals. In the aquatic world the plants are algae and to a lesser extent rooted aquatics. The debris may originate within the system or result from leaves and twigs of trees on the banks that fall into the stream. Indeed it is the leaves of terrestrial trees and the "fall-in" of terrestrial insects that furnish the larger part of the detrital segment of the aquatic food chain. Herbivores, which are animals that feed upon plants, exist in both the terrestrial and the aquatic world. In our terrestrial world we know them as cows, sheep, birds, and various kinds of wild animals. In the aquatic world these herbivores are protozoa or "one-celled" animals, insect larvae of various kinds, other invertebrates, and fish.

Most organisms are not strictly herbivores or carnivores but are omnivores, that is they eat both plant and animal foods. In the terrestrial world these are chickens, pigs, man, dogs, and so forth, whereas in the aquatic world they are, for example, insects, snails, crayfish, clams, and many kinds of Crustacea, organisms representing many of the major phyla. True carnivores, that is organisms that feed only on other animals, are relatively few. In the terrestrial world, foxes, lions, and tigers are organisms of this type, while in the aquatic world we find that some species of protozoa, insects, fish, mollusks, and various other kinds of organisms are carnivores. All these organisms with their varying food requirements form a food web represented by approximately four stages in the transfer of energy. We have at the base of the food chain the decomposers that take organic matter produced by organisms and convert it into soluble forms which are then used as a food for other organisms. The bacteria, fungi, and some of the invertebrates play this role as decomposers.

As stated above, the primary producers are mainly the plants; the herbivores feed upon plants and the carnivores feed upon herbivores; the nutrient or energy transfer from each step is relatively small. Slobodkin (1) has estimated that 10 - 15% of the nutrients in the form of plants are

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1 Slobodkin, L.B. Ecological energy relationships at the population level. In: W. E. Hazen, ed.; Readings in Population and Community Ecology. W. B. Saunders Co., Philadelphia, Pa., pp. 236-258. 1964.

transferred to herbivores and about 8 - 10% of that becomes carnivores. Thus, it is obvious that most of the organisms in the aquatic world, as in the terrestrial world, are plants and the omnivores or herbivores that feed upon them.

Biological Characteristics of Stream Ecosystems

In the aquatic stream systems most of the organisms composing these food chains are relatively small. Also, compared with many organisms that live on land and in the deep sea, they have relatively short life cycles. They typically produce many offspring and ecologists have referred to them as opportunists. These organisms can invade and quickly establish large populations which are then cut down by the changeable environment or by predator pressure, and in turn are succeded by some other species. The unpredictable and highly variable environment of streams has favored species that have these characteristics.

At each level in the food web the functions are performed by many species belonging to many different orders of plants or animals. These organisms, though usually having relatively short life cycles, have variable requirements, so that at any one point in time in a natural stream we find many different kinds of organisms or species performing the same function. In order to support this great diversity of fauna and flora there must be a great variety of habitats for them; otherwise they would compete in such a way that they would not survive. In a stream, the different habitats are made possible by the complex current patterns of the stream, the diversity of light, the great variability of types of substrates under different light and current conditions, and the diversity of water depth and of temperature regimes. In small streams this great variety of habitats is provided by the naturally-occurring pool, riffle, and slackwater sequence. It is this variability in stream structure that contributes to the very complex current patterns which are different on the downstream and upstream face of a rock, on the upper and under surfaces of rocks, in pools, and in slackwaters. Also in pools, riffles, and slackwaters of a small stream there are very different kinds of substrates. For example, in the riffle there are hard, clean rocks free of sediments. In the slackwaters are a combination of sand, mud, and small pebbles, while the pool supports in its bed soft mud and organic debris.

In large rivers this variability in current pattern and substrates is provided by the meanders of streams, oxbows, sloughs, and entrapped debris. Any meander of a large river will have a cutting edge with fast water and hard substrates and a shoaling edge which has depositing sediments and slow, shallow water habitats. These shallow water habitats are greatly augmented by sloughs and waters where the currents are less strong and they afford conditions similar to pools in shallow streams. It is here that sediments settle out and algal growth is permitted across the stream bed. These are the feeding and breeding grounds of many invertebrates and fish. One has only to study a river such as the Savannah River in its coastal plain to realize the great importance of these oxbows and backwaters to the maintenance of the productivity of the river.

Variable light patterns are also extremely important for the maintenance of different kinds of species, for some prefer more sunlight than others. This variability of light pattern in natural streams is provided by the natural stream meanders and the vegetation of its banks. Ordinarily, a natural river will flow from east to west in some segments and north to south in others. It will also have a great variety of trees and shrubs and, in some reaches, open grasslands along it banks. This tree canopy is also of great value in reducing the maximum temperatures in the summer. For example the removal of trees from the banks of the stream may increase summer temperatures which in turn eliminate stoneflies.

Many of the organisms live part of their lives in the banks of the stream and other parts within the open water. Examples are burrowing mayflies, that often form millions of burrows just above the water level and are frequently seen in the cutting edges along the Savannah River. Other organisms such as crayfish will drill holes and chimneys in the soft banks of the stream. Organisms such as muskrats and raccoons will feed on the clams and mussels within the stream.

The detrital part of the food web that is so important in our streams is also largely dependent upon the kinds of vegetation on the banks of the stream and in its wetlands. Recent work of Dr. Vannote (2) of the Academy of Natural Sciences has shown that organisms such as tipulid larvae actually prefer certain kinds of food, that is certain kinds of tree leaves, and if they are not fed the tree leaves of their preference runts develop and the species is adversely affected. Further research is showing that many species of organisms have preferences. For example, the *Spartina* of our marshes is a more desirable food than *Phragmites* for many

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2 Steele, Nancy. Autumn at White Clay Creek: new life for an old Stream. Frontiers, 37(1):2-7. 1972.

organisms. Not only is the vegetation along the banks and land adjacent to the stream important as a food source, but it is also important in trapping sediment and reducing the effects of flash flood drainage from the watershed. This buffer zone of natural vegetation brings about the deposition of silt from the flash floods before it enters the stream and also absorbs nutrients from the waters that traverse the flood plain, so that the amounts of nutrients entering the stream either dissolved or on the surface of colloids is greatly reduced. Flood plains are an integral part of any stream. Indeed one cannot separate a stream from its flood plain.

In the Southeastern and Gulf states these flood plains and swamps along the edges of rivers are well developed and of great value to these aquatic systems. During high flow the river flows over the flood plain and often deposits considerable sediment which in turn furnishes nutrients for the vegetation and the food web it supports. This flooding also creates flood plain ponds which act as breeding and nursery grounds for many kinds of organisms. In the spring of the year when these ponds are connected with the river, fish and invertebrates will enter them and lay their eggs. As the water recedes these organisms swim back into the river, leaving behind the eggs to hatch and the young to be reared, ready to enter the river the following year when again the spring floods occur.

Other organisms use these shallow water areas in various seasons to complete part of their life histories. Salamanders, frogs, alligators, and otters are but a few of these organisms. Large numbers of birds and mammals use these flood plains as feeding grounds. One has only to watch a flock of ducks and geese settle out on a flood plain pond in the fall where they feed upon the wild rice and other plants in the swamps to realize the importance of these areas to bird life. Many species are only found in the relatively impenetrable areas of swamps, and therefore it is here that we often have certain kinds of bird rookeries. An asset of these flood plains often not realized is that they harbor a great diversity of species. Indeed, in the eastern and southern part of the United States they are a great reservoir for species that are not common in other parts of our landscape. These reservoirs of species are essential for the continuation of our ecological environment, because man is destroying many species by the use of uplands and thus reducing the flexibility of our environment to meet change over geological time or to endure periods of stress. If these areas are destroyed the future stability of our ecosystem will be greatly endangered.

Chemical and Physical Characteristics of Stream Ecology

The numbers and kinds of species a stream can support is largely dependent upon the chemical and the physical structure of a stream. The chemical characteristics of the stream are largely derived from the surface runoff of the watershed; fall-in of vegetation and terrestrial and emergent forms of aquatic life; the chemicals carried in by precipitation; and the geological characteristics of the watershed through which the water percolates before the groundwater enters the stream. The size and shape of a stream or channel are determined by its discharge, the amount and type of sediment it must transport and the material composing its bed and banks. The discharge of a stream is the runoff from precipitation following infiltration, evaporation and transpiration.

The sediment that must be transported is almost entirely material eroded from the drainage basin and the channel beds and banks. This sediment load is of three types: suspended solids, bedload, and dissolved solids. The suspended solids are those particles that are carried along by the current. Whenever the current is slowed these suspended solids drop out, the amount and size of particles dropping out depending upon how much the current is reduced. The bed load consists of those sediments that are rolled along the bed of the stream. The roughness of the stream bed which is so important in developing the diversity of habitats for stream organisms, owes its existence to the high velocity associated with flood flows. Over bank deposition during flood flows is the major mechanism streams use for sediment loading.

The meandering shape is the natural shape of a stream. In other words, the flowing water takes the course of a random walk. This meandering allows the energy of flowing water to be evenly distributed along the stream. Typically the greatest amount of flow is toward the outer side or cutting edge of the meander and on the inner side curve sediment is deposited and shallow water conditions exist. It is on this shoaling side that most of the sediments are deposited. On the upstream side of the meander the sediments tend to be eroding, whereas on the downstream side of the meander the sediments are typically depositing, thus different kinds of environmental conditions exist which are habitats for different species or organisms.

As Leopold (3) has pointed out, even in straight stretches of a stream the main current is rarely straight; it meanders back and forth even within the straight reach of the channel.

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3 Leopold, Luna B., et al. Fluvial Processes in Geomorphology. W. H. Freeman, San Francisco. 522 pp. 1964.

In summary, then, a stream tends to assume the shape which affords least work and which allows the flow to come into equilibrium with the channel structure.

The channel bed roughness is related to the physical rigorosity of the stream bed; particle size, distribution, and configuration; as well as elements of resistance, such as dunes, bends, perturbances, and junctions. The degree of turbulence and circular flow is determined largely by channel roughness.

One of the most conservative characteristics of the stream is its gradient. This rarely changes under natural conditions, and if for any reason it is changed, the stream then tends to degrade upstream and deposit sediments downstream so as to bring the gradient back into equilibrium with the discharge. This shift in stream characteristics inevitably brings about a shift in the aquatic life.

Typically much of the watershed and the banks of a stream in eastern United States is covered with vegetation, which minimizes the erosion of the banks and the watershed.

Leopold (4) has shown that the cutting down of the forest may increase the sediment load 8 times that which existed before the forest was cut down. The recent work of Bormann (5) has demonstrated that clear cutting in Hubbard Brook of all the vegetation in one of the watersheds resulted in a 68% decrease in transpiration and a 40% increase in runoff. Also, since the clear cutting of the vegetation, nitrates have increased in considerable amounts in the stream that was deforested.

From various studies it is evident that the natural vegetation of the watershed and stream banks are extremely important in controlling excessive temperatures, furnishing food for the various aquatic organisms in the stream, and regulating flow and nutrients entering the stream. It is these natural conditions together with the shape of the channel of a stream, the roughness of its bed, the diversity of patterns of its current, and its interrelationship with the vegetation on its immediate banks that produces a set of conditions to which the stream ecosystems evolve over time. The vegetation on the immediate banks of a stream stabilizes the banks and prevents slumping into the channel proper and thus increases the sediment load. Typically these sediment loads are unstable in the

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4 Leopold, et al., op. cit. (3)

5 Bormann, F. H., et al. Biotic regulation of particulate and solution losses from a forest ecosystem. Bioscience, 19(7):600-610. 1969.

bed of the river and are continually shifting, thus rendering the bed of the river unsuitable as habitats of aquatic life. In these areas the center of the channel is rarely a suitable habitat for aquatic life.

The diversity of current pattern is largely induced by the roughness of the stream channel bed and the shape of the stream channel itself. As Ruttner (6) has pointed out, it is this diversity of currents that allows many different species to live on sometimes physically similar substrates. For example, the current pattern on the upstream side of a rock will be very different from that on the upper surface of a rock or on the downstream side of the rock. Various workers have shown that caddisflies, which prefer different kinds of current pattern, will sort out to species according to the current present.

One of the great values of the meanders of streams is that they increase the capacity of a stream to hold water and thus reduce the severity of the effect of a flood. Thus, during flooding conditions and bank-full stages in streams, a meandering stream that is relatively slow-flowing can contain much more water than a straight section of stream and thus even out flood effects by the retention of water. The flood plain is also an extremely important part of the stream during flooding. It absorbs a great deal of water and typically retains many of the sediments that would otherwise wash into the stream channel proper and eventually result in reducing the stream's water carrying capacity. Typically, as shown by Leopold (7), a stream meanders back and forth across its flood plain; thus it is important that this area be maintained in order to allow the natural shifts in stream structure to occur.

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6 Ruttner, Franz. Fundamentals of Limnology, 3rd edition. University of Toronto Press, Toronto, Canada. 295 pp. 1963.

7 Leopold, *et al.*, *op. cit.* (3)