1.0 Introduction

A methodical and detailed assessment of the abiotic resources within a given geographic area can be used to identify and cluster areas with similar geomorphological characteristics. The significance of the contrast between adjoining clusters may further be defined by the terrestrial ecosystems they support. The flora of a given area would then act as a bridge between the abiotic resources, such as bedrock, soil, and topography, and the fauna which depend on these resources for food, water and shelter.

Abiotic or non-living resources include soil, rock, physiography, topography, climate, and the occurrence of water. Interpretation, organization and presentation of abiotic resource information forms an essential component of most environmental monitoring projects. To ensure a thorough understanding and complete assessment is achieved, an orderly process must be followed when evaluating this information.

In 1995 and 1996, the Upper Thames River Conservation Authority completed the Oxford County Terrestrial Ecosystems Study to determine the health of the forest-dominated ecosystems and ultimately to develop a framework for ecosystem management in Oxford County. This study employed leading-edge assessment methodologies wherever possible, especially during the field assessment component of the project. Abiotic resource information was used to identify areas within the County which have similar geomorphological characteristics. "Trial landscapes" were selected from the clustered areas for a detailed field evaluation of the floral and faunal indicators. In addition, the abiotic resource information was assessed to identify relationships between the various abiotic components and the size, shape, distribution and composition of the remaining forest-dominated ecosystems in Oxford County.

The method of clustering areas based on geomorphological characteristics was adapted from existing resource evaluation technology. The following pages describe the method applied to the abiotic resource information considered in the Oxford County study. In addition, the method is evaluated through presentation and discussion of the background information and field data collected during the Oxford County study.

2.0 Oxford County Terrestrial Ecosystems Study - Overview

The Oxford County Terrestrial Ecosystems Study (OCTES) was designed by the Upper Thames River Conservation Authority, in partnership with Grassroots Woodstock and the County of Oxford, to determine the existing condition of forest-dominated ecosystems within Oxford County. The ultimate goal of the project is the "development of a natural heritage framework that will allow the terrestrial ecosystems of Oxford County to be self-maintaining." The initial phase of the project determined the extent of ecosystem impairments, and the second phase will recommend solutions which will benefit the overall health of the County's terrestrial ecosystems.

The initial stage of the OCTES project involved an intensive review of the existing abiotic, biotic and cultural resource information prior to any field data collection. Due to the size of the County and the budget considerations, field data collection was restricted to terrestrial ecosystems within "trial landscapes." Each trial landscape represented an area of the County which was determined by clustering areas with similar abiotic or geomorphological characteristics. Data collected within the trial landscapes was later evaluated to determine what relationships exist between the abiotic resources and the size, shape, distribution and composition of the remaining forest-dominated ecosystems. Assessing these relationships provided a method of testing the initial hypothesis and evaluating the technique.

3.0 Methodology - General

In general, the assembly and handling of abiotic resource information followed the process outlined in the ABC Resource Survey Method (Bastedo *et al.*, 1984). The ABC Method was originally developed for mapping and identifying boundaries of environmentally significant areas in the Canadian North through description, analysis and evaluation of abiotic, biotic and cultural aspects of the study area. The process involves four levels of data analysis including (1) raw data analysis, (2) interpretation of environmental significance and environmental constraints, (3) synthesis of significance and constraints, and (4) boundary and institutional arrangements. The first three steps were applied to the abiotic resource information to produce a synthesized map of Oxford County which divided the entire County into areas that have similar geomorphological characteristics.

The ABC Method presents each data group as an individual map layer and eventually synthesizes all of the map layers to produce a summary map or maps. Abiotic data maps illustrate structural information such as the physical features, and functional information such as major ecological processes. Through application of interpretive indices, the environmental significance and environmental constraints of the abiotic resources were identified and recorded on additional map layers. The indices incorporate criteria which can be defined by the user and therefore provide flexibility in the methodology. Synthesis of the map layers produces summary maps which illustrate sub-areas that were determined on the basis of their overall relative environmental significance and constraint. Boundary maps can be created from the synthesized maps for specific management purposes.

3.1 Delimiting Oxford County

For the Oxford County Terrestrial Ecosystems Study, the abiotic resource information considered for the study included bedrock, soil, physiography, topography and groundwater characteristics. The occurrence of surface water was considered by technical staff undertaking a review of the biotic resource information. Climatic information was not considered in this study due to the limited availability of monitoring stations within the County, and recognition of the need for very detailed climatic information.

Abiotic resource information collected and generated for the OCTES project would eventually become part of the Geographical Information System (GIS) database owned by the County of Oxford Planning Department. A preliminary assessment of the available literary sources identified a need for a common map scale for recording and presenting the information. Topographic maps were initially used as a base map and the level of detail required did not warrant larger scale maps; therefore, a scale of 1:50,000 was selected for presentation of abiotic resource data. Also, the 1:50,000 scale maps were based on 1990 aerial photography which represented the most recent data available.

The steps completed in the abiotic resources review, and a list of the maps created or considered for each step are illustrated in Table 1. In the data collection stage, bedrock, overburden, physiography, soil and topography comprised the structural maps. The functional maps displayed short-term ecological processes such as soil drainage and groundwater recharge potential as opposed to long-term geologic processes. The importance of the abiotic resources was displayed on significance maps for sand and gravel

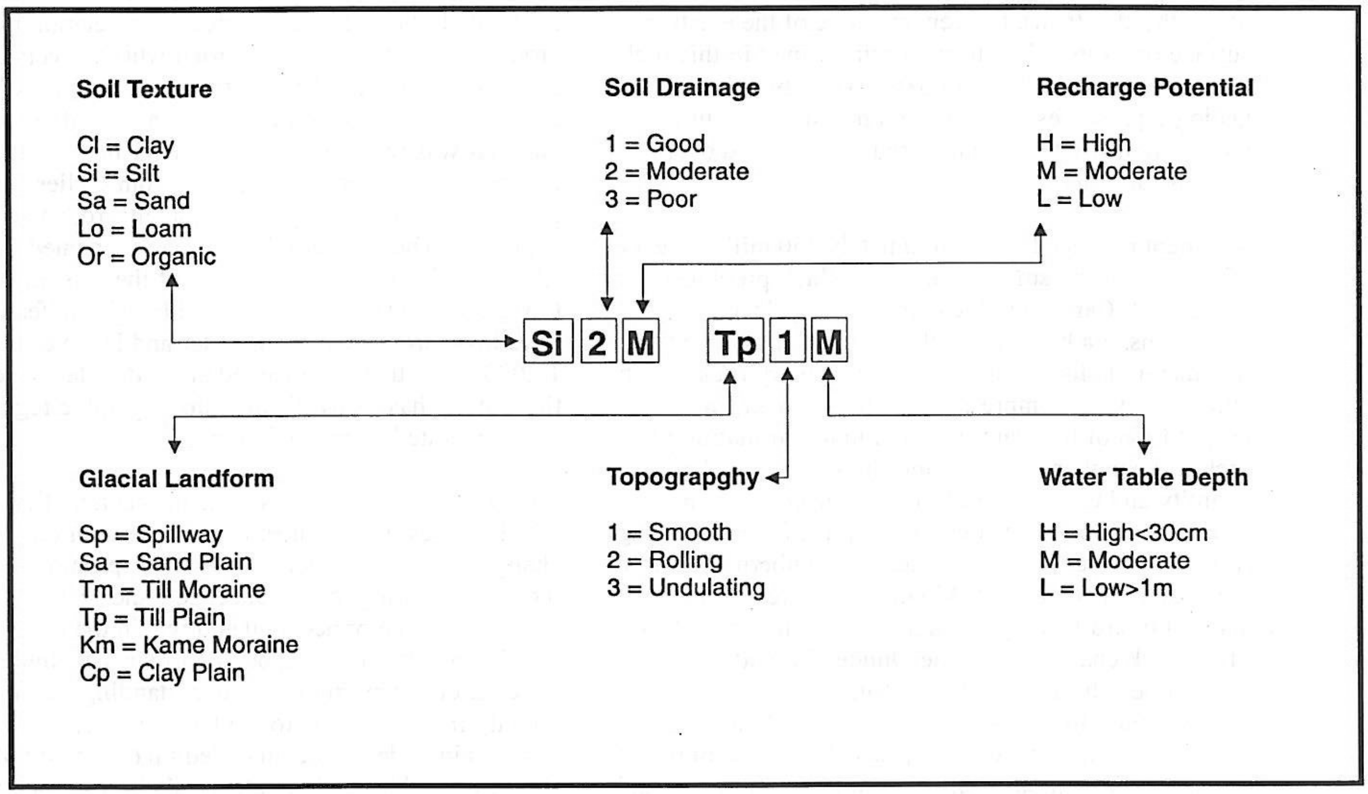
Table 1. A summary of the steps and tasks involved in the review of abiotic resource information for the OCTES Study and a list of the maps produced for each step.

Step Number	Step Description or Task	Abiotic Information Available
1.	Data Collection	structural maps • bedrock geology • overburden geology • physiography/surficial geology • topography • soil texture functional maps • soil permeability/drainage • groundwater recharge potential
2.	Data Interpretation	significance maps • sand and gravel resource areas • bedrock resource areas constraints maps • groundwater recharge/discharge areas • groundwater storage areas criteria selected • developed abiotic code system
3.	Synthesis	summary map • cluster and complex sites with similar geomorphological characteristics

resource areas, and bedrock resource areas. The environmental constraints maps illustrated groundwater recharge/discharge areas, and groundwater storage areas to recognize the importance of the numerous wetlands and shallow aquifers in the local groundwater regime.

An abiotic code system (Figure 1) was created to label the sub-areas on the synthesized map, and to facilitate clustering and complexing of areas with similar geomorphological characteristics. The OCTES study was focusing on terrestrial ecosystems; hence, soil texture was the primary factor considered in the development of boundaries between cluster areas. To simplify the task of clustering, the Oxford County soil map was "generalized" to illustrate soil texture by sand, silt, clay, loam and organic classes. The generalized soil map resembled the pattern of physiographic features which was the second factor considered in the development of boundaries.

Figure 1. The abiotic code system developed for the OCTES Study.



The remaining components of the abiotic code system were based on the general soil texture or the main physiographic feature. Soil drainage was determined from the information available on the Oxford County soil map. Groundwater recharge potential was estimated based on soil texture, soil drainage, topography and basic hydrogeologic principles. The depth to water table represents an estimate of where the water table would be found beneath a forest patch.

As a final step, the boundaries were determined for the areas which had similar characteristics within the boundary yet there was a significant difference in one or more characteristics outside of the boundary. From the summary map, a "trial landscape" was selected from each area for in-field study.

4.0 Abiotic Resources in Oxford County

4.1 Bedrock Geology

Deep beneath Oxford County, the Precambrian bedrock of the Canadian Shield provides a solid foundation for the layers of rock and soil which lie above. Precambrian refers to the ancient rock which is more than 1.5 billion years old and forms most of the landscape we see across Northern Ontario. Although this granitic rock is buried under more than 1500 metres (5000 feet) of sedimentary rock and 30 to 60 metres (100 to 200 feet) of overburden (soil), the general slope of the existing surface owes its origin to the basin formed in this rock layer. Named the Michigan basin, a combination of geologic processes created this bowl-like structure which gradually filled as material accumulated over millions of years.

Sediment produced by approximately 250 million years of erosion of the softer rock types which previously covered the Canadian Shield and the Appalachian Mountains, gradually filled the basin and provided the raw materials for the layers of sedimentary rock which currently exist. Compression of the sediments and evaporation of the water resulted in the formation of rock in a number of layers and thicknesses as the quantity and texture of sediment changed over time. From the surface, the rock layers form concentric rings from the centre of Michigan across Southern Ontario to the Niagara Escarpment. Moving from west to east across Oxford County through Embro, the upper layer of bedrock changes from the Dundee Formation (limestone), through the Lucas (limestone), Amherstburg (limestone, dolomite), Bois Blanc (limestone with chert or flint), Bass Island (dolomite), to the Salina Formation (shale, dolomite, gypsum and salt). Limestone and dolomite were formed from silt-sized particles while clay and sand form shale and sandstone respectively. The fossils found throughout the various layers confirm the existence of a marine environment during the depositional period.

The upper surface of the bedrock, and the individual rock layers, dip or slope gently towards the southwest. Bedrock slope was instrumental in establishing the general slope of the land surface and the initial surface drainage patterns. Overburden deposits on top of the rock vary in thickness from less than 15 metres (50 feet) along the South Branch of the Thames River to greater than 90 metres (300 feet) southwest of Sweaburg. Portions of the Thames River bed between Ingersoll and Woodstock have reportedly eroded to the bedrock surface. Sufficient cover of overburden exists across the County to isolate the terrestrial ecosystems from the bedrock layers.

In Oxford County, the underlying bedrock is an important resource from an economic perspective. The elevation of the bedrock surface was recently mapped in detail during an evaluation of the hydrogeologic resources. The minimum thickness of overburden covering the bedrock was 15 metres in the Beachville area with the exception of some areas along the Thames River corridor. At this depth, the bedrock would not influence the terrestrial ecosystems on the surface.

4.2 Physiography

The upper rock layers were scoured by glaciers as massive sheets of ice advanced across Ontario and into the United States. Several periods of glaciation have produced the layer of overburden which covers the bedrock to a depth of 60 metres (200 feet) or more. To produce the current soil thickness, an equal amount of material was removed from the upper layer of the bedrock by the glaciers. Deposits from earlier periods of glaciation were partially or completely eroded and re-deposited. The last period of glaciation, named the Wisconsinan, is the main source of the existing surface topography in Oxford County. Although the features have been eroded by wind, water and ice over the 10,000 years that have passed since the glacier receded, the County has many distinct physiographic regions which resulted from glaciation.

The glacial process begins with an accumulation period which causes the ice sheet to advance until climatic changes result in sufficient melting to promote recession. During the advance, soil and rock are pushed ahead of the ice or accumulated within the ice sheet. Melting results in the deposition of any accumulated material either by running water, standing water or directly from the ice onto the land surface. Glacial deposits include a material called till (a mixture of clay, silt, sand pebbles and boulders) laid by ice, sand and gravel from moving water (fluvial or outwash deposits), and clays, silts and sands from glacial lakes (lacustrine). In general, lacustrine deposits overlie fluvial and outwash deposits which cover glacial till. Post-glacial deposits within Oxford County include alluvium or sediment in existing stream channels, and peat or muck in wet depressions.

Recession of the last glacier initially produced an opening between two ice lobes which allowed meltwater to deposit sand and gravel over much of Blandford-Blenheim Township in the northeast quadrant of the County. Drainage followed the Middle Thames, South Thames and Trout Creek spillways to a glacial lake west of London. As the recession proceeded toward the south, a number of temporary pauses created the Mount Elgin Ridges across Southwest Oxford and Norwich Townships. Heading south from Highway 401, the

Ingersoll Moraine is the initial ridge followed by the St. Thomas, Norwich and Tillsonburg Recessional Moraines. Between the ridges, silt and clay were deposited either by standing water or directly from the melting ice. Meltwater flowing south entered a glacial lake and deposited sand and silt in a delta which is now called the Norfolk sand plain and covers the south half of Norwich Township.

A second ice lobe receded toward the north and produced the glacial landforms over the northern half of Oxford County. Between Ingersoll and Woodstock, and from Folden in the south to Tavistock in the north, the Oxford Till Plain covers nearly half of the County. The southeast portion of the till plain, especially southwest of Woodstock, contains numerous drumlins (elliptical or oval shaped hills) which vary in length and height. Drumlins are believed to result from glacial advance and remain as an indicator of the direction of ice movement. In Oxford County, the drumlins all point towards the southeast. In the northwestern corner of the County, the Stratford Till Plain extends southward from Wildwood Lake, along a kame moraine centred around Lakewood, to the Middle Thames River spillway at Thamesford. Also in the northern part of the County, a small clay plain extends southeast from Tavistock to Cassel and west towards Hickson in East Zorra Township (see map1, Appendix).

4.3 Topography

Across the County, the topography varies from the relatively smooth plain areas to the rolling and undulating glacial landforms in the south and east quadrants of the County. Recessional moraines, represented by the Mount Elgin Ridges, typically exhibit knobby or undulating topography as a result of their formation. In Oxford County, the moraines have a rolling surface possibly due to erosion or late glacial deposits. The Waterloo Sand Hills create undulating topography over the eastern portion of the County and the Woodstock Drumlin Field provides rolling to undulating topography in the southern portion of the Oxford Till Plain. Maximum change in elevation occurs between North Zorra Township at 370 metres (1200 feet) above sea level and south of Tillsonburg at 140 metres (460 feet).

4.4 Soil

Although each type of glacial deposit has a characteristic range of soil textures often arranged in well defined layers, the existing texture at the surface may not be indicative of the deposit below. Glacial deposits have been eroded over a 10,000 year period since the Wisconsinan stage of glaciation. Wind, water and ice have levelled the topography by lowering peaks and filling the lowlands between with sand, silt and clay. Existing soil maps provide a reasonably accurate description of the soil texture across the landscape.

Soil texture has a significant impact on moisture retention, drainage, nutrient retention, aeration and the ability of the individual particles to adhere to each other (cohesiveness). By grouping the soil series according to the predominant textural classification, the information illustrated on the Oxford County soil map was generalized and simplified. The revised soil map (map 2, Appendix) clearly illustrates the extent of the Norfolk Sand Plain in the southeast quadrant, the silt deposits from the St. Thomas, Norwich and Tillsonburg Moraines, and the clay-rich deposits between the moraines. The spreading effects of erosion and re-deposition of the moraine deposits are more apparent on this map.

In the central and northern half of the County, the Oxford Till Plain appears as three distinct groups with silt-rich southern and northern areas surrounding a loamy (sand, silt and clay mixture) central area. The boundary of the Stratford Till Plain in the northwest quadrant of the County is partially depicted by the clay-rich area. Adjacent to the plain, the sandy soil of the kame moraine at Lakewood is partially covered by organic and loam deposits. In the northeast, the small clay plain southeast of Tavistock is more evident. Sand deposits across Blandford-Blenheim Township outline the extent of the Waterloo Sand Hills physiographic region. Throughout the County, organic soil deposits fill depressions and indicate the location of wetland ecosystems. Alluvial deposits along the Middle and South branches of the Thames River, Trout Creek and the Nith River are also apparent.

4.5 Granular Resources

Previous studies have identified existing and potential sources of sand and gravel for aggregate extraction across the County. Glacial deposits of sand and gravel resulting from moving water comprise most of the aggregate resources in Oxford. The Waterloo Sand Hills and the Norfolk Sand Plain provide the bulk of the land mass where resources are known to exist. The kame moraine at Lakeside and deposits along the spillways now occupied by Cedar Creek, Deer Creek, Trout Creek, the Nith River, and both the Middle and South Branches of the Thames River contain the majority of the remaining resources.

4.6 Groundwater Resources

The hydrogeology of Oxford County was studied in detail by MacLaren Engineers (1990) as part of a Water Supply Master Plan. From this study, a map was produced which illustrated areas where groundwater recharge potential was significant. These areas coincide with the sand and gravel deposits on the aggregate resources map. More permeable soils, such as sand and gravel, will permit the vertical movement of water at greater rates than silt or clay. However, silt and clay-rich soils do allow vertical water movement and perform an important function in the hydrologic cycle as a result. More emphasis is placed on the sand and gravel areas because of their ability to yield sufficient quantities of water to wells for consumption. In summary, the land surface of the entire County, with the exception of built-up areas, would contribute recharge water to a certain extent.

5.0 Attributes of the Eight Cluster Areas or Abiotic Groups

A copy of the synthesized map illustrating the boundaries of the abiotic groups is included in the Appendix (map 3). The attributes of each abiotic group are outlined in the following paragraphs. The numbers correspond to the abiotic groups on the map.

1. More than half of Blandford-Blenheim Township in eastern Oxford County is covered by the Waterloo Sand Hills physiographic region. This distinct landscape is characterized by kame moraines subdivided by glacial spillways. Sandy soils provide high groundwater recharge potential and good drainage to the subsurface. Undulating topography creates low-lying wet environments where the water table intersects the surface which contrasts with the well-drained hills.

2a. The central portion of the Oxford Till Plain physiographic region, between the Middle and South Branches of the Thames River has a greater proportion of sand in the soil than the other two thirds of the plain. The higher sand content creates a loam soil which has moderate drainage and moderate groundwater recharge potential. The drumlins and spillway channels provide moderate to undulating topographic relief across the area. The water table is influenced by artificial drainage systems in many areas; however, within the woodlots, the depth to the water table was rated as moderate.

2b. The northern third of the Oxford Till Plain physiographic region is bounded by the Trout Creek Spillway and the Middle Branch of the Thames River. Silty soil provides moderate drainage and groundwater recharge potential. The topography is variable, especially where spillways have carved deep channels into the overburden. Overall the topography was rated as undulating due to the spillways. The depth to the water table is neither extremely high or low; however, drilled wells are used to obtain water from deep aquifers.

2c. The southern third of the Oxford Till Plain physiographic region, between the South Branch of the Thames River and County Road 46, contains the majority of the drumlins which comprise the Woodstock Drumlin Field. Drumlins create a more undulating topography where the steep slopes are occasionally maintained as woodlot. Silty soil provides moderate drainage, moderate groundwater recharge potential, and the depth to the water table is rated as moderate.

3. In the southeastern corner of the County, the Norfolk Sand Plain provides a distinct physiographic region. Sandy soils are well drained with high recharge potential and a low water table. The topography across this deltaic deposit is generally smooth except where rivers and creeks have eroded channels.

4. Clay-rich soil fills the area between the Ingersoll and St. Thomas Moraines south of County Road 46. According to the Oxford County soil map, this area has moderate drainage and groundwater recharge potential despite the fine-grained soil texture of the till moraine. Erosion has carried the fine-grain soil particles into this area and created a smooth topography during the process. Depth to the water table is expected to be moderate.

5. The southern half of the Mount Elgin Ridges physiographic region exhibits silty soil with moderate soil drainage and groundwater recharge potential. Erosion has levelled the typically knobby recessional moraines to produce a smooth topography across the till plain. The water table is expected to be at a moderate depth under these soil and topographic conditions.

6. Centred around Lakeside, a variety of glacial landforms combine to create a unique area in the County. Till plain, kame moraine and spillway are all represented within the trial landscape in this area. Soil texture is mainly sandy but silt is also represented. Soil drainage is good to moderate and groundwater recharge potential will be controlled by the soil texture. Topography ranges from rolling to undulating across this area. Other portions of the County were included in this abiotic group due to the similarities in soil texture and glacial landform.

6.0 Evaluation of the Methodology

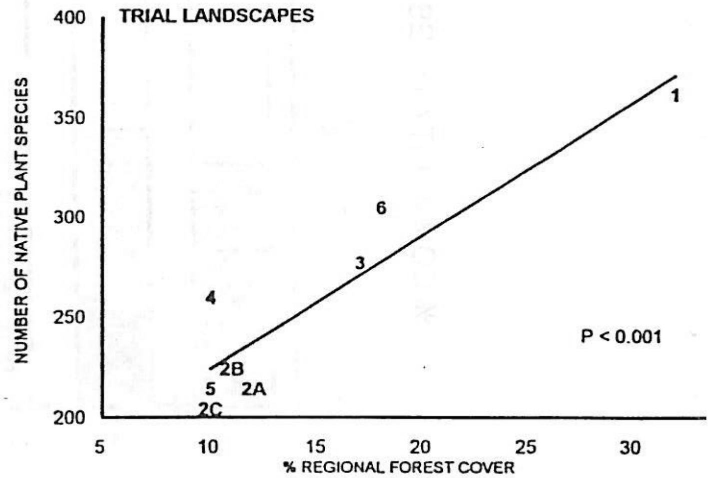
Soil texture was the primary factor considered in the development of boundaries for the abiotic groups. In locations where the soil texture was dominated by sand, the forest patches were typically large, irregularly shaped and frequently linked to other patches (see map 4, Appendix). Floral community diversity within the patches was high where sandy soil existed. Areas dominated by silt, clay and loam soils had smaller, dispersed woodlots in the "back 40" of the individual farms. Species composition was poor in comparison to the sandy areas and total coverage was typically half of the forest cover on sandy soil.

The physiography or glacial landform was the second factor considered in the development of abiotic group boundaries. In Oxford County, the spillways and kame moraines had forest patches that were typically large, irregularly shaped and frequently linked to other patches. These patches also had the greatest floral diversity and covered the greatest area. The till plains and till moraines had the smaller, well dispersed patches with poor species composition.

Other factors considered in the development of boundaries were based on either the soil texture or the physiography. Sandy soils with good drainage and high recharge potential were found in glacial spillways and kame moraines where the topography was undulating and groundwater recharge potential was high. These areas had larger patches, more coverage, and greater diversity in comparison to the silt and clay of the till plains and till moraines.

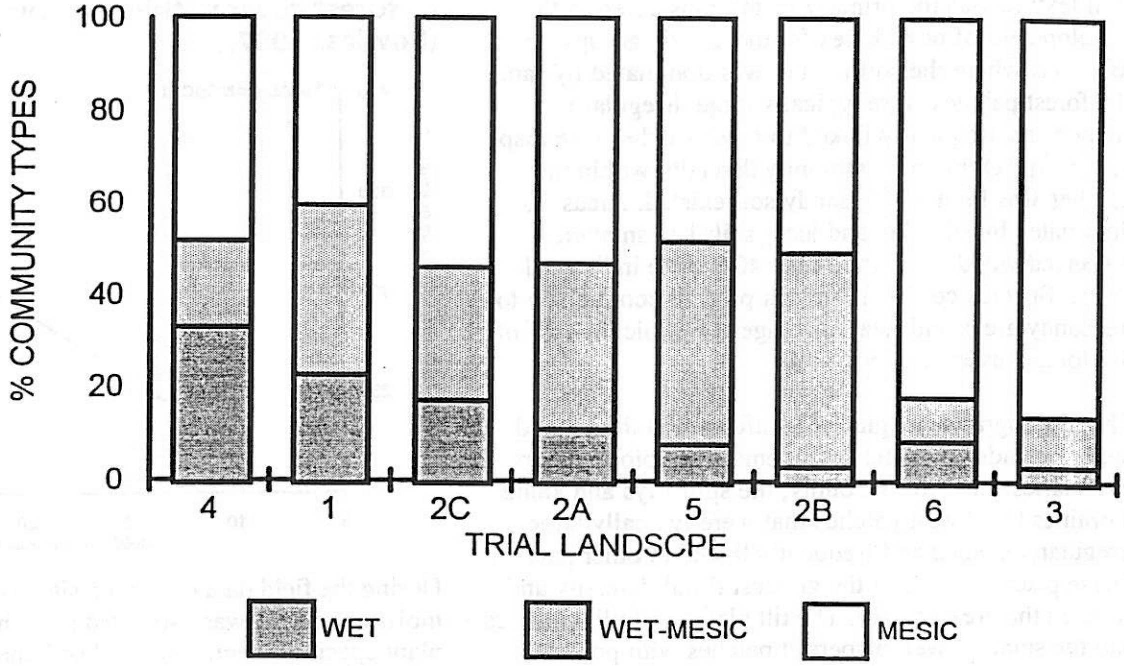
The in-field data collection component of the OCTES study was not specifically designed to validate the abiotic methodology; however, some of the data collected has implications for the discussion. Figure 2 illustrates the results of a regression analysis of the total number of native plant species found within each of the trial landscapes of the eight abiotic groups, and the percentage of forest cover within the abiotic group. Groups 1, 3, 4 and 6 are obviously separated from the remaining four groups. Groups 1, 3 and 6 have approximately two to three times more forest cover than the other groups, and these groups occur in the spillways and kame moraines where the sandy soils exist. Although group 4 has only 10% forest cover, the total number of native plant species was similar to group 3 where the forest cover was 17%. Groups 2a, 2b, 2c and 5 had relatively poor diversity in comparison with the other groups. These abiotic groups represent the till moraines and plains where the dominant soil texture was clay, silt or loam. For a more thorough discussion of the statistical analysis of the data, the reader should consult the original text (Bowles, 1997).

Figure 2. Regression analysis of the total number of plant species and the percentage of forest cover within the abiotic group (Bowles, 1997).



During the field data collection site visits, the "soil moisture regime was estimated at each site based on plant species assemblages and soil characteristics" (Bowles, 1997). The descriptors used in the OCTES study included dry mesic, mesic, wet mesic, wet, very wet and aquatic. Mesic is defined as a soil moisture regime that is intermediate between wet and dry (Bowles, 1997). Figure 3 depicts the differences between the percentage of wet, wet mesic and mesic vegetation communities in the trial landscapes of the abiotic groups.

Figure 3. Proportion of mesic, wet mesic and wet community moisture regimes within the trial landscapes (Bowles, 1997).



Abiotic groups 2a, 2b, 2c, 4 and 5 had approximately the same percentage of mesic communities while group 1 had slightly more and groups 3 and 6 had significantly more mesic forest communities. Groups 3 and 6 had comparatively few wet mesic and wet communities in relation to all of the other abiotic groups. Wet communities were more common in groups 1, 2c, and 4 than the other groups.

The beach deposit in group 3, and the spillway-dominated group 6 where the sandy soils were well drained, had a greater proportion of mesic communities. The sandy kame moraine in group 6 which is subdivided by spillways had the smallest number of mesic communities. The differences in these proportions would suggest that physiography is actually a better factor to use for determining boundaries where sandy soil is dominant.

In group 4, represented by the clay-rich till moraine, there was a large proportion of wet communities. Clay-rich soils are typically poorly drained but the clay soils found within this abiotic group are better drained than clay soils found in other parts of Southwestern Ontario. When the proportion of wet communities in group 4 were compared to the groups which had silty soils in till plains (groups 2a, 2b, 2c and 5), there were approximately twice as many wet communities. These differences would also suggest that physiography is a suitable factor to use for determining boundaries where silt and clay soils are dominant.

7.0 Summary

The steps completed to produce a summary map of the areas with similar geomorphological characteristics provided a method of delimiting Oxford County. The process identified a total of eight abiotic groups in the County. In each abiotic group, a "trial landscape" was selected where field studies were completed within the forest patches to gather information on the existing flora and fauna. The field data was assessed for the purposes of the OCTES project and a portion of the data analysis was used to verify the abiotic methodology.

A combination of soil texture, soil drainage, groundwater recharge potential, depth to water table, physiography and topography were used to produce the boundaries for the eight abiotic groups. After these groups were identified, the forest-related information from the biotic resources review was considered in conjunction with the abiotic resource information. The results of this assessment indicate that there were larger patches, more coverage and greater species diversity in abiotic groups where sandy soil was dominant. In groups where silt, clay and loam soils were dominant, the forest patches were smaller, geometrically shaped and well dispersed within the group area. If soil texture was the only abiotic factor considered in conjunction with the forest resources information, the summary map would only illustrate two abiotic groups. .

After the field data was evaluated, the relationship between both the species diversity and soil moisture was compared to the abiotic resource factors. The diversity of plant species was greatest within the glacial spillways, kame moraines and the beach deposit where the sandy soils exist. The till moraines and till plains, where the silt, clay and loam textures were dominant, had much less diversity in terms of total plant species. When the soil moisture data was evaluated and the results were illustrated as the percentage of community moisture types, each of the eight abiotic groups had a distinct combination of moisture regimes. If this data were available prior to establishing boundaries, the summary map would illustrate the same eight groups determined through the use of the textual resource information.

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