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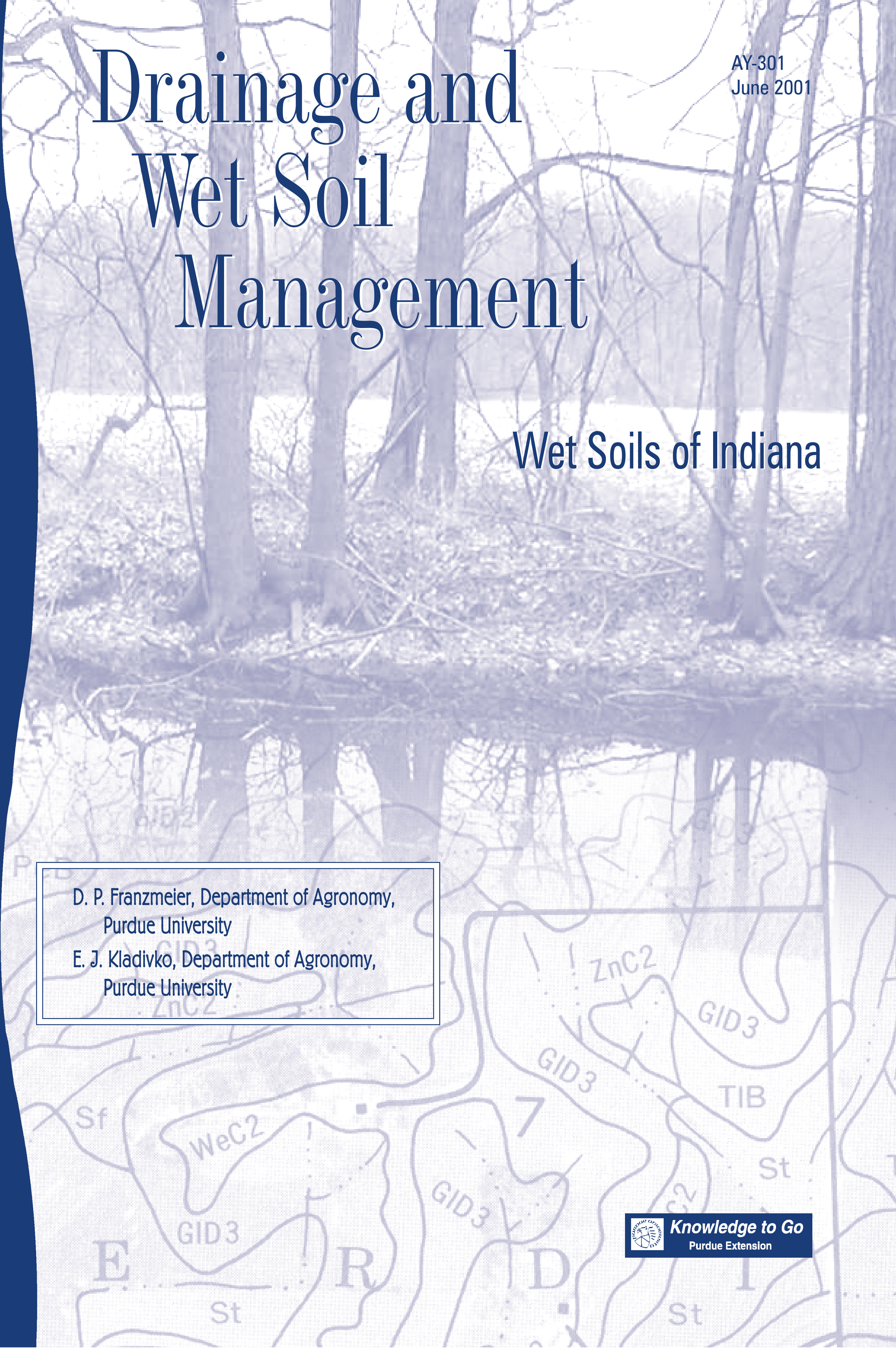
Drainage and Wet Soil Management

Wet Soils of Indiana



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DRAINAGE AND WET SOIL MANAGEMENT

WET SOILS OF INDIANA

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Soils are one of Indiana's greatest natural resources. Wet soils are of special interest because of their hydrologic and ecological importance when kept in their natural state and their importance for agricultural production when drained. As used here, "wet soils" refers, in a general sense, to soils that have excess water at some time of the year and are important for crop production. This publication discusses the basic characteristics of wet soils, how they function in their natural state, and how they might react to drainage for agricultural production. It supports a publication on wetlands and several publications on drainage in this series of publications.

CLASSIFICATION OF WET SOILS

For many years, people have been interested in classifying soils according to how wet they are. Several schemes are in use.

NATURAL DRAINAGE CLASSES

Natural drainage classes are mentioned frequently in this and related publications. They refer to the frequency and duration of wet periods in the natural condition of the soil. A *catena* is a set of soils that differ in landscape position and natural drainage, but are similar in other characteristics. The soils of a catena occur together in a landscape and are also called a *toposequence*. Seven natural drainage classes are defined according to how rapidly water is removed from the soil and how long the soil is wet during the year (Table 1).

When mapping or describing soils, however, soil scientists do not have information about rate of water movement or seasonal patterns of soil moisture, so they rely on soil morphology, mainly color, to determine the natural drainage class, as outlined in Table 2. In general, the grayer a soil horizon and the closer the gray colors are to the soil surface, the more poorly drained the soil. Excessively and somewhat excessively drained soils have the same range of color as well drained soils, but are much more shallow or are on very steep slopes. Some soils of Indiana have been drained with a tile system for many years, but the color of these soils is not noticeably different from nearby soils that have not been drained. From that we conclude that artificial drainage affects soil morphology very little.

It must be explained that the terms *drained* and *drainage* are used in two different senses in this and other publications on draining soils. *Natural drainage* refers to the wetness and oxidation/reduction conditions of natural soils. *Drained, drainage, tile drainage* or *artificial drainage* refers to systems people have installed in soils to remove water from them. It should be clear from the context which meaning is intended. For example, the statement, “The farmer drained the poorly drained Brookston soil,” means that he installed a tile drainage system in the Brookston soil, which is very wet (poorly drained) in its natural state.

TABLE 1. SOIL SURVEY MANUAL (SOIL SURVEY STAFF, 1993) DEFINITIONS OF NATURAL DRAINAGE CLASSES.

Natural Drainage Class	Description
Excessively drained	Water is removed from the soil very rapidly. Soils commonly are coarse textured and have very high permeability or are very shallow.
Somewhat excessively drained	Water is removed from the soil rapidly. Soils commonly are coarse textured and have very high permeability or are very shallow.
Well drained	Water is removed from the soil readily but not rapidly. Water is available to plants most of the year, but wetness does not significantly inhibit growth of roots.
Moderately well drained	Water is removed from the soil somewhat slowly during some periods of the year. The soils are wet for only a short time during the growing season, but long enough to affect most crop plants.
Somewhat poorly drained	Water is removed slowly so that the soil is wet at a shallow depth for significant periods during the growing season. Wetness markedly affects the growth of crop plants unless drainage is provided. These soils often have a slowly permeable limiting layer.
Poorly drained	Water is removed so slowly that the soil is wet at shallow depths periodically during the growing season or remains wet for long periods. Most crop plants cannot be grown unless artificial drainage is provided.
Very poorly drained	Water is removed so slowly that free water remains at or above the ground surface during much of the growing season. Most crop plants cannot be grown unless artificial drainage is provided.

TABLE 2. COLOR OF SUBSOIL IN SOILS OF DIFFERENT NATURAL DRAINAGE CLASSES.

Natural Drainage Class (Depth of diagnostic zone)	Description
Well and better drained (B horizon, down to 40 inch depth)	Diagnostic zone is entirely brownish, with few or no gray mottles or gray clay films. Some soils have silt coats in the upper B horizon.
Moderately well drained (B horizon, down to 40 inch depth)	Upper part of the diagnostic zone is brownish with few or no gray mottles (similar to well drained). Between 18 and 40 inches there are gray mottles, gray clay films, or both. Many soils have silt coats in the upper B horizon. Many soils have black Mn concentrations in the lower part of the zone.
Somewhat poorly drained (B horizon down to 18 inch depth)	Brownish colors predominate in the diagnostic zone, but above 18 inches there are gray mottles, gray clay films, or both. Most blocky peds have clay films, generally brownish in upper part and gray in lower part of the zone. Many soils have silt coats in the upper B horizon. Many soils have black Mn concentrations in and below the zone.
Poorly drained (upper 10 inches of B horizon)	Subsoils are almost entirely gray. Where the surface horizon is dark-colored, the colors are dark gray and dark ped coats and fillings are common. Where the surface is light-colored, the ped interior, clay films, and fillings are all light gray. There are common or many brownish mottles. Black Mn-rich concentrations are in patches throughout the B horizon.
Very poorly drained (upper 10 inches of B horizon)	Subsoils are almost entirely gray, mostly olive gray. Commonly, dark soil material coats peds and fills cracks, channels and burrows. There are few or common brownish mottles.

Technical definitions. Munsell color designations (where hue is not specified, any qualify): Gray - Value $\geq$ 4, chroma $\leq$ 2. Olive gray - 2.5Y or 5Y hue, value $\geq$ 4, chroma $\leq$ 2. Brownish - Value $\geq$ 4, chroma $\geq$ 3. Dark - Value $\leq$ 3, chroma $\leq$ 3. Black - near 10YR 2/1. Amount of surface coats: Few - < 2% of surface. Common 2 - 20%. Many > 20%. Surface coats, such as clay films and silt coats, are coatings of clay or silt on the surfaces of soil peds, which are natural aggregates or chunks of soil.

SOIL TAXONOMY CLASSES

The U.S. soil classification system, *Soil Taxonomy* (Soil Survey Staff, 1999), divides the soil wetness spectrum of Indiana into two major soil moisture regimes (Table 3). *Udic* soils are freely drained soils of humid climates, and *aquic* soils are periodically saturated. Both of these moisture regimes are again subdivided, as shown by the words in parentheses in Table 3. *Typic* refers to the typical soils of a class; *aquic* and *oxyaquic* refer to soils that are wetter than typical soils; and *aeric* refers to drier ones. Table 3 shows the relationship of natural drainage classes and *Soil Taxonomy* classes for two soil catenas.

HYDRIC SOILS AND WETLANDS

The term "wetlands," has been used in a general way for soils that are periodically wet. The term is also used more specifically to identify areas that are meant to be preserved in their natural state, and are protected by governmental regulations, as explained in the *Wetlands Regulation* publication of this series. In that sense, wetlands have three essential characteristics: hydric soils, hydrophytic vegetation, and wetland hydrology. Hydrophytic vegetation is plant life growing in water or in soils that are periodically deficient in oxygen as a result of saturation of the soil with water, such as cattails, sedges, and willows. Wetland hydrology refers to periodic inundation (flooding or ponding) or saturation to the soil surface, usually for a week or more. Hydric soils are those that are saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions in the upper part. The saturated soil conditions of the hydrology factor, the soil oxygen deficiency of the vegetation factor, and the anaerobic conditions of the soil factor are all related, as discussed later.

All soils are either hydric or they are not, so this classification has only two classes, compared with seven natural drainage classes, and the five or so *Soil Taxonomy* classes. In general, all poorly and very poorly drained soils, and some somewhat poorly drained soils are hydric soils because of high water tables (Table 4). Soils of any drainage class can be hydric because of flooding, but the more poorly drained soils are more likely to be hydric because they lie lower on the floodplain and thus remain saturated longer after a flood. Table 4 shows that about 26% of the state has hydric soils. Before any drainage systems were installed, practically all of these soils would have qualified as wetlands by the current definition. Recent observations in undrained areas, however, show

TABLE 3. RELATION OF NATURAL DRAINAGE CLASSES AND *SOIL TAXONOMY* CLASSES FOR TWO CATENAS.

Soil Taxonomy		Natural drainage class	Soil series	
Moisture regime	Subgroup		Miami catena	Russell catena
(Typic) Udic	Typic Hapludalfs	Well		Russell
(Oxyaquic) Udic	Oxyaquic Hapludalfs	Moderately well	Miami	
(Aquic) Udic	Aquic Hapludalfs	Moderately well	Celina	Xenia
(Aeric) Aquic	Aeric Epiaqualfs	Somewhat poorly	Crosby	Fincastle
(Typic) Aquic	Typic Argiaquolls	Poorly	Brookston	Cyclone

TABLE 4. AREA OF INDIANA AND THAT HAS A POTENTIAL RESPONSE TO SUBSURFACE DRAINAGE AND THAT QUALIFIES AS HYDRIC SOILS. *

Natural Drainage Class	Total	Potential for drainage†	Hydric soils‡	
			Area	Reason
	thousands of acres			
Excessively and somewhat excessively	655			
Well	9,044			
Moderately well	2,133	427	63	Flooding
Somewhat poorly	5,049	5,049	380 320	Flooding Water table
Poorly	4,418	4,197	4,418	Water table (some also flood)
Very poorly	356	178	356	Water table
All soils	21,654	9,851	5,537	
(% of total area)	(100%)	(45%)	(26%)	

* Data from the soil survey of Indiana. Excludes urban land, pits, quarries, and other miscellaneous lands.

† Assumptions: 20% of moderately well drained soils respond to drainage, all somewhat poorly drained soils respond, and 5% of poorly drained and 50% of very poorly drained soils cannot be drained because of lack of outlets or other problems.

‡ "Flooding" means that soils are flooded for one week or more during the growing season. "Water table" means that the soils meet the criteria for hydric soils. Practically all hydric soils were wetlands before the land was cleared and drained.

that hydrophytic vegetation does not extend quite as high in the landscape as do hydric soils. Thus at the time of European settlement, about 5,400,000 acres or 25% of Indiana would have qualified as wetlands.

Now there are only 700,500 acres of wetlands (1997 National Resources Inventory, Natural Resources Conservation Service), so 87% of the wetlands have been drained, filled, or otherwise modified.

SUBSURFACE DRAINAGE CLASSES

Over the years, farmers have learned that it pays to drain some soils but not others. The criteria for natural drainage classes developed when the main application of that information was to decide which soils would respond to subsurface drainage, so it is likely that subsurface drainage considerations influenced where limits were placed along the continuous soil wetness spectrum. As concepts developed, it paid to drain very poorly, poorly, and somewhat poorly drained soils, and very small areas of better drained soils. Table 4 lists the area of soils in each drainage class for the state. It also gives an estimate of the area that is suitable for subsurface drainage. The areas unsuitable for drainage may be low-lying pockets that have no outlet except by pumping, they may be on floodplains that flood frequently, or they may have other physical limitations. Hydric soils preserved as wetlands are not subtracted from the "suitable" acreage in that table. About 45% of the land area of the state is suitable for subsurface drainage according to Table 4. In another publication in this series, *Drainage Recommendations for Indiana Soils,* all soils are placed in one of 21 soil drainage associations. Some associations require drainage for efficient crop production, some may require drainage, and others do not need it.

WATER RETENTION AND MOVEMENT

Soils are made up of three phases, solid, liquid, and gas. The solid part consists of *mineral* material, such as sand or clay particles, and *organic* material, such as decomposing corn stalks. The space between the solid particles, or pore space, can be filled with water or gases such as nitrogen, oxygen, and carbon dioxide. The more water in the soil, the less room there is for gases. Plant roots need both water and air in the soil, and a major function of drainage is to maintain an adequate amount of air-filled pore space.

Plant roots and soil microorganisms respire to keep alive, and this process uses oxygen (O_2) and produces carbon dioxide (CO_2). Therefore soil air usually contains more CO_2 and less O_2 than atmospheric air. Oxygen diffuses through water much more slowly than through air, so roots growing in a saturated soil in which the water is stagnant quickly remove the oxygen from the soil water. Oxygen cannot diffuse through the water fast enough to keep up with the demands of the plant, so many plants (especially crops) suffer and may die. Some soils, however, have relatively high water tables but do not have the gray colors indicative of lack of oxygen. Apparently water is moving in these soils, rather than becoming stagnant, which allows the soil water to be replenished with oxygen.

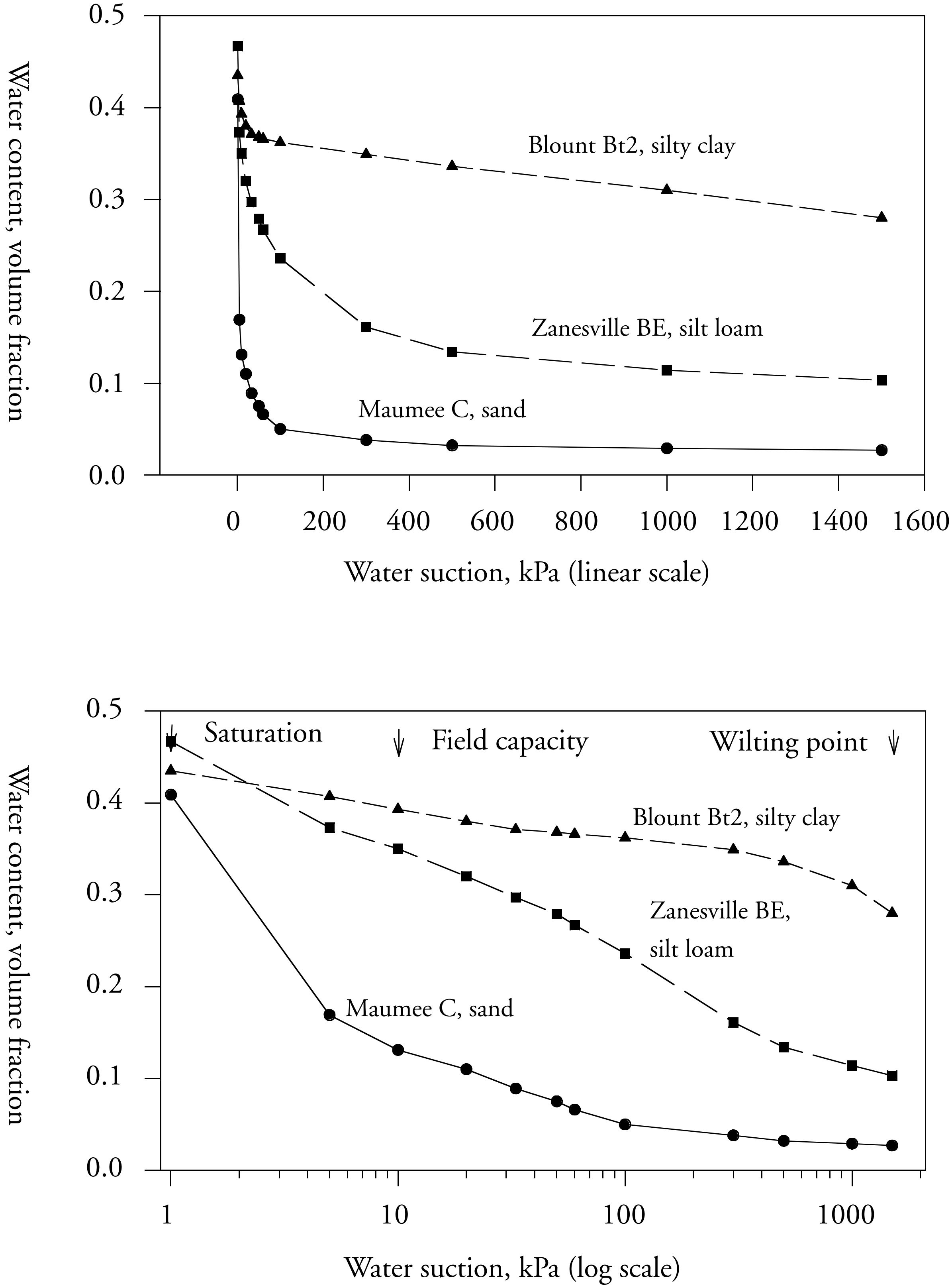
Many soils become saturated with water sometime during the year. When the soil is saturated, all pores are filled with water instead of air. As a saturated soil drains, water is first removed from large pores, and replaced with air, by the pull of gravity. The water that remains is held by surface forces and does not drain so readily, but it can be removed by plants, which exert a suction to do so. Some water is held so tightly that plants cannot remove it from the soil. Water content is expressed as a volume fraction, the volume of water in a unit volume of soil, and suction is expressed as kilopascals (kPa), a unit that appears on some tire pressure gauges, for example. The relationship between the water content of the soil and the suction required to remove it is called the water retention curve. Water retention curves for coarse-, medium-, and fine-textured Indiana soils (sand, silt loam, and silty clay textures, respectively) are shown in Fig. 1, as a linear plot and a log plot that better separates saturation and field capacity. Three points along the curves have special significance for field water relations. *Saturation* is when all soil pores are filled with water. It corresponds to a suction of zero kPa (represented as 1 kPa in the log plot). At saturation all three soils hold about 0.41 to 0.47 cm^3 of water in 1 cm^3 of soil. *Field capacity,* the water content of a soil horizon after it has been saturated or nearly saturated and then drained for a few days, corresponds to a suction of about 10 kPa. At 10 kPa, most of the water has drained from the sand, about one-quarter has drained from the silt loam, and little has drained from the silty clay soil. *Wilting point* is the water content when a plant has removed all the water it can from the soil. It corresponds to 1500 kPa. Even at this suction, the soil holds some water, ranging from 0.03 to 0.28 volume fraction for the three soils. The difference between the water contents at field capacity and wilting point is the available water capacity of the soil. It is 0.10 inch of water per inch of soil for the sand, 0.25 inch per inch for the silt loam, and 0.11 inch per inch for the silty clay.

These relationships are significant for designing soil drainage systems. Tile lines or open ditches drain soils to about field capacity. Fig. 1 shows that much more water will be removed from a sandy soil than a clayey soil by subsurface drains. They remove so much from sandy soils that it is advantageous to shut off the drains in the spring once the water table is low enough to support field operations. On the other hand, a fine-textured soil will dry out very slowly, even with tile drainage.

The concept of field capacity is based on a permeable soil without any layers that restrict water movement. This applies to some soils in Indiana, but most of them, especially those used for crop production, have restricting layers, such as dense till, fragipans, and paleosols, that impede downward water movement. Soils on nearly level slopes and with restricting layers are still almost saturated a few days after initial saturation from a rainstorm. These are the soils that need drainage systems for best crop production. Soils with a subsurface drainage system will reach a field capacity point that is determined by the depth of the tile, approximately 10 kPa near the so0il surface if the tiles are 3.5 feet deep.

FIGURE 1.

Water retention curves for coarse-, medium-, and fine-textured soil horizons with potential plotted on a linear and a log scale (data from Wiersma, 1984).



SOIL OXIDATION/REDUCTION PROCESSES

The brownish and reddish colors of well drained soils are due to iron oxide minerals in which iron (Fe) is in the oxidized state (Fe^{3+}) . These small minerals lie on the outside of silicate minerals, especially clays, like sesame seeds on a bun, but at low magnification they appear to coat the silicates. In contrast, the gray subsoil color of wet soils is due to the color of the silicate minerals themselves after the iron oxide minerals have been dissolved. This section explains how different color patterns develop in soils, and how soil scientists use color patterns to place soils in different soil drainage classes.

Soil microorganisms use dead organic material in the soil as a source of energy, and during this decomposition process they produce carbon dioxide and electrons through respiration. In an unsaturated soil, oxygen gas accepts the electrons and is reduced to water. Some microorganisms have the ability to use compounds other than oxygen as electron acceptors, thereby reducing those compounds. In soils these compounds mainly contain nitrogen (N), manganese (Mn), and iron (Fe).

The water table is higher and of longer duration in more poorly drained soils than in better drained soils. In well drained soils, oxygen accepts the electrons produced by soil microorganisms because oxygen from the atmosphere readily diffuses through air in soil pores. Oxygen diffuses very slowly through water, however, so the oxygen dissolved in water in the saturated subsoils of poorly drained soils is quickly used up, and new oxygen arrives very slowly by diffusion. When the oxygen supply is completely depleted, other elements must accept the electrons. Nitrate-N is first to accept them. When a poorly drained soil is ponded after a rain, nitrate (NO_3^-) accepts electrons and is reduced to a gas (e.g., N_2) which is volatile and leaves the soil. The result of this process is seen as nitrogen deficiency of crops in areas of a field that had been ponded. When the nitrate supply is used up, Mn compounds accept electrons. During wet periods, Mn^{4+} is reduced to Mn^{2+} which is soluble. During dry periods Mn^{2+} is oxidized to MnO_4 or other compounds containing Mn^{4+}, which appear as black spots and coatings in soil profiles. If the water table remains high, if there is enough organic matter in the soil to feed the microorganisms, and if the temperature is warm enough to make them active, reducing conditions continue and Fe is next to be reduced. The Fe^{3+} of the brownish and reddish Fe-oxide minerals is reduced to Fe^{2+}, which is soluble. In some tile drained soils Fe^{2+} is oxidized and precipitates as iron ochre when it comes in contact with oxygen near tile lines that are not running completely full. If reducing and leaching conditions prevail, Fe^{2+} is leached from the soil, and some gets into the ground water. It may appear again when it oxidizes on sinks and in toilet bowls, for example. Sometimes the water table recedes before the Fe^{2+} is leached completely out of the soil, and the Fe^{2+} moves only short distances in a soil horizon. When the rain stops and oxygen again becomes available, Fe^{2+} is oxidized to Fe^{3+} and precipitates as brown iron oxides. These iron oxides stain a small volume of soil brownish, and these areas are scattered among the grayish areas devoid of iron oxides to form a mottled color pattern in the subsoil.

Soil scientists depend largely on the color pattern of subsoils that result from oxidation and reduction of iron to place soils into different drainage classes (Table 2) and to identify the soils that will benefit from tile drainage. Over the years, experience has shown that when soils with a significant content of gray colors are drained, the yield of crops grown on them increases. So, it is likely that when reduction processes are strong enough to reduce Fe, the oxygen supply is low enough to suppress crop growth.

Natural drainage class is mentioned frequently in the Soil Drainage Association bulletin. It is determined in the field mainly by observing the color pattern of subsoils—soils with more extensive gray colors are placed in more poorly drained classes (Table 2). This color pattern has developed over thousands of years and integrates the soil wetness over that time period. In this sense, morphological markers are more reliable than measurement of water tables for one year, or even a few years, because those particular years might be abnormal. Comparison of soil color pattern and water table measurements over several years helps to validate the reliability of color patterns for predicting water table trends. That was the main purpose of the studies from which the water table depth data presented later were derived.

SOILS, LANDSCAPES, AND WATER REGIMES IN INDIANA

The geographic distribution of wet soils and the seasonal soil moisture regime at a certain location are controlled by precipitation, *soil stratigraphy*, and *soil geomorphology*. *Stratigraphy* refers to the strata within the soil profile. Some of these strata originated from depositional processes and some from soil formation processes. *Geomorphology* refers to the shape of the land surface, including the slope gradient. Stratigraphy controls downward seepage of water, geomorphology largely controls surface runoff (along with permeability of surface horizons), and both control throughflow, lateral water movement through the soil profile.

STRATIGRAPHY

The rate of downward seepage depends on the permeability of various layers or horizons of the soil, which, in turn is influenced greatly by the kind of parent material, the geologic material from which the soil developed. Parent material terms are defined in Table 5. Some are illustrated in Fig. 2 where they are shown on the vertical (cut) surfaces of the diagram. In general, most alluvial deposits, outwash, eolian sand, and loess have relatively fast permeability. Parent materials that have undergone few soil formation processes are called C horizons. Slowly permeable layers, or *limiting layers*, hold up water tables and are responsible for many wet soils in Indiana. Some types of limiting layers are discussed below.

Dense till (Cd soil horizon) is especially significant to soil hydrology because it is so extensive in Indiana. This till was compacted by the weight of the glacial ice that transported it, and it may also have some chemical cementation. It has a bulk density of almost 2.0 g/cm^3. For reference, a good plow layer in Indiana has a bulk density of about 1.3 g/cm^3, and granite has a density of about 2.6 g/cm^3, so dense till is closer in density to granite than to a good topsoil. Dense till has about half as much pore space as the plow layer, which leaves little room in till for water to move through. Dense till occurs within six feet of the soil surface in much of the northern two-thirds of Indiana.

Fragipans (Bx or Btx horizons) have slow permeability, probably because they have poor soil structure and thus pores are not continuous through the horizon. Most formed in loess and they are extensive in southern Indiana. Their bulk density is not as high as dense till.

Paleosols (2Btb horizons) are old soils, that usually were eroded, and buried by more recent material such as loess. They have slow permeability because their soil structure has deteriorated after burial. Often they are below fragipans.

Fine-textured lacustrine deposits (C horizons) have slow permeability because they have relatively few large pores, and they have horizontal layers that are not conducive to vertical water movement. They are important in scattered areas of the state.

Shale bedrock (R horizon) is a soil parent material that is even more impermeable than dense till. In most of Indiana, shale bedrock is buried so deeply by other deposits that it has little affect on soil moisture in the major rooting zone of crops. Bedrock is within six feet of the surface in some soils of southern Indiana but generally they are so steep that most of the rain runs off the surface or moves downslope through the soil. Weathered bedrock (Cr horizons) may also be slowly permeable.

GEOMORPHOLOGY

The shape of the land surface also greatly affects soil wetness. Water runs off the surface or through the soil profile rather rapidly on sloping soils, so there are few wet soils that might need tile drainage on slopes steeper than 2%. Most tile drainage systems are installed in soils with less than 2% slope, so the shape of these land surfaces is a very important consideration in determining the most effective drainage system. In Indiana, most soil landscapes with slope of 2% or less are gently undulating and are made up of *swells* and *depressions*. Swells are the higher convex areas (ball-shaped), and *depressions* or *swales* are the lower concave areas (bowl-shaped). Generally the surface horizons are darker in depressions than on swells. Water tends to move off swells, and collects in or slowly moves across depressions. Some landscapes with slope of 2% or less are so flat that they have no noticeable undulations. They are mainly in southern Indiana.

Landscape terms are defined in Table 5. In the table, *Landform* refers to larger parts of soil landscapes and *Landform component* refers to smaller parts. Some of these terms are illustrated in Fig. 2, a landscape typical of northern Indiana, where landscape names (till plain, till plain bevel, swell, depression, etc.) are on the land surface. Many landscapes consist of *plains*, extensive nearly level or gently rolling areas, and *bevels*, sloping surfaces that cut and descend from plains. Often the bevels include many ravines.

Wet soils may occur high or low in the landscape. Soils high in the landscape, on till plains or bedrock flats, often have limiting layers that hold up or perch the water table. This limiting layer is dense till in the northern two thirds of the state and a combination of a fragipan and a paleosol in the south. Generally there is a paleosol over bedrock flats, but in some places the bedrock itself holds up the water table.

SOILS OF INDIANA

In northern Indiana, glaciers deposited till and other materials around 15,000 to 20,000 years ago. They left gently undulating till plains with swell-and-depression topography. During soil formation more organic matter accumulated in

Table 5. Definitions of Parent Materials, Landforms, and Landform Components Used in the Descriptions of Soil Drainage Associations.

Definitions of Parent Materials

Alluvium - Material deposited by a stream in relatively recent time.

Bedrock - Rock that underlies soil. In Indiana, bedrock includes sedimentary rocks, such as sandstone, siltstone, shale, and limestone.

Eolian sand - Sand transported and deposited by the wind, mainly medium and fine sand.

Lacustrine deposit - Relatively fine-textured inorganic material deposited in a lake or other body of still water by non-biological processes. Particle size is mainly finer than sand.

Loess - Mainly silt-size material transported and deposited by the wind.

Organic deposit - An accumulation of plant material. Usually it occurs as thick deposits in former lakes or as thin surface layers, overlying mineral soil material, under forest.

Outwash - Stratified coarse-textured material washed out from a glacier by meltwater streams and deposited in front of the margin of an active glacier Particle size is mainly sand and gravel.

Till - Unsorted and unstratified material deposited by glacier ice, and consisting of a heterogeneous mixture of clay, silt, sand, gravel, stones, and boulders; **dense till** has a bulk density of $\geq$ 1.75 g/cm^3, and **friable till** has a bulk density of < 1.75 g/cm^3.

Definitions of Landforms

Bog - A lake or depression filled with organic soil. The term is used in a general sense; more specific definitions may differentiate among bog, marsh, swamp, fen, or other names.

Dune - A low mound, ridge, bank, or hill of loose, wind-blown sand; collectively, *dunes*.

Flood plain - The surface or strip of relatively smooth land adjacent to a river channel, constructed by the present river in its existing regimen and covered when the river overflowed its banks.

Kame - A low mound, knob, hummock, or short irregular ridge composed of stratified sand and gravel deposited by a subglacial stream as a fan or delta at the margin of a melting glacier.

Lake plain - The nearly level surface marking the floor of an extinct lake, filled in by well-sorted deposits, mostly silt and clay size, from inflowing streams.

Loess plain - A nearly level surface underlain by deep loess (>6 feet); usually another landform controls the topography, but the nature of this plain may not be known because of the thick loess cover.

Moraine - A mound, ridge, or other distinct accumulation (depositional surface) of glacial drift, predominantly till.

Outwash plain - A broad, gently sloping sheet of outwash, not contained in a valley, deposited by meltwater streams flowing in front or beyond a glacier.

Sand plain - A sand-covered plain consisting of sandy outwash.

Terrace - A long, narrow, relatively level or gently inclined surface, bounded on one edge by a steeper descending slope (terrace bevel) and along the other edge by a steeper ascending slope, contained in a valley and composed of unconsolidated material such as outwash.

Terrace bevel - A sloping surface that descends from a terrace.

Till plain - An extensive area, with a flat to undulating surface, underlain mainly by till.

Till plain bevel - A sloping surface that descends from a till plain.

Definitions of Landform Components

Drainageway - A course along which water moves in draining an area; narrow area of joined footslopes if cross section is U-shaped, or of joined backslopes if it is V-shaped.

Hillslope - A part of a hill between its crest (or summit) and the drainage line at the toe of the slope.

Natural levee - A long, broad, low ridge or embankment of sediment, built by a stream on its flood plain along its channel, especially in time of flood when water overflowing the normal banks is forced to deposit the coarsest part of its load.

Plain components:

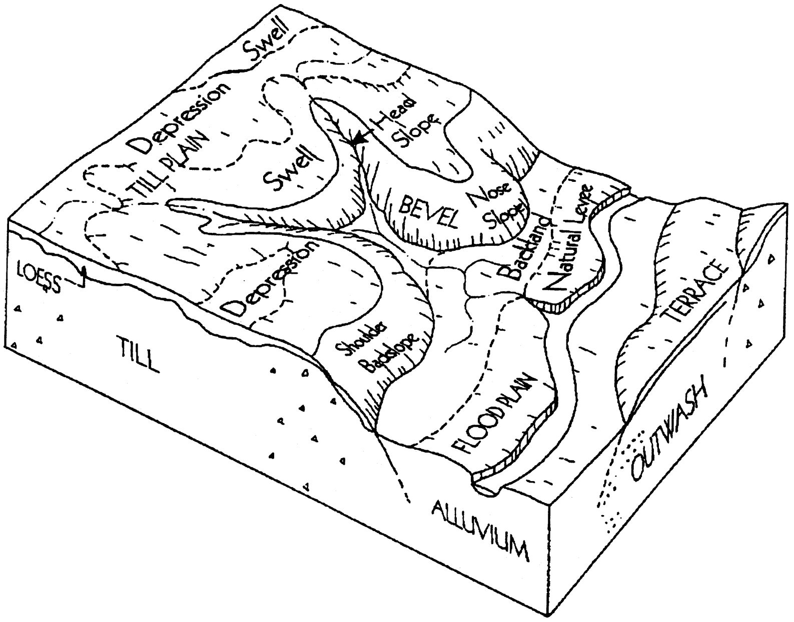
- **Swell** - A well-rounded hill with gentle slopes.
- **Flat** - A general term for a level or nearly level surface marked by little or no relief; a surface with no apparent convexity or concavity. The term may be modified or replaced by words that describe more specifically a location within the flat, such as **interior** or **rim**.
- **Depression** - A slightly concave area in the midst of generally level land; an **open depression** has a natural outlet for surface drainage, and a **closed depression** has no natural outlet.
- **Pothole** - A pot-shaped pit or hole, not over limestone, with no outlet; deeper than a depression with steeper sidewalls.

the soils in the depressions, making them darker, than in soils on the swells because the depressions were wetter. This resulted in a random pattern of dark- and light-colored soils, like the spots on a Dalmatian dog or Holstein cow. Dense till is within six feet of the surface of the till plain, and holds up water in the soil profile in several Soil Drainage Associations (see *Drainage Recommendations for Indiana Soils* in the Wet Soil Management Series).

When the glacier melted, meltwater washed material out of the glacier. The coarser material, outwash, was deposited in broad upland areas to form outwash plains and in flood plains in valleys. When meltwater streams cut through the flood plains, they became stream terraces. The finer material was carried further downstream, and where the streams were ponded, the material settled out as a lacustrine deposit to form sand plains and lake plains.

FIGURE 2.

Block diagram illustrating parent materials (uppercase lettering on sides of diagram), landforms (uppercase lettering on land surface), and landform components (lowercase lettering on surface) in northern Indiana (Franzmeier, 1998).



Some of the material on the terraces and outwash plains was picked up by the wind. Sands were carried a short distance by the wind and deposited near the source of the material in dunes, and silts were carried further and deposited all over the countryside as loess. Loess deposits become thinner with distance from the source streams. During loess deposition, winds were predominantly from the west, as they are now, so loess thins eastward mainly from the Wabash, White, and Ohio Rivers. Loess is significant for soil drainage because it was deposited from the air, like sifting flour, and is much more permeable than the till, paleosols, and most other materials it covers.

The relatively recent glaciers of northern Indiana did not reach the southern part of the state. Some parts of the south were glaciated a few hundred thousand years ago, and other parts were never covered with a glacier. Many soils that had formed on these older glacial deposits and bedrock were eroded and later buried by several feet of loess that originated from the glacial deposits that covered northern Indiana around 20,000 years ago. The buried soil is called a paleosol. Fragipans formed in this loess, above paleosols. Fragipans are subsurface horizons that restrict root growth and water movement. They have moderately high bulk density, often around 1.5 to 1.6 g/cm^3, but they have slow permeability, almost as low as dense till. They are cemented by silica, which may further reduce their permeability. Paleosols are clay-enriched B horizons of former soils. Most have slow permeability because they have been consolidated by the weight of the overlying loess and their structure has been weakened due to weakened activity of processes that create and maintain structure, such as wetting-drying, freezing-thawing, root growth, and worm activity. Paleosols also have slow permeability. Soils in which fragipans, paleosols, or both hold up the water table are in Soil Drainage Association 8.

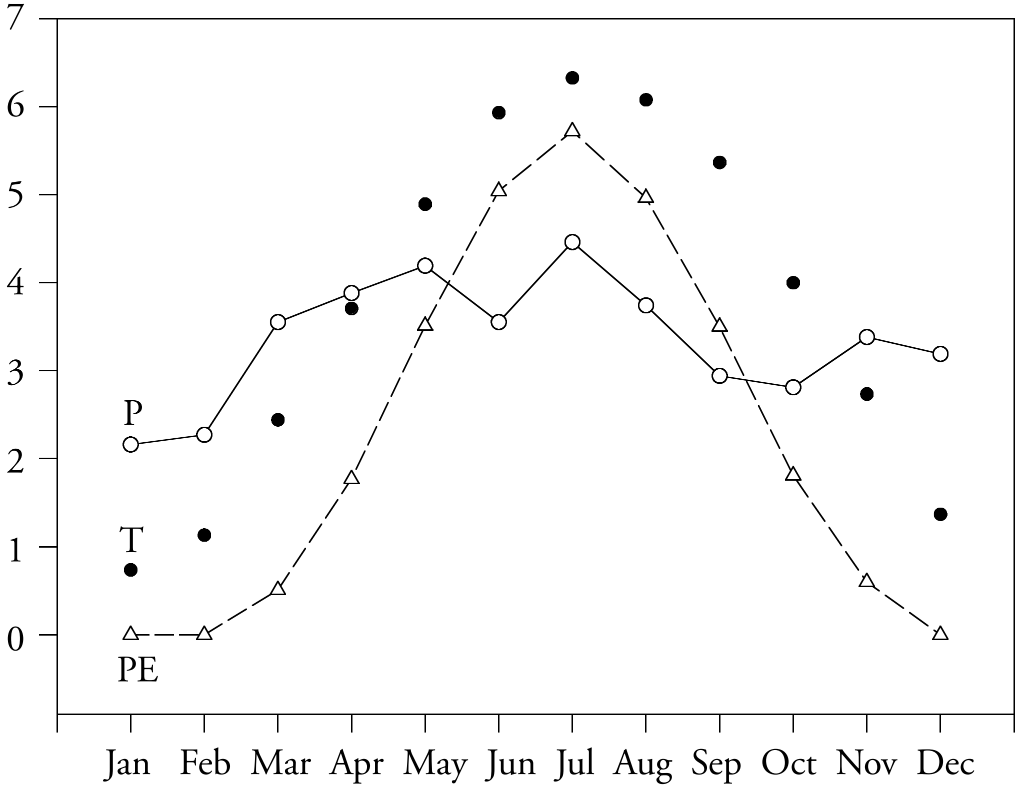
SEASONAL WATER REGIMES

Precipitation and evapotranspiration (direct evaporation of water and transfer of water from the soil to the atmosphere through plants) control the main pattern of the water regime of Indiana soils. Surface runoff and run-on and movement of water within the soil have an additional effect. In Indiana, precipitation is somewhat greater in the spring than in the fall, but these seasonal differences are much less than the differences in potential evapotranspiration (Fig. 3). Thus, evapotranspiration largely controls water table depths in soils. They rise rapidly when precipitation exceeds evapotranspiration and fall rapidly when evapotranspiration is greater.

Fig. 4 includes nine graphs that show water table depths in soils. In all graphs, a certain drainage class is represented by the same symbol. Curves for soils of different natural drainage classes tend to stack over each other, like a pile of traffic cones, best illustrated in Fig. 4g, which illustrates five drainage classes. Each graph represents a toposequence (or catena) of soils, a set of soils in a landscape that differ in hillslope position and in natural drainage class, but are otherwise similar. The different graphs represent the major soil regions of the state, as shown in Figure 5. Figures 4a, 4b, and 4c represent the medium-textured soils of Soil

FIGURE 3.

Average Monthly Precipitation (P) and Temperature (T) based on 1961-1990 records for central Indiana, and potential evapotranspiration (PE) calculated by the method of Thornwaite (1948).



Regions 6, 8, and 9; Fig, 4d, the loess-covered plains of Regions 5 and 10; Fig. 4e, the finer-textured soils of Region 7; Fig. 4f, the soils in loess and weathered bedrock of Region 11; and Fig. 4g, the sandy soils of Regions 1, 3, and 4.

Water table depth curves have two distinct segments. The rising segment begins after plants become dormant, evapotranspiration rates fall, and the relatively dry soil soaks up the excess water. Typically this occurs in November or December, but later in some years. The falling segment begins when plant growth begins and evapotranspiration increases in the spring, typically in late April, May, and June. In some years, water table depth curves have a third segment. A summer rain event may result in a water table spike (for example, June 1995, Fig. 4d).

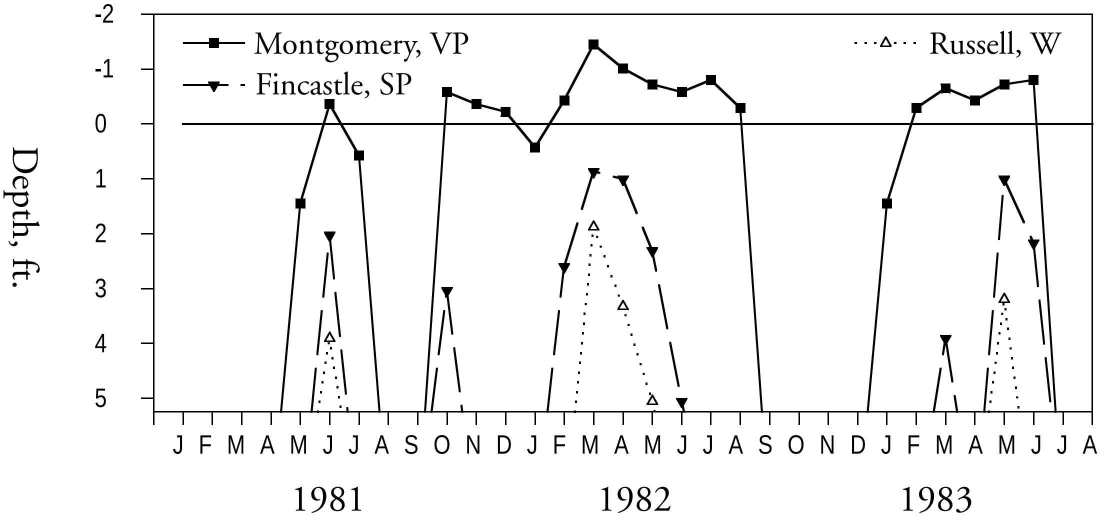
Water table depth curves vary greatly among soils and from year to year for the same soil. The time of the rising segment varies greatly. It is typically around November, but may be as late as March. The steep part of the falling segment occurs mainly in July and August, but may be as late as September and October. Overall, the water table is highest in April and May, and lowest in September, but these periods can vary by several months. Occasionally, the summer spike in the water table curve is so broad that it lasts through what is typically the low water table period. In some years, the water table may be near or above the soil surface for a year or more, but in other years, it may fall below 5 to 7 feet in the same soils.

The level to which water tables rise depends largely on precipitation patterns, but it does follow some patterns.

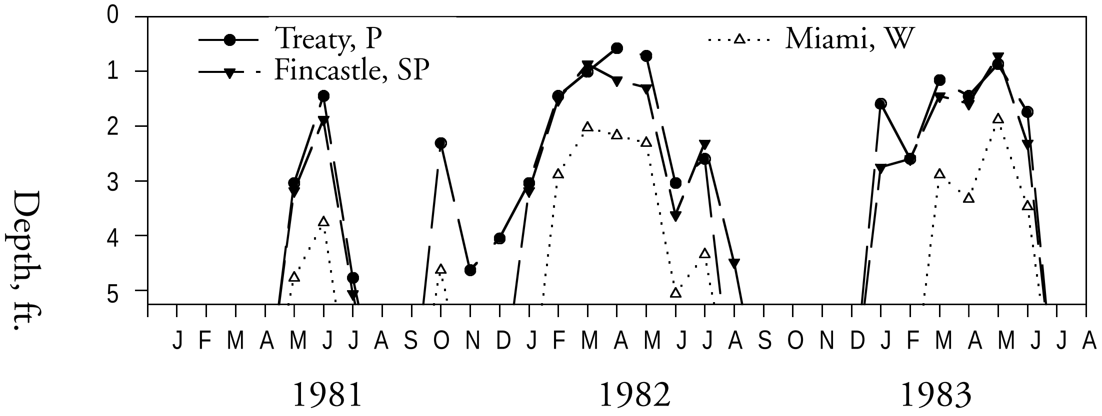
- Very poorly drained soils (plotted in Figs. 4a and 4g) often have water tables ponded above the surface. These soils are in closed depressions. The duration of ponding varies. In some years it does not happen, and in other years it may last an entire year.
- Poorly drained soils (Figs. 4b, 4c, 4d, and 4g) have water tables that are near or slightly above the surface in most years.
- In somewhat poorly drained soils, plotted in all graphs, the water table typically rises to within one or two feet of the surface, but it could reach the surface (Fig. 4d) or never rise above 3 1/2 feet (Fig. 4g, 1999).
- The water table level in moderately well drained soils varies greatly. It may be almost as high as in somewhat poorly drained soils to about a foot lower (Figs. 4d, 4e).

FIGURE 4

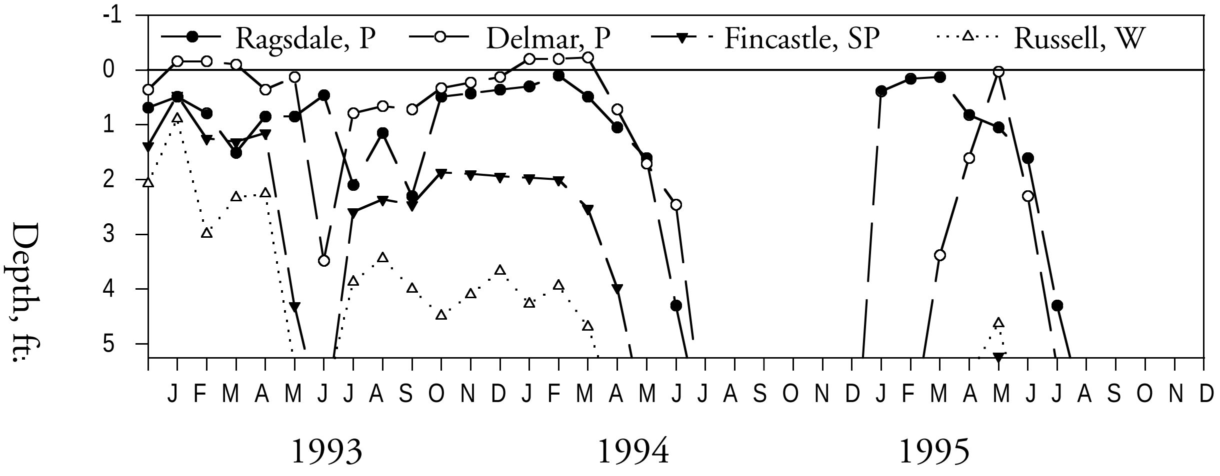
a) Soils in loess over dense till in Soldiers' Home Woods, Tippecanoe County (Evans and Franzmeier, 1986). Water tables remained low (below 4 ft.) during the rest of 1983 and the summer of 1984.



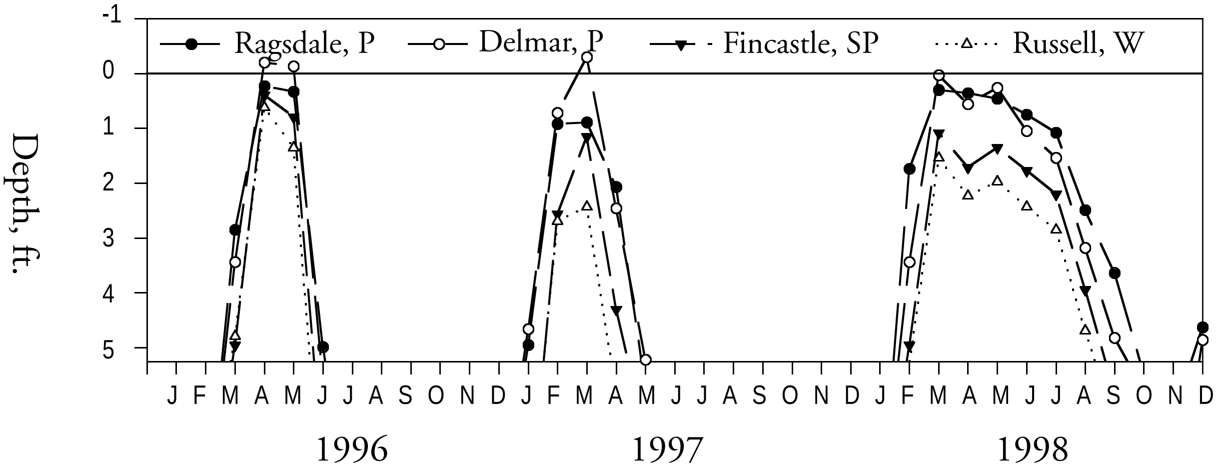
b) Soils in loess over dense till in McCormick's Woods, Tippecanoe County (Evans and Franzmeier, 1986).



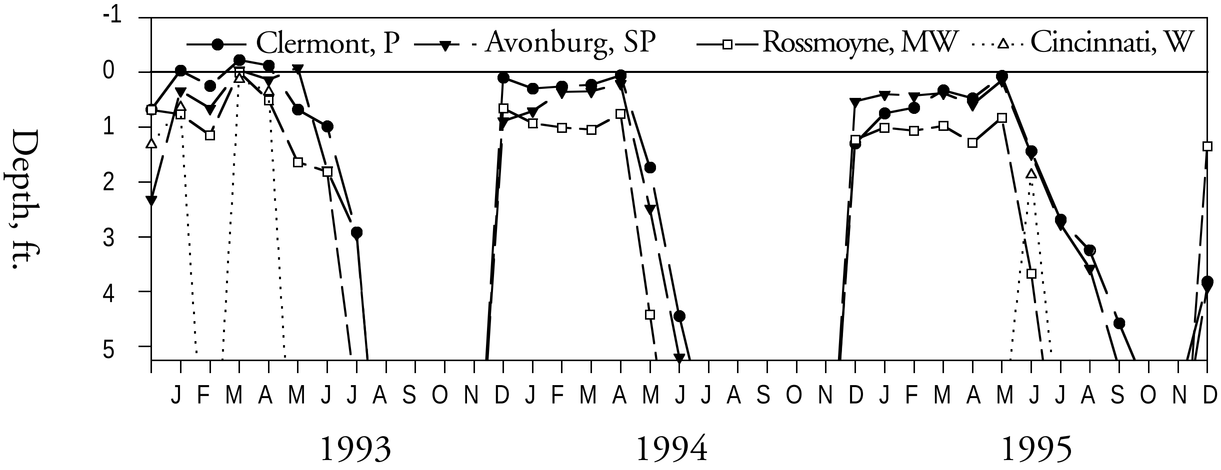
c') Soils in loess over dense till in Moore's Woods, Parke County (Jenkinson, 1998).



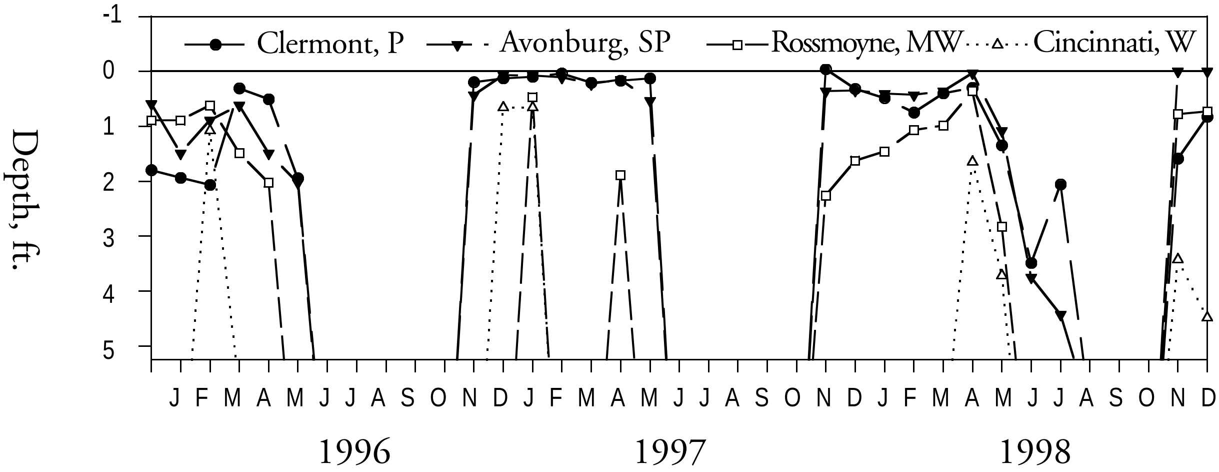
c²) Soils in loess over dense till in Moore's Woods, Parke County (Jenkinson, 1998).



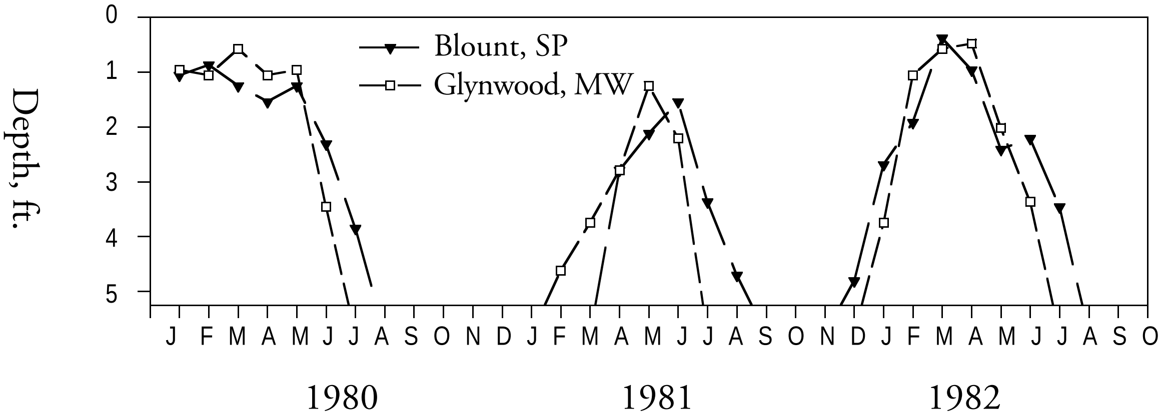
d¹) Soils with fragipans in deep loess over Sangamon paleosols in Jennings County (Jenkinson, 1998).



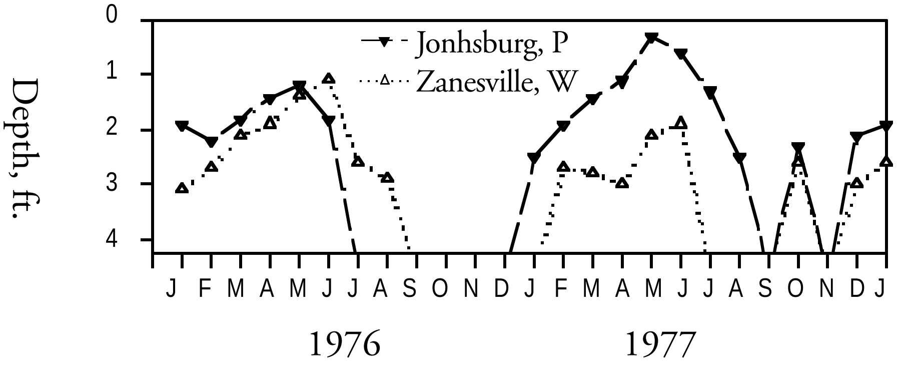
d²) Soils with fragipans in deep loess over Sangamon paleosols in Jennings County (Jenkinson, 1998).



e) Soils in dense, fine-textured till in Jay County (Franzmeier et al., 1984)



f) Soils with fragipans in loess weathered bedrock in DuBois County (Franzmeier et al., 1984)



g) Soils in eolian sand in Jasper County (Unpublished data, Jenkinson). During the period shown in the graph, the water table in Oakville (W) varied from 8 to 16 feet deep.

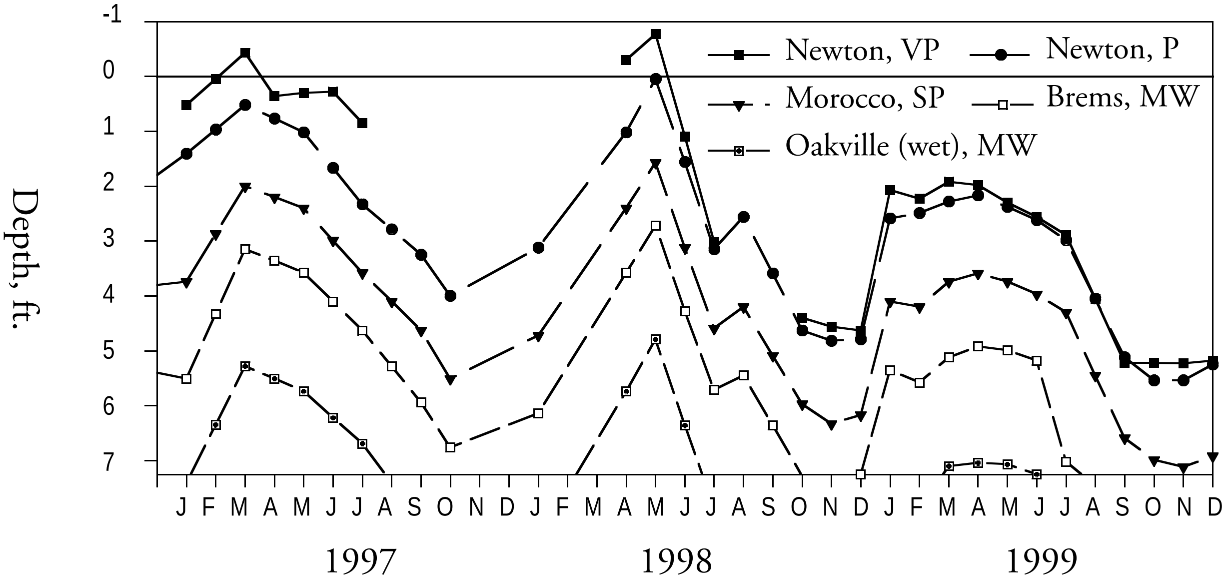
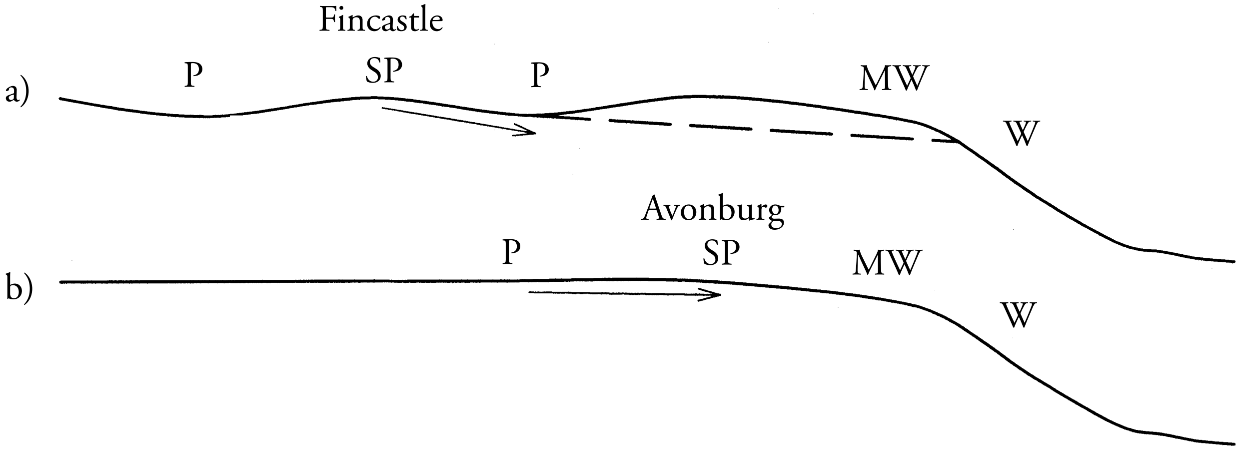


FIGURE 6

Cross section through dissected plains. a) Gently undulating landscape with soils similar to those represented in Figs. 4a, 4b, and 4c. b) Flat landscape with soils similar to those represented in Fig. 4d.



- Well drained soils have water tables that vary greatly in level and in time. They are plotted, or mentioned in the caption, of all graphs. The variability is well illustrated in Fig. 4c. In some years it is almost as high as in somewhat poorly drained soils, and in other years it is much lower. The well drained soils in these graphs were considered to be well drained at the time of the study. Since then, the drainage class of Miami and Cincinnati soils was changed to moderately well.

The significance of minor changes in landform and topography is illustrated by the Tippecanoe County graphs. Both locations are on loess-covered dissected till plains. At the Soldiers' Home location (Fig. 4a), Fincastle is on a swell and Montgomery is in a nearby closed depression. Although, both are nearly level, water apparently moves by surface runoff and throughflow from Fincastle to Montgomery. Because the upper soil horizons are rapidly permeable, the throughflow component may be more important than runoff. Water was ponded on the Montgomery soil for a few weeks during the summer of 1981 and for almost a whole year later in 1981 and 1982. In the summer of 1984 (not plotted), however, the water table never rose above a depth of four feet, illustrating the difference in water regime of a soil from one year to another. In contrast, at the nearby McCormick's Woods location (Fig. 4b), the Treaty soil is in an open depression. Its water table never rose above the soil surface, and it closely paralleled the associated Fincastle soil.

A similar soil catena is represented in Fig. 4c. The graph is divided into two parts because six years of data are plotted. Again, water tables depths varied greatly in depth and duration. In 1993-94 the water in the poorly drained Delmar and Ragsdale soils was at or near the surface most of the time for a 16-month period. In 1996 and 1997, it was high for only a month or two. Also, in 1995 the water table of Russell never got above 4.5 feet, but in 1996 it was near the surface. From August 1999 to January 2001 (not plotted), the water table never rose above six feet.

Figure 4d represents a toposequence of soils with fragipans. It is also divided into two parts because it represents six years. Especially noteworthy is how fast the water table rises, usually in late fall and winter. In fragipan horizons, roots grow mainly in the planar voids between large prisms, so there are few roots *within* prisms to extract water. It is likely that the interiors of the large prisms become saturated or almost so during the winter months, but roots cannot extract very much of that water during the summer, so the soil would never get much drier than field capacity. Consequently a few rain events will cause these horizons to become fully saturated, and free water fills the large soil pores and the water table monitoring tube.

In another example of the importance of landscape position, compare the water regimes in cross sections of two dissected till plains (Fig. 6). In a gently undulating landscape (a), somewhat poorly (SP) drained soils and poorly (P) drained soils are randomly arranged in the landscape and water moves *from SP to P*, and then winds its way between swells to the bevel (dashed line) with well (W) drained soils. In a flat landscape (b), somewhat poorly drained soils are on a rim surrounding large flats with poorly drained soils, and water moves *from P to SP* and then down the bevel. Because water tends to move *from* Fincastle in landscape (a) and *into* Avonburg in landscape (b), Avonburg tends to have a higher water table than Fincastle, even though the soils are in the same natural drainage class (Figures 4c and 4d).

In Jay County (Fig. 4e), the water table is held up by dense till. Water table levels are very similar in the somewhat poorly and moderately well drained soils. The reason that the Blount soil appears to be more reduced than Glynwood may be that water is more stagnant in Blount but moves through Glynwood which is on a somewhat steeper slope.

In DuBois County (Fig. 4f), water tables are held up by fragipans. Again, the levels are fairly similar between the well and somewhat poorly drained soils, probably for the same reason as suggested for the Jay County sites.

Water tables do not rise as fast in the sandy soils (Fig. 4g) as in most other soils. The sandy soils have no root-restricting layer, so roots are free to grow and extract water all through the soil. At the end of most growing seasons, they have depleted available water down to the wilting point throughout much of the profile, which is about 2 % by volume (Fig. 1). Before a water table develops, however, the soil must become saturated, which is about 42 volume %. The difference is 40 volume %, and it shows that 0.4 foot (4.8 inches) of water is required to bring one foot of soil from wilting point to saturation. On the other hand, many other soils have restricting layers that prevent roots from growing into large volumes of soil, as mentioned earlier. The soils represented by Figures 4(a, b, c) and 4d have dense till and fragipan limiting layers, respectively. Very few roots grow into the large prisms of these soils, so they are near field capacity or wetter much of the year. Field capacity is around 38 volume % in these soils, and saturation is about 42 volume %, so only 0.04 foot (0.5 inch) of water per foot of soil is required to bring these horizons from their "moist" state to saturation, one tenth as much as for sandy soils.

In several toposequences, water tables were almost as high in the well and moderately well drained soils (those with oxidized colors) as in the poorly and very poorly drained ones (reduced colors). The water tables tended to drop more rapidly in the spring in the well and moderately well drained soils, however, which would improve trafficability at a critical time for agricultural operations. The well and moderately well drained soils were on shoulders of till plain bevels in which water could be moving from the till plain to the backslope (Fig. 2). This is evidence that chemical reduction processes, which take over after oxygen has been depleted from the soil water, do not develop when the soil water is moving. These water table relations also suggest that, in addition to trafficabilitiy reasons, we drain soils largely to improve oxygen relations. Both sets of soils had seasonally saturated subsoils, but one set was oxidized and one reduced. The saturated-reduced soils respond, in terms of crop yield, to subsurface drainage systems but the saturated-oxidized soils do not.

In non-agricultural applications, however, the presence of water itself may be more important than the oxidation/reduction status. These include using soils for housing. If water gets into a basement, the homeowner is not very concerned whether or not it contains a little bit of oxygen. Also, for on-site waste disposal, the presence of water itself is very important. If the soil in which a system has been installed is saturated but not reduced originally, it will likely become reduced quickly when effluent is added. The extra organic matter and the warmer temperature will enhance the activity of microorganisms that use up all the oxygen in the soil, and then reduce other materials.

TIME OF SATURATION

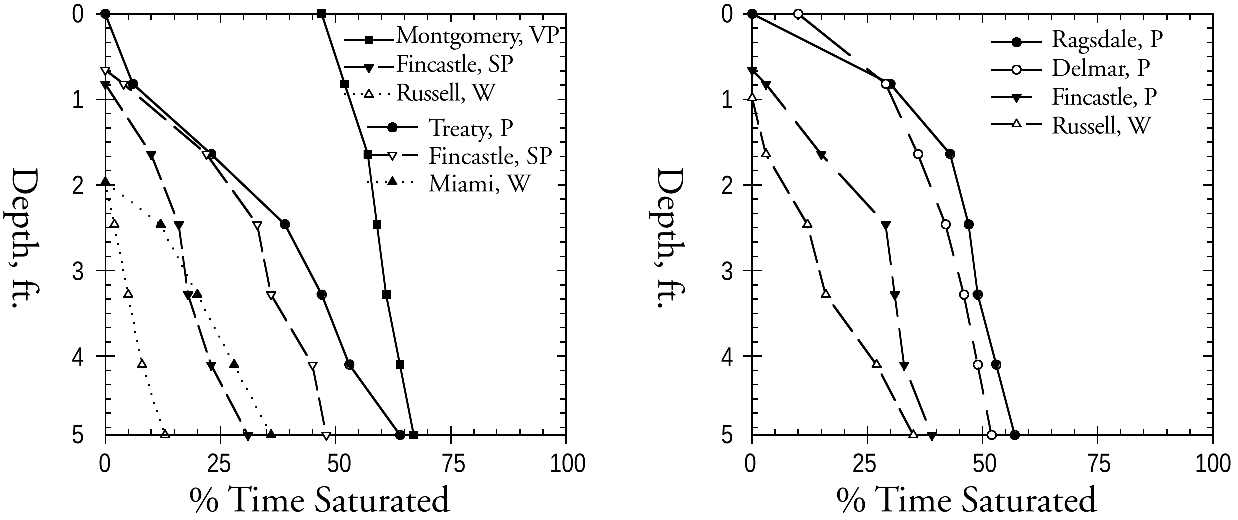
Another way to compare relative wetness of soils is to plot the percent of time the soil is saturated versus depth (Fig. 7). These graphs are for the same soils represented in Fig. 4, and they use the same letter designation, e. g, Fig. 4c and 7c both represent soils in Parke County. If a line in Fig. 7 joins the upper horizontal axis, water is ponded on the soil surface for a time. For example, water is ponded on Montgomery almost 50% of the time (Figs. 7a+b), and on Clermont, 7% of the time of the study (Fig. 7d). The soils showing most ponding (Montgomery, Ragsdale, Maumee) are in closed depressions. Poorly drained soils in open depressions or large flat areas (Treaty, Delmar, Newton, Clermont) are saturated just to the surface or are ponded for only a small percent of the time of the study.

The point at which a line crosses the left vertical axis of the graph indicates the highest level the water table reached in a soil during the course of the study (except for very brief spikes in the water table curve). For example, the water table very seldom rises above a depth of 8 inches in Fincastle (Fig. a-b).

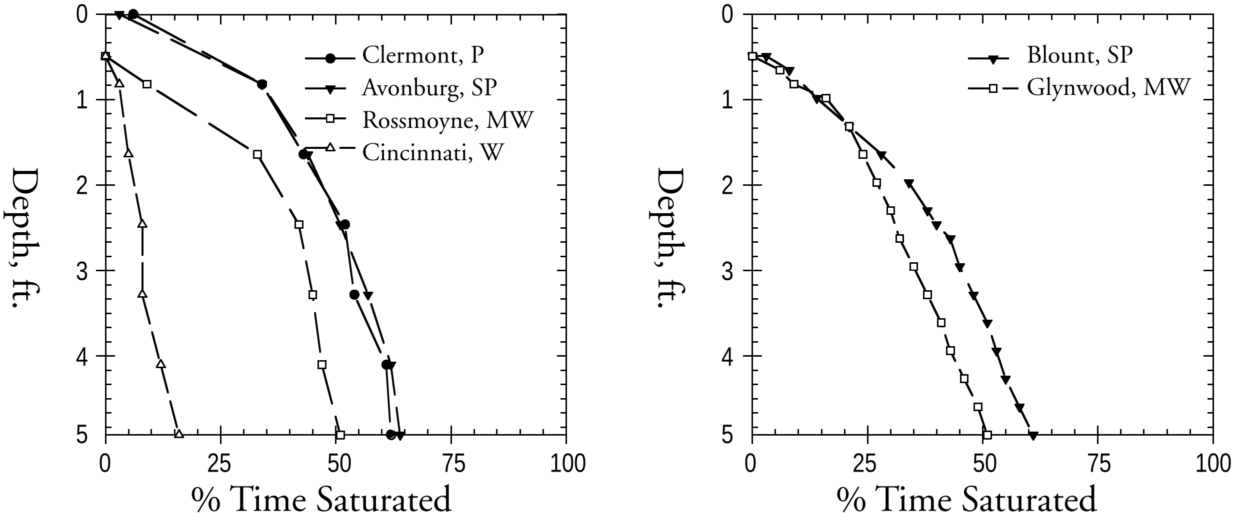
For all soils, the deeper in the profile, the longer the soil horizon is saturated (lines slope from upper left to lower right.) The point at which a line crosses the lower horizontal axis of the graph indicates the percentage of time the soil is saturated at five feet. Many soils are saturated more than half the time at that depth. Sometimes crop plants show signs of drought stress even though there is ample available water, or even free water, deep in the soil because the roots have not grown deep enough or fast enough to make use of this water.

FIGURE 7

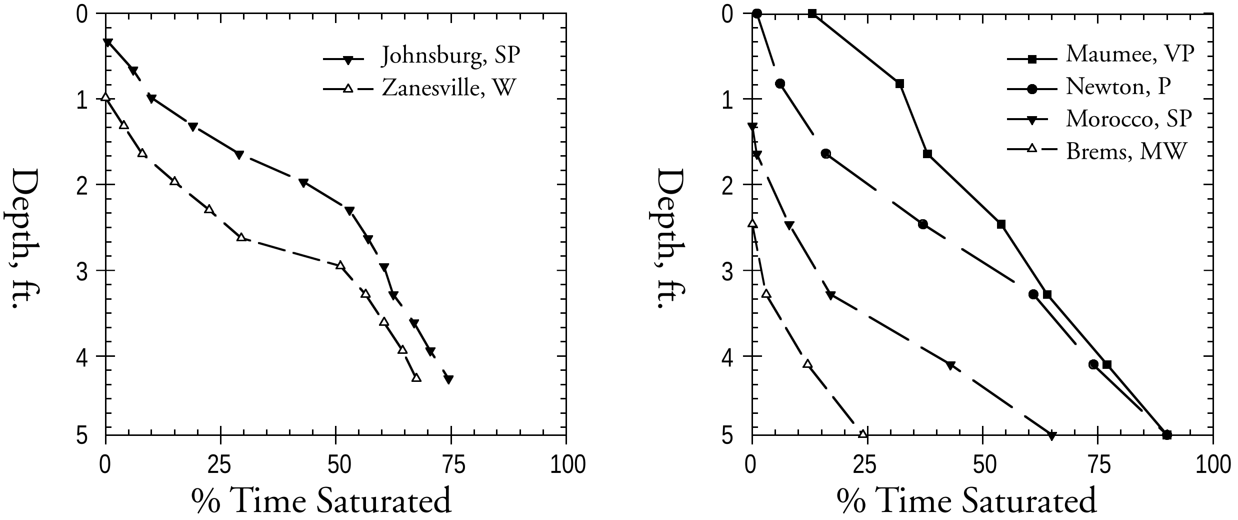
Percent of time different soil layers are saturated. The lower case letters that identify each graph are the same as those in Fig. 4


a) and b) Tippecanoe Co.

c) Parke Co.


d) Jennings Co.

e) Jay Co.


f) DuBois Co.

g) Jasper Co.

PRESERVING WETLANDS

Wet soils can be preserved as wetlands or drained for agricultural production. Some wetlands have been preserved in their natural state and others are reverting to their natural state after having been farmed and often drained. They reduce the potential for water pollution because many man-made chemicals are applied to agricultural fields, but are seldom or never used on wetlands. The bulletin, *Wetland Regulations*, in this series, provides more information about preserving wetlands. It lists these ecological and hydrologic benefits of wetlands:

- Help keep surface water and groundwater clean.
- Store floodwater.
- Trap sediment and attached nutrients.
- Function as green space and recreation areas.
- Contribute to groundwater recharge.
- Provide habitat to fish and wildlife (including many endangered species).
- May be important to reduce global warming.

DRAINING WET SOILS

Wet soils, after drainage, are the most productive soils of the state. They provide more tolerance to drought than most better-drained soils because the relatively high water table and movement of water into low-lying soils maintains a supply of available water during the summer to tide the crop over between rains. Draining wetlands also improved the health of people because it reduced the population of mosquitoes and other vectors that spread diseases such as malaria.

We install drainage systems to remove water from soils that are too wet in the spring for farm operations and to allow oxygen to reach plant roots. In many years spring planting is delayed because the physical properties of wet soils prevent field operations. Draining these soils often allows the farmer to get into the field a few days or even weeks earlier. Also, plant roots need oxygen to grow. If a soil is saturated with water, roots can grow while the soil water contains oxygen, but when it runs out of oxygen most crop plants struggle. A few plants such as rice and bald cypress trees, however, grow well in stagnant water because they have structures that transmit oxygen from the shoot to the roots.

SUMMARY

Soils of the state range from very wet to very dry in their over-all moisture regime, and people have divided this continuum into distinct classes. The most widely used system, natural soil drainage, divides the continuum into seven classes. *Soil Taxonomy*, of interest mainly to soil scientists, divides it into four or five classes. The classification for wetlands divides it into two classes—hydric or non-hydric. Recommendations for subsurface drainage systems, presented in another publication of this series, divides soils of Indiana into essentially three classes—those that require drainage for effective crop production, those that may require drainage, and those that do not require it. Of the total land area of Indiana, about 25% of the state consisted of wetlands at the time of European settlement. About 45% of the state has soils wet enough to hinder the growth of most crops unless the soils are drained.

Soils vary greatly in the amount of water they can hold and the rate at which water moves through the soil. These properties are influenced by certain limiting layers —layers that limit water retention, water movement, and limit root growth. The main limiting layers in Indiana soils are dense till, fragipans, bedrock, and coarse outwash. The first three have very low permeability for water and restrict root growth. Coarse outwash has very rapid permeability and does not hold enough water to support root growth. For an individual soil, the moisture regime is controlled mainly by evapotranspiration. Precipitation is relatively constant during the year, so whether a soil gains or loses water depends on how much water is lost to the atmosphere.

There is much competition for use of wet soils. Some must be kept in their natural state to remove contaminants from water, facilitate groundwater recharge, and provide habitat for wildlife. Some must be drained for agricultural production if we are to feed ever increasing numbers of people. If soils are drained, the job should be well done. Greater crop production from some wet soils will allow others to be preserved in their natural state.

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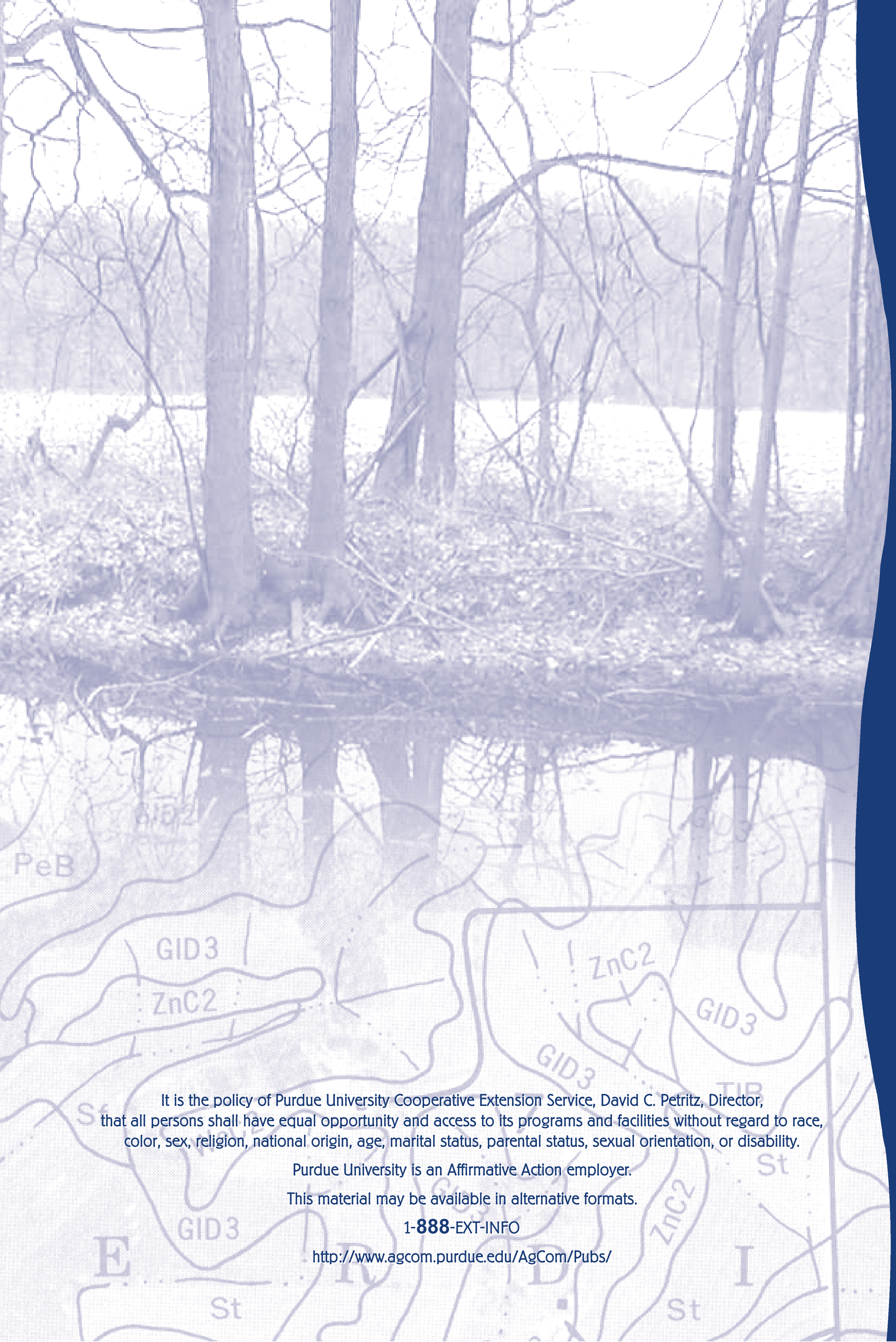

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