RELATIONSHIP BETWEEN OBSERVED GROUNDWATER AND SOIL MORPHOLOGY IN THE SAND PLAIN OF CENTRAL WISCONSIN

BY

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ABSTRACT

The presence of low chroma (1 or 2) mottles is used by many soil scientists as an indication of seasonal saturation. The Friendship series of central Wisconsin is seasonally saturated within 1.5 m of the soil surface, however, low chroma mottles do not exist within the profile. Also, many areas within central Wisconsin have been drained through channelization of stream downcutting. A method of determining newly attained high groundwater levels has not been developed and the persistance of relic mottles is largely unknown.

Groundwater levels and soil observations were made in Friendship soils in an area of natural and altered drainage to determine the relationship between high groundwater levels and soil morphology. The general area investigated is located at the northern extent of the central Wisconsin 'Sand Plains' in southeast Wood County. The pH, temperature, oxygen, iron and manganese content of the groundwater was measured to determine the origin of certain soil features such as mottles, nodules and cementation.

It was found that in areas of natural drainage the upper level of mottling is associated with high groundwater levels. Iron and manganese nodules and cementation may or may not be correlated with the high groundwater level. In areas of altered drainage, cementation and an increase of manganese nodules may indicate new high groundwater levels. It was determined that iron and manganese in mottles, nodules and cementation was from the groundwater system and not the soil. Persistance of mottling in such soils after an alteration of drainage probably exceeds several thousand years.

PREFACE

Recent problems in the enforcement of septic tank regulations in Wood County, Wisconsin have prompted this study. Accurate determinations of high groundwater levels are a necessity in evaluating site suitability for septic tank systems.

Much speculation has been made as to the relationship between seasonal saturation and soil morphology. A moderate amount of studies have been made in fine textured soils to define this relationship. Detailed investigations of the connection between observed groundwater levels and certain soil features such as mottling have been lacking in the sandy soils.

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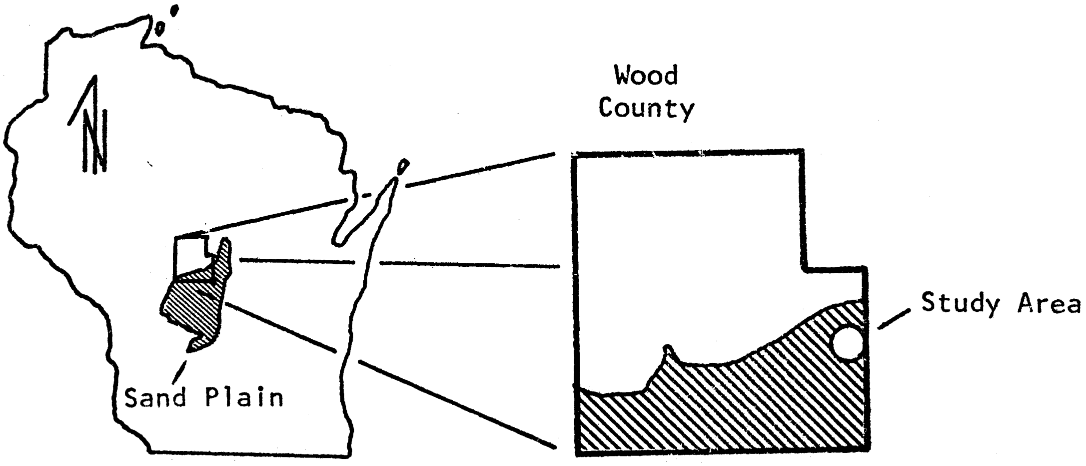

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INTRODUCTION

Accurate determinations of seasonal high groundwater levels are essential to estimating soil suitability for various land uses. Direct observations of groundwater are time consuming, costly and often not representative since monitoring during near normal climatic conditions is necessary. For these reasons soil scientists rely on soil morphologic features as an indication of the occurrence of groundwater. Of particular interest is the presence of mottles.

Soil Taxonomy, a publication of the U.S. - Soil Survey Staff (1975) puts a strong emphasis on the use of mottles with chromas of 2 or less to be associated with soil saturation or groundwater. Such emphasis in a well accepted guide to soil classification may be misleading since this criteria does not characterize soil-groundwater relationships in some soils (Daniels, et al., 1971, Daniels, et al., 1973 and Shelling, 1960). Factors contributing to the formation of the grey mottles may not be accomplished in all saturated soil environs. It may be necessary to review both the soil morphology and the factors affecting mottling in order to properly evaluate the occurrence and extent of high groundwater levels (Daniels, et al., 1973).

An objective of this study is to observe the relationship of soil morphologic features to groundwater in a soil of the 'Sand Plains' of central Wisconsin which does not possess mottles with chromas of 2 or less; however, is subject to seasonal saturation. A second objective is to investigate the relationship between soil morphology and groundwater in areas of altered drainage. Many portions of the 'Sand Plains' have been drained or subjected to rather drastic alterations due to natural stream downcutting. A method of determining newly attained high groundwater levels has not yet been proven.

LITERATURE REVIEW

Published information on the relationship of soil morphology to saturated conditions is available. A limited portion of this information is directed toward soils subjected to drainage alteration. Selected references are reviewed.

Relation of Soil Morphology to Saturated Conditions

Various soil morphologic features are used to determine saturated conditions in moderately well drained soils. Selected features include mottles, glaebules and certain matrix colors. Presence of these features and their abundance, size, color and/or contrast may be used by soil scientists in determining the height and longevity of saturated conditions in soil.

Soil mottles are spots of contrasting colors, usually bright yellow-orange to dull grey-brown. Although mottles may be formed from the weathering of different kinds of material, they are usually associated with a fluctuating groundwater level. A glaebule, according to Brewer (1976) is, "a three dimensional unit within the s-matrix of the soil material, and is usually approximately prolate to equant in shape, its morphology is incompatible with its present occurrence being within a single void in the present soil material. It is recognized as a unit either because of a greater concentration and/or a difference in fabric compared with the enclosing soil material, or because it has a distinct boundary with the enclosing soil material." Included within the definition of glaebules are concretions and nodules. Concretions having a generally concentric internal fabric and nodules an undifferentiated internal fabric. Of interest in this study are glaebules formed from iron and/or manganese. Nodules and concretions are probably formed by accretion of the metals around a nuclei; generally of precipated material or sand grains (Brewer, 1976). The certain matrix colors referred to are 'dull' soil material background colors associated with relatively long periods of wetness.

In well drained soil the matrix color is generally yellow or brown to red due to finely divided ferric iron particles (Hem, 1970). Soil will retain a brown uniform color unless it is subjected to continual or periodic saturation. When saturated, iron and manganese in the soil may become reduced and mobile. The continued reduction, removal or precipitation of the reduced iron and, to a lesser degree, manganese will govern the type and character of soil morphologic features produced.

The mechanics of the formation of the soil morphologic features have been accurately described and some research follows.

Eh (oxidation-reduction potential) and pH govern the form and mobility of iron and manganese of a soil system (Hem, 1970 and Collins and Buol, 1970). The soil Eh is a relative measure of the oxidizing or reducing conditions in a system and is related to the electron activity. Oxidation being the loss of electrons and reduction a gain of electrons. Positive potentials are assigned to oxidizing systems and negative potentials to reducing systems. The magnitude of the positive or negative value is a measure of the reducing or oxidizing tendency of the system. Soil pH is a measure of the relative acidity or alkalinity; more specifically, the negative log of the hydrogen ion activity in moles per liter. Collins (1968) has developed a chart illustrating his findings on the interrelationship of pH-Eh to the form of iron and manganese (Refer to Figure 2).

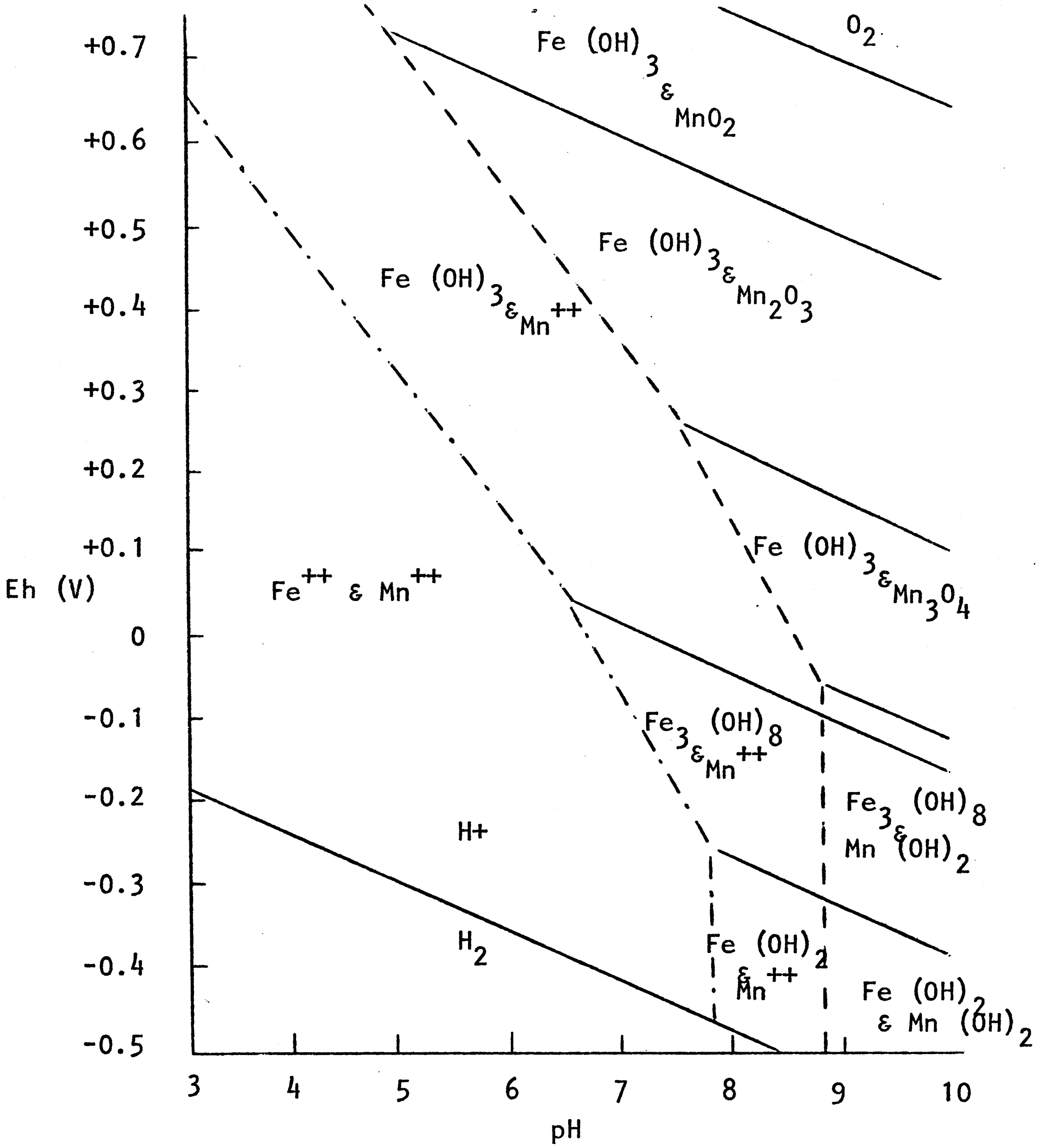

FIGURE 2. Stability fields of iron and manganese related to Eh and pH. (Collins, J., 1968. Ph.D. Thesis, N.C. State Univ.)

Iron in its ferrous form (Fe^{++}) is soluable and as denoted in Collins' (1968) graph is stable at low Eh and pH levels. Ferric iron (Fe^{+++}), on the other hand, generally precipitates as a hydroxide and is stable at relatively high Eh and pH values. The same graph illustrates that in a very acid system, ferrous iron remains stable even though strongly oxidizing conditions may prevail. Conversely, at a pH of 8, or greater, one would not expect to find ferrous iron even in a moderately reducing system. Also note that soluable manganese (Mn^{++}) is stable at a greater Eh and pH level than iron. Insoluable manganese may be found in the plus 3, 4, 6 and 7 valence state and is generally precipitated as an oxide or hydroxide. Collins (1968) graph is based upon stability relationships for iron or manganese bearing solution. Collins and Buol (1970) discovered that the presence of iron precipitates caused some manganese to be removed from solution below theoretical or pure solution levels.

Collins and Buol (1970) suggest the following reaction to illustrate the conversion of ferrous iron to the ferric iron precipitate in most soils;

$$Fe^{++} + 3H_2O \longrightarrow \underline{Fe(OH)_3} + 3H^+ + e-.$$

Manganese reactions in most soils, according to the same researchers is as follows:

$$2\ Mn^{++} + 3H_2O \longrightarrow \underline{Mn_2O_3} + 6H^+ + 2e-, \text{ or}$$

$$Mn^{++} + 2H_2O \longrightarrow \underline{MnO_2} + 4H^+ + 2e-.$$

Bonner and Ralston (1968), Waksman (1952), Alexander (1961), Meek, et al., (1968) and Clark, et al., (1967) have noted the direct influence of microbes on the oxidation and reduction of both iron and manganese. Reduction may occur in a number of ways. Iron may be reduced as a result of electron transport with iron functioning as an electron acceptor in cell respiration (Alexander, 1961). The same reaction is possible with manganese. However, most reduction is attributed to microbial activity under water-logged conditions. Microbes utilize free oxygen in the soil atmosphere producing carbon dioxide and organic acids (Meek, et al., 1968). Depletion of oxygen as a consequence of microbial action will lower the Eh and lead to reduction (Alexander, 1961). Meek, et al. (1968) suggests oxygen associated with iron and manganese may be utilized by microbes following removal of the oxygen from the soil atmosphere. Alexander (1961) also notes that acids and by-products produced through fermentation favors iron and manganese mobility. Becking, et al.,(1960) note the heterotrophic bacteria-green bacteria and sulfate reducers are important in the promotion of the conversion of ferric to ferrous iron. Alexander (1961) has found that following oxygen consumption there is a shift of the microbe population from aerobes to anaerobes near 0 mv-Eh.

In order for microbial activity to take place, it is necessary that suitable temperatures be maintained. Bonner and Ralston (1968) found that at temperatures of 5° C reducing potentials developed very slowly. It is generally accepted that 5° C is the minimum temperature at which significant microbial activity will take place (Soil Survey Staff, 1975). In contrast, Bonner and Ralston (1968) discovered that at 21° C to 27° C reduction was sufficient to cause gleying during 25 days of incubation. Daniels, et al.,(1973) achieved reducing conditions within six days of incubation at a temperature of 17° C to 27° C. It should be noted that incubation was conducted at saturated conditions in both experiments.

Also vital to microbial existence is an energy source. To illustrate this point Daniels, et al.,(1973) incubated three identical soil samples at saturation and equivalent temperatures for a ten day period. Two of the three samples received sugar solutions, an energy source, and a third did not. Reduction occurred after six days in the two samples that did receive sugar solutions. Conversely, no visible signs of reduction were noted in the sample that did not receive the sugar solutions. Research undertaken by Meek et al.,(1968), Bonner and Ralston (1968), Alexander (1961) and Christensen, et al., (1950) reinforce Daniels, et al.,(1973) findings. The natural source of energy for microbes is water soluable carbon translocated from humus rich surface horizons by infiltrating water (Daniels, et al., 1973). Thus, it is important to consider the stage and rate of decomposition of vegetative litter and the relation to precipitation (Daniels, et al., 1973).

It would be expected that saturated conditions prevail in order for total consumption and reducing conditions to result. However, Veneman, et al.,(1976) found that reduced environs can be accomplished in soil 95 per cent up to 100 per cent saturated for six or more weeks. Complete saturation in the soil occurred for a period of less than one week. In the same study evidence of slight to moderate reduction occurred in soil saturated for less than a day. The occurrence of reduction below 100 per cent saturation was attributed to the relationship of texture and structure to soil moisture. Soils under study were well structured and the texture of the horizons investigated was silty clay loam. Small pores associated with the fine textured ped material retained moisture for extended periods of time and did not permit adequate oxygen diffusion from drained planar voids and channels to the interior of the peds to promote oxidation. Similar results were obtained in a study by Vepraskas, et al., (1974).

This brings forth the need to consider the source of soil moisture and the soil texture and structure. In non-layered soil, saturated conditions are generally due to fluctuating regional groundwater levels during wet seasons and high moisture contents immediately above the groundwater table due to capillarity. Bouma, et al., (1974) describes capillarity as the phenomena of the rise of water into a tube inserted in water, due to its surface tension. The finer the tube, the higher the capillary rise. Cedergren (1967) estimates theoretical capillary rise in coarse sand to be near 10 cm, about 30 to 60 cm in fine sand, near 300 or 365 cm in silt and over 30 m in clay. Actual capillary rise is not anticipated to reach theoretical levels because most soils tend to have a mixture of partical sizes and capillary pores are generally discontinuous due to the presence of large planar voids.

Capillarity also plays an important role in the retension of moisture and perched water tables. Water infiltrating through the soil will be taken into and retained within soil peds by capillary forces. Failure of moisture to be removed from peds is due to the low capillary potential exhibited by large planar voids. A similar situation may occur in stratified soils where fine textured material such as loess overlies coarse particle sizes such as sand. Fine pores of the loess will retain water from flowing into the sand which exhibits low capillary potential. High moisture contents in the silty clay loam which was associated with reducing environs in the study by Veneman, et al., (1976) was due to the high capillary potential of the fine textured silty material that was underlain by freely drained sand.

It should be noted that perched water tables may also exist where permeable soil overlies a slowly permeable or impervious layer. In such a case infiltrating waters may collect above the impervious layer long enough for reducing conditions to occur.

Thus far, the soil has been considered the sole source of iron, but ferrous iron may also be supplied by the groundwater system. Hem (1970) states the most common form of iron in solution in groundwater is the ferrous ion. From a collection of data, Becking, _et al_.,(1960) found most near-surface groundwater systems to have a pH from 5 to 8 and an Eh ranging from -200 mv to +400 mv and generally between +200 mv and +400 mv. Such levels fall primarily in the ferric iron stability range. However, Hem (1970) states that in this range a considerable concentration of ferrous iron can be maintained in equalibrium. It would not be expected that intense reduction of iron would occur unless biologic or chemical reduction would be an influencing factor.

Movement of reduced iron and manganese is dependent on the groundwater system and/or void relationship is structured soil. Reduced iron and manganese may be translocated a great distance or completely removed from soil if groundwater movement extends laterally (Daniels, _et al_., 1973). This is most probable in coarse textured soil. Movement of the metals may be upward from the gravitational surface with capillary water. If freely drained, iron and manganese reduced within the peds may migrate to the well aerated outer edge of the peds prior to becoming oxidized.

Oxidation of the reduced metals occurs with the introduction of oxygen containing gases and microbial action (Meek, _et al_.,1968). Gases may enter upon the lowering of groundwater, or through diffusion. Howeler and Bouldin (1971), suggest the upper few centimeters of the groundwater table may be oxidized from oxygen diffusion in soils with a low biotic activity. Studies undertaken by Daniels, _et al_.,(1973) suggest oxygen rich groundwater may also bring about oxidation. Clark, et al.,(1967), Alexander (1961) and Meeks, et al.,(1968) state that heterotrophic bacteria will promote oxidation of iron by deriving all or part of their energy from the inorganic iron and manganese.

When the oxidation of manganese occurs its color changes from light tan to dark brown or black. The color of iron changes from green to brown or yellow-orange upon precipitation.

Interpretation of Soil Morphology as Related to Saturated Conditions

In order for iron and manganese to become mobile it has been shown that a number of factors must be met. Reduction, movement and oxidation of the metals in soil cause definite color patterns. The variation of these processes give rise to different color patterns that may be noted by the trained eye. Identification of these characteristics and an understanding of their formation would make it possible to estimate the level of saturated conditions in the soil profile.

Researchers have found that the soil matrix, or background, color may be a guide to the degree a soil is saturated. A soil matrix that has color hues of N, 5GY or 5G would be considered reduced since the hues reflect the ferrous iron color according to Daniels, et al.,(1961). In the analysis of sediments, the researchers found samples with a hue of 2.5Y and 5Y were associated with low ferrous iron contents which suggest the material was not intensely reduced at the time of sampling. The hue 10YR had relatively high ferric iron and low ferrous iron contents. Again, intense reduction is not related to the more red hues.

Daniels, et al., (1971) and McKeague (1965) observed the 2.5Y to 5Y and 10YR to 7.5YR hues to be in soil horizons that are saturated for several months or more. From information gathered by McKeague (1965) it appears that the 2.5Y and 5Y hues does suggest limited reduction accompanied with saturation. It can be inferred that N, 5GY and 5G hues denote intense reduction under prolonged saturated conditions. The 2.5Y and 5Y hue may be the product of moderate reduction and the 2.5YR to 10YR hues are not an indication of moderate or intense reduction; however, may be found in soil horizons saturated for more than several months of the year. In general, the more red the soil matrix the less the likelihood of prolonged saturation.

Simonson and Boersma (1972) studied the matrix color value and chroma relationship to saturation. They had observed that within a toposequence the highest value and lowest chroma indicated the most poorly drained situation. No consistent correlation between soil value and chroma to observed groundwater was found. Colors noted by Veneman, et al.,(1976), Daniels, et al.,(1971) and McKeague (1965) suggest values greater than 4.5 and chromas of 3 or less are related to reduction under saturated conditions. Higher values and lower chromas indicating greater reduction and/or removal of iron. Daniels, et al.,(1973) postulated the grey matrix color, 10YR 6/2, of a soil under study to be caused by the removal of iron and the display of iron-poor clay and quartz.

Other than matrix color, mottling and glaebules are generally used in estimating the wetness of soil. Mottling is used extensively by soil scientists to determine soil wetness and the accuracy of their use has been verified by Latshaw and Thompson (1968). As with matrix coloration it appears that factors influencing reduction of iron control the color and type of mottles formed under saturated environs. In a sandy clay loam, Daniels, et al.,(1971) observed mottles with a color of 10YR 6/3 to 10YR 7/3 in horizons saturated 25 percent of the time and 10YR 7/2 and 10YR 6/2 colored mottles in horizons saturated 50 percent of the time. However, in the same study adjoining soils saturated less than 25 percent of the time had mottles of 10YR 5/2 in color. Evidently some factor(s) other than duration of saturation was involved. A study done by Daniels, et al.,(1973) on a similar soil indicated high groundwater levels were associated with yellowish brown (presumably 10YR 5/4 to 10YR 5/8) mottles. From the study it was shown that reducing conditions were not encouraged in the soil because water soluable carbon, an energy source, probably did not reach microbes in the saturated horizons. It was suggested that the upper portions of the B-horizon probably filtered out most of the soluable carbon. McKeague (1965) in two studies found mottles with values of 5 and chromas between 2 and 6 in saturated horizons. However, the matrix of the same horizons had the same color value but chromas of 1 and 2. Schelling (1960) found a good correlation between grey mottling and the mean high groundwater level in clay. The strong correlation did not hold for sandy soils.

The size and prominence of mottles are probably the product of factors influencing oxidation-reduction potentials rather than duration of saturation. Simonson and Boersma (1972) studied silty alluvial deposits and determined faint mottling was present in soils saturated 60 percent of the time from January through June and distinct mottling was observed in soils saturated 70 percent of the time during the same months. On the other hand, Schelling (1960) noted no fixed relation between soil saturation and size or prominence of mottles. Thomasson and Bullock (1975) postulated slow precipitation does favor more coarse mottles. Mottle formation has also been noted in soil horizons that are not generally considered waterlogged. This phenomenon results from impeded moisture flow in stratified soil. McKeague (1965) noted mottle formation in 16 inches of silty clay loam which rested on well drained clay. The occurrence of gravitational water was not observed in the silty clay loam. Veneman, et al.,(1976) studied a reverse situation in which silty clay loam loess was deposited over sand. Depth to groundwater in the sand was about 12 meters below the soil surface. In this soil which was saturated only several days at a time, mottles with a 10YR 6/2 color formed. Because of the high capillary tension of the fine ped material the soil remained 95 percent saturated for four months of the year. Apparently the slow diffusion of air into the water filled pores was at a rate lower than microbial consumption.

Schwertmann and Fanning (1976) have found that in horizons subjected to extended periods of saturation mottling or loss of iron and manganese is experienced. However, above mottling in the profile where definite wetting and drying occurs, glaebules were often found. (Note: In the following discussion glaebules will be used to include nodules and concretions unless otherwise stated). According to Blume (1968) maximal formation of glaebules occurs in soils with medium to low air content and high air conductivity that have a rapid change in aeration. Thomasson and Bullock (1975) also agree that rapid diffusion of oxygen will promote the formation of glaebules.

Schwertmann and Fanning (1976) studied the presence of glaebules in a silty drainage catena. The wettest soil was formed under an aquic moisture regime and possessed no glaebules. A somewhat better drained soil contained black, well rounded and hard glaebules. A somewhat poorly drained soil had rusty irregular and medium hard glaebules. No glaebule formation occurred in the well drained soil due to a lack of wetting and drying. The black glaebules were determined to be primarily made up of manganese (up to 10 percent of the total volume). Brown glaebules tended to be iron rich (11.4 to 17.5 percent of total volume). Blackish interiors were noted in many of the brown glaebules. Schwertmann and Fanning (1976) postulated that at late stages of development when surfaces were forming, manganese was largely exhausted from the surrounding soil. At early stages of glaebule development both manganese and iron were available. All brown glaebules noted in the same study were probably formed recently. The researchers went on to state that black glaebules could form with brown interiors if a moderately high Eh was experienced. In such a situation iron would oxidize first and form the interior portion of the glaebule. As Eh values rise manganese would oxidize to form the outer most portion of the glaebule.

In a well drained silt loam, Phillippe , _et al_.,(1972) observed reddish brown to brown, hard, spherical concretions which became more irregular with depth and presumably wetness. Concretions observed by the same group in a somewhat poorly drained silt loam tended to be brown to black, becoming more black, irregular and soft with depth. Veneman, _et al_.,(1976) found manganese nodules in the B-horizon of a silty clay loam that was saturated less than a day and near saturation for less than a month. Reduction was not intense enough to cause solubility of iron. In a somewhat wetter situation, where saturation lasted a few days and near saturation for several months, iron nodules formed as did mottling. McKeague (1965) observed glaebule formation in an apparently well to excessively drained soil. An explanation of the glaebule origin was not given. Although a sand texture was given for all horizons it may be possible that variability within the separate range caused some retainment of infiltrating water for a period great enough for some reduction to occur.

Simonson and Boersma (1972), Phillippe, et al.,(1972) and Schwertmann and Fanning (1976) note that the amount of glaebules increase with increasing wetness, barring extended saturation. As suggested by Schwertmann and Fanning (1976), composition of glaebules may vary with the intensity of reducing and oxidizing conditions.

Studies by Schwertmann and Fanning (1976) and Phillippe, et al., (1972) show discrepancies in glaebule morphology as related to soil moisture contents. Brewer (1976) states there is limited use in the interpretation of glaebules and a lack of strong development may be related to similarities between the glaebule and surrounding soil material. Drosdoff and Nikiforoff (1940) suggest strong drying encourages sharp glaebule boundaries.

Cutans which are "a modification of the texture, structure or fabric at natural surfaces of soil material due to a concentration of soil constituents or modifications of plasma" (Brewer, 1976) have been related to soil moisture regimes. Veneman, et al., (1976) and Vepraskas, et al. (1974) noted iron and manganese cutans in soil saturated less than a day yet near saturation for several months of the year. Iron cutans were present in horizons saturated less than a week but near saturation for several months. Cutans, according to the profile description, appear to become more prominent with increased wetness. The cutans noted are probably due to the oxidation of iron and manganese on ped surfaces following movement from the reduced interior.

Relation of Morphologic Features to Groundwater in Soils of Altered Drainage

A very limited amount of literature is directed toward changes in soil morphology as a result of improved drainage. The most well known study was undertaken by Schelling (1960) who investigated reclaimed hydro-morphic soils. In the research no differentiation could be made between recent and fossil gley phenomena in mineral horizons using existing color criteria.

Some speculation can be made, however, on the persistence of mottling. High chroma (yellow-brown) mottles and iron glaebules are composed of stable ferric iron (Collins and Buol, 1970). Redispersal of the concentrated ferric iron in mottles and glaebules even under short periods of reduction is not appreciable (Collins and Buol, 1970). Translocation of ferric iron via infiltrating water, possibly aided by increased solubility from organic colloidal involvement such as is present in the formation of spodic horizons, may cause destruction of high chroma mottles over extended periods of time. Such action may obliterate grey mottles or horizons devoid of iron. Influence of iron translocation would rely very heavily on soil forming factors. Weathering of iron bearing minerals in grey areas may in time mask relic mottles. Also, structural alteration by frost action, shrink-swell and biotic forces may aid in destroying relict mottles.

Groundwater and Soil Observations

Physical observations of groundwater have been made in partially perforated wells of varying diameters; generally greater than 2.54 cm made of a variety of materials (Daniels, et al., 1973, Simonson and Boersma, 1972 and Latshaw and Thompson, 1968). Methods and frequency of observations have varied depending on required accuracy of information. In studies by Veneman, et al., (1976) and Vespraskas, et al., (1974) tensiometric measurements were used to determine moisture contents. Use of a tensiometer was prompted because of the fine pores within soil.

Of particular interest, in a number of studies, is the determination of the oxidizing or reducing potential of groundwater. As noted, Becking, et al.,(1960) compiled a large amount of data relating Eh values to natural systems. Eh levels were gained through the use of electrode measurement. Hem (1970) states that many problems may be encountered when determining the Eh of groundwater due to the possible contact of air to the water. Even slight contact with air will give potentials related to dissolved oxygen rather than other system components. Because of the potential problems involved with direct Eh measurements, Hem (1970) suggests use of the D.O. (dissolved oxygen) content to determine the systems oxidizing or reducing potential. Daniels, et al.,(1973) observed D.O. levels below 0.2 ppm are indicative of intense reduction based upon the formation of gleying and inferrence to the redox stability diagram of Collins (1968). Lack of dissolved oxygen would suggest negative or near ferrous-ferric stability Eh values. D.O. levels of 1 to 7 ppm were shown in Daniels, et al., (1973) study to fall within the ferric stability range. Measurements of D.O. by Daniels, et al.,(1973) were made with an oxygen meter. Use of an oxygen meter has been shown to be as accurate as the chemical (Winkler) methods (Reynolds, 1969).

Other criteria of groundwater quality that have been investigated in soil morphology - groundwater studies include pH and temperature. The pH strongly governs iron and manganese solubility and influences microbial activity and can be easily and accurately measured with a pH meter (Hem, 1970). Temperature measurements provide a comprehension of suitability for microbial activity. Many oxygen meters are adopted to measure temperature with a great deal of accuracy (Yellow Spring Instrument Co., 1977).

From information reviewed it is apparent soil color, structure and texture plus a description of the color, fabric, size and abundance of mottles, glaebules and cutans is essential in determining soil morphology - groundwater relationships. Observations of horizonation, structure and mottle and glaebule formation would be most accurate if performed in an excavation.

METHODS AND MATERIALS

Study Area

The study area is located at the northern extent of the 'Sand Plains' of central Wisconsin in the Town of Grand Rapids, Wood County (Figure 3). Soils in the study area developed on nearly level, sand outwash of Cary age (∼ 13,000 years before present). Surface elevations generally range from 320.0 m to 315.0 m above mean sea level. Approximately 10.0 m or 12.0 m of the sandy material overlies Precambrian age crystalline rock which in most areas supports a thin veneer of Cambrian age sandstone. Jack pine (*Pinus banksiana*), white pine (*Pinus strobus*), northern pin oak (*Quercus ellipoidalis*), choke cherry (*Prunus virginiana*), blackberry (*Rubus, sp.*) and hazel (*Corylus, sp.*) are the predominant vegetative species.

Two groundwater-sheds are located in the study area (Weeks and Strangland, 1971). Groundwater flows north and northwesterly at a slope of approximately 0.9 m/km (.09%) to the Wisconsin River in the northern watershed and southwesterly at a slope of 1.9 m/km (.19%) to the Fourmile Creek in the southerly watershed. Groundwater levels in the northerly watershed are relatively natural with minor influences of channelization. Three sites were selected in this area for study, as denoted in Figure 3. The soil at sites #1 and #2 is mapped as the moderately well drained Friendship series (sandy, mixed, mesic Typic Udipsamment). Site #1 is located adjacent and above the Wisconsin River and it's floodplain to which the groundwater flows. Site #2 is located near the groundwater divide. Soil at site #3 is mapped as the excessively drained Plainfield series (sandy, mixed, mesic Typic Udipsamment). Site #3 was randomly selected as a control site for a comparison of soil

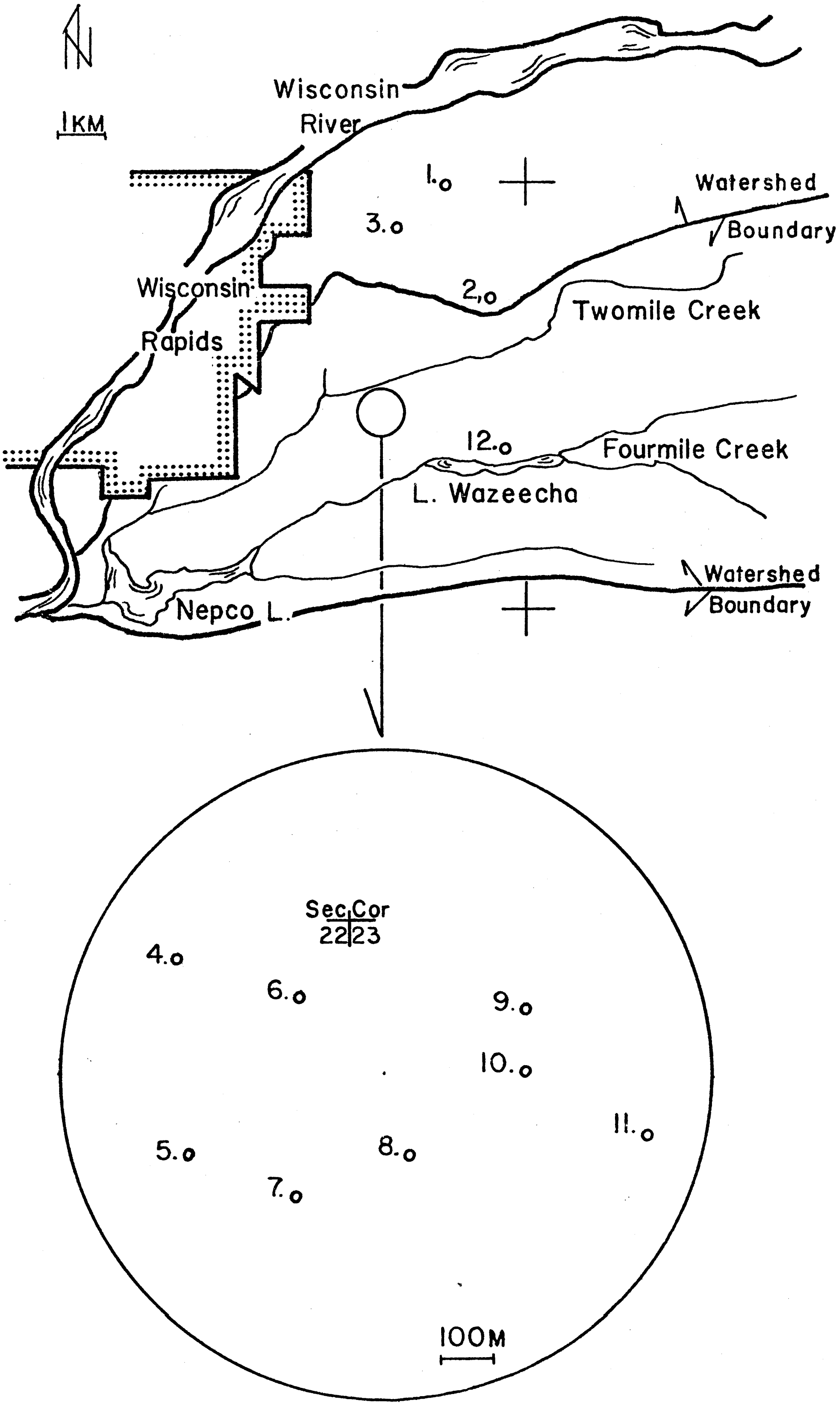

Figure 3: Location of wells in the study area.

morphology between soils subjected to seasonal saturation and a soil that is not.

Channelization and natural stream down-cutting has significantly lowered groundwater levels in the southern watershed. Twomile Creek was channelized between 1907 and 1915. Fourmile Creek is a tributary to the Wisconsin River and flows from east to west across the township. This waterway has, over the last 13,000 years, eroded a channel which extends approximately 7.0 m below the elevation of the surrounding land surface. Continued down-cutting was retarded by the formation of Nepco Lake in 1926 and Lake Wazeecha in 1936. Both of these lakes are impoundments on the creek. Nine sites have been selected for study in this area (Figure 3). Soil at sites #4 through #11 is mapped as the Friendship series. These sites are located in an area of known groundwater alteration. In a previous study, Shimek (1976) monitored the groundwater level at 29 locations which were inpart randomly selected. Exact well locations were governed by the landowners in the area. The locations of sites #4 through #11 was strongly influenced by the ability to obtain permission of landowners to construct observations pits on their property. Site #12 is adjacent and above the Fourmile Creek to which the groundwater flows. It was suspected the depth to groundwater at this site was greater than 2.0 m and it was known that mottling existed in the soil profile. Soil at site #12 is mapped as the Plainfield series.

The average annual precipitation in the area is 77.27 cm. Annual precipitation from 1970 through 1976 was 80.51 cm, 95.98 cm, 88.72 cm, 97.74 cm, 63.65 cm, 82.60 cm and 58.52 cm, respectively. During the months of limited evapotranspiration, September through May, the average precipitation is 49.76 cm. From September, 1975 through May, 1976 55.88 cm of precipitation was received. The low 1976 annual precipitation was attributed to extremely limited rainfall in the summer and fall of that year. Groundwater levels were expected to be near normal elevations during the spring of 1976. A U.S. - Geological Survey observation well is located approximately 2.5 km to 5.2 km west of the study sites near the divide of the two watersheds, in similar outwash deposits. The average high groundwater level recorded from 1959 through 1976 was 167.0 cm below the soil surface. A high groundwater level of 155.0 cm below the soil surface was observed in 1976. This level was surpassed in 1966 at 143.0 cm, in 1967 at 146.0 cm and in 1973 at 143.0 cm.

Procedure

Groundwater observations were made in schedule 40, PVC solid pipe monitoring wells, 5.08 cm in diameter and 1.5 m to 2.0 m long. A PVC cap with a 0.5 cm by 2.0 cm opening for measurement was placed at the top end. The lower end was open for free movement of water. Non-perforated pipe was used to eliminate the washing-in of sand that occurs with the use of perforated pipe. Previous observations indicated no difference in groundwater levels in the perforated vs. non-perforated pipe in the relatively homogenous sand. The Wisconsin Division of Health has since adopted a similar well design for groundwater observations. The wells were placed in a 7.62 cm auger hole, which extended no further than the desired depth of the well. Excavated sand was used to backfill the auger hole. Observations were made by means of direct measurements of groundwater in an unlined auger hole at site #1, #3 and #12. Groundwater was allowed to equilibrate 10 to 15 minutes prior to measurement. Measurements of the groundwater were made with a chalk-coated retractable metal ruler. Measurements were made at weekly to bi-monthly intervals in the spring of 1976 and 1977 and at monthly intervals the balance of the year. Groundwater observations started mid-March, 1976 and continued through June, 1977.

Total iron and manganese, pH, temperature and dissolved oxygen of the groundwater was determined at site #2 and #10. The samples were taken at a depth less than 50.0 cm. The iron, manganese and pH levels near the aquifer surface were compared to those 1.0 m to 3.0 m below the aquifer surface. Karnauskas (1977) obtained the deep groundwater samples from wells located 1.25 km northeast of site #2 and within 0.5 km of sites #4 through #11. Iron and manganese sampling was conducted to determine the source of iron in soil mottles and nodules. Temperature of the near surface groundwater was observed to gain insight on the suitability for biotic activity which governs the consumption of oxygen in waterlogged soils and promotes iron reduction. Dissolved oxygen and pH was determined to ascertain the relative oxidation state of iron and manganese near the surface of the aquifer.

Wells were drained twice prior to sampling by an Isco Water Sampler. The water that entered the wells after draining should have closely resembled the natural chemical status of the groundwater. Samples for the analysis of iron, manganese and pH were also obtained with use of the Isco pumping apparatus. The Wisconsin Laboratory of Hygiene determined iron content by the phenanthroline method, manganese by the flame-atomic absorption method and pH with a Corning glass electrode pH meter (refer to Standard Methods, 1965). Temperature and dissolved oxygen were determined in the field with a Yellow Springs

Instrument Company, model #54 oxygen meter. The instrument was air calibrated in a damp cloth and altitude and temperature adjusted prior to use. Accuracy of temperature measurements is ± 0.6° C with the oxygen meter (Yellow Springs Instrument Co., Inc., 1977). Reynolds (1969) has shown that oxygen meters are as accurate as the Winkler method in determining dissolved oxygen. The limited contact of air with the water in the wells following draining is not believed to have significantly increased dissolved oxygen contents of the groundwater. Aggitation of the water surface was minimal and oxygen diffusion rates in water is low (Howeler and Bouldin, 1971). Water samples were taken on May 16, 1976 after the peak rise of the groundwater. Gains in oxygen through diffusion and possible precipitation of iron and manganese should have occurred by mid-May.

Pits were dug at sites #2 and #4 through #12. Bucket auger samples were examined at sites #1 and #3. Soil profiles were described with the terminology used in the Soil Survey Manual (Soil Survey Staff, 1951), Soil Taxonomy (Soil Survey Staff, 1975) and Fabric and Mineral Analysis of Soils (Brewer, 1976). Special emphasis was given to color, texture, mottles, structure, cementation and nodules. A casual observation of single-grained samples was made under a 40X and 100X optical microscope. Microscopic observations were made of the B and C horizons at sites #1, #2, #7, #10 and #12. Use of the microscope was required to determine the character and composition of sand coatings, mottles and nodules. Descriptions of the minerology of coatings and nodules are based upon color as observed under incandescent light. Schwertmann and Fanning (1976) had noted brown glaebules tended to be iron rich and black glaebules manganese rich.

RESULTS

Area of Natural Drainage

High groundwater was observed at 97.0 cm at site #1 and at 86.0 cm at site #2. The depth to groundwater exceeded 1.5 m at site #3 throughout the entire study period. A record of groundwater and monthly precipitation levels was made (see the Appendix). The highest groundwater level was observed between April 23 and April 26, 1976. A rapid drop of the groundwater table occurred during the summer of 1976 due to a lack of precipitation. Groundwater levels observed in the Spring of 1977 also reflected the low amount of precipitation received in mid to late 1976 and early 1977.

Quality of the groundwater in May of 1976 is shown in Table I. The iron, manganese and pH of the near surface groundwater at site #2 is compared to the data collected by Karnauskas (1977) at a depth 2.0 m below the groundwater surface. The location of the Karnauskas (1977) sampling site is about 1.25 km northeast of site #2. Groundwater quality below site #2 may be somewhat different from the Karnauskas (1977) site due to local variations (Holt, 1965). The iron concentration appears to decrease with depth, whereas manganese and pH increase with depth. The temperature was very close to the biologic zero of 5° C (Soil Survey Staff, 1975). The dissolved oxygen level was relatively high and indicated a well aerated near surface groundwater condition (Daniels, et al., 1973).

Detailed soil profile descriptions were made at each site (see the Appendix). A summary of the soil observations is given in Table 2.

TABLE I

Groundwater quality in an area of natural drainage in the Town of Grand Rapids, Wood County, Wisconsin.

	Upper 50 cm	Below 2 m *
Iron (ppm)	1.30	0.43
Manganese (ppm)	-0.04	0.09
pH (su)	5.9	6.3
Temperature (°C)	7.0	
Dissolved Oxygen (ppm)	8.2	

* Source: Karnauskas, R., 1977. M.S. - Thesis, U.W. - Madison

Table 2. Relationship of high groundwater levels to soil morphologic features

Natural Drainage

Horizon	Depth (cm)	Munsell Color	Texture	Mottle	Structure	Cementation	Nodules	High Groundwater (cm)
					Site #1			
A_p	0-21	10YR 3/2	ls		mlgr			
B_{21}	21-48	7.5YR 5/6	ls		clsbk			
B_{22}	48-65	7.5YR 5/8	s		mlsbk			
B_3	65-90	10YR 5/8	s		mlsbk			
C_1	90-138	10YR 5/4	s	m3d	sg			97
C_2	138-150	10YR 6/4	s	m3d	sg			
					Site #2			
A_p	0-20	10YR 3/2	ls		flsbk			
B_{21}	20-40	7.5YR 4/4	ls		mlsbk			
B_{22}	40-76	7.5YR 5/6	s		mlsbk			

Table 2. (cont)

Natural Drainage

Horizon	Depth (cm)	Munsell Color	Texture	Mottle	Structure	Cementation	Nodules	High Groundwater (cm)
Site #2 (cont)								
B_3	76-94	10YR 5/6	s	m3d	sg	cwv	X	86
C_1	94-144	10YR 6/4	s	c3d	sg			
C_2	144-150	10YR 5/3	s	c3d	sg			
Site #3								
A_p	0-21	10YR 3/3	ls		m1gr			
B_{21}	21-50	7.5YR 5/6	s		m1sbk			
B_{22}	50-83	10YR 5/6	s		sg			
B_3	83-100	10YR 6/6	s		sg			
C_1	100-140	10YR 6/4	s		sg			
C_2	140-150	10YR 5/4	s		sg			

Table 2. (cont)

Altered Drainage

Horizon	Depth (cm)	Munsell Color	Texture	Mottle	Structure	Cementation	Nodules	High Groundwater (cm)
					Site #4			
A_p	0-21	10YR 3/2	ls		clgr			
B_{21}	21-46	7.5YR 4/4	ls		mlsbk			
B_{22}	46-67	7.5YR 5/6	s	m2d	mlsbk			
B_3	67-86	10YR 5/6	s	m3d	sg	cwv	X	
C_1	86-120	10YR 6/3	s	m3p	sg			
C_2	120-145	10YR 6/3	s	m3p	m	cwv	X	123
					Site #5			
A_p	0-21	10YR 3/3	ls		clgr			
B_{21}	21-49	7.5YR 4/4	ls		clsbk			
B_{22}	49-100	5YR 5/6	s	m3d	sg		X	

Table 2. (cont)

Altered Drainage

Horizon	Depth (cm)	Munsell Color	Texture	Mottle	Structure	Cementation	Nodules	High Groundwater (cm)
				Site #5 (cont)				
B_3	100-120	10YR 5/6	s	m3p	sg	cwv	X	
C_1	120-150	10YR 6/3	s	m3d	sg			
C_2	150-196	10YR 5/3	s	c3d	m	cwv	X	153
C_3	196-200	10YR 5/3	s	c3d	sg			
				Site #6				
A_p	0-18	10YR 3/2	ls		clgr			
B_{21}	18-40	7.5YR 4/4	ls		clsbk			
B_{22}	40-54	5YR 5/6	s	c3d	clsbk			
B_3	54-65	7.5YR 5/8	s	m3d	m	cwv	X	
C_1	65-96	10YR 5/4	s	c3d	sg			

Table 2. (cont)

Altered Drainage

Horizon	Depth (cm)	Munsell Color	Texture	Mottle	Structure	Cementation	Nodules	High Groundwater (cm)
				Site #6 (cont)				
C_2	96-115	10YR 5/4-6	s	m3p	m	cwv	X	100
C_3	115-120	10YR 6/3	s	c3d	sg			
				Site #7				
A_p	0-18	10YR 3/3	ls		m1gr			
B_{21}	18-46	10YR 4/4	ls		m1sbk			
B_{22}	46-72	5YR 5/8	s		m1sbk			
B_3	72-105	10YR 5/6	s	m3d	sg	cwv	X	
C_1	105-152	10YR 5-6/4	s	m3p	sg		X	
C_2	152-200	10YR 5/3	s	c3d	m	cwv	X	177

Table 2. (cont)

Altered Drainage

Horizon	Depth (cm)	Munsell Color	Texture	Mottle	Structure	Cementation	Nodule	High Groundwater (cm)
Site #8								
A_p	0-21	10YR 3/2	ls		clgr			
B_{21}	21-51	7.5YR 4/4	ls		clsbk			
B_{22}	51-74	7.5YR 5/8	s	c2d	clsbk			
B_3	74-107	10YR 5/6	s	m3p	sg	cwv	X	
C_1	107-152	10YR 6/3	s	c3p	sg			
C_2	152-182	10YR 5/3	s	m3d	m	cwv	X	171
C_3	182-200	10YR 5/3	s	c3d	sg			
Site #9								
A_p	0-15	10YR 3/4	ls		mlgr			
B_{21}	15-52	7.5YR 4/4	ls		mlsbk			

Table 2. (cont)

Altered Drainage

Horizon	Depth (cm)	Munsell Color	Texture	Mottle	Structure	Cementation	Nodule	High Groundwater (cm)
				Site #9 (cont)				
B_{22}	52-69	7.5YR 5/6	s		clsbk			
B_3	69-143	7.5YR 5/8	s	m3d	m	cwv	X	137
C_1	143-163	10YR 5/4	s	c3d	sg			
C_2	163-200	10YR 6/3	s	c3d	sg			
				Site #10				
A_p	0-21	10YR 3/2	ls		mlgr			
B_{21}	21-42	7.5YR 4/4	ls		clsbk			
B_{22}	42-58	7.5YR 5/6	s		clsbk			
B_3	58-72	7.5YR 5/8	s	c2f	mlsbk			
C_1	72-119	10YR 5/4	s	m3p	m	cwv	X	

Table 2. (cont)

Altered Drainage

Horizon	Depth (cm)	Munsell Color	Texture	Mottle	Structure	Cementation	Nodule	High Groundwater (cm)
				Site #10 (cont)				
C_2	119-134	10YR 6/4	s	m3p	sg		X	131
C_3	134-182	10YR 5/3	s	m3d	m	cwv	X	
C_4	182-200	10YR 6/4	s	f3f	sg			
				Site #11				
A_1	0-9	10YR 3/2	ls		clgr			
B_{21}	9-54	5YR 4/4	ls		clsbk			
B_{22}	54-78	5YR 5/8	s		clsbk			
B_3	78-97	10YR 5/6	s	m3p	m	cwv		
C_1	97-145	10YR 5/4	s	m3d	m	cwv		
C_2	145-188	10YR 6/4	s	c3d	sg			

Table 2. (cont)

Altered Drainage

Horizon	Depth (cm)	Munsell Color	Texture	Mottle	Structure	Cementation	Nodule	High Groundwater (cm)
Site #11 (cont)								
C_3	188-200	10YR 5/4	s	c3d	m	cwv	X	189
Site #12								
A_p	0-18	10YR 3/2	ls		mlgr			
B_{21}	18-53	5YR 4/6	ls		clsbk			
B_{22}	53-81	7.5YR 5/6	s		clsbk			
B_3	81-100	10YR 5/8	s		clsbk			
C_1	100-160	10YR 6/4	s	m3d	sg			
C_2	160-200	10YR 6/3	s	c3d	sg			+450

Soil matrix hue of 10 YR was observed in the soil profile. Both hues were found in the horizon at the high groundwater level. Underlying horizons had a matrix hue of 10 YR. The matrix values ranged from 3 through 6 and chromas from 2 through 8. A chroma of 2 was noted in the A_p-horizon. Values of 5 or 6 and chromas of 3 or more were observed in all horizons subjected to saturation. The yellow to brown color of the solumn was found to be largely associated with thin partial coatings of sand grains with iron. Few to no iron coatings were observed in horizons with a chroma of 3 or 4.

Mottling was observed in and below the horizon in which high groundwater was observed at site #1 and #2. Mottle chromas greater than 5 and values from 5 through 7 were noted. The hue of the mottles was 10 YR or 7.5 YR. The redder hue did not exist below the horizon of observed groundwater. Value and chroma of mottles varied with depth in no consistent pattern. Abundance of mottles decreased with depth and the size and contrast remained relatively constant. The difference between observed high groundwater and the upper level of mottling was 7.0 cm at site #1 and 10.0 cm at site #2. No mottling existed in the soil profile at site #3.

Iron concentration, coverage and thickness of iron coatings, was found to be greater in mottles than in the adjoining sand. Intensity of color appeared to be related to the degree of iron accumulation on the sand grains. High values and a 10 YR hue were found in mottles with relatively thin and infrequent iron coatings.

Very weak cementation of medium to fine sand grains to coarse sand and gravel was noted at the high groundwater level at site #1. The small sand grains were attached to partial iron coatings on the surface of the coarse sand and gravel. Masses of gravelly material were not cemented. Due to the darkness of some of the cementing agent it is possible that manganese may be associated with the iron. At site #2 discontinuous zones of iron cementation were observed at the high groundwater level; partially cemented zones were observed at 50% of the sites where seasonal groundwater fluctuations occurred. Cementation occurred at points of contact between sand grains where partial iron coatings joined together. Some manganiferrous material was present in the coatings. The coatings were suitably abundant so that prism-like fragments could be formed upon disturbance of the cemented areas. The fragments could bear only careful handling and would break into subangular blocky-like fragments. Cementation weakened upon drying. No cementation was observed at site #3.

Sesquioxidic nodules with glaebular haloes were observed at the high groundwater level at site #2, a 50 percent rate of occurrence. Nodules consisted of masses of thickly coated sand grains. Their shape tended to be irregular and boundaries diffuse. Nodules were not noted in horizons above or below the zone of high groundwater fluctuation nor in the soil profile at site #3.

Area of Altered Drainage

Groundwater was observed at site #4 through #11 for only four months during the first year of study. The depth to groundwater exceeded 3.0 m throughout the study at site #12. High groundwater levels observed at each site are shown in Table 2. A record of groundwater levels was made (see the Appendix). A rapid decline and poor recovery of the groundwater table reflected the droughty conditions experienced from mid 1976 through early 1977.

Groundwater quality in this area in May of 1976 is shown in Table 3. As in the area of natural drainage, constituents of near surface groundwater are compared to data collected by Karnauskas (1977) at greater depths. The location of the Karnauskas (1977) sampling sites is within 0.5 km of site #10. In general, iron, manganese and pH levels increase with depth. Temperature of the groundwater was near the biologic zero of 5° C (Soil Survey Staff, 1975). The dissolved oxygen concentration of 6.0 ppm suggests an oxidizing environment at the surface of the aquifer (Daniels, *et al.*, 1973).

Table 3.

Groundwater quality in an area of altered drainage in the Town of Grand Rapids, Wood County, Wisconsin.

	Upper 50 cm	Below 1-3 m *		
Iron (ppm)	0.04	0.09	1.40	0.15
Manganese (ppm)	-0.04	0.01	0.24	0.01
pH (su)	7.0	6.0	7.1	6.6
Temperature (°C)	7.0			
Dissolved oxygen (ppm)	6.0			

* Source: Karnauskas, R., 1977. M.S. - Thesis, U.W. - Madison

Detailed soil profile descriptions were made (see the Appendix). A summary of the descriptions is given in Table 2. Matrix hues ranged from 5 YR through 10 YR. The 10 YR or 7.5 YR hue was observed at the high groundwater level. Only the 10 YR hue was found in horizons below the high groundwater level. Values of the matrix ranged from 3 through

6 and chromas from 2 through 8. The chroma of 2 was found in the A_p- and A_1-horizons. A matrix value of 5 or 6 and chroma of 3 or more wereobserved below the B_3-horizon and below the high groundwater level. The matrix hue generally became less red with depth. Value of the matrix increased with depth, whereas the chroma decreased. A slight decrease in value and/or increase in chroma was observed at sites #5, #6, #10 and #11 (50 percent of the sites) at the high groundwater level. Partial iron coatings on sand grains contributed to the brown color of the solumn. Few or no iron coatings existed in the matrix of the C-horizons except in mottles, nodules and at the observed high groundwater level. The lower value and higher chroma at the high groundwater level appeared to be due to a very slight increase in the amount, and possibly thickness of iron coatings.

Mottling was noted above, at or below the level of observed high groundwater. Hues of 10 YR to 2.5 YR were observed in mottles existing at and above the high groundwater level. A hue redder than 7.5 YR was not observed in mottles that occurred below the high groundwater level. The value of the mottles ranged from 4 through 7 and generally increased with depth. Abundance of mottles decreased with depth at sites #4, #5, #7, #9, #11 and #12 of (66.6 percent of the sites). At sites #6, #8 and #9 (37.5 percent of the sites) an increase in the abundance of mottles was observed at the high groundwater level. Size of mottles was rather consistent with depth except at sites #4, #8 and #10 where medium size mottles were observed in the B_{22}-horizon and coarse mottles existed below. Mottle contrast at sites #4 and #5 (25 percent of the sites) increased at the level of high groundwater. The contrast of mottles tended to be less pronounced in the B_{22}-horizons as compared to underlying horizons.

Groundwater was observed 60.0 cm to 1.2 m below the upper level of mottling at sites #4 through #11. The difference was found to be greater at sites located to the south. Mottling was observed over 3.5 m above high groundwater at site #12.

At all sites, except sites #9 and #12, there was two levels of soil cementation. One level of cementation was observed at site #9 and no cementation was noted at site #12. The upper level of cementation was observed in the B_3-horizon at all sites; a horizon below noticeable structural development. Mottling was noted at or above this level at all sites. At some sites, such as site #11, cementation extended into the C horizon. Cementation was rather continuous to intermittent. Iron was the primary cementing agent with lesser amounts of manganese. The cementation was similar to that observed at site #2.

Below the upper level of cementation was a horizon of single grained sand. The color of the uncoated sand tended to be more pale than the overlying horizons and had a hue of 10 YR, value of 5 or 6 and chroma of 3 or 4. At some level below was a second layer of cementation. This second layer of cementation was not observed at sites #9 or #12. Cementation was found to be weaker, yet more continuous, than that observed in the B_3-horizon. Matrix hue in the horizon was 10 YR, the value was 5 or 6 and the chroma ranged from 3 through 6. The quantity of iron responsible for cementation was not great enough to produce pronounced matrix colors. Microscopic observations indicate the iron coatings are very thin and discontinuous. Apparently, the iron present in the thin coatings is the cause of cementation. The horizon appeared to be more dense than adjoining horizons. Prism-like fragments were formed by disturbance of the horizon. The prism-like fragments could be further broken down to subangular blocky-type fragments. High groundwater was observed within the lower cemented horizon at sites #4 through #9 and #11 (87.5 percent of the sites). The water table was observed 3.0 cm above the lower cemented layer at site #10. Thickness of this horizon ranged from 19 cm to 48 cm. The lower cemented horizon tended to be thinner to non-existent (site #9) at the more northerly sites. It should be noted that the existence of cementation was generally overlooked when using a typical bucket auger. Apparently, the cutting action of the bits destroyed much of the weak cementation. Also, in areas of intermittent cementation it would be probable that cemented zones could be missed when using a bucket auger.

Nodule formation was noted at sites #4 through #10 within the B_3-horizon. At site #5 nodules were observed at the upper level of mottle formation in the B_{22}-horizon. Iron was the primary constituent of nodules in the B_3-horizon. Glaebular haloes were associated with nodules. Size and abundance of nodules decreased with depth. A transition from sesquioxide nodules to manganiferrous nodules with depth, was observed. The manganiferrous nodules were fine in size and were most abundant at the high groundwater level. Glaebular haloes did not surround the manganiferrous nodules. However, many of the manganiferrous nodules appeared to be an aggregation of sand size nodules. The mass of manganiferrous material imparted the appearance of fine, brown mottles.

DISCUSSION

Area of Natural Drainage

Mottling was observed at the high groundwater level in the area of natural drainage. The mottling was 'high chroma mottling' of strong brown, yellowish brown, yellow and yellowish red. No mottles of a chroma of 2 or less were observed at the high groundwater level. In fact, no mottles of a chroma of 2 or less were observed within any of the profiles investigated. Mottles of a chroma of 2 or less are associated with the reduction and migration of iron (Daniels, et al., 1961 and 1971). The occurrence of high chroma mottles and the lack of mottles of a chroma of 2 or less or matrix colors associated with reduced iron strongly suggests that iron which formed mottles did not originate within the soil profile. The mottles observed in the Friendship series are probably formed by the accretion of iron since the iron coatings on sand grains increased in coverage and thickness toward the center of the mottles. The increased thickness and coverage of iron coatings was directly related to an increase in the redness of the mottle color.

Matrix colors at and below the high groundwater level ranged from 10 YR 5/3 to 10 YR 6/4. According to Daniels, et al., (1961) a 10 YR hue is not an indication that iron is reduced, however, may be observed in saturated soil horizons. Except for the value and chroma combination of 5/3 in the C_2-horizon at site #2, the matrix values and chromas observed do not suggest reduction of iron. Veneman, et al., (1976), Daniels, et al., (1971) and McKeague (1965) have suggested that values greater than 4.5 and chromas of 3 or less are related to iron reduction under saturated conditions. The author attributes the 5/3 value and chroma combination to the color of uncoated sand grains rather than reduced iron, however, iron coating removal may be the result of iron reduction and migration.

A comparison of the moderately well drained Friendship series and excessively drained Plainfield series provides evidence that cementation in the B_3-horizon is a product of a fluctuating groundwater table rather than illuviation of sesquioxidic compounds from overlying horizons. Cementation is due to the joining of iron coatings at the points of contact between sand grains. It is suspected, however not verified, that these points of contact between sand grains may serve as a nucleus for iron accretion in mottle formation. The nonexistence of mottles of a chroma of 2 or less and matrix colors associated with iron reduction indicates iron contributing to cementation does not originate from within the solumn.

Nodules were observed at site #2 at the high groundwater level. The nodules appeared to be formed by an accretion of iron and, to a lesser degree, manganese. Accretion of the metals is suggested by glaebular haloes and diffuse boundaries (Brewer, 1976). The formation of nodules is promoted by rapid aeration (Blume, 1968). Lack of nodules at site #1 at the high groundwater level may be related to the coarse nature of the material. The gravel and coarse sand have not provided a foundation or base for iron accretion and glaebule formation. Again, the occurrence of nodules is not associated with mottles of a chroma of 2 or less or matrix colors associated with reduced iron. It is evident that iron and small amounts of manganese are being deposited by the fluctuating groundwater since the soil colors do not indicate translocation from within the profile.

The iron concentration near the surface of the groundwater table was greater than at depths exceeding 1.0 m in the area of natural drainage. This would suggest the iron which formed mottles, nodules and cementation was derived from the soil and not the groundwater. However, the reverse is true in the area of altered drainage. The fact that the comparison wells in the area of natural drainage are so far removed from each other allows for a rather great variation in the observed iron concentrations (Holt, 1965). If the trend observed in the area of altered drainage is accepted, it appears that the iron present in mottles, nodules and cementation is from the groundwater rather than the soil. The lower concentration near the groundwater table surface is probably caused by the precipitation of iron onto the sand grains. Manganese levels also increased with depth below the aquifer surface. As with iron, this suggests soil features containing manganese were formed through precipitation of the material from the groundwater. Iron in the groundwater is primarily due to the disassociation of iron from underlying sandstone (Holt, 1965) and possible iron coatings on the outwash sand.

Lack of reducing environs are probably due to unfavorable conditions for biotic activity and oxygen depletion. In order for microbes to deplete the oxygen of a saturated soil there must be a limited oxygen supply and suitable conditions for growth, such as proper temperatures and an energy source. Dissolved oxygen readings of 8.2 ppm observed at site #2 indicate well aerated conditions (Daniels, et al., 1973). Microbial utilization of oxygen apparently is far surpassed by diffusion of oxygen into the groundwater. Also, the temperature is a limitation to microbial activity. With a soil-water temperature of 7° C it is anticipated that biotic activity would be extremely low (Bonner and Ralston, 1968). Precipitation of iron and manganese from the groundwater would be promoted because of the low biotic activity since oxidation of the upper surface of the groundwater table is probable through air diffusion in soils with low biotic activity (Howeler and Bouldin, 1971). A portion of the metals found in mottles, nodules and cementation may have been oxidized and precipitated from the capillary fringe which should range from 10 cm to 15 cm above the groundwater (Soil Survey Staff, 1975). The slight reduction in pH near the groundwater surface may be caused by H+ released as ferrous ions are oxidized and precipitated as ferric hydroxide (Hem, 1970). A reduction in pH was not observed at all sites, however.

Maximum mottle formation was observed at the high groundwater level. The maximum accumulation of iron is not due to a prolonged retention of the groundwater at that particular depth. An increase in the oxidizing potential may well be the cause for the increase in mottle formation near the high groundwater level. The closeness of the groundwater surface to the soil surface possibly influences the degree of aeration of the groundwater. Maximum aeration of the groundwater surface during its peak rise would exhaust iron and manganese from the groundwater surface. This would leave only a limited concentration of the metals in the surface of the groundwater table for mottle formation as the groundwater recedes. The same principles can be used to explain the formation of nodules and cementation.

It appears that the upper level of mottling, nodule formation and cementation is associated with the high groundwater level. The iron and manganese found in these morphologic featuresare precipitated from the groundwater. The following formula suggested by Byron Shaw (personal communication) probably represents the process:

$$4Fe^{+2} + O_2 + 10H_2O \longrightarrow \underline{4Fe(OH)_3} + 8H^+ + 4e^-;$$

and

$$4Mn^{+2} + 3O_2 \longrightarrow \underline{2Mn_2O_3} + 4e^-$$

The intensity of mottling would be directly related to the iron concentration of the groundwater and the degree of aeration. More pale colored mottles would be associated with a groundwater table with a low iron content. In turn, poor nodule formation and cementation would probably be found in areas where the iron concentration of the groundwater is low. The lack of mottling, nodules or cementation in a soil horizon would generally indicate well drained conditions, however, because of variations in the hydrogeologic setting and groundwater quality in the Sand Plain it may be possible that high groundwater levels can occur in a soil profile above these morphologic features.

Absence of nodules and cementation at the high groundwater level may be anticipated in the Friendship series. Apparently the particle size distribution is an important factor in the formation of nodules and cementation. In a horizon with a high percentage of gravel and coarse sand there is minimal nodule formation and cementation.

Area of Altered Drainage

As would be expected, mottling in most areas was observed above the high groundwater level. At sites #4 through #8, #10 and #11 the upper level of mottles, nodules or cementation occurs from 60.0 cm to 1.2 m above the high groundwater level. Mottles were observed over 3.5 m above observed groundwater at site #12. The presence of these soil features obviously is from a period of time when groundwater levels rose above the elevations at which they are presently observed. The thickness of the cemented layer at site #9 indicates groundwater levels were probably somewhat higher in the past. From a previous study (Shimek, 1976) it was found that the Twomile Creek has a substantial influence on the groundwater flow in the area of site #4 through #11. Near surface groundwater flowing from the northeast is intercepted and diverted in the stream. Groundwater flow was altered by the channelization of Twomile Creek shortly before 1915. The alteration of the depth to groundwater at the southerly sites (#5, #7, #8 and #11) may also be influenced by the downcutting of the Fourmile Creek. Downcutting was retarded between 1926 and 1936. Since that time seasonal high groundwater levels should have stabilized. The mottling observed at site #12 formed during the early development of the Fourmile Creek channel. Lowering of the groundwater due to the downcutting of the Fourmile Creek had probably been rather continuous until 1926 to 1936.

The upper level of mottling, nodules and cementation at sites #4 through #11 are very similar to the features observed in the area of natural drainage. Some differences include the presence of medium versus coarse mottles in the B_{22}-horizon and the lack of cementation at the upper level of mottling where mottling occurs in the B_{22}-horizon. Maximal iron concentration was observed near the center of most mottles with lower concentrations toward the periphery in the area of natural drainage. It may be possible that the outer portions of mottles in the B_{22}-horizon have been destroyed by biotic mixing, leaving the more concentrated central portion of the mottle. Another explanation for the medium sized mottles may be the quick oxidation of iron due to the proximity of the B_{22}-horizon to the soil surface. Thomasson and Bullock (1975) suggest fast precipitation of iron favors less coarse mottles.

The lack of cementation in the B_{22}-horizon is probably due to a mixing of soil material by soil fauna and flora and physical disruption by frost action and wetting and drying. The intermittent or non-continuous nature of the cementation of the B_3-horizon may also be attributed to biotic activity, frost action and wetting and drying.

At site #12 mottling was observed in the C-horizons. Apparently, the thin iron coatings on the sand grains within mottles are resistant to disruption. In the C-horizons, at site #12, chemical removal of iron would require the reduction of the iron, which would not be expected in this well aerated and excessively drained soil. Although not observed in the soil profile at site #12, nodules and cementation may have been in the soil at one time. If so, destruction of the nodules and cementation obviously was completed in less than 13,000 years, yet more than 60 years before present since these features are still intact at sites #4 through #11. Destruction of nodules and cementation below the solumn is probably accomplished by frost action and wetting and drying. The average frost depth in central Wisconsin is somewhat greater than 1.0 m and the droughty soil conditions experienced most summers are preceded by a thorough wetting of the soil profile in the spring of the year. It is also possible that mottling, nodules and cementation were present at one time in the B-horizons at site #12. These features may have been masked by illuviation of iron or disrupted by biologic activity,frost action and drying cycles.

At all sites, except #9 and #12, a horizon (s) of single grained, non-cemented sand was observed between two cemented zones. There was an obvious reduction in the continuity and thickness of iron coatings in the horizon. The boundary between the non-cemented horizon and the lower horizon of cementation was poorly defined by color. The occurrence of the non-cemented horizon suggests that the groundwater alteration in the area of sites #4 through #11 was rapid. A rapid drop in the groundwater table would be associated with the channelization of Twomile Creek.

At some depth which correlated quite well to the level of observed groundwater a second or lower level of cementation was observed. An increase in chroma or decrease in value, as compared to adjoining horizons, was observed at 50 percent of the sites. The slight darkening of the horizon was imparted by an increase in iron and manganese coatings. This horizon also appeared to retain moisture longer than adjoining horizons upon excavation of the soil pits. Bridging of some of the sand grains by the oxides and hydroxides of iron and manganese probably aides in the retention of moisture as the groundwater recedes. Obviously, bridging of sand grains and cementation occurs before mottle formation becomes prominent since an increase in the abundance of mottling, as compared to overlying horizons, was observed at only 37.5 percent of the sites. Nodule formation was very weak at the observed groundwater level and most nodules were manganiferrous. The depth to the groundwater table may have had an influence on the increased occurrence of manganiferrous nodules over sesquioxidic nodules. Aeration of the groundwater table is probably not as rapid or complete in the area of altered drainage as compared to the area of natural drainage due to the differences in depth to the observed groundwater level. The dissolved oxygen reading taken at 100 cm in the area of natural drainage was substantially higher than the reading at 140 cm in the area of altered drainage, which may be an indication of the depth-aeration relationship. Admittedly, other factors may account for the variation in the dissolved oxygen readings. Manganese will precipitate out of solution at a lower redox potential than iron and thus its prominence at the high groundwater level where aeration is probably limited.

Soil Genesis

During the course of this study several ideas on the formation of the Friendship series were developed. Following are the interpretations of field observations.

The A-horizon was a dark brown or very dark greyish brown loamy sand with weak structural development. An abundance of ants were observed in this horizon and appeared to be a major contribution to the mixing of organic material. A lack of earthworms was also noted and is probably due to the droughty nature of the soil throughout most of the summer months. In most soils of the humid regions of the nation earthworms play a vital role in mixing organic materials in the soil surface horizons.

Generally, the B-horizons were a loamy sand in texture. The color of the B_{21}-horizon ranged from 7.5 YR 5/6 to 5 YR 4/4 and the underlying B_{22}-horizon ranged in color from 5 YR 5/8 to 7.5 YR 5/6. The color of the B_3-horizon ranged from 10 YR 5/6 through 10 YR 5/8 and appeared to be transittional in color, from the B_{22}-horizon to the C-horizon. A sand texture was assigned to the B_3-horizon at all sites.

The B_{21}-horizon was darker, more red, than the B_{22}-horizon. This sequence of horizons strongly resembles a weakly developed Spodosol. DeConinck, et al., (1974) would probably consider this soil to be in the second stage of Spodosol development. The first stage of development is recognized by the formation of a Bir-horizon with a hue of

7.5 YR or 10 YR, values from 4 through 6 and chromas of 3 through 6. A leached (A_2-horizon) generally overlies the weak Bir-horizon.[1] An A_2-horizon has been observed by the author in the Friendship series in isolated areas. The second stage of development is associated with the formation of two subhorizons. The lower subhorizon is the unaltered remnant of the first stage of Spodosol development and the upper subhorizon is darkened by organic matter.

Iron and lesser amounts of organic matter make up the Bir-horizon of the second stage Spodosol described by DeConinck, et al., (1974). The movement of iron to form an evenly colored Bir-horizon is accredited to chelation of sesquioxides with organic acids (McKeague, et al., 1967). A soluable complex forms which is free to be translocated by percolating water. Solubility of the complex is retained until the sesquioxidic concentrations reach a critical level and precipitate (McKeague, et al., 1967). The near surface source of iron in parent materials which are relatively iron free is attributed to weathering of primary minerals and biocycling (Soil Survey Staff, 1975). An illuvial A_2-horizon would be expected to form above a Bir-horizon if iron accumulation was due to illuviation. However, cultivation and fauna and floramixing could have destroyed any evidence of an illuvial horizon in most areas.

In the second stage of Spodosol development described by DeConinck, et al.,(1974) the upper portion of the B-horizon is darkened by organic matter, while the lower portion resembles the color developed during the initial stage. The formation of two subhorizons is common to the

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[1] The horizon symbols ir (iron accumulation) and hir (humus and iron accumulation) may be used to describe soil horizons that exhibit iron and/or humus accumulations but are not diagnostic, according to U.S.D.A. - S.C.S., National Soil Handbook-Part 2.

Friendship series. DeConinck, et al., (1974) describes two additional stages of development which are recognized by further color development and cementation which is not observed in the Friendship series.

Spodic horizons may be identified by cracked iron coatings on soil particles and associated silt size pellets (Soil Survey Staff, 1975). Bullock (1974) has postulated the disruption of iron coatings and subsequent formation of silt size pellets is the result of physical degradation of the iron coating primarily due to wetting and drying. Cracked iron coatings and silt size pellets were not observed in the Friendship series. It is the opinion of the author, after viewing the B-horizons of the Friendship series and the Gogebic series (an Alfic Fragiorthod with easily recognized cracked coatings), under a microscope, that the iron coatings on sand grains in the Friendship series have not yet attained a thickness which would be susceptible to extensive physical degradation. Apparently the Friendship series is developing as a Spodosol, however, has not reached a stage of development to be classified as such.

From the classification viewpoint, the Friendship series is in an awkward stage of development. The series can not be classified as a Spodosol since cracked coatings have not developed or chemical identification criteria can not be met. (Soil Survey Staff, 1975). In fact, according to Soil Taxonomy (Soil Survey Staff, 1975) the Friendship series can not be classified as a Spodic Udipsamment since an albic horizon does not overlie the weakly developed spodic horizon. The albic horizon requirement for the use of the spodic modifier seems without merit since DeConinck (1974) has noted spodic horizon development without the formation of an A_2- or albic horizon. Unfortunately, the Friendship series is classified as a Typic Udipsamment which connotes extremely poor development.

Also, it has been shown by observation of the groundwater table that the Friendship soil series in areas of unaltered drainage are seasonally saturated to the upper level of mottling. As illustrated in Table 2 mottling and groundwater were observed within one meter of the soil surface. Mottling of a chroma of 2 or less was not observed within one meter of the soil surface or at the high groundwater level.

It is the opinion of the author the classification of the Friendship series should reflect the fact that seasonal saturation may occur within one meter of the soil surface during some portion of the year. However, according to Soil Taxonomy (Soil Survey Staff, 1975) the Aquic subgroup to the Udipsamments may be utilized only if mottles with a chroma of 2 or less exist within one meter of the soil surface. From a review of the literature it appears that the reduction of iron and/or removal of iron must occur for mottles with a chroma of 2 or less to be formed. The results of this study suggest the reduction of iron does not occur in the Friendship series, however, the soil is seasonally saturated. A more logical requirement for the utilization of the Aquic modifier on the subgroup level would be the occurrence of mottles, of no specific color, within one meter of the soil surface.

Taking into account the development of the Friendship series as a Spodosol and the seasonal saturation to within one meter of the soil surface, the author proposes the reclassification of the soil investigated from Typic Udipsamment to Aquodic Udipsamment. Aquodic Udipsamsemt is not an established classification, however, the Soil Survey Staff (1975) has stated that the taxonomic classification system is flexible and should be open to such alteration.

The C-horizon, or parent material, of the Friendship series is generally a medium to coarse sand with a very small percentage of silt or clay. The A- and B-horizons, on the other hand, contain an appreciable amount of silt and clay and are texturally classified as a loamy sand. The increased amount of silt and clay in the A- and B-horizons are probably a product of weathering. As noted earlier, weathering of primary minerals may be the source of iron for the formation of the developing spodic horizins. During the late stages of the outwash plain development silt deposits of the Mississippi floodplain were being carried eastward by the prevailing winds. Areas surrounding the outwash plains are mantled with these loess deposits, however, the Sand Plain is devoid of the silt mantle. The author suspects that some of the silt and possibly clay and fine sand found encorporated in to the A- and B-horizons may have originated as aeolian material.

Obviously, this is an overview of the soil genesis of the Friendship series and more detailed work should be undertaken.

CONCLUSION

The Friendship series, in the study area, does not possess low chroma mottles of 2 or less, yet is seasonally saturated within 1.5 m of the soil surface. Lack of low chroma mottles is due to insufficient reducing conditions. High oxygen contents at the surface of the groundwater table indicate air diffusion into the groundwater exceeds consumption by microbes. Also, the low temperature observed is not condusive to microbial activity.

The lack of reduction and thus mobility of iron and manganese within the soil indicates the metals found in mottles, nodules and cementation are from the groundwater. The groundwater has a relatively high concentration of iron and manganese and the well oxidized surface of the groundwater table promotes their precipitation.

In areas of natural or unaltered drainage the upper level of mottling was found to be a good indicator of high groundwater levels. Due to variations in groundwater fluctuations it is probable that during some years the groundwater table rises above the upper level of mottling. It is expected that faint mottling would be observed if the iron concentration of the groundwater is low or the depth to the high groundwater level is sufficient to cause poor or inadequate diffusion of oxygen for oxidation of reduced iron.

The presence of nodules and cementation enforce the high groundwater level prediction, however, their non-existence is not an indication of well drained conditions. Iron and manganese content of the groundwater, texture of the soil at the high groundwater level, depth to high groundwater and oxidation of the groundwater were found to be extremely important factors in the production of nodules and cementation.

The relationship of these various factors would determine if nodules and cementation could be produced at the high groundwater level. It is doubtful if cementation would occur at high groundwater levels within the B_{21}- and B_{22}-horizon in the study area due to biotic influences. It appears that the bridging of sand grains with iron and very weak cementation can be produced in somewhat less than 60 years. The formation of mottles and manganiferrous nodules probably follows the bridging of sand grains since the bridges and iron coatings may act as a nucleus for mottle and nodule formation. Mottles and nodules appeared to have formed by accretion of iron and manganese.

The destruction of mottles over time, in the Friendship series, is extremely slow. Mottles were found to be intact in the C-horizons of a soil profile which was seasonally saturated within the last 13,000 years but probably well drained for the last several thousand years. Mottles within the B-horizons may have been masked or destroyed by iron illuviation,biotic mixing, frost action or drying cycles. Nodules and cementation probably developed in the soil profile while it was subjected to a fluctuating groundwater table. These features are no longer identifiable within the profile. In the soil profiles where alteration of the groundwater table occurred about 60 years ago, nodules and cementation still persist. Apparently more than 60 years and less than several thousand years are required for the destruction of nodules and cementation. The destruction of these features is also attributed to frost action, biotic activity and wetting and drying.

In areas of altered or improved drainage, the use of cemented horizons may be of value in predicting new high groundwater levels. The amount of time since groundwater alteration occurred, the degree of alteration and factors influencing the formation of cementation must be considered. In the study area rather abrupt changes in the groundwater table were observed so a distinct, yet very weak, horizon of cementation developed in less than 60 years. However, without a previous knowledge of the alteration the features at the new high groundwater level would have been overlooked since the cementation is easily destroyed by the cutting action of a typical bucket auger. Soil pits were required for the observation of the cementation. A slight increase in the number of mottles was noted at some sites. Manganiferrous nodules were observed at the new groundwater level, within the weakly cemented horizon. The increased occurrence of manganiferrous nodules over sesquioxidic nodules is attributed to the depth-aeration relationship. It is suspected that in areas where only slight alteration occurred or a slow continuous lowering of the groundwater table took place, such as adjoining a stream, the use of a second level of cementation is limited. A drastic change in the groundwater level to a depth below the upper cemented zone is required to produce a distinct lower level of cementation. It should be noted that the conclusions drawn from this study on the formation of mottles, nodules and cementation may not apply to well structured soils, loamy or clayey soils, areas of vastly different hydrogeologic conditions or soils of different drainage classes.

From field observations it appears the Friendship series, in the study area, is developing as a Spodosol. The soil investigated is probably a second stage Spodosol as described by DeConinck, et al., (1974). Two subhorizons have developed in the Friendship series; the upper subhorizon is darkened by the accumulation of organic matter and the lower subhorizon has retained a reddish color from iron illuviation which occurred during the first stage of Spodosol development. Although an albic horizon does not overlie the horizons of humus and iron enrichment, it is the opinion of the author that the spodic modifier should be used on the subgroup classification level. Also, it has been shown that the Friendship series is seasonally saturated to within 1.0 m of the soil surface and 'high chroma' mottles are observed at the high groundwater level. No mottles of a chroma of 2 or less are observed within 1.0 m of the soil surface thus the Aquic modifier may not be utilized at the subgroup classification level according to the Soil Survey Staff (1975). The author suggests that the occurrence of seasonal saturation within one meter of the soil surface should be reflected in the subgroup classification of the soil series. Thus, the author proposes the reclassification of the soil investigated from Typic Udipsamment to Aquodic Udipsamment.

APPENDIX A. Groundwater Observations

(Depth in cm below soil surface)

DATE	SITE #											
1976	1	2	3	4	5	6	7	8	9	10	11	12
3-23	119	110		139	172	152		NO	176	163		
4-7	108	98		140	170	118		182	NO	143		
4-19	103	90		133	162	112	180	172	NO	NO		
4-26	97	86		123	153	100	177	171	137	131	189	
5-6	106	100		138	161	113	182	175	144	140	190	
5-18	110	113		138	165	118	189	182	150	NO		
5-28	119	118		155	172	132	194	187	157	152		
6-8	NO	NO		162	NO	NO		NO	NO	NO		
6-21	132	129		NO	198	150				165		
8-13	NO	NO										
:												
3-25		NO										
4-7		160										
4-22	199	154										
5-5	199	155										
5-23	168	129										
6-6	180	137		177								

NO - no observations made. BLANK - no water was observed in well.

APPENDIX B. Precipitation Levels (inches)

PRECIPITATION 1970

MONTH	AMOUNT	AMOUNT (cumulative)
January	1.23	1.23
February	.37	1.60
March	1.23	2.83
April	1.45	4.28
May	8.36	12.64
June	1.98	14.62
July	3.33	17.95
August	1.60	19.55
September	5.37	24.92
October	3.46	28.38
November	2.17	30.55
December	1.15	31.70
YEARLY TOTAL		31.70

APPENDIX B. (cont)

PRECIPITATION 1971

MONTH	AMOUNT	AMOUNT (cumulative)
January	2.20	2.20
February	2.64	4.84
March	.66	5.50
April	1.82	7.32
May	3.65	10.97
June	3.70	14.67
July	9.52	24.19
August	2.91	27.10
September	3.01	30.11
October	2.09	32.20
November	2.89	35.09
December	2.70	37.79
YEARLY TOTAL		37.79

APPENDIX B. (cont)

PRECIPITATION 1972

MONTH	AMOUNT	AMOUNT (cumulative)
January	.79	.79
February	.56	1.35
March	2.62	3.97
April	1.59	5.56
May	1.84	7.40
June	1.76	9.16
July	4.57	13.73
August	6.54	20.27
September	8.38	28.65
October	2.33	30.98
November	1.35	32.33
December	2.60	34.93
YEARLY TOTAL		34.93

APPENDIX B. (cont)

PRECIPITATION 1973

MONTH	AMOUNT	AMOUNT (cumulative)
January	.74	.74
February	1.03	1.77
March	3.67	5.44
April	5.63	11.07
May	7.98	19.05
June	4.98	24.03
July	2.83	26.86
August	3.34	30.20
September	2.98	33.18
October	2.40	35.58
November	1.36	36.94
December	1.54	38.48
YEARLY TOTAL		38.48

APPENDIX B. (cont)

PRECIPITATION 1974

MONTH	AMOUNT	AMOUNT (cumulative)
January	.72	.72
February	1.20	1.92
March	2.56	4.48
April	2.42	6.90
May	4.02	10.92
June	3.03	13.95
July	2.11	16.06
August	2.82	18.88
September	1.23	20.11
October	2.12	22.23
November	1.38	23.61
December	1.45	25.06
YEARLY TOTAL		25.06

APPENDIX B. (cont)

PRECIPITATION 1975

MONTH	AMOUNT	AMOUNT (cumulative)
January	1.37	1.37
February	1.16	2.53
March	1.73	4.26
April	3.67	7.93
May	2.07	10.00
June	4.14	14.14
July	1.48	15.62
August	8.25	23.87
September	2.64	26.51
October	.92	27.43
November	3.46	30.89
December	1.63	32.52
YEARLY TOTAL		32.52

APPENDIX B. (cont)

PRECIPITATION 1976

MONTH	AMOUNT	AMOUNT (cumulative)
January	1.96	1.96
February	2.04	4.00
March	3.30	7.30
April	4.07	11.37
May	1.98	13.53
June	1.30	14.65
July	5.54	20.19
August	1.04	21.23
September	.49	21.72
October	.68	22.40
November	.04	22.44
December	.60	23.04
YEARLY TOTAL		23.04

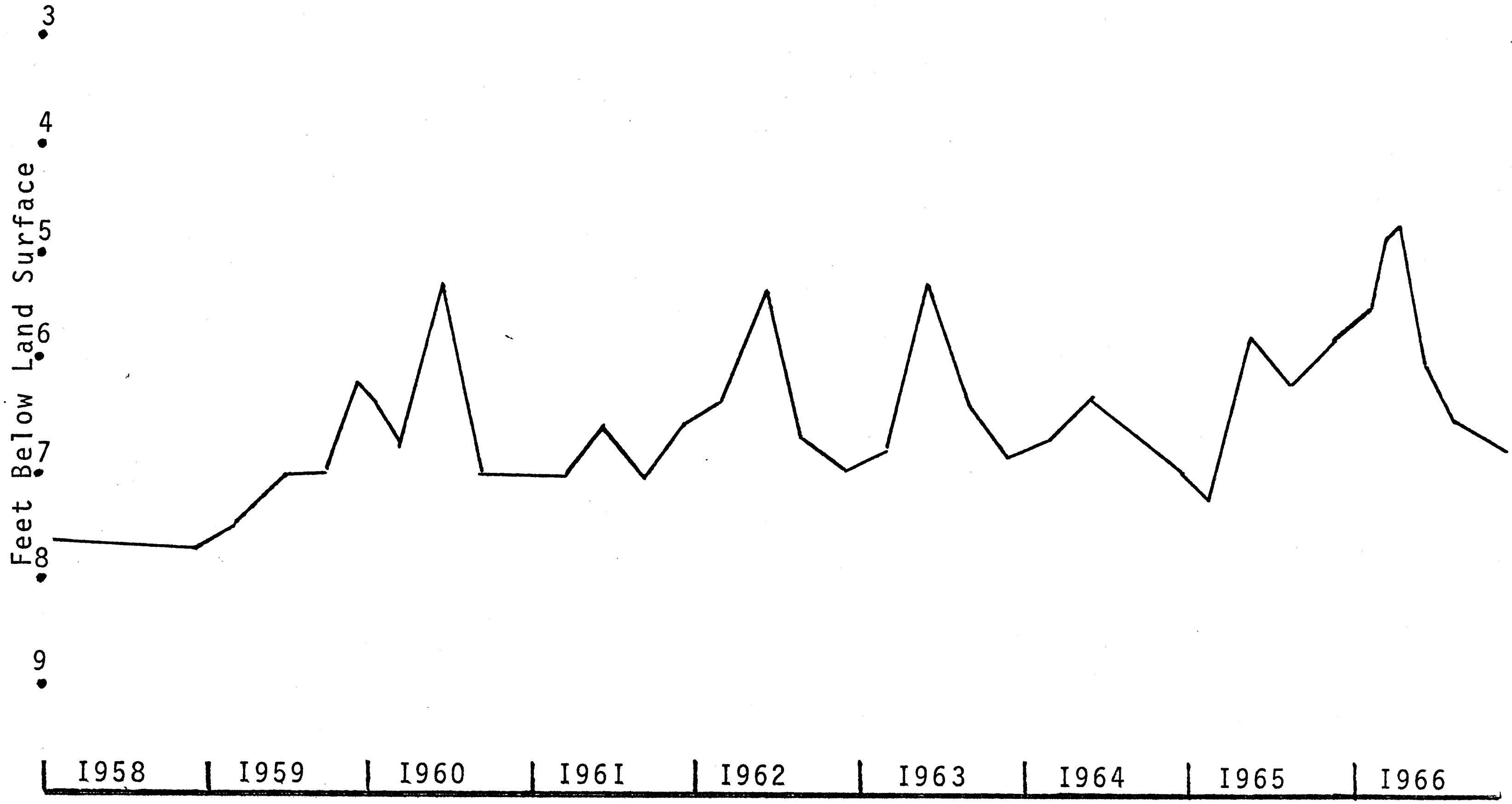
APPENDIX B. (cont)

PRECIPITATION 1977

MONTH	AMOUNT	AMOUNT (cumulative)
January	.62	.62
February	1.19	1.81
March	3.68	5.49
April	3.08	8.57
May	3.81	12.38
June	3.38	15.76
July		
August		
September		
October		
November		
December		
YEARLY TOTAL		

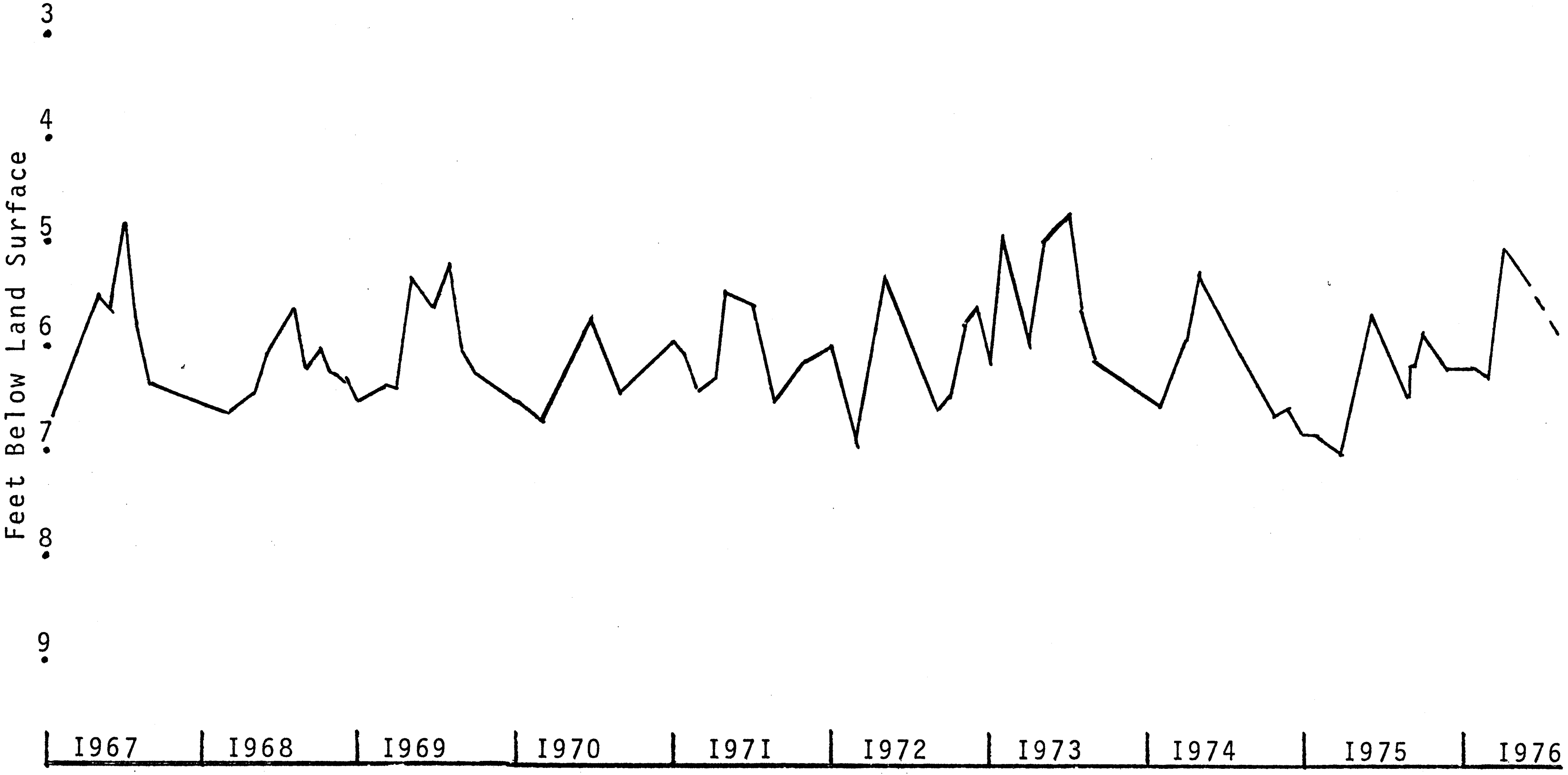
APPENDIX C. U.S. - Geological Survey Groundwater Observations
Wd - 22/6/16-1. City of Wis. Rapids. SE1/4,NW1/4. Driven well in deposits of Pleistocene age, diam 11/4 in, depth 25 ft, cased to 23, well point 23-25.

Measured Biweekly - all plotted



APPENDIX C. U.S. - Geological Survey Groundwater Observations (continued)
Wd - 22/6/I6-I. City of Wis. Rapids. SEI/4,NWI/4. Driven well in deposits of Pleistocene age, diam II/4 in, depth 25 ft, cased to 23, well point 23-25.

Measured Biweekly - all plotted



APPENDIX D. Soil Profile Descriptions

SITE #1

Soil Profile Description

(Description for moist soil)

A_p -- 0-21 cm -- Very dark greyish brown (10YR 3/2) loamy sand; weak, medium, granular structure ; abrupt, smooth boundary.

B_{21} -- 21-48 cm -- Dark brown (7.5YR 5/6) loamy sand, weak, coarse, subangular blocky structure; gradual wavy boundary.

B_{22} -- 48-65 cm -- Strong brown (7.5YR 5/8) sand, weak, medium, subangular blocky structure; clear, wavy boundary.

B_3 -- 65-90 cm -- Yellowish brown (10YR 5/8) sand, very weak, medium, subangular blocky structure; gradual, wavy boundary.

C_1 -- 90-138 cm -- Yellowish brown (10YR 5/4) gravelly coarse sand; many coarse, distinct mottles of yellowish brown (10YR 5/8); single grained; intermittent, very weak, sesquioxidic cementing of individual sand grains; gradual, wavy boundary.

C_2 -- 138-150 cm -- Light yellowish brown (10YR 6/4) sand, many coarse, distinct mottles of yellowish brown (10YR 6/8); single grained.

SITE #2

Soil Profile Description

(Description for moist soil)

A_p -- 0-20 cm -- Very dark greyish brown (10YR 3/2) loamy sand; weak, fine, subangular blocky structure, abrupt, smooth boundary.

B_{21} -- 20-40 cm -- Dark brown (7.5YR 4/4) loamy sand; weak, medium, subangular blocky structure; gradual, wavy boundary.

B_{22} -- 40-76 cm -- Strong brown (7.5YR 5/6) sand; weak, coarse, subangular blocky structure; clear, gradual boundary.

APPENDIX D. (cont)

SITE #2
(cont)

B_3 -- 76-94 cm -- Yellowish brown (10YR 5/6) sand; many coarse, distinct to faint mottles of strong brown (7.5YR 5/8) and yellowish brown (10YR 5/4); single grained; discontinuous, very weakly sesquioxide cemented, breaking to coarse, prism-like fragments; common, coarse, irregular, diffuse, strongly adhesive, nodules with glaebular haloes and few, fine, irregular, rather sharp, weakly adhesive, manganiferrous nodules, clear, wavy boundary.

C_1 -- 94-144 cm -- Light yellowish brown (10YR 6/4) sand; common, medium and coarse, distinct mottles of yellow (10YR 7/6); single grained, gradual, wavy boundary.

C_2 -- 144-150 cm -- Brown (10YR 5/3) sand; common, medium and coarse, distinct mottles of yellowish red (10YR 5/6); single grained.

SITE #3

Soil Profile Description

(Description for moist soil)

A_p -- 0-21 cm -- Dark brown (10YR 3/3) loamy sand; weak, medium, granular structure; abrupt, smooth boundary.

B_{21} -- 21-50 cm -- Strong brown (7.5YR 5/6) sand; weak, medium, subangular blocky structure; clear, wavy boundary.

B_{22} -- 50-83 cm -- Yellowish brown (10YR 5/6) sand; single grained; clear, wavy boundary.

B_3 -- 83-100 cm -- Brownish yellow (10YR 6/6) sand; single grained; clear, wavy boundary.

C_1 -- 100-140 cm -- Light yellowish brown (10YR 6/4) sand; single grained; gradual, wavy boundary.

C_2 -- 140-150 cm -- Yellowish brown (10YR 5/4) sand; single grained.

APPENDIX D. (cont)

SITE #4

Soil Profile Description

(Description for moist soil)

A_p -- 0-21 cm -- Very dark greyish brown (10YR 3/2) loamy sand; weak, coarse, granular structure; abrupt, smooth boundary.

B_{21} -- 21-46 cm -- Dark brown (7.5YR 4/4) sand; weak, coarse, subangular blocky structure; clear, wavy boundary.

B_{22} -- 46-67 cm -- Strong brown (7.5YR 5/6) sand; many medium and coarse, distinct mottles of yellowish red (5YR 5/8); weak, coarse, subangular blocky structure; clear, wavy boundary.

B_3 -- 67-86 cm -- Yellowish brown (10YR 5/6) sand; many coarse, distinct mottles of strong brown (7.5YR 5/8) and yellowish red (5YR 5/8); single grained discontinuous, very weakly sesquioxidic cemented, breaking to coarse, prism-like fragments; common, coarse, irregular and convolate, diffuse, strongly adhesive, sesquioxidic nodules with glaebular haloes; and few fine irregular, rather sharp, weakly adhesive manganiferrous nodules; clear, wavy boundary.

C_1 -- 86-120 cm -- Pale brown (10YR 6/3) sand; many coarse, prominent mottles of strong brown (7.5YR 5/8); single grained; gradual, wavy boundary.

C_2 -- 120-145 cm -- Pale brown (10YR 6/3) sand; many coarse, distinct to prominent mottles of yellowish brown (10YR 5/8) and yellowish red (5YR 5/8); massive; rather continuous, very weakly sesquioxidic and manganiferrous cemented, breaking to medium, prism-like fragments; common, fine to medium, irregular, rather sharp, adhesive manganiferrous nodules, gradual, wavy boundary.

C_3 -- 145-200 cm -- Pale brown (10YR 6/3) sand; common, coarse, distinct mottles of brownish yellow (10YR 6/8); single grained.

APPENDIX D. (cont)

SITE #5

Soil Profile Description

(description for moist soil)

A_p -- 0-21 cm -- Dark brown (10YR 3/3) loamy sand; weak, coarse, granular structure; abrupt, smooth boundary.

B_{21} -- 21-49 cm -- Dark brown (7.5YR 4/4) loamy sand; weak, coarse, subangular blocky structure; clear, wavy boundary.

B_{22} -- 49-100 cm -- Yellowish red (5YR 5/6) sand; many coarse, faint to distinct mottles of yellowish red (5YR 5/8) and red (2.5YR 4/8); single grained; common to many coarse, irregular, diffuse, strongly adhesive to moderately adhesive, manganiferrous and sesquioxidic nodules with glaebular haloes; clear, wavy boundary.

B_3 -- 100-120 cm -- Yellowish brown (10YR 5/6) sand; many coarse prominent mottles of yellowish red (5YR 5/8) and red (2.5YR 4/8); single grained, discontinuous, very weakly, sesquioxidic cemented, breaking to coarse, prism-like fragments; common to many coarse, irregular, diffuse strongly adhesive to moderately adhesive, manganiferrous and sesquioxidic nodules with glaebular haloes; clear, irregular boundary.

C_1 -- 120-150 cm -- Pale brown (10YR 6/3) sand; many coarse, distinct mottles of brownish yellow (10YR 6/8); single grained; clear, irregular boundary.

C_2 -- 150-196 cm -- Brown (10YR 5/3) sand; common, coarse, distinct mottles of yellowish brown (10YR 5/6); massive rather continuous, very weakly, sesquioxidic and manganiferrous cemented, breaking to coarse, prism-like fragments; few, fine, irregular rather diffuse, strongly adhesive, manganiferrous nodules; gradual, wavy boundary.

C_3 -- 196-200 cm -- Brown (10YR 5/3) sand; few to common, coarse, distinct mottles of yellowish red (10YR 5/6); single grained.

APPENDIX D. (cont)

SITE #6

Soil Profile Description
(Description for moist soil)

A_p -- 0-18 cm -- Very dark greyish brown (10YR 3/2) loamy sand; weak, coarse, granular structure; abrupt, smooth boundary.

B_{21} -- 18-40 cm -- Strong brown (7.5YR 4/4) loamy sand; weak, coarse, subangular blocky structure; clear, wavy boundary.

B_{22} -- 40-54 cm -- Yellowish red (5YR 5/6) sand; common, coarse, distinct mottles of red (2.5YR 4/8); weak, coarse, subangular blocky structure; clear, wavy boundary.

B_3 -- 54-65 cm -- Strong brown (7.5YR 5/8) sand; many coarse, distinct mottles of red (2.5YR 4/8) and yellowish red (5YR 5/8); massive; rather continuous, very weakly, sesquioxidic cemented, breaking to medium, prism-like fragments; few, fine to medium irregular, diffuse, moderately adhesive, sesquioxidic nodules with glaebular haloes; clear, irregular boundary.

C_1 -- 65-96 cm -- Yellowish brown (10YR 5/4) sand; common, coarse distinct to prominent mottles of yellowish brown (10YR 5/8) and strong brown (7.5YR 5/8); single grain; clear, irregular boundary.

C_2 -- 96-115 cm -- Yellowish brown (10YR 5/4 and 10YR 5/6) sand; many coarse, prominent mottles of strong brown (7.5YR 5/8); massive; rather continuous, very weakly, sesquioxidic cemented, breaking to coarse, prism-like fragments, common, medium, irregular, diffuse, moderately adhesive, sesquioxidic nodules with glaebular haloes; clear, wavy boundary.

C_3 -- 115-120 cm -- Pale brown (10YR 6/3) sand; common, coarse, distinct mottles of yellowish brown (10YR 5/8); single grained.

APPENDIX D. (cont)

SITE #7

Soil Profile Description

(Description for moist soil)

A_p	--	0-18 cm	--	Dark brown (10YR 3/3) loamy sand; weak, medium, granular structure; abrupt, smooth boundary.
B_{21}	--	18-46 cm	--	Dark yellowish brown (10YR 4/4) loamy sand; weak, medium, subangular blocky structure; clear, wavy boundary.
B_{22}	--	46-72 cm	--	Yellowish red (5YR 5/8) sand; many coarse, distinct mottles of red (2.5YR 4/8); weak, medium, subangular blocky structure; gradual, wavy boundary.
B_3	--	72-105 cm	--	Yellowish brown (10YR 5/6) sand; many coarse, faint to prominent mottles of yellowish brown (10YR 5/8) and red (2.5YR 4/8); single grained; intermittent, very weakly, sesquioxidic cemented, breaking to medium, prism-like fragments, common, medium and coarse, irregular, diffuse, strongly adhesive, sesquioxidic nodules with glaebular haloes and common, fine to medium, irregular, diffuse to rather sharp, weakly adhesive, manganiferrous nodules; diffuse, smooth boundary.
C_1	--	105-152 cm	--	Light yellowish brown (10YR 6/4) sand; many coarse, distinct mottles of yellowish brown (10YR 5/6-8) and strong brown (7.5YR 5/8); single grained; common, fine to medium, irregular, rather sharp, weakly adhesive, manganiferroud nodules; diffuse, wavy boundary.
C_2	--	152-200 cm	--	Brown (10YR 5/3) sand; common, coarse, distinct mottles of brownish yellow (10YR 6/8); massive; rather continuous, very weakly, sesquioxidic and manganiferrous cemented, breaking to coarse, prism-like fragments; common, fine, irregular, rather sharp, weakly adhesive, manganiferrous nodules.

APPENDIX D. (cont)

SITE #8

Soil Profile Description

(Description for moist soil)

A_p -- 0-21 cm -- Very dark greyish brown (10YR 3/2) loamy sand; weak, coarse, granular structure; abrupt, smooth boundary.

B_{21} - 21-51 cm -- Dark brown (7.5YR 4/4) loamy sand; weak, coarse, subangular blocky structure; clear, wavy structure.

B_{22} -- 51-74 cm -- Strong brown (7.5YR 5/8) sand; common, medium, distinct mottles of red (2.5 YR 4/8); weak, coarse, subangular blocky structure; clear, irregular boundary.

B_3 -- 74-107 cm -- Yellowish brown (10YR 5/6) sand; many coarse, prominent mottles of strong brown (7.5YR 5/8) and red (2.5YR 4/8); single grained; discontinuous, very weakly, sesquioxidic cemented, breaking to medium, prism-like fragments; few, coarse, lenticular to irregular, diffuse adhesive, manganiferrous nodules with glaebular haloes; gradual, irregular boundary.

C_1 -- 107-152 cm -- Pale brown (10YR 6/3) sand; common, coarse, prominent mottles of strong brown (7.5YR 5/8); single grained; clear, wavy boundary.

C_2 -- 152-182 cm -- Brown (10YR 5/3) sand; many coarse, distinct mottles of yellowish brown (10YR 5/8); massive; rather continuous, very weakly, sesquioxidic and manganiferrous cemented, breaking to medium and coarse, prism-like fragments; few, fine to medium irregular, rather diffuse, moderately adhesive, manganiferrous nodules; gradual, wavy boundary.

C_3 -- 182-200 cm -- Brown (10YR 5/3) sand; common, coarse, distinct mottles of yellowish brown (10YR 5/6); single grained.

APPENDIX D. (cont)

SITE #9

Soil Profile Description

(Description for moist soils)

A_p -- 0-15 cm -- Dark yellowish brown (10YR 3/4) loamy sand; weak, medium, granular structure; abrupt, smooth boundary.

B_{21} -- 15-52 cm -- Dark brown (7.5YR 4/4) loamy sand; weak, medium, subangular blocky structure; gradual, wavy boundary.

B_{22} -- 52-69 cm -- Strong brown (7.5YR 5/6) sand; weak, coarse, subangular blocky structure; gradual, wavy boundary.

B_3 -- 69-143 cm -- Strong brown (7.5YR 5/8) sand; many coarse, distinct mottles of yellowish red (5YR 5/8) and red (2.5YR 4/8); massive; rather continuous, very weakly, sesquioxidic cemented, breaking to medium and coarse, prism-like fragments; few, fine, irregular, rather sharp, weakly adhesive, manganiferrous nodules; gradual, wavy boundary.

C_1 -- 143-163 cm -- Yellowish brown (10YR 5/4) sand; common, coarse, distinct mottles of yellowish brown (10YR 5/8) and strong brown (7.5YR 5/8); single grained; gradual, wavy boundary.

C_2 -- 163-200 cm -- Pale brown (10YR 6/3) sand; common, coarse, distinct mottles of yellow (10YR 7/6); single grained.

SITE #10

Soil Profile Description

(Description for moist soils)

A_p -- 0-21 cm -- Very dark greyish brown (10YR 3/2) loamy sand; weak, medium, granular structure; abrupt, smooth boundary.

B_{21} -- 21-42 cm -- Dark brown (7.5YR 4/4) loamy sand; weak, coarse, subangular blocky structure; clear, wavy boundary.

APPENDIX D. (cont)

SITE #10
(cont)

B_{22}	42-58 cm	Strong brown (7.5YR 5/6) sand; weak, coarse, subangular blocky structure; clear, wavy boundary.
B_3	58-72 cm	Strong brown (7.5YR 5/8) sand; common, medium, faint mottles of yellowish red (5YR 5/8); very weak, medium, subangular blocky structure; clear, irregular boundary.
C_1	72-119 cm	Yellowish brown (10YR 5/4) sand; many coarse, distinct to prominent mottles of yellowish brown (10YR 5/8) and yellowish red (5YR 5/8); massive; rather continuous, very weakly, sesquioxidic cemented, breaking to coarse, prism-like fragments; common, medium, irregular, very diffuse, strongly adhesive, sesquioxidic nodules with glaebular haloes; few, fine, irregular, rather sharp, weakly adhesive, manganiferrous nodules; gradual wavy boundary.
C_2	119-134 cm	Light yellowish brown (10YR 6/4) sand; many coarse, prominent mottles of strong brown (7.5YR 5/8); single grained; common, fine, irregular, rather sharp, weakly adhesive, manganiferrous nodules; gradual, wavy boundary.
C_3	134-182 cm	Brown (10YR 5/3) sand; many coarse, distinct mottles of yellowish brown (10YR 5/8); massive; rather continuous, very weakly, manganiferrous and sesquioxidic cemented, breaking to medium and coarse, prism-like fragments; common, fine to coarse, irregular, rather sharp, weakly adhesive, manganiferrous nodules; gradual, wavy boundary.
C_4	182-200 cm	Light yellowish brown (10YR 6/4) sand; few, coarse, faint mottles of brownish yellow (10YR 6/8); single grained.

APPENDIX D. (cont)

SITE #11

Soil Profile Description

(Description for moist soil)

A_1 -- 0-9 cm -- Very dark greyish brown (10YR 3/2) loamy sand; weak, coarse, granular structure; abrupt, wavy boundary.

B_{21} -- 9-54 cm -- Reddish brown (5YR 4/4) loamy sand; weak, coarse, subangular blocky structure; gradual, wavy boundary.

B_{22} -- 54-78 cm -- Yellowish red (5YR 5/8) sand; weak, coarse, subangular blocky structure; clear, irregular boundary.

B_3 -- 78-97 cm -- Yellowish brown (10YR 5/6) sand; many coarse, distinct to prominent mottles of strong brown (7.5YR 5/8) and red (2.5 YR 4/8); massive; rather continuous, weakly, sesquioxidic cemented, breaking to coarse, prism-like fragments; clear, wavy boundary.

C_1 -- 97-145 cm -- Yellowish brown (10YR 5/4) sand; many coarse, faint to prominent mottles of yellowish brown (10YR 5/6), strong brown (10YR 5/8) and yellowish red (5YR 5/8); massive; rather continuous, weakly, sesquioxidic cemented, breaking to coarse, prism-like fragments; clear, wavy boundary.

C_2 -- 145-188 cm -- Light yellowish brown (10YR 6/4) sand; common, coarse, distinct mottles of yellowish brown (10YR 5/6); single grained; gradual, wavy boundary.

C_3 -- 188-200 cm -- Yellowish brown (10YR 5/4) sand; common, coarse, faint to distinct mottles of yellowish brown (10YR 5/6) and 10YR 5/8); massive; rather continuous, very weakly, manganiferrous and sesquioxidic cemented, breaking to coarse, prism-like fragments; common, fine, irregular, rather sharp, weakly adhesive, manganiferrous nodules.

APPENDIX D. (cont)

SITE #12

Soil Profile Description

(Description for moist soil)

A_p -- 0-18 cm -- Very dark greyish brown (10YR 3/2) loamy sand; weak, medium, granular structure; abrupt, smooth boundary.

B_{21} -- 18-53 cm -- Yellowish red (5YR 4/6) loamy sand; weak, coarse, subangular blocky structure; clear, wavy boundary.

B_{22} -- 53-81 cm -- Dark brown (7.5YR 5/6) sand; weak, coarse, subangular blocky structure; clear, wavy boundary.

B_3 -- 81-100 cm -- Yellowish brown (10YR 5/8) gravelly sand; very weak, coarse, subangular blocky structure; clear, irregular boundary.

C_1 -- 100-160 cm -- Light yellowish brown (10YR 6/4) sand; many coarse, distinct to prominent mottles of yellowish brown (10YR 5/6) and strong brown (7.5YR 5/6); single grained; gradual, wavy boundary.

C_2 -- 160-200 cm -- Pale brown (10YR 6/3) sand; common, coarse, distinct mottles of yellowish brown (10YR 6/8); single grained.

APPENDIX E. Selected Definitions

Concretion - "Glaebules with a generally concentric fabric about a center which may be a point, a line, or a plane." Brewer, 1976.

Cutan - "A modification of the texture, structure, or fabric at natural surfaces in soil materials due to concentration of particular soil constituents or *in situ* modification of the plasma; cutans can be composed of any of the component substances of the soil material." Brewer, 1976.

Glaebular Haloes - "Weak accumulations of some fraction of the plasma surrounding much stronger glaebular features and having an undifferentiated fabric and very diffuse to diffuse external boundaries." Brewer, 1976.

Glaebule - "A three dimensional unit within the s-matrix of the soil material, and usually approximately prolate to equant in shape, its morphology (especially size, shape, and/or internal fabric) is incompatible with its present occurrence being within a single void in the present soil material. It is recognized as a unit either because of a greater concentration of some constituent and/or a difference in fabric compared with the enclosing soil material, or because it has a distinct boundary with the enclosing soil material." Brewer, 1976.

Mottle - A mixture or variation of soil color. In soils with restricted internal drainage, gray, yellow, red and brown colors are intermingled giving a multi-colored effect.

Nodules - "Glaebules with an undifferentiated internal fabric; in this context undifferentiated fabric includes recognizable rock and soil fabrics." Brewer, 1976.

S-matrix (matrix) - "The soil matrix is the material (plasma and/or skeleton grains and associated voids) within the simplest (primary) peds, or composing apedal soil materials that does not occur as pedological features other than plasma separations; it may be absent in some soil materials, for example, those that consist of entirely of pedological features." Brewer, 1976.

APPENDIX E. (cont)

Soil Fabric - "The physical constitution of a soil material as expressed by the spatial arrangement of the solid particles and associated voids." Brewer, 1976.

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