Spatial attributes of the soil-landscape-groundwater system of the lower Wisconsin River valley : final report. [DNR-088] 1993

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Madison, Wisconsin: Wisconsin Department of Natural Resources, 1993

Spatial Attributes of the Soil-Landscape-Groundwater System of the Lower Wisconsin River Valley

SPATIAL ATTRIBUTES OF THE SOIL-LANDSCAPE-GROUNDWATER SYSTEM OF THE LOWER WISCONSIN RIVER VALLEY

FINAL REPORT

Special thanks to Brian Hess, John Kabrick, and Dong Wang who helped with field work and drilling; to Walter Hall who operated the drill rig; and to Heidi Hampt, who helped with the laboratory work.

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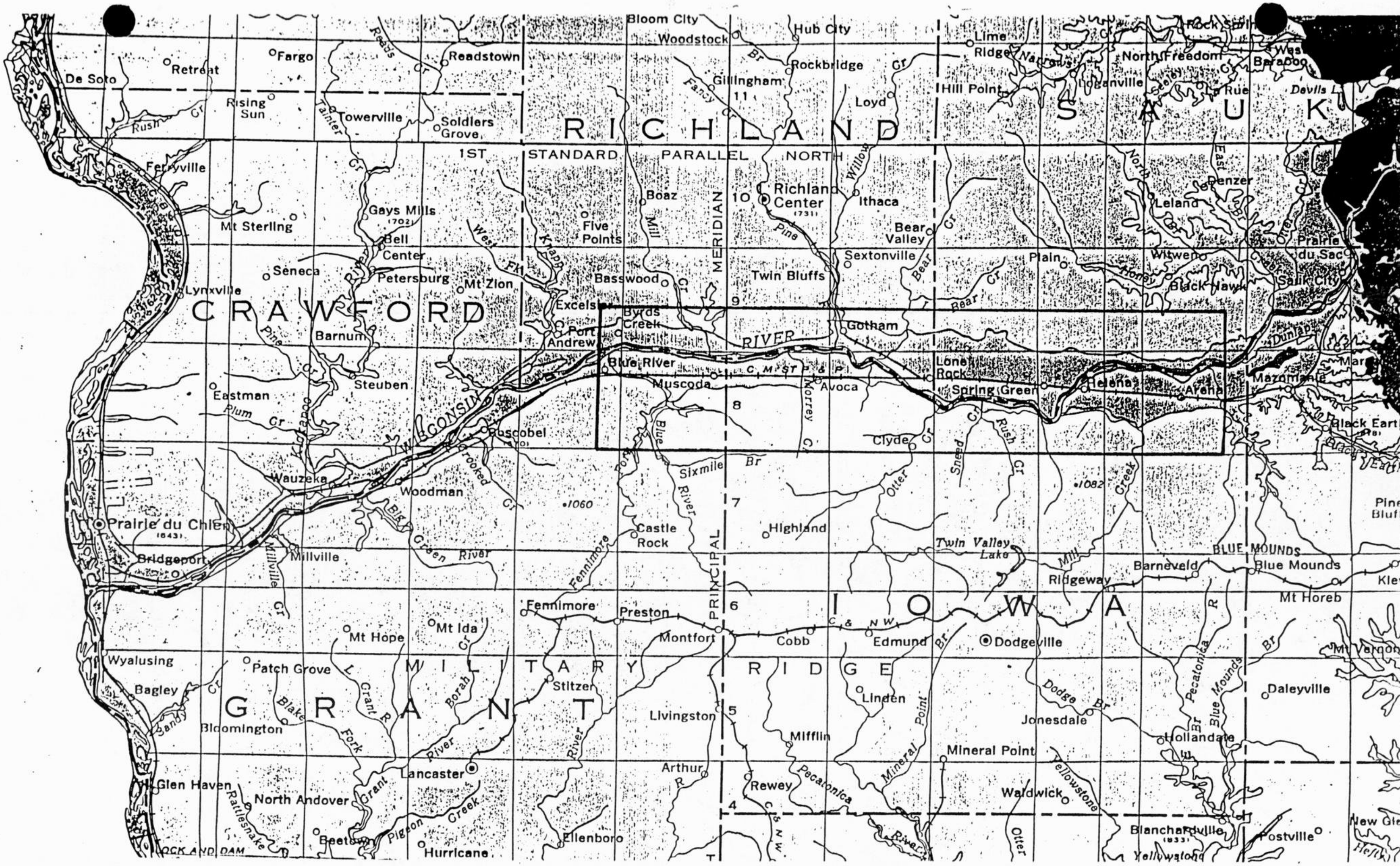
PURPOSE OF INVESTIGATION

This study was conducted to determine if differences in the stratigraphy exist which effect waterflow through the sediments found on the lower terraces of the Wisconsin River. This area of late has been the scene of groundwater contamination by agrichemicals. The goal is to locate sites which appear to be more or less susceptible to groundwater contamination. This data can then be used at some future time to predict where groundwater contamination will occur or to devise land use schemes that will prevent its development.

To this goal the following projects were initated. Geomorphic and soils layers were developed for the study area to be used in a Geographic Information System at the Wisconsin Natural History and Geological Survey. Well logs were analyzed and saturated conductivity calculated from information included in the well logs. Drilling was conducted on each of the terrace surfaces to obtain samples of the sediments for analysis. Trenching of an area of patterned ground and an area of surface silt deposits was undertaken. Data on water well contamination in the study area were consulted. Samples from soils representative of the various landforms and terraces in the Lower Wisconsin River Valley (LWRV) were collected and analyzed. The majority of this report is devoted to the results of the analysis. Following the results of the analysis, is a discussion of the significance of the results and the conclusions, which can be drawn from them.

On the following page is a map (Map 1) showing the location of the study area in the LWRV. The study area streches from Arena to Blue River, Wisconsin. The geomorphic and soils coverage also include parts of Dane County. Three of the drilling sites are also located in Dane County. The information gleaned from upstream locations in Dane County proved insightful into processes which were occurring downstream.



Map 1: Location map of the study area in the Lower Wisconsin River Valley

STRATIGRAPHY

Initially, well logs for the valley were analyzed in an attempt to obtain an idea of what the stratigraphy of the sediments in the valley were like. We then hoped to use these data to plan where to drill. This procedure however was plagued with technical and ligistical problems. We were not able to drill the first year of the project, since the new drill rig arrived too late in the season. We were also limited as to the depth to which we could drill, since sand tends to collapse in the drill hole binding the drill. The maximum depth we reached was 85 feet, which was not deep enough to penetrate through the late Pleistocene terrace sediments. Sediments in the valley can be over 300 feet thick. During the waning of the Pleistocene, a high energy depositional environment prevailed in the LWRV, thus high variability would be expected in the sediments. This proved to be the case, to the extent that even when we drilled near previously drilled sites there was little resemblence in the stratigraphy. This was especially apparent when we attempted to locate organic layers.

On the following page is a map (Map 2) showing the location of the drilling sites and delineating the various terrace surfaces. Nine sites were drilled in all. Analysis of the particle size distribution of the drilling samples indicated the presence of four different terrace deposits. Site 1 is the late Pleistocene low terrace; sites 2, 3, 4, and 5, the late Pleistocene high terrace; site 6, the Holocene terrace; and sites 7, 8, and 9 are late Pleistocene intermediate terrace sediments. Map 2 does not show the areal extent of the Holocene terrace, since it was impossible to map it using aerial photography. (See section 'Digital Data' for a further discussion of this problem.) Included in 'Appendix 1' are graphs of the particle size distribution of sites 1, 2, 6, and 8, which are representative of each of the four terrace deposits. Also included in 'Appendix 1' are dry and moist color, effervescence, and pH data for the four representative sites. Discussions of the four terrace deposits follow.

The late Pleistocene high terrace has a perponderence of 500-250 micron sand size particles, which increase near the surface of the deposit. The next most prevalent sand size is the 1000-500 micron size. A few pebbles are found in the lower part of the profile at approximately 60 to 70 feet. Patterned ground is common on this surface indicating a late Pleistocene age. The original alluviation of the valley occurred about 15,000 years ago (Clayton and Attig, 1990) so the terrace sufaces in this part of the valley are no older than the late Pleistocene.

The late Pleistocene intermediate terrace has a finer texture in the upper 30 feet of the profile, with 250-106 micron size sand the dominant size. Contrary to particle size trends on the high terrace, the 500-250 micron size sand falls off approaching the surface of the sediments. Gravel is a major component of the terrace sediments between 30 and 50 feet, although this is not clear from looking at the graphs. Since we were augering the deposits, if the gravel was very large it was not brought up on the auger flights. It was possible to tell by the sound and the pressure exerted by the drill that we were drilling through gravel. Patterned ground is also found on this surface, indicating a late Pleistocene age for the sediments.

The late Pleistocene low terrace has a prominent gravel layer between 16 and 27 feet. Beneath the gravel layer the sediments are relatively uniform with depth, with the 500-250 microns the dominant sand size. Gravel occurs to a lesser degree down to 58 feet. Once again the presence of patterned ground indicates a late Pleistocene age.

The Holocene terrace exhibits a perponderence of 500-250 micron size sand throughout most of the profile. A gravel layer occurs at 40 to 43 feet. These terrace sediments are characterized by a large variation in sand size with depth. The pH is also interesting at this site, since the pH tends to be higher than for the other three terrace deposits, especially in the upper part of the profile. This phenomina is probably due to less weathering of these sediments, which implies an age somewhere in the Holocene for these sediments. Due to their close proximity to the river the surface of these deposits is probably still recieving alluvial additions when the river floods. Patterned ground does not occur on this suface, which is another indication that these sediments are younger.

Saturated conductivity for sites in the valley was calculated using a computer program devised by Bradbury and Rothschild (1985). This program uses well log data to calculate an average saturated conductivity over the entire thickness of the deposits. Only seven drill holes have penetrated to bedrock in the LWRV so an estimate has to be made as to the thickness of the deposits. In this case, an estimate of 185 feet was used. Near Sauk City bedrock may be as deep as 375 feet, while at Muscoda, bedrock was reached at 160 feet. The value of 185 feet is probably a somewhat conservative estimate. Other parameters for the program were taken from tests done at the time the wells were drilled. For many, if not most, of the well logs information was incomplete or nonexistant, so they could not be used. Listed in 'Appendix 1' are the location and saturated conductivity for the wells for which there was complete data.

SPARTA: A SOIL FOR ALL TERRACES

The Sparta series soils occur on all the terrace surfaces, with perhaps the exception of the Holocene terrace, whose areal extent is unknown. Since all the terraces are approximately the same age, clay minerals, iron minerals, and lithologies of the soils should be quite similar. Thus a study of Sparta soil characteristics should be applicable to the majority of the sandy soils in the valley.

Located in 'Appendix 2' under low terrace soil profile, is a profile description for a Sparta soil (mesic, uncoated Typic Quartzipsamment), (Seybold, 1992). Low silt and clay contents are typical for soils on the late Pleistocene terraces of the LWRV. The soils also tend to be acidic throughout the profile. Most of the soils on the terraces are well-drained; although they do exhibit some mottling in the lower horizons. Another common feature is banding in the C horizon, due to an accumulation of iron.

On the following page (Fig. 1) is the x-ray diffraction pattern from the Bw2 horizon. Chlorite is the dominant clay mineral present, goethite and lepidocrosite are the dominant crystalline iron minerals and quartz and feldspar minerals are the major mineral constituents of the soil.

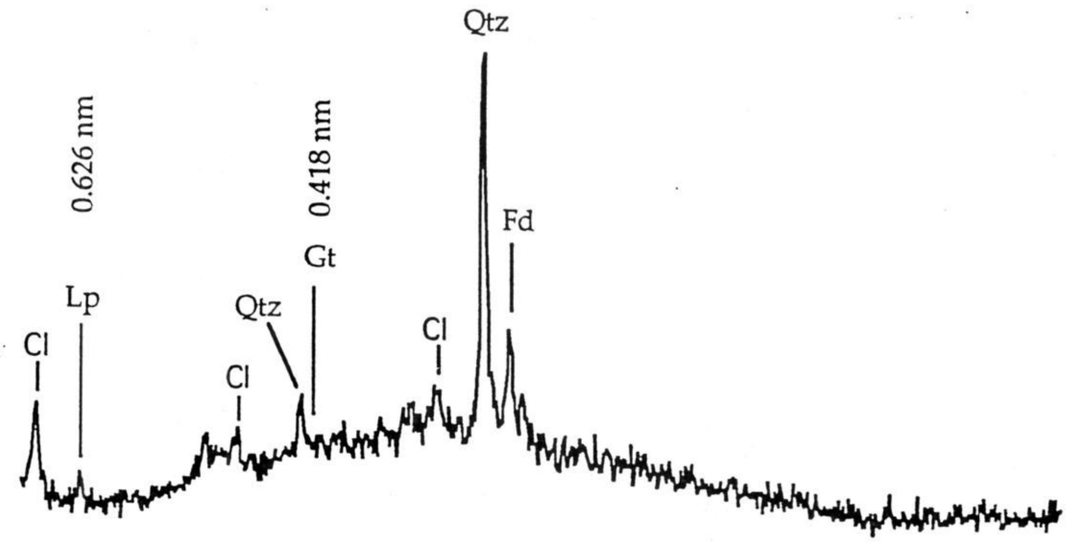


Figure 1: X-ray diffraction pattern of the Bw2 horizon of a Sparta soil
Gt=Geothite, Lp=Lepidocrosite, Qtz=Quartz, Cl=Chlorite, Fd=Feldspar
(Seybold,1992).

Chlorite and hydroxy-interlayered-vermiculite are not individually distinguished in the x-ray diffraction pattern. They make up the majority of the clay minerals present. Small amounts of vermiculite, illite, and smectite are also present. Figure 2 illustrates the type of clay minerals present and their distribution with depth. Vermiculite levels are higher in the surface horizon, which may mean there has been aeolian additions; while smectite is present throughout the profile and was probably inhereted from the parent material, (Seybold, 1992).

The table (Fig. 3) at the end of this section shows the distribution of extractable Mn, Fe, Al, and Si with dithionite, acid oxalate, and Na-pyrophosphate. Dithionite extractable Fe includes iron in crystalline and amorphous oxides and that complexed with organic matter. Trends show an increase at the surface, which drops off in the lower horizons. Crystalline iron oxides reach a maximum in the B horizon, with lepidocrosite and geothite the major species present, (Seybold, 1992).

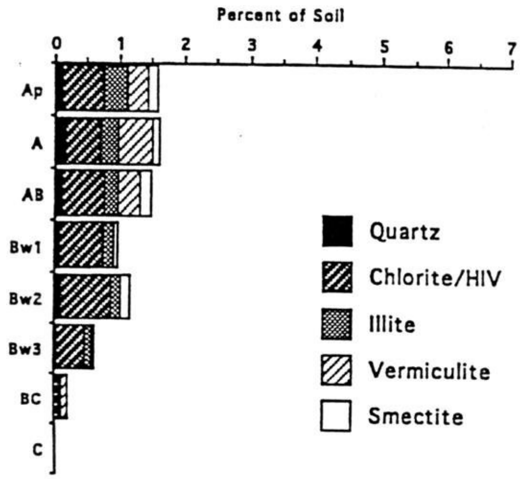


Figure2: Type of clay mineral and their distribution with depth, (Seybold, 1992)

The mineralogy of the light mineral fraction with a density of less than 2.74 makes up at least ninty-five percent of the nonclay fraction and consists mostly of quartz and feldspar. The maximum feldspar content is about 5 % and occurs in the lower horizons Micas and chlorites make up the medium-density mineral fraction (2.74-2.96), which is less than one percent of the nonclay fraction. The heavy mineral fraction (density > 2.96), which is less than 1.25 % of the nonclay fraction, includes hornblende, magnetite, garnet, hematite, zircon, blende, and tourmaline, (Seybold, 1992).

	Depth	Mn_d	Mn_o	Mn_p	Fe_d	Fe_o	Fe_p	Al_d	Al_o	Al_p	Si_o	Fe_d-Fe_o	Fe_o-Fe_p	Al_o-Al_p	$Si_o/(Al_o-Al_p)$
	cm	<-------------------						g Kg^{-1}						------------------->	
Ap	0-23	0.13	0.13	0	1.78	0.80	0.22	0.48	0.85	0.42	0.21	0.98	0.58	0.43	0.50
A	23-33	0.13	0.13	0	1.93	0.86	0.45	0.70	1.08	0.78	0.16	1.07	0.41	0.30	0.53
AB	33-43	0.09	0.12	0	1.68	0.78	0.43	0.58	1.12	0.78	0.15	0.89	0.35	0.34	0.45
Bw1	43-54	0.10	0.10	0	1.80	0.82	0.47	0.66	1.20	0.80	0.21	0.99	0.35	0.41	0.51
Bw2	54-66	0.04	0.07	0	1.88	0.80	0.43	0.77	1.57	0.89	0.49	1.08	0.38	0.69	0.71
Bw3	66-84	0.02	0.02	0	0.82	0.34	0.13	0.51	1.23	0.58	0.37	0.49	0.20	0.64	0.57
BC	84-135	0.01	0.01	0	0.52	0.23	0.03	0.22	0.70	0.26	0.24	0.30	0.20	0.44	0.54
C	135-160	0.03	0.03	0	0.56	0.22	0.00	0.16	0.48	0.16	0.16	0.34	0.21	0.33	0.49

† **Mn_d, Fe_d, Al_d** = Dithionite extractable Mn, Fe and Al; **Mn_o, Fe_o, Al_o, Si_o** = Oxalate extractable Mn, Fe, Al, and Si; **Mn_p, Fe_p, Al_p** = Na-pyrophosphate extractable Mn, Fe, and Al

Figure 3: Distribution of extractable Mn, Fe, Al, and Si with dithionite, acid oxalate, and Na-pyrophosphate, (Seybold,1992)

OTHER TERRACE SOILS

Included in 'Appendix 2' are profile descriptions for soils occurring on the major landforms and terraces in the LWRV. The profile descriptions are choosen to be representative of each particular landform or terrace; however other soils also occur on these surfaces in most cases. Profile descriptions are included for the sand dunes, patterned ground (both wedge and polygon), the late Pleistocene high terrace, the late Pleistocene intermediate terrace, the late Pleistocene low terrace, and the Holocene terrace.

Sand dune soils

Soils of the sand dunes have textures dominated by sand. Silt and clay accumulations in the A horizon are probably due to aeolian additions. This particular profile probably has a higher organic matter content than is average for the sand dune soils, however the amount of organic matter will vary with position of the soil on the dune. The greatest amount of organic matter will probably be found in soils formed at the base of the dune, while the least amount will be on the eroding side slopes. Soil development, while still greatest at the base of the dune, is least at the crest of the dune. These soils are acidic, especially at depth in the profile.

Patterned ground soils

Patterned ground is the result of permafrost conditions prevalent during the late Pleistocene in the LWRV and occurs on all three late Pleistocene terrace surfaces. Profile descriptions are included for polygons and ice wedge casts between the polygons. The water table is located at about 80 cm, although it fluctuates throughout the year. Colors, especially those of the wedge soils, indicate frequent water logged conditions. The texture of the soils is dominated by sand. Both soils are acidic with depth. The wedge soils are more acidic than the polygon soils. This is probably due to the presence of peat bogs in the past, located in the depressions between the polygons, which were highly acidic. Organic matter occurs in higher concentrations and to greater depths in the wedge soils. These soils have some of the highest concentrations of organic matter of any of the soils in the valley.

Late Pleistocene high terrace soils

Colors of this soil indicate well drained conditions. Although the texture is still dominated by sand, this soil shows an increase in the silt fraction to a depth of 73 cm. Clay also shows a slight increase. The amount of silt and clay present in these soils is variable with location. Considering that the LWRV is a sand dominated system, these soils are significant for the amount of silt and clay they contain. The pH of these soils is not as acidic as the soils mentioned above.

Late Pleistocene intermediate terrace soils

Large parts of this terrace surface are covered with sandy textured soils; however in some locations a mantle of silt covers the terrace surface. This mantle may be up to two meters in thickness, but in most locations it is less than one meter in thickness. These silt deposits are exclusive to this terrace. Outwash sands underlie the silt deposits. In a pit, located in an old channel near Spring Green, analysis of the silt deposits showed that the deposit was made up of two separate silt deposits. Shown below is a graph of the silt size fraction of this deposit, (Fig. 4). The upper silt deposit has a finer texture than the lower silt deposit.

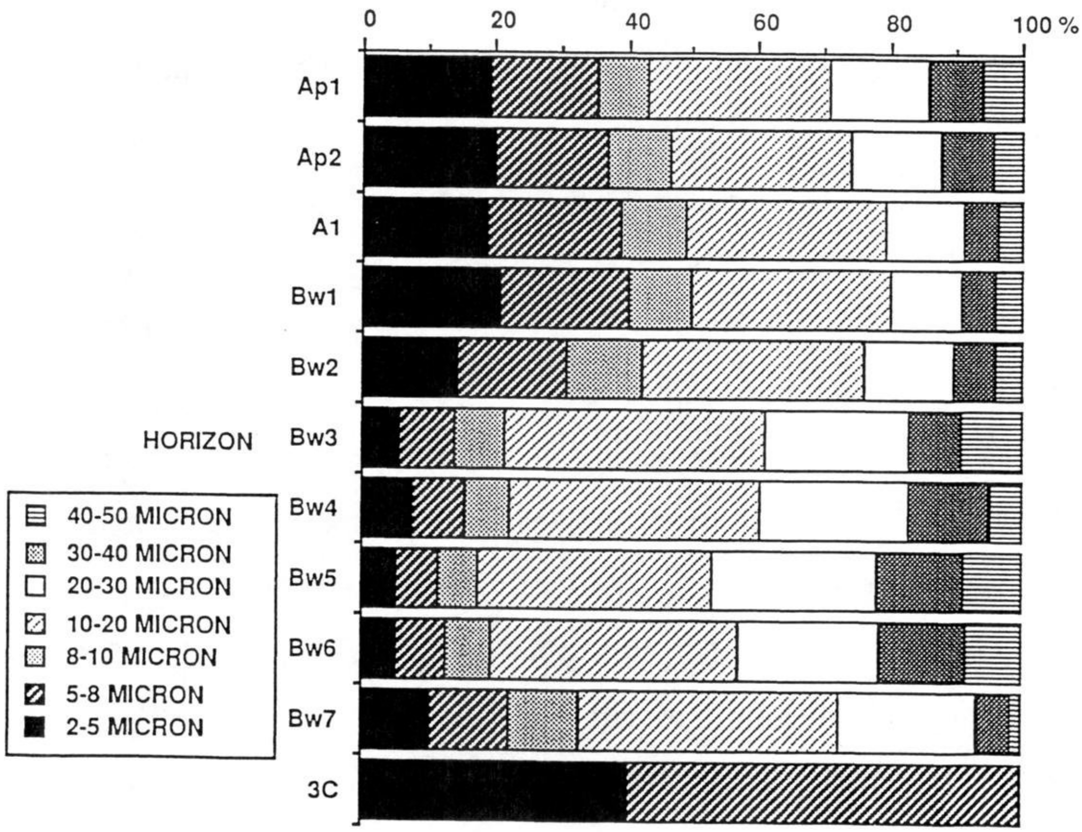


Figure 4: Silt size fractions of the pit deposits

The mottling present in the lower horizons of the soil indicates frequent periods of saturation. At certain times of the year the water table is located within the soil profile. The texture of the soil is dominated by the silt fraction, however the clay fraction also makes up a significant fraction. The upper silt deposits contain significant amounts of organic matter over that of the lower pit deposits. Both deposits are acidic in nature. The low position of the deposits on the landscape has promoted colluviation from higher landscape positions. Due to this addition of sediments over time, one or more buried Ap horizons have formed. Plow pans associated with the Ap horizons appear to constrict drainage in some cases.

Late Pleistocene low terrace soils

The Sparta soil series is the dominant soil of this terrace, but it is also common on the intermediate and high terraces. This soil is described in detail in the previous section. These soils are sandy in texture, acidic, and have relatively low amounts of organic matter. Some fluctuations in the water table probably occur, as evidenced by mottling in the lower horizons.

Holocene terrace soils

Colors of these soils indicate an oxydizing environment. The soils are redder in color than most of the soils in the valley. The other major difference in these soils is the lack of weathering of the soil profile as evidenced by the relatively high pH values. Sand still makes up the major textural component, although silt and clay fractions are higher in the upper horizons than most of the sandy textured soils in the valley. The increases in silt and clay are probably due to additions by frequent flooding. The terrace surface is located about 8 feet above the river.

DIGITAL DATA

Soil and geomorphic digital data were developed for the LWRV. The digital data for both the soil and geomorphic layers were processed using pc ARC/INFO-34d. Digitizing was carried out on an Altek digitizing table. Source material for the soil layer was supplied by the Soil Conservation Service (SCS). The original SCS mylar sheets were used as the base map; with the exception of Iowa County, where a published soil survey served as the base map. For a more detailed explanation of the steps involved in the development of the soil data consult 'Appendix 3'.

The geomorphic layer was developed using aerial photography of the LWRV to map the terrace surface. Information was transferred to 7.5 minute topographic maps and digitized. Areas of sand dunes and patterned ground were not included in the geomorphic layer, due to difficulties in establishing their exact boundaries. The boundaries of the sand dunes vary depending on the year the air photos were taken, since in drier years the dunes tend to migrate if not stabilized by vegetation. The location of the patterned ground is even more difficult to pinpoint. Only during periods of drought stress, when soil moisture differences are at their most extreme, do the differences show up between polygons and wedges. Thus, it is fortuitous if aerial photography is taken at the exact time when conditions are ideal. Patterned ground has been identified as far west as Lone Rock, but its westward extent may be even greater. The Holocene terrace also presented a problem. It probably occurs as small isolated remnants along the river throughout the study area. The scarp between the low and Holocene terraces is only about two feet high making it difficult to map using aerial photography. It would be neccessary to map the terrace in the field which was not feasible, so this terrace was not included in the geomorphic layer.

Eight surfaces are identified in the geomorphic coverage of the valley. They are listed below with the symbols used to identify each surface.

UL - Uplands

UWT - Upper Wisconsin Terrace (Late Pleistocene high terrace)

IWT - Intermediate Wisconsin Terrace (Late Pleistocene intermediate terrace)

LWT - Lower Wisconsin Terrace (Late Pleistocene low terrace)

BRPT - Bridgeport Terrace

KD - Kame Delta

TAT - Tributary Alluvial Terrace

TAF - Tributary Alluvial Floodplain

WRFP - Wisconsin River Floodplain

DISCUSSION AND CONCLUSIONS

As mentioned previously, the high, intermediate, and low terraces are all late Pleistocene in age due to the permafrost polygons formed in their surfaces. Conditions were only favorable for patterned ground formation during the late Pleistocene. Each of the terraces is associated with an erosional-depositional event. Several moraines associated with the retreat of the Green Bay Lobe probably correspond to these terraces. Due to the dissection and erosion of the terrace surfaces, these terraces can not easily be traced back to the moraine they are time-stratigraphically associated with. Because the dominant sand sizes are very similar, for the high terrace 500-250 microns and for the intermediate terrace 250-106 microns; the gradients are similar, 1.50 ft/mi for the high terrace and 1.375 ft/mi for the intermediate terrace; and the terraces are close together in elevation, separated by only a few feet; it is imposible to tell them apart in the field or on a topographic map. Only by drilling or where the silt cap overlies the intermediate terrace can these two terraces be separated.

All of the terraces described above are probably within 1000-1500 years in age of each other. Except for the small area of silty soils found on the intermediate terrace, the soils are very similar on all three terrace surfaces. This is to be expected since they are all relatively the same age. This similarity in age creates a problem, comparisons of soil properties with respect to differences in development over time between terraces is not possible. Another problem is that sandy textured soils do not preserve differences in development well.

A river choked with outwash generally flows as a braided stream. Due to the high energy depositional environment formation of sand and gravel bars can occur in near proximity to each other as the velocity if the water changes in individual streams. The sediments deposited in these cases are highly variable and can change in composition over very short distances. This holds true for the Wisconsin River. This factor makes it possible to make only general statements about the stratigraphy of the three terrace deposits and for all practical purposes stratigraphically they can all be treated as one unit at least the top 85 feet. The Holocene terrace sediments deposited under flood conditions are also subject to high variability. Thus, for the remainder of the report all for terrace deposits will be treated as a single unit.

Saturated conductivity of the sediments does not follow any set pattern. Saturated conductivity values tend to be higher near the river, but there are several exceptions. Concentrations of gravels somewhere in the stratigraphy may be the source of isolated higher values. More values are needed to obtain a better understanding of the saturated conductivity of the valley sediments. Comparison with well contamination data shows that in the majority of cases the wells where K_{sat} was calculated are not the wells which have been tested for contamination, thus no conclusions can be drawn.

The factor that probably has the most effect on whether or not groundwater contamination will occur is the texture of the surficial deposits and the amount of organic matter in the soils. The silt deposits of the intermediate terrace, with their high silt and clay contents, are probably quite effective in preventing contaminants from reaching the groundwater especially in the thick deposits. Their ability to prevent groundwater contamination will vary with thickness of the deposits. Deltas extend from many of the tributary valleys onto the terrace surfaces. These deltaic sediments are predominately composed of silt and clay and in some cases exceed in thickness the intermediate terrace silt deposits which came from upstream. Even soils low in silt and clay can lower the potential of groundwater pollution if they contain an appreciable amount of organic matter. Organic matter is even better at attenuating pesticides than clay. The patterned ground soils are examples of soils with high organic mater contents and low silt and clay contents. These soils with or without the presence of patterned ground occur in low spots on the terrace surfaces.

In summation, the stratigraphy of the sediments of the lower terraces of the LWRV are highly variable. There does not appear to be any significant differences between each individual terrace deposit that would effect groundwater flow, so the deposits can all be treated as one unit. The silt and clay rich surficial deposits or soils high in organic matter are probably more significant in predicting suseptibility of a site to groundwater contamination.

REFERENCES

Bradbury, K. R., and Rothschild, E. R.; 1985, A computerized technique for estimating the hydraulic conductivity of aquifers from specific capacity data, Groundwater 23(2):240-246.

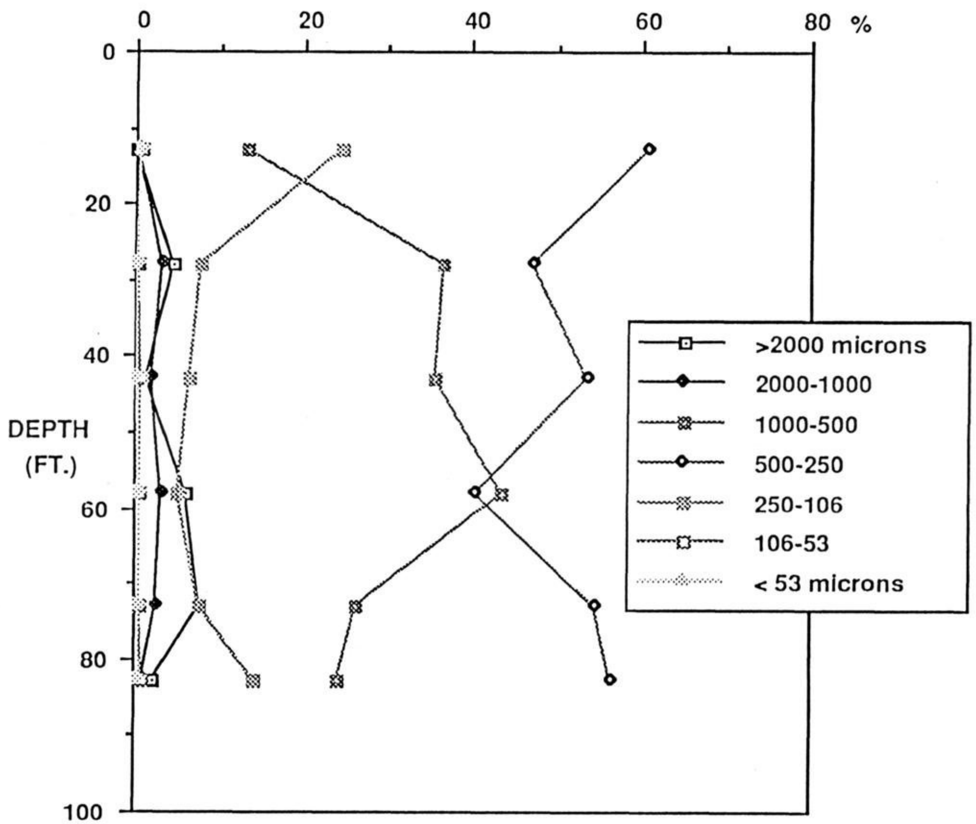
Clayton, Lee, and Attig, J. W.; 1990, Geology of Sauk County, Wisconsin, Wisconsin Geological and Natural History Survey, Information Circular 67, 68 p.

Seybold, C. A.; 1992, Characterization of sandy soils from Wisconsin: relation to atrazine adsorption and pedogenesis, Doctorial Dissertation University of Wisconsin-Madison, Madison, Wisconsin, 189 p.

APPENDIX 1

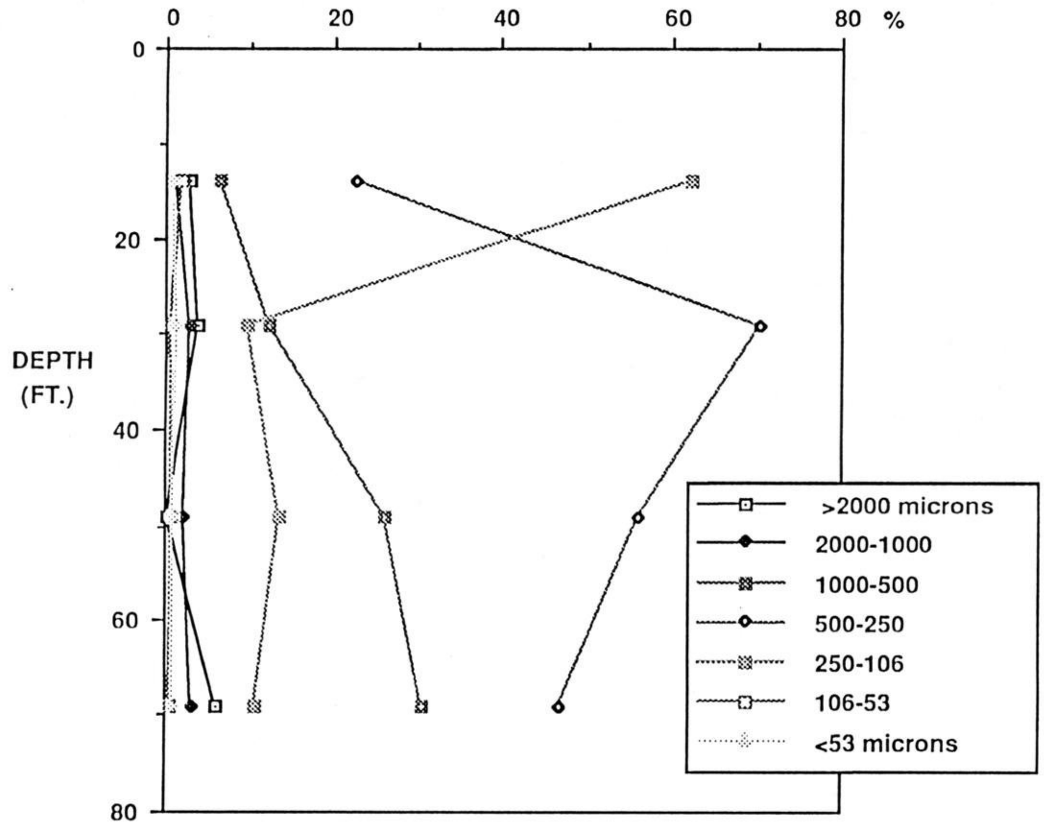
LATE PLEISTOCENE HIGH TERRACE

SAND SIZE FRACTIONS HOLE 2



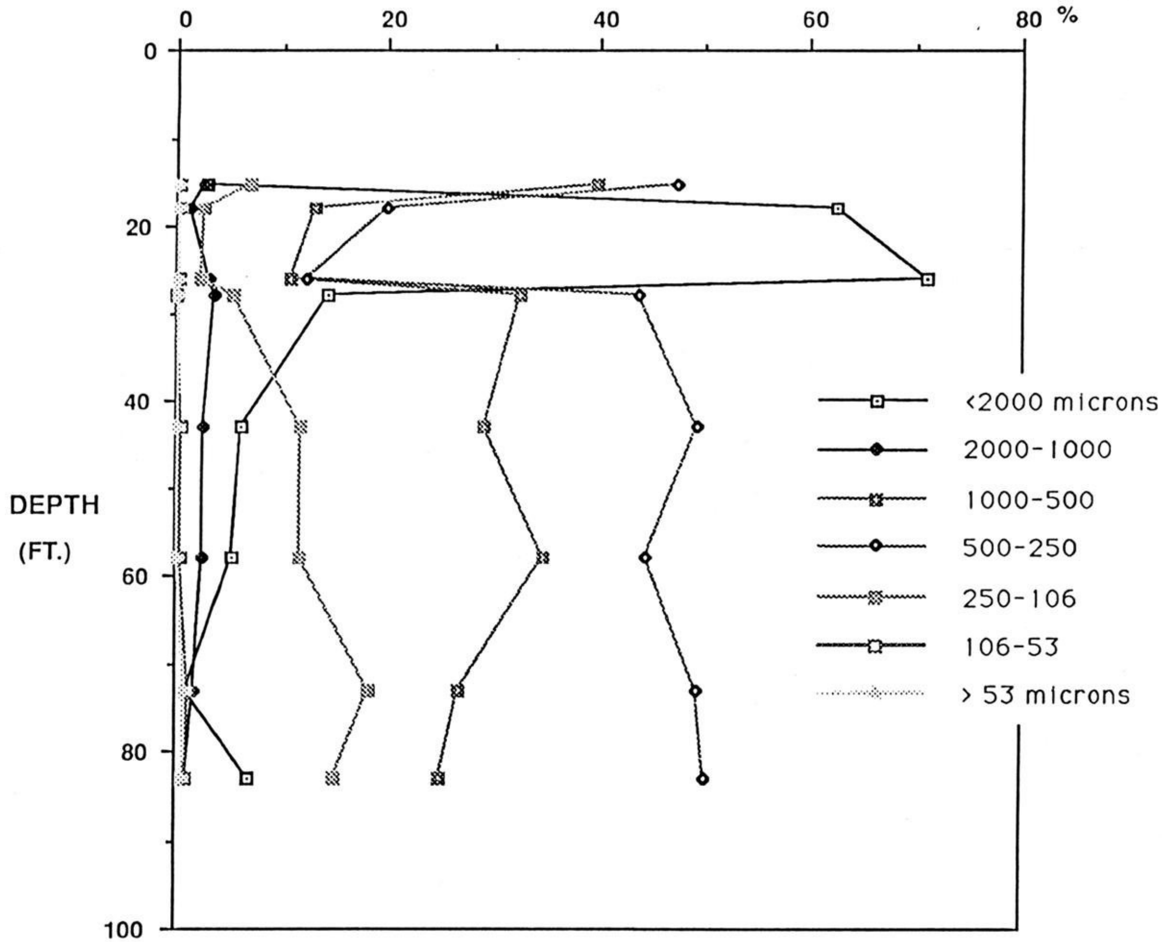
LATE PLEISTOCENE INTERMEDIATE TERRACE

SAND SIZE FRACTIONS HOLE 8



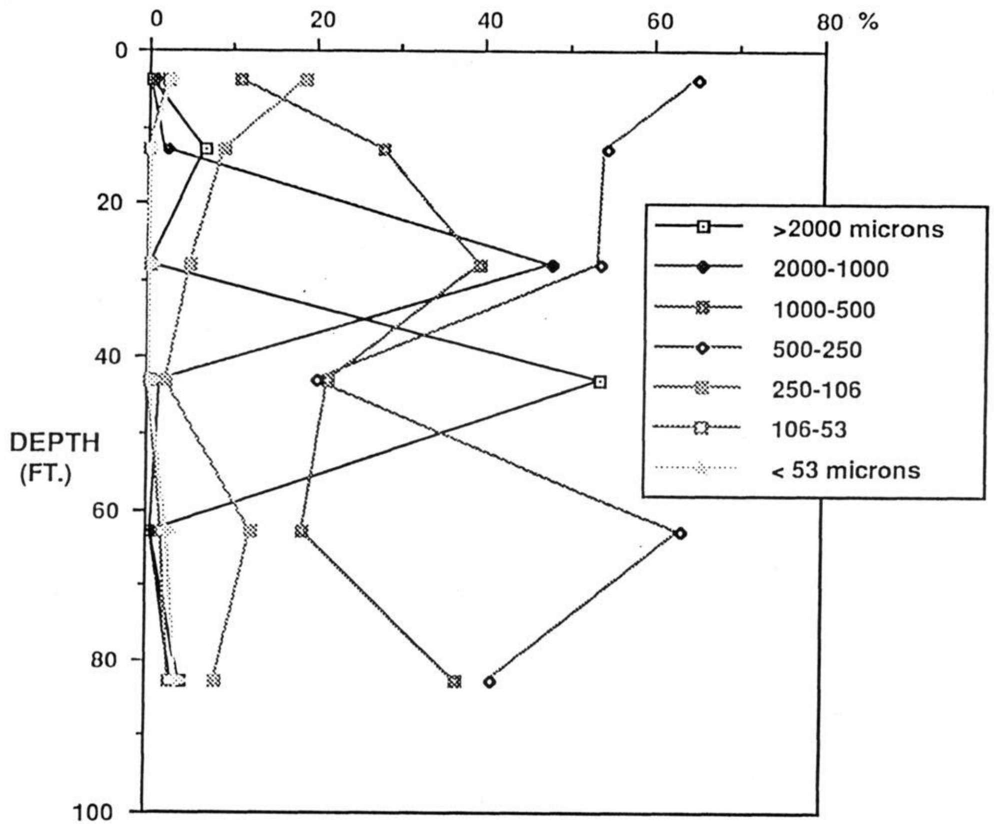
LATE PLEISTOCENE LOW TERRACE

SAND SIZE FRACTIONS HOLE 1



HOLOCENE TERRACE

SAND SIZE FRACTIONS HOLE 6



Dry and Moist Colors, Effervescence, and pH of the Four Terrace deposits

High Terrace

Depth	Dry Color	Moist Color	Effervescence	pH
15 feet	10YR 6/4	10YR 4/3	none	7.64
30 feet	10YR 6/4	10YR 4/4	slight	7.81
45 feet	10YR 7/3	10YR 5/3	slight	7.96
60 feet	10YR 7/3	10YR 5/4	strong	8.68
75 feet	10YR 7/3	10YR 5/3	strong	8.91
85 feet	10YR 6/3	10YR 4/3	strong	8.95

Intermediate Terrace

Depth	Dry Color	Moist Color	Effervescence	pH
14 feet	10YR 6/4	10YR 4/4	none	6.31
29 feet	10YR 6/3	10YR 4/4	slight	7.96
49 feet	10YR 6/4	10YR 5/4	strong	8.29
69 feet	10YR 6/4	10YR 4/4	slight	8.55

Low Terrace

Depth	Dry Color	Moist Color	Effervescence	pH
15 feet	7.5YR 6/4	7.5YR 5/4	none	6.01
17 feet	10YR 6/4	10YR 4/4	slight	6.77
26 feet	10YR 5/4	10YR 3/4	slight	7.33
28 feet	10YR 7/4	10YR 4/4	slight	7.01
43 feet	10YR 7/3	10YR 5/4	strong	7.50
58 feet	10YR 7/3	10YR 5/4	strong	7.77
73 feet	10YR 7/3	10YR 4/3	violent	8.15
83 feet	10YR 7/3	10YR 4/3	strong	8.20

Holocene Terrace

Depth	Dry Color	Moist Color	Effervescence	pH
13 feet	7.5YR 6/6	7.5YR 4/4	none	8.35
28 feet	10YR 7/3	10YR 4/4	none	8.40
43 feet	10YR 6/4	10YR 4/3	slight	8.52
63 feet	10YR 7/3	10YR 4/3	strong	8.75
83 feet	10YR 7/3	10YR 4/4	slight	9.06

Saturated Conductivity Based on Well Log Data

Dane County

Location	Saturated Conductivity
NW1/4, NE1/4, SW1/4, Sec 7, T9N, R7E	0.8815E-04
SW1/4, SW1/4, SE1/4, Sec 7, T8N, R6E	0.2651E-01
NE1/4, SE1/4, NE1/4, Sec 18, T8N, R6E	0.1494E-02
C, SE1/4, NE1/4, Sec 8, T8N, R6E	0.3072E-03
C, S1/2, Sec 28, T9N, R6E	0.6525E-03
SW1/4, NE1/4,Sec. 4, T8N, R6E	0.4977E-03

Sauk County

C, SE1/4, SW1/4, Sec 3, T8N, R3E	0.2772E-03
C, SW1/4, NE1/4, Sec 32, T9N, R3E	0.2604E-03
C, SW1/4, Sec 32, T9N, R3E	0.3065E-03
W of C, SW1/4, Sec 33, T9N, R3E	0.2867E-03
C, NE1/4, Sec 11, T8N, R3E	0.3460E-03
C, SE1/4, Sec 34, T9N, R3E	0.3752E-03
C, SE1/4, Sec 3, T8N, R3E	0.3753E-03
C, NW1/4, Sec 1, T8N, R3E	0.4216E-03
C, E1/2, Sec.18, T8N, R4E	0.3725E-03
NW1/4, SE1/4, SE1/4, Sec 12, T8N, R3E	0.3384E-02
NW1/4, SW1/4, Sec 6, T8N, R3E	0.9704E-03
SE1/4, NW1/4, Sec 6, T8N, R3E	0.8354E-03
SE1/4, NW1/4, Sec 5, T8N, R3E	0.7872E-03
SW1/4, NW1/4, Sec 32, T9N, R3E	0.8354E-03
C, NE1/4, Sec 3, T9N, R6E	0.1269E-03
C, NE1/4, NW1/4, Sec 9, T9N, R6E	0.1560E-03
W of C, N1/2, Sec 26, T10N, R6E	0.2933E-03
C, S1/2, Sec 5, T9N, R6E	0.2285E-03
C, S1/2, Sec 9, T9N, R6E	0.1208E-02
C, NE1/4, Sec 34, T10N, R6E	0.5385E-03
SW1/4, SE1/4, Sec 35, T9N, R3E	0.8147E-03
C, SW1/4, Sec 2, T8N, R3E	0.4012E-03
NW1/4, SE1/4, Sec 10, T8N, R3E	0.2269E-03
NW1/4, NW1/4, Sec 36, T10N, R6E	0.6112E-03
C, NW1/4, Sec 1, T9N, R6E	0.9841E-03

Iowa County

NE1/4, SE1/4, Sec 16, T8N, R4E	0.3113E-02
E1/2, NW1/4, NW1/4, Sec 14, T8N, R4E	0.3995E-03
C, NW1/4, Sec 20, T8N, R5E	0.6097E-03
NE1/4, NE1/4, Sec 13, T8N, R5E	0.3093E-03
W1/2, SE1/4, NW1/4, Sec 12, T8N, R4E	0.3883E-03
NW1/4, Sec 13, T8N, R4E	0.2424E-02
NW1/4, NE1/4, Sec 25, T8N, R4E	0.1217E-01
SE1/4, SW1/4, Sec 10, T8N, R4E	0.3052E-02
SW1/4, NW1/4, Sec 15, T8N, R4E	0.2538E-02
S1/2, NE1/4, SE1/4, Sec 19, T8N, R5E	0.1109E-02

Richland County

SE1/4, NW1/4, Sec 29, T9N, R2E	0.6511E-03
C, SE1/4, Sec 29, T9N, R2E	0.5372E-03
C, SW1/4, Sec 1, T8N, R2E	0.8424E-03
NW1/4, NW1/4, Sec 3, T8N, R2E	0.3430E-02
C, NW1/4, Sec 36, T9N, R2E	0.6971E-03
SW1/4, NW1/4, Sec 34, T9N, R2E	0.3693E-03
NE1/4, SW1/4, Sec 33, T9N, R2E	0.4053E-04
C, NE1/4, Sec 12, T8N, R2E	0.1383E-02
SE1/4, SW1/4, Sec 34, T9N, R2E	0.9016E-03
NW1/4, NE1/4, Sec 33, T9N, R2E	0.1068E-02

APPENDIX 2

Sand Dune Soil Profile

	Field Properties						Laboratory Properties				
Horizon	Depth	Moist Color	Mottle Color	Structure	Moist Consistence	Boundary	Sand	Silt	Clay	Organic Matter	pH
Ap	0-17 cm	10YR 2/2		gr	vf	cs	92.5%	5.35%	2.15%	1.10%	6.14
A	17-27cm	10YR 2/1		gr	vf	gs	94.5%	4.2%	1.3%	1.46%	5.38
B/A	27-39.5 cm	10YR 2/2		gr	vf	gs	96.5%	2.0%	1.5%	0.72%	4.93
B	39.5-52 cm	10YR 3/2		sg	lo	gs	98.0%	0.85%	1.15%	0.83%	4.94
C	52+ cm	10YR 3/6		sg	lo		98.0%	1.8%	0.2%	0.36%	4.68

gr=granular, sg=single grain, vf=very friable, lo=loose, cs=clear smooth, gs=gradual smooth

Patterned Ground Wedge Soil Profile

	Field Properties						Laboratory Properties				
Horizon	Depth	Moist Color	Mottle Color	Structure	Moist Con- sistence	Boundary	Sand	Silt	Clay	Organic Matter	pH
Ap	0-28 cm	10YR 2/1		sbk->gr	vf	cs	83.14%	10.66%	6.20%	7.49%	5.9
A	28-33 cm	2.5Y 2/0		pl	f	ai	84.54%	10.16%	5.30%	5.69%	5.15
A2	33-55 cm	5YR 2/1		pl	vf	gs	90.26%	5.94%	3.80%	2.43%	4.65
BA	55-74 cm	2.5Y 3/2		sg	lo	gw	94.50%	3.0%	2.50%	0.70%	4.65
B	74+ cm	2.5Y 5/4	5YR 5/8	sg	lo		98.74%	0.26%	1.0%	0.17%	4.85

sbk=subangular blocky, gr=granular, pl=platy, sg=single grain, vf=very friable, f=friable, lo=loose, cs=clear smooth, ai= abrupt irregular, gs=gradual smooth, gw=gradual wavy

Patterned Ground Polygon Soil Profile

Field Properties							Laboratory Properties					
Horizon	Depth	Moist Color	Mottle Color	Structure	Moist Consistence	Boundary	Sand	Silt	Clay	Organic Matter	pH
Ap	0-20 cm	2.5Y 2/0		sbk->gr	vf	cs	82.98%	10.07%	6.95%	5.91%	6.1
A	20-30 cm	5YR 2.5/1		sbk	vf	gs	89.6%	7.05%	3.35%	1.88%	5.8
BA	30-41 cm	10YR 3/3		sg	lo	gs	93.26%	4.07%	2.67%	1.01%	5.4
B	41+ cm	10YR 4/4		sg	lo		96.56%	2.44%	1.00%	0.41%	4.8

sbk=subangular blocky, gr=granular, sg=single grain, vf=very friable, lo=loose, cs=clear smooth, gs=gradual smooth

High Terrace Soil Profile

Field Properties							Laboratory Properties				
Horizon	Depth	Moist Color	Mottle Color	Structure	Moist Consistence	Boundary	Sand	Silt	Clay	Organic Matter	pH
A	0-40 cm	10YR 2/2		sbk->gr	vf	gs	84.5%	9.8%	5.7%	1.24%	6.26
B1	40-53cm	7.5YR 3/2		sbk->gr	vf	gs	80.0%	13.0%	7.0%	0.98%	5.78
B2	53-73 cm	7.5YR 3/4		sbk	vf	cs	81.0%	12.0%	7.0%	0.61%	5.59
B3	73-83 cm	7.5YR 4/6		sbk->sg	lo	gs	97.0%	1.3%	1.7%	0.26%	5.26
C	83+ cm	7.5YR 5/8		sg	lo		99.0%	0.85%	0.15%	0.21%	5.39

sbk=subangular blocky, gr=granular, sg=single grain, vf=very friable, lo=loose, gs=gradual smooth, cs=clear smooth

Intermediate Terrace Soil Profile

	Field Properties						Laboratory Properties				
Horizon	Depth	Moist Color	Mottle Color	Structure	Moist Consistence	Boundary	Sand	Silt	Clay	Organic Matter	pH
Ap	0-20 cm	7.5YR2.5/1		pl->abk	f	as	16.5%	65.0%	18.5%	4.59%	5.17
2Apb	20-34 cm	10YR 2/1		pl->abk	fi	as	14.0%	67.5%	18.5%	4.38%	5.14
2A1	34-48 cm	10YR 2/2	10YR 5/6	sbk->gr	f	cs	11.0%	66.5%	22.5%	4.73%	5.13
2Bw1	48-58 cm	7.5YR3/4		sbk	f	cs	12.0%	64.5%	23.5%	1.44%	4.90
2Bw2	58-86 cm	7.5YR4/4	2.5YR 3/6 N 2.5/	pr->abk	fi	cs	8.0%	62.0%	30.0%	0.70%	4.72
2Bw3	86-97 cm	10YR5/4	N 2.5/ 2.5YR 3/6 2.5YR 5/4	pr->abk	fi	cs	15.0%	60.5%	24.5%	0.34%	4.74
2Bw4	97-128 cm	10YR5/3	N 2.5/ 5YR 4/6 2.5YR 3/6	pr->pl	fi	cs	12.0%	64.0%	24.0%	0.33%	4.85
2Bw5	128-160cm	10YR5/3 10YR 5/4	7.5YR2.5/1 2.5YR 3/6 5YR 4/6	pr->pl	fi	cs	9.0%	68.0%	23.0%	0.13%	4.92
2Bw6	160-175cm	7.5YR 5/3 10YR 5/3	7.5YR2.5/1 7.5YR4/6 5YR 4/6	pr->pl	fi	aw	24.0%	58.0%	18.0%	0.13%	5.15
2Bw7	175-183cm	7.5YR 4/6 7.5YR 5/3 5YR 6/4	5YR 4/6	pl	fi	aw	57.5%	29.0%	13.5%	0.13%	5.28
4C	183+ cm	7.5YR 7/3		sg	lo		98.5%	1.0%	0.5%	0.07%	5.64

pl=platy, abk=angular blocky, sbk=subangular blocky, gr=granular, pr=prismatic, sg=single grain, f=friable, fi=firm, lo=loose, as=abrupt smooth, cs=clear smooth, aw=abrupt wavy

Low Terrace Soil Profile (Sparta Series)

Horizon	Depth	Moist Color	Mottle Color	Structure	Moist Consistence	Boundary	Sand	Silt	Clay	Organic Matter	pH
	Field Properties						Laboratory Properties				
Ap	0-23 cm	10YR 2/2		sbk->gr	vf	as	95.7%	2.7%	1.6%	0.60%	6.4
A	23-33 c3	10YR 2/2		sbk	vf	cw	96.2%	2.2%	1.6%	0.57%	6.0
AB	34-43 cm	7.5YR 3/2		sbk	vf	cw	96.2%	2.3%	1.5%	0.54%	5.4
Bw1	43-54 cm	7.5YR 4/6		sbk	vf	cw	96.5%	2.5%	1.0%	0.54%	5.5
Bw2	54-66 cm	10YR 4/6		sg	lo	cw	96.9%	2.0%	1.2%	0.15%	5.3
Bw3	66-84 cm	10YR 5/6		sg	lo	gw	99.0%	0.4%	0.6%	0.18%	5.6
BC	84-135 cm	10YR 6/6 10YR 6/4	7.5YR 5/8	sg	lo	gw	99.7%	0.1%	0.2%	0.08%	5.7
C	135-160cm	10YR 6/3 10YR 7/3	7.5YR 5/6	sgl	lo		99.7%	0.1%	0.2%	0.03%	5.8

sbk=subangular blocky, gr=granular, sg=single grain, vf=very friable, lo=loose, as=abrupt smooth, cw=clear wavy, gw=gradual wavy. Profile description by Cathy Seybold (1992).

Holocene Terrace Soil Profile

Field Properties							Laboratory Properties					
Horizon	Depth	Moist Color	Mottle Color	Structure	Moist Consistence	Boundary	Sand	Silt	Clay	Organic Matter	pH
A1	0-46 cm	10YR 2/2		gr	vf	cw	79.0%	14.5%	6.5%	1.96%	7.10
A2	46-61cm	7.5YR 3/2		sbk	vf	cw	78.5%	12.25%	9.25%	1.00%	7.08
B/A	61-91 cm	5YR 3/3		sbk	vf	cw	83.0%	9.65%	7.35%	0.51%	6.93
B	91-122 cm	7.5YR 4/4		sg	lo	gw	96.0%	1.65%	2.35%	0.18%	6.69
C	122+ cm	7.5YR 4/6		sg	lo		99.0%	0.5%	0.5%	0.10%	6.70

gr=granular, sbk=subangular blocky, sg=single grain, vf=very fine, lo=loose, cw=clear wavy, gw=gradual wavy

APPENDIX 3

Development of Digital Soils Data for the The Lower Wisconsin River Project

OVERVIEW

This report accompanies digital soil data from the Lower Wisconsin River. The objective of this report is to give a detailed explanation of the processing involved in automating soil data. This report should be read prior to using any part of this data set. Support for the Lower Wisconsin River Project came from funding for Atrazine studies being conducted at the Wisconsin Geologic and Natural History Survey and The University of Wisconsin - Madison, Department of Soil Science. The project lasted from November 1991, through August 1992. Tom Gould was hired as the project assistant and he was responsible for all digitizing and processing involved in automating this data set.

The digital soils data span four counties along the lower portion of the Wisconsin River, including; portions of Sauk, Richland, Grant and Iowa Counties. In general, determining which soil sheets were selected for the project was based on the sheet's proximity to the river and the river's bluffs. If a sheet was adjacent to the river or its bluffs it was included in the project. From this selection process a continuous soils map, which stretched from Sauk City to Boscobel and followed the path of the Wisconsin River, was constructed.

Source Material
The Soil Conservation Service (SCS) provided the data necessary to produce a stable base for this project. This base map was constructed from the original mylar used to produce actual SCS soil surveys. Mylar is preferred to paper because it does not warp or distort due to aging or weathering. Mylar was used as the base for the entire project with the exception of Iowa County, where a published soil survey acted as the base map.

Establishing Control
The next step involved locating reference points which later would be used when transforming the soil maps from inch space into real word coordinates. Reference points - or tics - had to be recognizable on both individual soil sheets and quad maps. Because of the differing scales and ages of the two maps, locating viable landmarks proved to be a challenge for some soil sheets. Where possible, major road intersections were chosen as reference points. Road intersections where chosen because they are easily identifiable on both maps and they are more stable than natural resource boundaries. When not enough road intersections could be identified (four are required), intersections of the Southern Zone of the State Plane Coordinate System, which were identified on the soil surveys, were used as reference points. All reference points received individual reference numbers, which were recorded on both soil and quad maps.

Digitization
The GIS software pcARC/INFO-34d was used to process all of the digital data. Digitizing was executed on an Altek digitizing table using ARC's ADS function and carried out in stream mode. All of the soil sheets were digitized in inch space and initially cleaned with a fuzzy tolerance of .003 of an inch and a dangle length of .01 inch. No line thinning programs were used on the soil coverages. The digitizing process consisted of digitizing tics and their unique identification number and then adding in arcs and nodes where they were needed.

In addition to digitizing soil sheets, all reference tics from the quad maps were digitized and stored in a coverage called CONTROL. This process involved digitizing the corners of the quad maps and then digitizing all the tics along with their unique identification number. These numbers matched their counterparts on the soil sheets. This cover would later be used for transforming the individual soil coverages from inch space into State Plane Coordinates.

Processing the Coverages
Once the all the soil sheets for a county were digitized they had to be processed. Processing digital data consists of closing polygons where needed, and removing dangling arcs and pseudo nodes. Once this was done each coverage had to be cleaned and built for topology. After the coverage was built, it had to be rechecked for errors. If errors were located they had to be removed and the coverage had to be recleaned and rebuilt.

Labeling Polygons
After necessary processing, labels were added to every soil polygon. Once every soil polygon had a label point, individual soil names were added to each polygon. Soil names are located in the database under that name MUSYM, which stands for Map Unit SYMbol. MUSYM has a width of 6 and is a character symbol.

Check Plotting
Upon completing the labeling, soil maps of each soil sheet were plotted and checked against the soil surveys. While most errors were rectified without problem, some which reflected inconsistencies in soil surveys needed more attention. These inconsistencies occurred when two soil sheets were edge-matched and the soils from one border did not correlate with those from the other. When mismatches occurred, they were rectified with cartographic editing.

Transformation
The next step involved joining individual soil sheets to form continuous county-wide coverages. Finally, the county-wide coverages had to be transformed from inch-space into the Wisconsin State Plane Coordinate system. This was done using an inverse distance weighted affine transformation. An SML would take the tics from their inch space coverage and match them up with the tics in the CONTROL coverage. Because these tics were in the southern zone of the Wisconsin State Plane Coordinates, all of the soils polygons could be transferred into Wisconsin State Plane Coordinates.

WHAT WAS DIGITIZED

Sauk County
All data used to generate a digital coverage of Sauk County's soils were derived from the Sauk County Soil Survey report published in 1980. The following is a list the of soil sheets digitized in Sauk County: 110, 111, 117, 118, 124, 125, 126, 127, 128, 129, 130, and 131. The mylar used for digitizing Sauk County was clearly the most advanced. Rather than one mylar containing all the information, it was divided into three separates. The separates included soil polygons, soil names, and major roads.

Richland County
Data used to produce a digital coverage of Richland County came from the Richland County Soil Survey report published in 1949. The following is a list of soil sheets digitized for the Richland County soil layer: 44, 45, 46, 47, 48, 49, 50, and 51. Because Richland County's soil survey is much older than the Sauk County survey, all soil data is contained on one mylar rather than separates.

Grant County
All data used to generate a digital coverage of the soils of Grant County were obtained from Grant County's soil survey report published in 1951. The following is a list of soil sheets digitized in Grant County: 57, 41, 28, and 42. Like Richland County, one mylar stores all the soil data.

Iowa County

All data used to generate a digital coverage of Iowa County were obtained from Iowa County's soil survey report published in 1962. The following is a list of soil sheets digitized in Iowa County: 1, 10, 19, 27, 28, and 36. Because mylar could not be located for Iowa County, all of the soils data were digitized directly off of the Soil Survey's paper maps.

LOWIS Directory
The LOWIS directory houses all of the digital soils data for the Lower Wisconsin River Project. This directory is divided into four sub-directories: LOG, CONTROL, INCH, and SOILCOVS. There is a diagram at the end of this report which should clarify the layout of the directory. The following is an explanation of each directory.

LOG Directory
The LOG directory is nothing more than a log of the steps included in creating a digital coverage. The log is automatically created and updated by the ARC/INFO software.

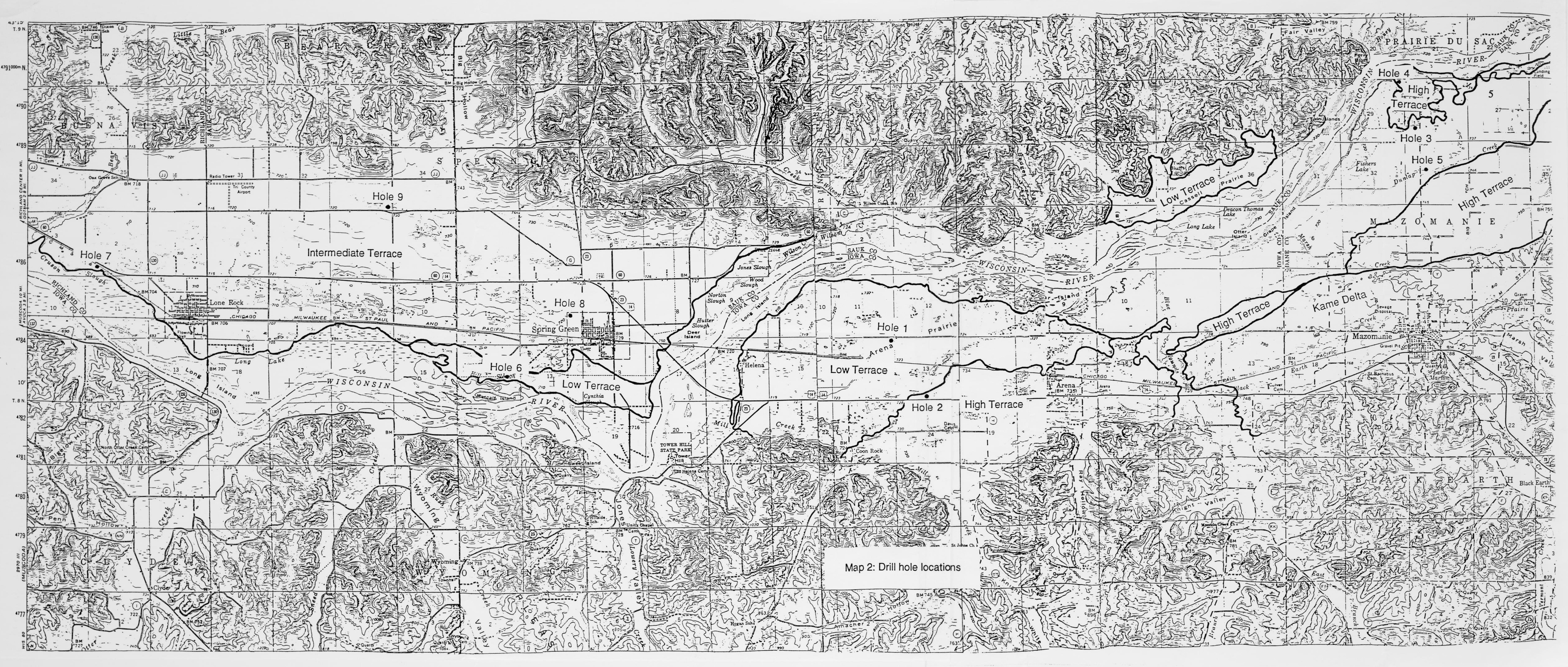
CONTROL Directory
This directory contains one coverage, which is the CONTROL coverage. The coverage's coordinate system is the southern zone of the Wisconsin State Plane Coordinate system. Every TIC used in the transformation process can be found in this coverage.

INCH Directory
The INCH directory is comprised of four sub-directories. The four sub-directories which refer to particular counties are: Iowainch, Grntinch, Richinch and Saukinch. Within each sub-directory are the Counties' soil sheets, which are in inch space, unedited and lack topology. To locate a specific soil sheet one must first get into the specific county directory e.g., for Sauk County the directory would be SAUKINCH. Once in the directory soil sheets are identified by the first letter of the county, the soil sheet number and the word inch. For example, to retrieve a Sauk County soil sheet numbered 117, you would enter S117INCH.

SOILCOVS Directory
The SOILCOVS directory is comprised of four sub-directories. The four sub-directories are: GRANT, IOWA, SAUK, and RICH. Coverages within these sub-directories contain edited, labeled and topologically corrected versions of each county's digital soils map. Because of size limitations of the GIS software, two of the Counties' soil maps are divided into two separate coverages. They are Richland County's coverages RSOIL1 and RSOIL2, and Iowa County's coverages IOWASOI1 and IOWASOI2. The data from the two other counties, Sauk and Grant, were stored in one coverage. Sauk County's soils are in the coverage SAUKSOIL and GRANT soils are in GNTSOIL.

Directory Structure - Lower Wisconsin River Project Soils

```
\LOWIS_
   |
   |-----LOG
   |-----CONTROL
   |-----INCH----------| -IOWAINCH
   |                   |   -GRNTINCH
   |                   |   -SAUKINCH
   |                   |   -RICHINCH
   |
   |-----SOILCOVS-------| -IOWA-----------| -IOWASOI1
                        |   |             | -IOWASOI2
                        |   |
                        |   -GRANT--------| -GNTSOILS
                        |   -SAUK---------| -FINSAUK
                        |   -RICH---------|    | -RSOIL1
                                               | -RSOIL2
```



Map 2: Drill hole locations

Spatial Attributes of the Soil-Landscape-Groundwater System of the Lower Wisconsin River Valley