Field Evaluation of On-Site Sewage Disposal Systems and Broad-Scale Suitability Mapping, Morgan County, Indiana

Indiana Geological Survey Open-File Study 09-04

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ABSTRACT

In this study, the nitrogen loading of groundwater underlying OSDS systems in four different soil/topographic settings in Morgan County, Indiana, was determined by undertaking an intensive program of monitoring in and beneath septic distribution fields at each of the field sites. The sites selected were different from one another in setting and soil texture, and were representative of a broad range of soil types within the county. At each study site, sensors were installed to measure soil-water tension in the unsaturated zone, soil-moisture content, and water-table elevations. Each site was monitored for 10 months (late October 2004 through late August 2005). Samples of water were collected from the saturated or unsaturated zones, or both, at each of the four study sites on 16 separate occasions. All water samples were analyzed in the laboratories of the Indiana State Department of Health in Indianapolis.

The information and understanding of processes gained from the intensive hydrochemical monitoring study described in this report were used in an analysis of on-site sewage disposal systems (OSDS) in Morgan County. Geographic information systems software was used to conduct an analysis of similar hydrogeologic settings that would yield an assessment of the suitability of installing on-site sewage disposal systems in different areas of Morgan County. In this analysis, the following parameters were considered: (1) depth to water table, (2) susceptibility of surface failure of OSDS, (3) permeability of geologic materials and soils, (4), thickness of unconsolidated materials (includes depth to bedrock), (5) topographic setting, and (6) observed function of septic systems studies.

All the available hydrogeological data layers were evaluated in conjunction with the results of the monitoring study, and the input data layers were analyzed to identify the most suitable and least suitable areas for OSDS in Morgan County, Indiana. The characteristics for the *most* suitable areas include:

- Well-drained surficial materials (typically glacial outwash gravel, or sand and gravel);
- Thick unconsolidated materials (> 15 meters);
- Moderately deep to deep water table (> 7.5 meters below ground surface);
- Protected aquifer (either confined aquifer or aquifer with protective capping materials).

The least suitable areas for OSDS include the following characteristics:

- Poorly drained surficial materials (clays or silty clays);
- Thin unconsolidated materials (<7.5 meters), shallow bedrock;
- Shallow water table (<7.5 meters below ground surface);
- Susceptible to surface failure from surface flooding (located in floodplain);
- Susceptible to surface failure from perched water table.

Recommendations for identifying suitable locations for installation of OSDS in Morgan County, Indiana, would include:

- Continue site-specific evaluation of potential OSDS locations;
- Attempt to assess the presence of adequate unconsolidated material thickness below the proposed OSDS;
- Attempt to assess the permeability of unconsolidated materials and soils at and below the proposed OSDS;
- Avoid locations where surface failures owing to perched water tables or surface flooding might occur.

INTRODUCTION

Currently, more than 800,000 on-site sewage disposal systems (OSDS, also known as septic systems) are located in Indiana. For the state to make informed management decisions concerning the suitability of on-site sewage disposal systems in different landform and soil settings, evaluation of nitrogen loading of water-table aquifers owing to natural recharge in multiple soil settings must be done. Morgan County, Indiana, with its wide range of soils and topographic settings was selected for intensive site-specific pilot investigations and geographical information systems (GIS) analysis. Many of the citizens of Morgan County use on-site sewage disposal systems as their primary method of wastewater treatment. Provided that the systems are properly designed and installed, they can be cost-effective and efficient methods of treating wastewater. However, some areas of Morgan County may not have the types of soils or be in topographic settings that are suitable for these systems. Consequently, there is potential to degrade ground- and surface-water quality from septic leachate in some areas of the county. This potential water-quality degradation is a public health concern because of the increased possibility for transmission of waterborne diseases in contaminated drinking water.

In this project, which took place from October 1, 2003 through September 30, 2005, the investigators determined the nitrogen loading of groundwater underlying OSDS systems in four different soil/topographic settings in Morgan County. This was accomplished by undertaking an intensive program of monitoring in and beneath septic distribution fields at each of the field sites. The sites selected were different from one another in setting and soil texture, and were representative of a broad range of soil types within the county. The process of site selection involved cooperation with personnel of the Indiana State Department of Health as well as other state agencies and took roughly a year to complete. Each site was monitored for 10 months, at which time funding ceased (the project was originally intended to continue for at least one more year) because of federal funding constraints. The results of the monitoring were used to calculate rates at which nitrogen was recharging into groundwater. These loading rates and their relationship to topographic and geologic factors were subsequently used to guide a geographical information system analysis of the entire county and to derive a preliminary map showing various degrees of OSDS suitability.

STUDY SITES AND HYDROCHEMICAL MONITORING INSTALLATIONS

Hydrochemical monitoring systems were installed in and beneath the septic distribution fields at four homes within the county. Site A (gravel parent material) was located on a high terrace above the White River in the northeastern part of the county; Site B (interlayered clay, silt, and sand parent material) was located on an upland area underlain by ablation till in the central part of the county; Site C (sandy parent material) was located on a low, dune-capped terrace adjacent to the White River in the southwestern part of the county; and Site D (loess and weathered siltstone parent material) was located on the Norman Upland in the central part of the county, a few kilometers northwest of Site B. Sites A and C had highly permeable soils, Site B had moderately permeable soil and Site D had slowly permeable soil. The locations of the four sites are shown in Figure 1; soil profiles are shown in Figure 2. Figure 3 shows the results of grain-size analyses conducted for the soil profiles at each of the sites.

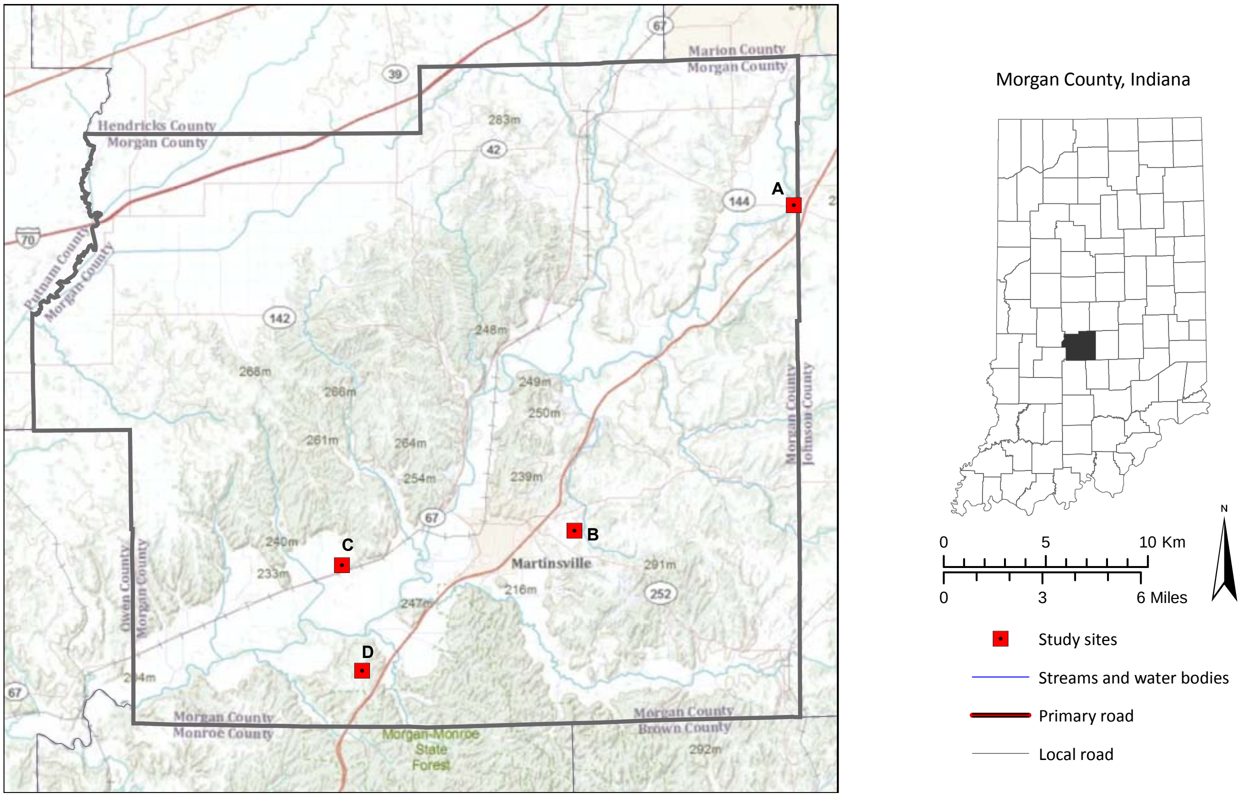

Figure 1. Map of Morgan County, showing locations of study sites.

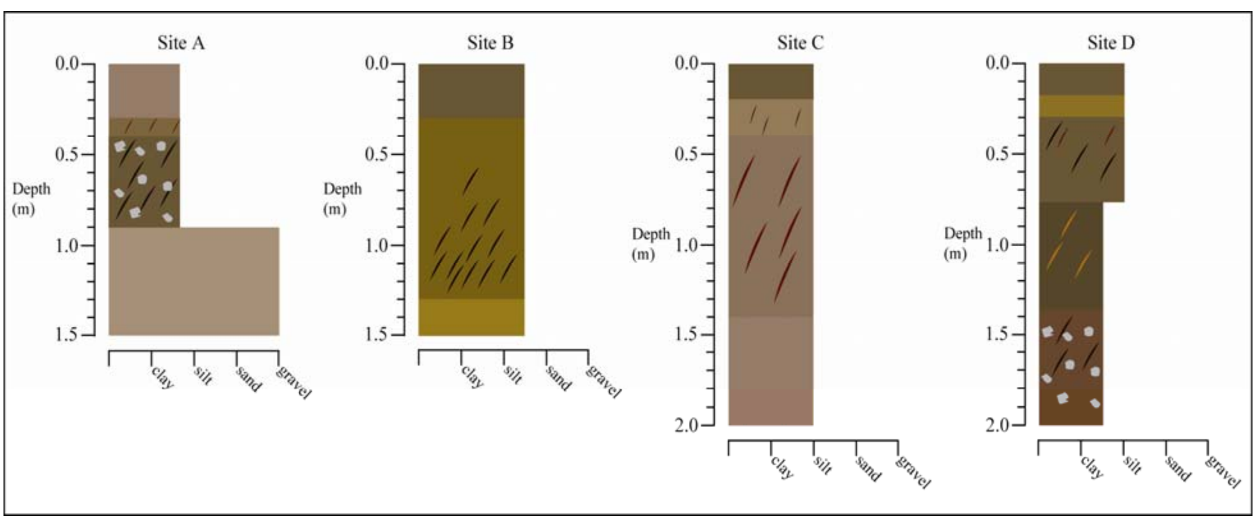

Figure 2. Graphic representation of upper portion of soil cores at each of the study sites (see Figure 1 for locations). Site A (gravel parent material) was located on a high terrace above the White River in the northeastern part of the county; Site B (interlayered clay, silt, and sand parent material) was located on an upland area underlain by ablation till in the central part of the county; Site C (sandy parent material) was located on a low, dune-capped terrace adjacent to the White River in the southwestern part of the county; and Site D (loess and weathered siltstone parent material) was located on the Norman Upland in the central part of the county, a few kilometers northwest of Site B.

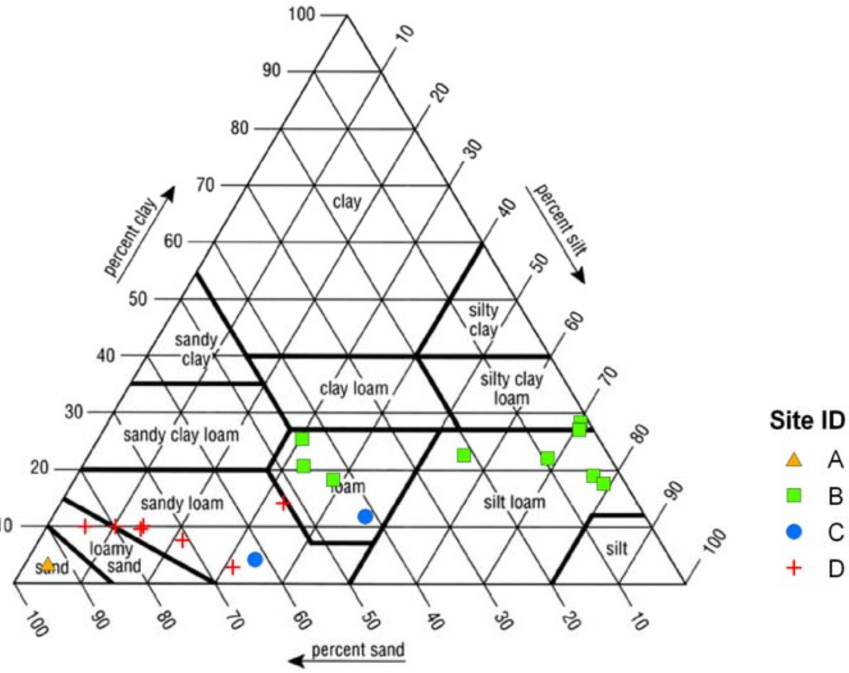

Figure 3. Results of grain-size analysis for soils at each of the study sites (see Figure 1 for locations).

At each study site, sensors were installed to measure soil-water tension in the unsaturated zone and water-table elevations (fig. 4). The measurements of soil-water tension and moisture content were made at three depths (15 cm, 30 cm, and 60 cm). Aluminum access tubes were installed to allow measurements of soil-moisture profiles using a neutron soil-moisture gauge, and pressure-vacuum soil-water samplers were installed to allow water to be extracted from the unsaturated zone for chemical analysis. Measurements of precipitation were made at two of the houses (Sites A and D). These were combined with data on potential evapotranspiration (from a different site in Indiana) to facilitate calculations of vertical soil-water flux and water-table recharge. Table 1 summarizes the instruments installed at each location.

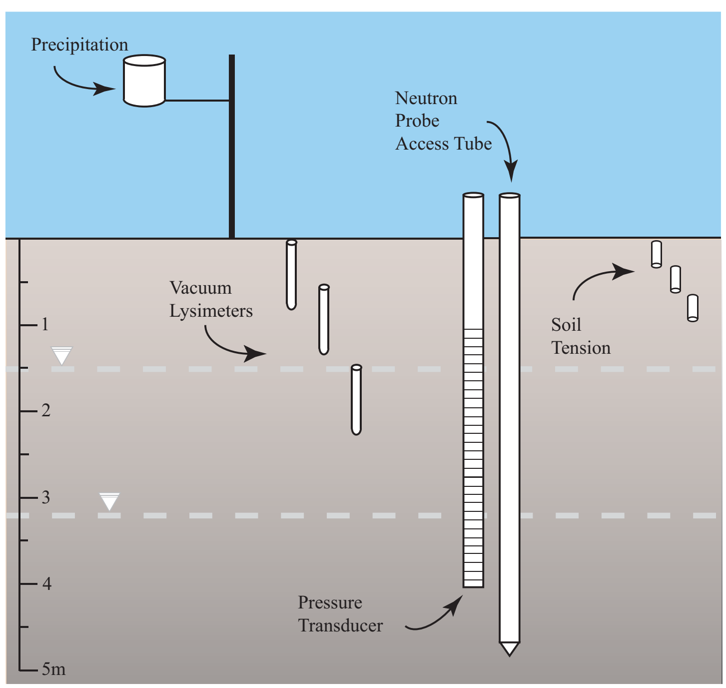

Figure 4. Sketch map showing types of instrumentation installed for the study.

Table 1. Description of physical setting and instrumentation installed at each site in the study

Site A	**Description of site and instruments**
Location	High outwash terrace above the White River in northern Morgan County
Parent Material	glacial outwash (gravel)
Soil series	Fox loam (FoB2), and/or Ockley loam (OcA)
Well	Water table deeper than well (>23 meters bgs)
L1	Unsaturated zone, vacuum lysimeter at 1-meter depth
L2	Unsaturated zone, vacuum lysimeter at 2-meter depth
L3	Unsaturated zone, vacuum lysimeter at 3-meter depth
Other	Rain gauge, neutron probe access tube, soil-tension blocks
Site B	**Description of site and instruments**
Location	Upland area underlain by ablation till (or mixed drift) in east-central Morgan County
Parent Material	Interlayered clay, silt, and sand
Soil series	Princeton fine sandy loam (PrC)
Well	Water table between 3.4 and 4 meters bgs
L1	Unsaturated zone, vacuum lysimeter at 1-meter depth
L2	Unsaturated zone, vacuum lysimeter at 2-meter depth
L3	Unsaturated zone, vacuum lysimeter at 3-meter depth
Other	Neutron probe access tube (for soil-moisture profiles), soil-tension blocks
Site C	**Description of site and instruments**
Location	Low terrace adjacent to the White River in southwestern Morgan County
Parent Material	Sand; loess, glacial till, or outwash parent material
Soil series	Martinsville loam (MeA), and/or Whitaker loam (Wr), and/or Ockley loam (OcA)
Well	Water table varies between 1.3 and 2.5 meters bgs
L1	Unsaturated zone, vacuum lysimeter at 1-meter depth
L2	Varies between saturated and unsaturated zone, vacuum lysimeter at 6-foot depth
L3	Saturated zone, vacuum lysimeter at 3-meter depth
Other	Neutron probe access tube (for soil-moisture profiles), soil-tension blocks
Site D	**Description of site and instruments**
Location	Norman Upland in the south central part of Morgan County
Parent Material	loess and weathered siltstone
Soil series	Berks channery silt loam (BfG), and/or Alford silt loam (AfB)
Well	Water table varies between 2.7 and 3 meters bgs
L1	Unsaturated zone, vacuum lysimeter at 1-meter depth
L2	Unsaturated zone, vacuum lysimeter at 2-meter depth
L3	Saturated zone, vacuum lysimeter at 3-meter depth
Other	Rain gauge, neutron probe access tube, soil-tension blocks

DATA COLLECTION

Over the course of the study period, which commenced in late October 2004, and ended in late August, 2005, an attempt was made to collect samples of water from the saturated or unsaturated zones (or both) at each of the 4 study sites on 16 separate occasions. Several of the samples were collected immediately after rain storms. An attempt was made to collect water from each well and all three soil-water samplers at each study site; however, this was not fully accomplished because at times the soil-water tension was too high to allow extraction from the unsaturated zone using vacuum pumps. Also, we were unable to obtain samples from the saturated zone at Site A because the water table there was deeper than the monitoring well placed at a maximum depth of 23 meters (maximum depth capability of the Indiana Geological Survey's auger drill rig).

All water samples were analyzed in the laboratories of the Indiana State Department of Health in Indianapolis. On all 16 occasions the water samples were analyzed for nitrogen (nitrate + nitrite). For samples collected on December 3, 2004 and December 16, 2004 a more in-depth chemical analysis was conducted that included determinations of ammonia and phosphorus concentrations. The chloride and suspended solids concentrations in samples from the monitoring wells were also determined on December 16. The monitoring well samples were tested for nitrite, BOD-5, and CBOD-5 on the same date. This report focuses on nitrogen, but all the results of the chemical analyses are provided in Appendix 1.

Soil-moisture profiles were measured at each of the study sites on 12 occasions and the measured soil-moisture contents are presented in Appendix 2.

SUMMARY OF PROJECT RESULTS

Hydrochemical Monitoring

During the period of monitoring the rain gauge located at Site A recorded 79 cm of precipitation, and the rain gauge located at Site D recorded 82 cm. During that time two periods of pronounced water-table rise were recorded at Sites B and C, while seven were recorded at Site D. At Sites C and D heavy rainfall in early January induced a drastic water-table rise that caused flooding and the loss of electronic monitoring equipment. Such hydrogeologic conditions prohibit proper function of OSDS and constitute a failure of the system.

Site A

The highest concentrations of nitrogen at Site A occurred in late spring in association with stormy periods that triggered recharge events (fig. 5). These could be identified by times when the near-surface soil-water tension fell below 0.1 bar, which defines the threshold between field capacity and gravity drainage. As shown in Figure 6, this occurred in mid-May. The wetting caused nitrogen concentrations to peak first at 1-m and then at 2-m about a month later (fig. 6). Note that the nitrogen concentrations at 3-m remained relatively constant. This indicates that either the higher concentration did not percolate down to that level or that the leachate from above was flushed through to a greater depth. The lack of data from the saturated zone makes these two possibilities hard to resolve, but it is likely that very little recharge would have still been generated by the time the wetting front propagated through 100 ft of unsaturated soil (the approximate depth to water at Site A). Because of the great distance to the water table and the high permeability of the outwash-derived soil, this site never experienced a failure during the period of monitoring.

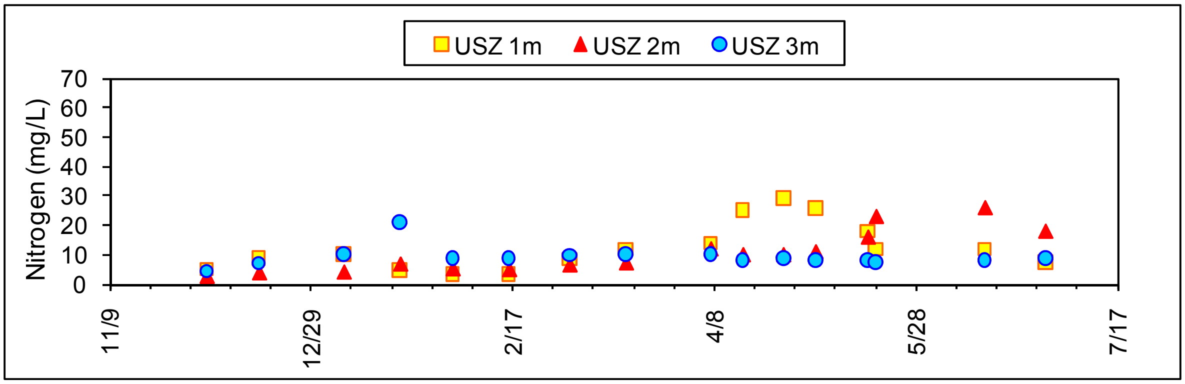

Figure 5. Graph showing the values of nitrogen concentration for Site A plotted versus time. USZ = unsaturated zone.

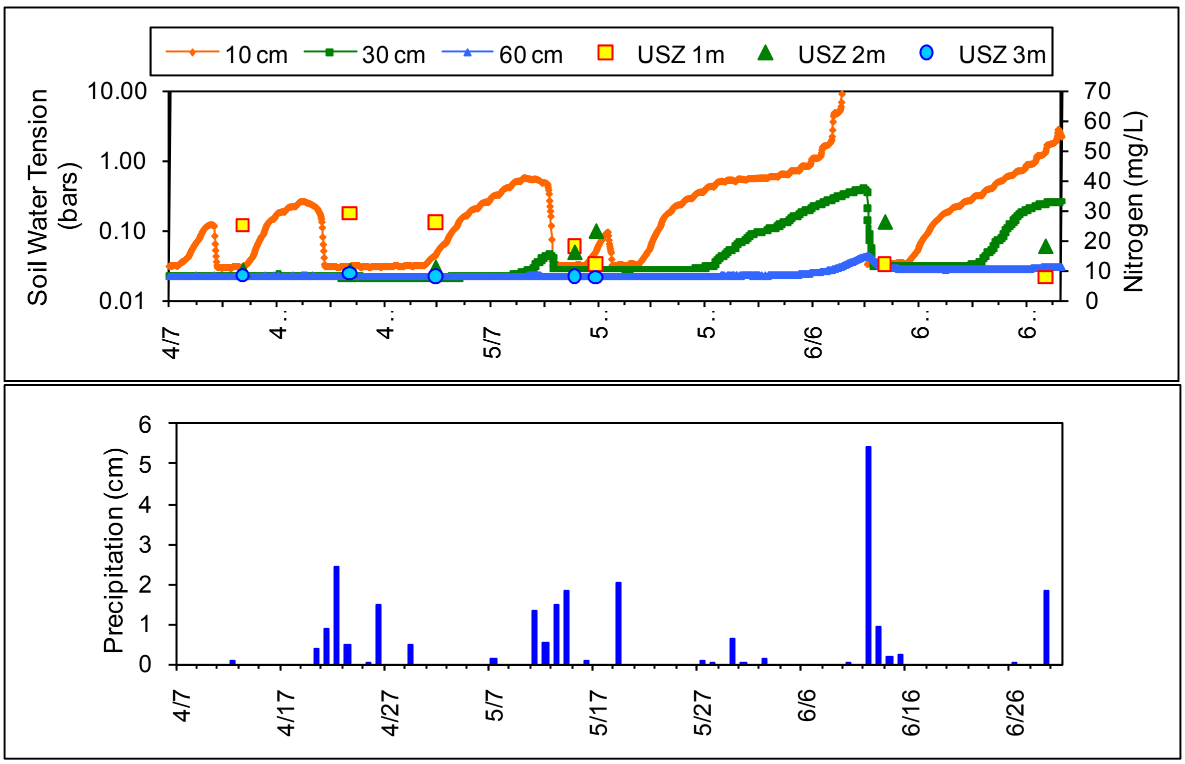

Figure 6. Soil-water tension in the unsaturated zone and nitrogen concentrations during the late spring for Site A are shown in the upper graph; precipitation for the same period is shown in the lower graph. The soil-water tension is below the lower limit of field capacity (0.1 bar) during late April and mid-May; therefore, rainfall during those periods can induce gravity drainage and vertical groundwater recharge. USZ = unsaturated zone.

Site B

The highest concentrations of nitrogen observed at any of the study sites occurred at the 3-foot depth at Site B. The nitrogen levels remained above 50 mg/L during the months of December and January and peaked at 63 mg/L in early January. The following months show steadily decreasing nitrogen concentrations and by early May the nitrogen concentration was below 10 mg/L (fig. 7). Throughout this period, the concentrations in the saturated zone remained relatively constant at just under 10 mg/L. A rain event that occurred in early January induced a period of recharge that caused the nitrogen concentration in the water table to increase to its highest level over the entire study. The nitrogen concentration in the water table went from a consistent average near 7 mg/L to 14 mg/L in 3 weeks (fig. 8). The 14-mg/L concentration is very close to the value of 15 mg/L at the 2-m depth and an increase in the water table may have been accompanied by a recharge event that contained septic leachate. A recharge event containing such a low concentration is not considered problematic. The fact that the nitrogen concentrations were so much lower in the soil below the septic trench attests to the excellent performance of the system at this site. This site also never experienced flooding from the surface or water table during the period of monitoring.

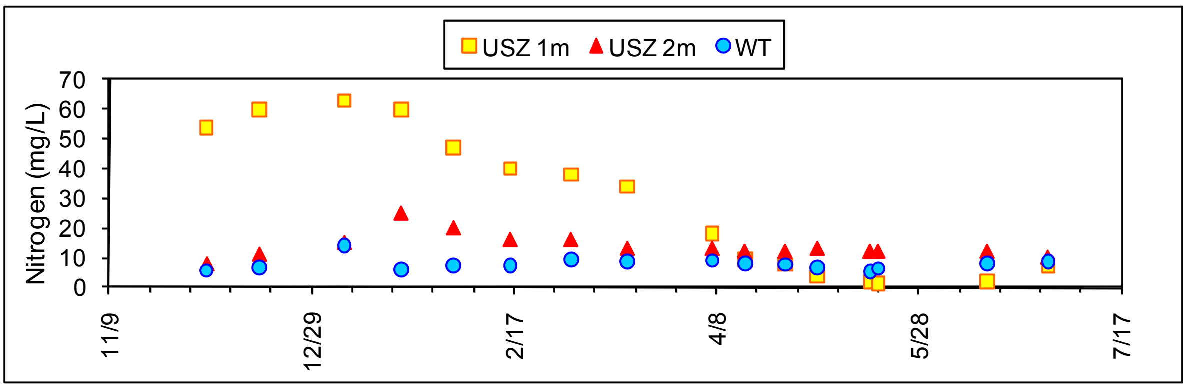

Figure 7. Graph showing the values of nitrogen concentration for Site B plotted versus time. USZ = unsaturated zone; WT = water table.

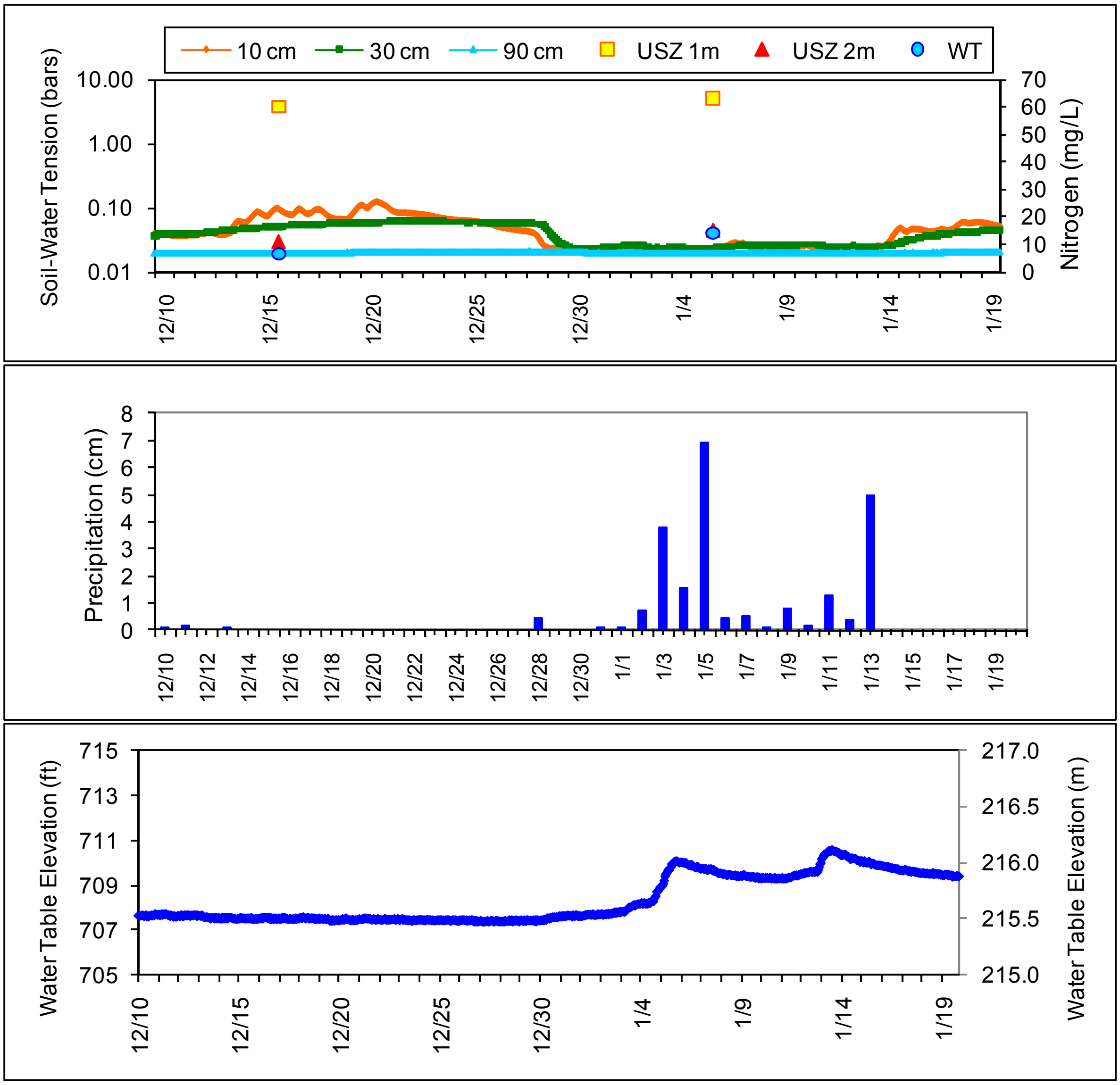

Figure 8. Soil-water tension in the unsaturated zone and nitrogen concentrations from mid-December to mid-January for Site B are shown in the upper graph; precipitation for the same period is shown in the lower graph. The soil-water tension is below the lower limit of field capacity (0.1 bar) during early January indicating that the rainfall during this period induced a period of gravity drainage and vertical groundwater recharge. WT = water table.

Site C

Site C had a higher concentration of nitrogen within the saturated zone than the other three study sites. However, the low values of nitrogen concentrations at 1-m and 2-m indicate that either minimal loading was occurring on site or that the nitrogen was readily flushing through the sandy soil and into the shallow zone of saturation (fig. 9). Note that between early February and mid-April 2005, soil-water tension at Site C was below field capacity (fig. 10), indicating that gravity drainage and vertical groundwater recharge was capable of occurring. However, precipitation was lacking (fig. 11) and the water table was declining, so it is difficult to resolve whether the septic leachate was migrating vertically or not. Because of its low elevation relative to the nearby White River, this site experienced flooding from water-table rises twice during the period of monitoring.

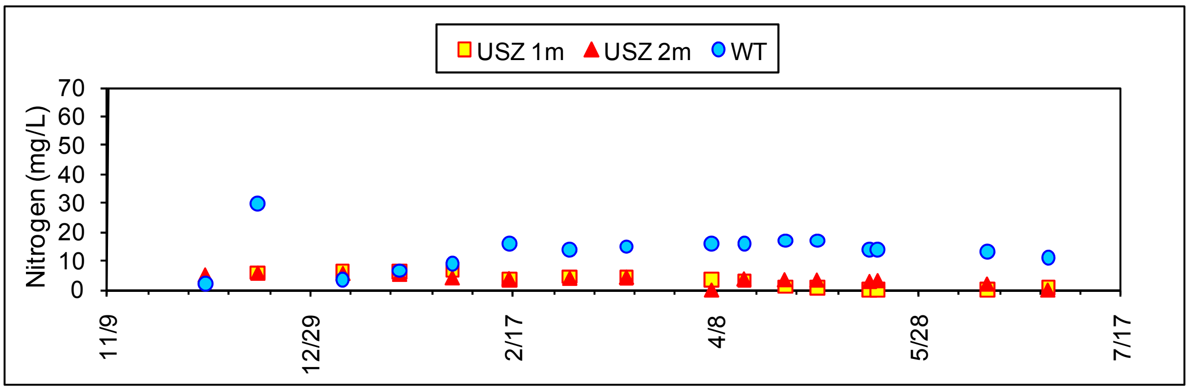

Figure 9. Graph showing values of nitrogen concentration for Site C plotted versus time. USZ = unsaturated zone; WT = water table.

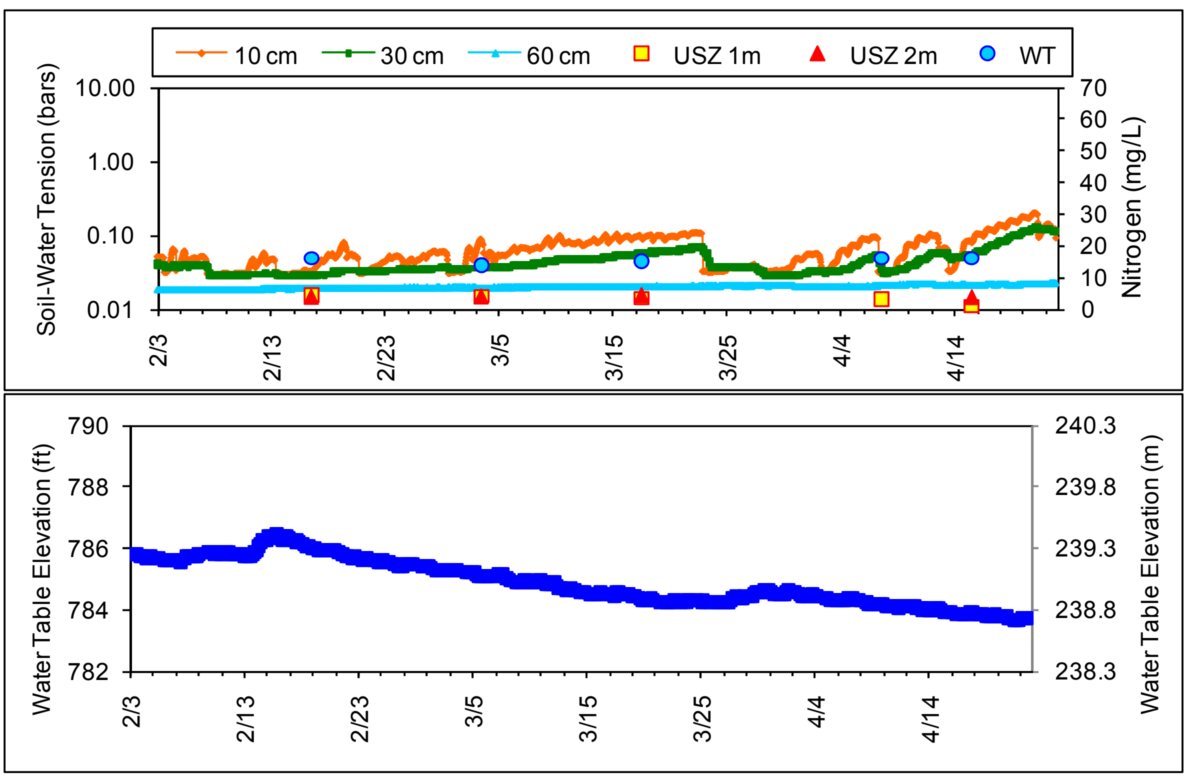

Figure 10. Soil-water tension in the unsaturated zone and nitrogen concentrations from early February to late April for Site C are shown in the upper graph. The soil-water tension is below the lower limit of field capacity (0.1 bar) during much of the time period, indicating that gravity drainage and vertical groundwater recharge were capable of occurring. The bottom graph shows the declining water table over the early February to late April time period. WT = water table.

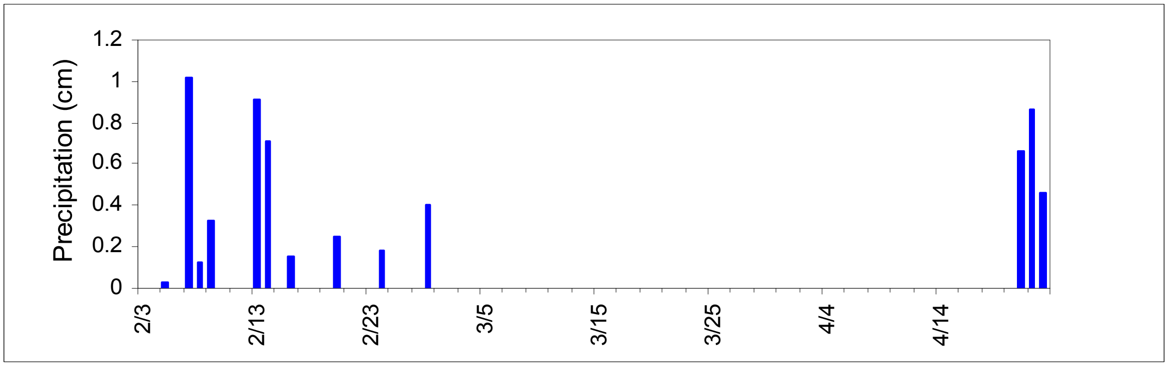

Figure 11. Graph showing precipitation levels from early February to mid-April 2005.

Site D

Nitrogen concentrations at Site D remained consistently low throughout the study (fig. 12). In addition, nitrogen concentrations decreased with depth; these two factors indicate that the nitrogen was being filtered out as the water percolated down through the soil. From mid-December 2004 through mid-January 2005, the soil-water tension at Site D was below field capacity, indicating that gravity drainage and vertical groundwater recharge were possible. The rain event that occurred in early January, indeed, caused a period of recharge that allowed the water-table elevation to increase. This was associated with an increase of the nitrogen concentration in the saturated zone of 5.5 mg/L (fig. 13). When compared to the concentrations at the other study sites, this value was still very low, however. Near the end of the study period, a very intense rainstorm caused water to pond at the surface; this ponding eventually led to a water-table rise that destroyed all the electronic instrumentation at Site D.

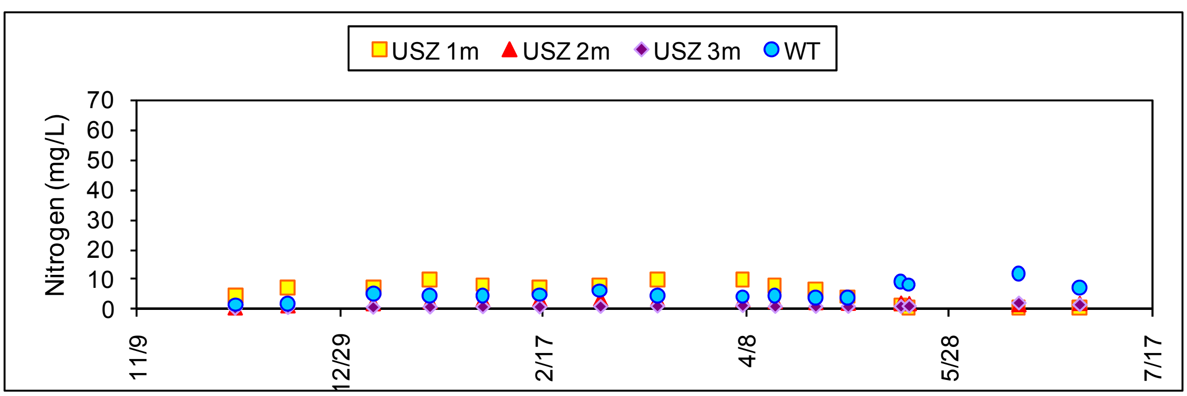

Figure 12. Graph showing values of nitrogen concentration for Site D plotted versus time. USZ = unsaturated zone; WT = water table.

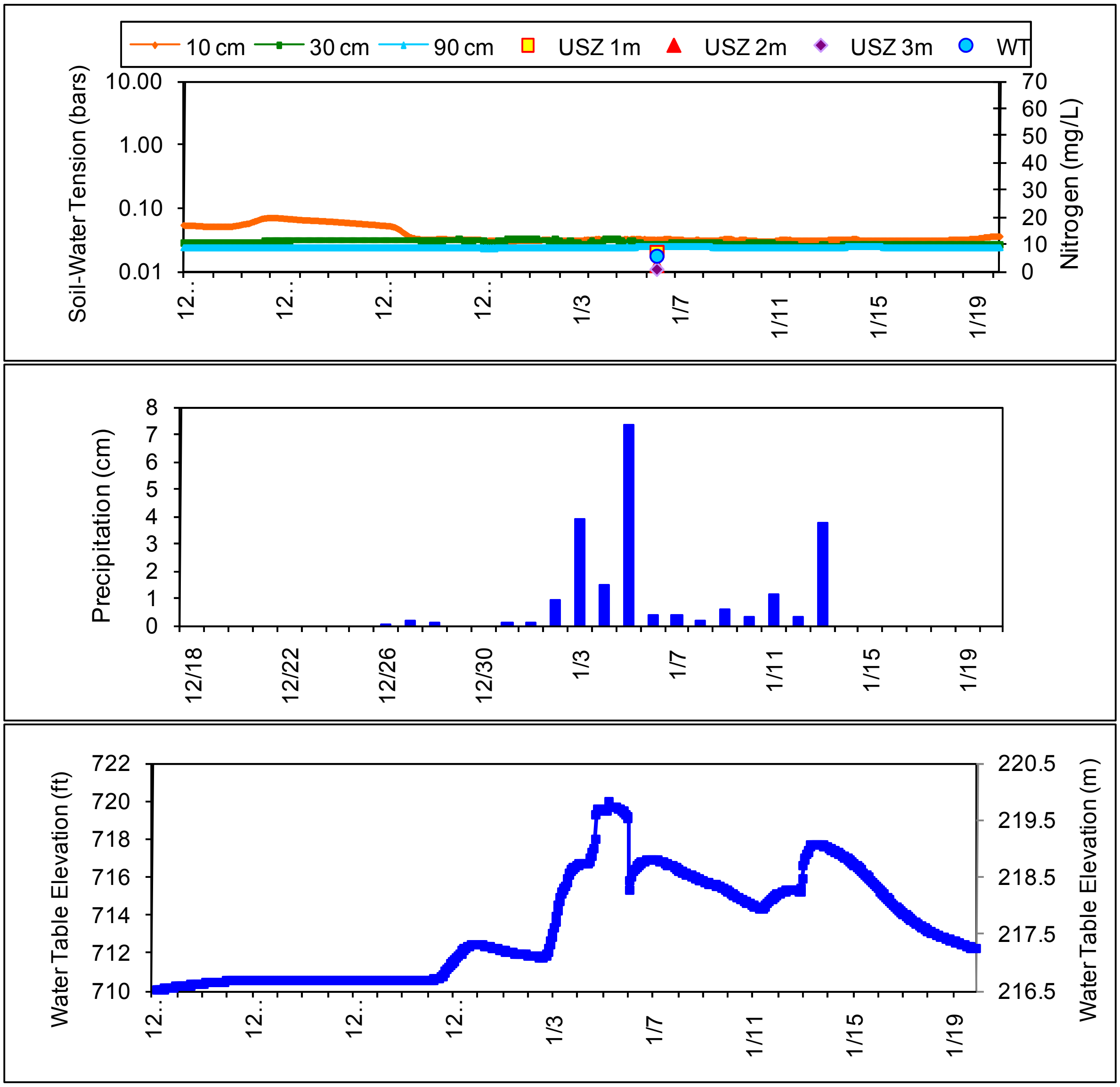

Figure 13. Soil-water tension in the unsaturated zone and nitrogen concentrations during the mid-December to mid-January time period for Site D are shown in the upper graph; precipitation for the same period is shown in the graph below it. The soil-water tension is below the lower limit of field capacity (0.1 bar) during early January indicating that the rainfall during this period induced a period of gravity drainage and vertical groundwater recharge. The third graph shows the water table elevation (hydrograph) for the same period. WT = water table.

Calculations of Recharge and Nitrogen Loading

Measured soil-moisture profiles using the neutron moisture gauge were combined with data on the net surface flux (precipitation-potential evapotranspiration) between the days of measurement to calculate the flow of water through the unsaturated zone. The flow calculations are based on the continuity equation for vertical unsaturated flow:

$$\frac{\partial \theta}{\partial t} = -\frac{\partial v}{\partial z} \qquad (1)$$

where θ is the moisture content at depth z and time t, and v is the Darcy flux. A finite-difference solution to the differential equation gives:

$$v_z = v_{z+\Delta z} + \frac{\Delta \theta}{\Delta t} \Delta z \qquad (2)$$

where $v_{z+\Delta z}$ is the flux in the finite-difference cell above the calculation cell (Δz = 1 ft) and $\Delta\theta$ is the change in moisture content at elevation z over the period Δt (number of days between moisture-profile measurements). At the top of the moisture profile, the value of $v_{z+\Delta z} = v_z^o$ (boundary condition) was set equal to the net surface flux over the period between moisture profile measurements. Figure 14 shows how moisture-profiles measurements are used in the net flux calculation to estimate recharge. Over the period of study, data were available to evaluate the flux through the unsaturated zone a total of eleven times. The results of the flux calculations are presented in Table 2 and Figure 15. The analysis indicated that four recharge events (net downward flux through the profile) occurred at Site A, two recharge events at Site B, three recharge events at Site C, and six recharge events at Site D. Based on these calculations total recharge was determined to be 5.15 cm/day at Site A, 4.82 cm/day at Site B, 8.34 cm/day at Site C, and 7.55 cm/day at Site D.

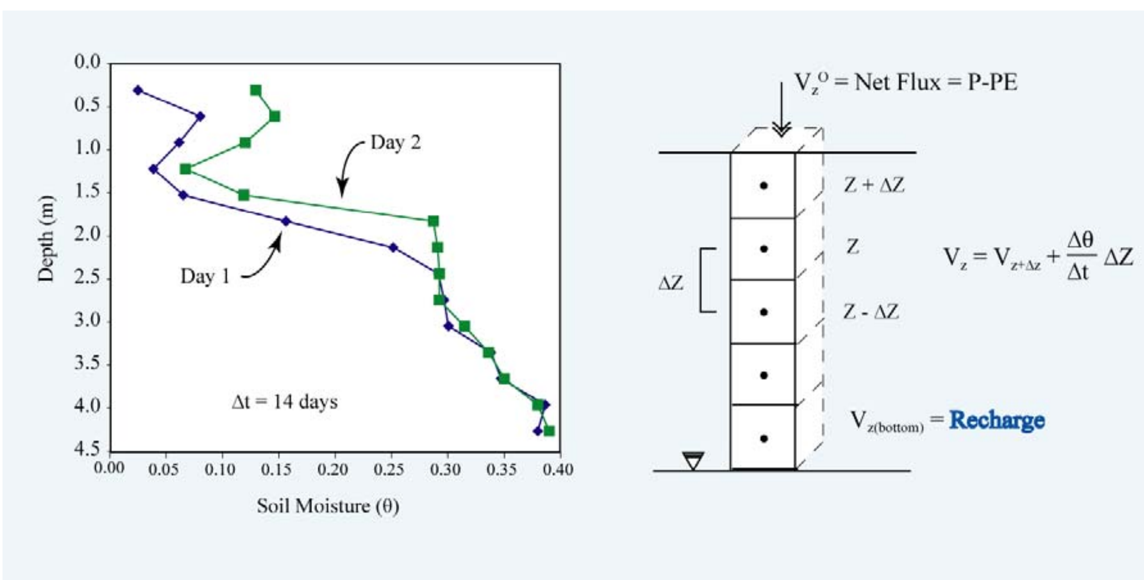

Figure 14. Diagram showing how vertical soil-moisture profiles are used to calculate the net moisture flux (recharge) to the water table.

The calculated recharge totals were combined with average nitrogen concentrations in the unsaturated zones at each study site (14.38 mg/L at Site A, 8.06 mg/L at Site B, 1.55 mg/L at Site C, and 2.25 mg/L at Site D) to estimate the seasonal total nitrogen loading of the water table by flushing through the unsaturated zone. The calculations are equivalent to 6.6 lb/acre at Site A; 3.5 lb/acre at Site B; 1.2 lb/acre at Site C; and 1.5 lb/ acre at Site D.

Table 2. Calculated recharge and loading for each site in the study. Loading is calculated as recharge times average nitrate concentration in the unsaturated zone. The estimates are per day over the recharge period, which is the number of days between moisture-profile measurements.

	Recharge	**Unsaturated Zone Average Nitrate Concentrations**		**Loading (per day)**		
	(cm/day)	(mg/L)	(g/cm^3)	(g/cm^2 N)	(kg/km^2 N)	(lb/acre N)
Site A	5.15	14.38	0.00001438	7.418E-05	741.85	6.6
Site B	4.82	8.06	0.00000806	3.886E-05	388.61	3.5
Site C	8.34	1.55	0.00000155	1.293E-05	129.32	1.2
Site D	7.55	2.25	0.00000225	1.701E-05	170.12	1.5

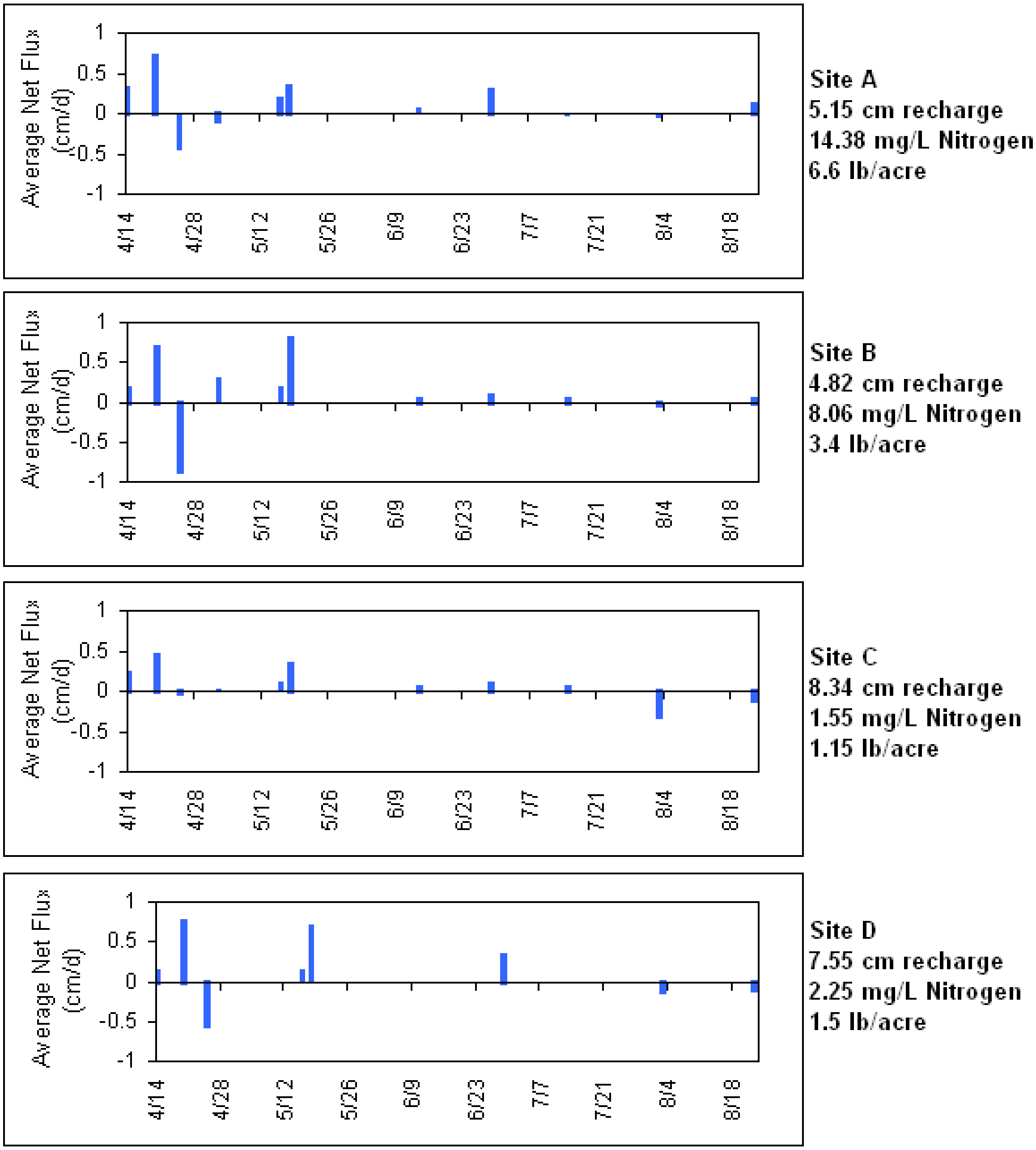

Figure 15. Graphs showing the results of the flux calculations for each site in the study. Four recharge periods (net downward flux through the profile) occurred at Site A, two recharge periods at Site B, three recharge periods at Site C, and six recharge periods at Site D.

GIS ANALYSIS OF OSDS SUITABILITY

The information and understanding of processes gained from the intensive hydrochemical monitoring study described above were used to guide a countywide assessment of on-site sewage disposal systems suitability in Morgan County. Based on our findings to date, the most suitable areas for OSDS are those having well-drained surficial materials, thick unconsolidated materials to allow proper leachate filtration, a moderate to deep water table, and an aquifer protected by an impermeable layer at a sufficient depth that it will not serve as a perching layer. If an aquifer is at a sufficient depth, even without a protective impermeable cap, it will be protected from septic system leachate by the amount of filtration that will occur through unsaturated permeable materials.

A known issue in Morgan County is the potential for surface failure of an OSDS by a perched water table. This can occur if an impermeable layer such as a clay bed is located below a septic system. If a large amount of rainfall is received and cannot infiltrate through the impermeable layer, a shallow water table will develop above the impermeable layer and can flood the OSDS from below. This could occur in Morgan County in two separate geologic conditions: a clay layer within the unconsolidated sediments, or shallow bedrock with an insufficient unconsolidated thickness to provide reliable filtration. In these situations the septic systems will operate properly until the infiltrated rainwater encounters the impermeable layer and perching occurs.

Many of the most permeable sediments in the county are located within floodplains. These areas are usually regulated to reduce damage or loss because of flooding. The caution taken with construction in a floodplain should also be observed with regard to installation of OSDS in floodplains. Inundation of an OSDS because of water-table rise or river flooding would lead to system failure, as well as the potential release of nutrients, bacteria, and viruses to both surface- and groundwater resources.

Geographic information systems (GIS) software was used to conduct a spatial analysis that would lead to a map showing degrees of OSDS suitability throughout the county. In this analysis, the following parameters were considered:

- Depth to water table
    - Confined aquifers
    - Unconfined aquifers
- Susceptibility to surface failure of OSDS
    - Likelihood of perched (shallow) water table
    - Likelihood of surface flooding
- Permeability (or impermeability) of surficial geologic materials
- Runoff potential of surficial geologic materials
- Soil characteristics, and soil development (evaluation of distribution of NRCS-mapped soils)
- Depth to bedrock; thickness of unconsolidated materials
- Topographic setting

Several parameters were extracted or derived from the Indiana Department of Natural Resources, Division of Water groundwater well-log database for Indiana. This database includes location, well construction, and lithologic information for water wells in the state of Indiana. For this analysis, the database was queried to extract all well logs for Morgan County. The parameters extracted from the database include static water level, depth to water-bearing formation, and location of wells with a thick (greater than 4.6 meters) clay layer at surface. Parameters derived from the database include determination of unconfined versus confined aquifers, identification of wells developed in unconsolidated aquifers versus wells developed in bedrock aquifers, depth to clay confining layer (if present), and thickness of clay confining layer (if present).

The Soil Survey Geographic (SSURGO) database from the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) was used to identify soil properties and characteristics that would yield an understanding of the effect that soil properties have on the function of OSDS. The digital SSURGO data layers have detailed spatial information; however, the level of attribute data included for each soil series is not equivalent to the data included in the soil-series volume for Morgan County (Sturm, 1981). Therefore, attributes concerning soil parent material, permeability, and drainage characteristics were manually added to the database tables. In addition, available tables containing information about the composition of soils at various depths were used to make spatial data layers for characteristics of shallow (usually < 0.6 meter), medium (usually 0.6 to 0.9 meter), deep (usually 0.9 to 1.3 meters), and very deep soils (usually > 1.3 meters). This information was used to identify areas having very shallow unweathered bedrock, areas having full thicknesses of impermeable materials, and areas having full thicknesses of well-drained materials.

All the available hydrogeological data layers were evaluated in conjunction with the results of the monitoring study, and the input data layers were analyzed to identify the most suitable and least suitable areas for OSDS in Morgan County, Indiana. These characteristics were then used to identify areas of Morgan County, Indiana, that exhibit qualities or characteristics controlling OSDS suitability. These areas were aggregated to create a generalized suitability map. The Quaternary geology map by Gray (1989) was used as a base layer, and the merged characteristics of suitable and unsuitable areas were assigned to each polygon in the Morgan County portion of the map. The resultant suitability analysis is shown with major roads for context, and the study site locations and observed OSDS function are also shown. A larger version of the map is included as Plate 1 for printing, if desired. Because there is a wide spatial distribution of hydrogeologic characteristics within each category, as well as across the county, the map is intended to be used as only a guide to understanding the processes that contribute to the proper function, or the failure, of on-site sewage disposal systems. Individual locations should be evaluated for potential problems.

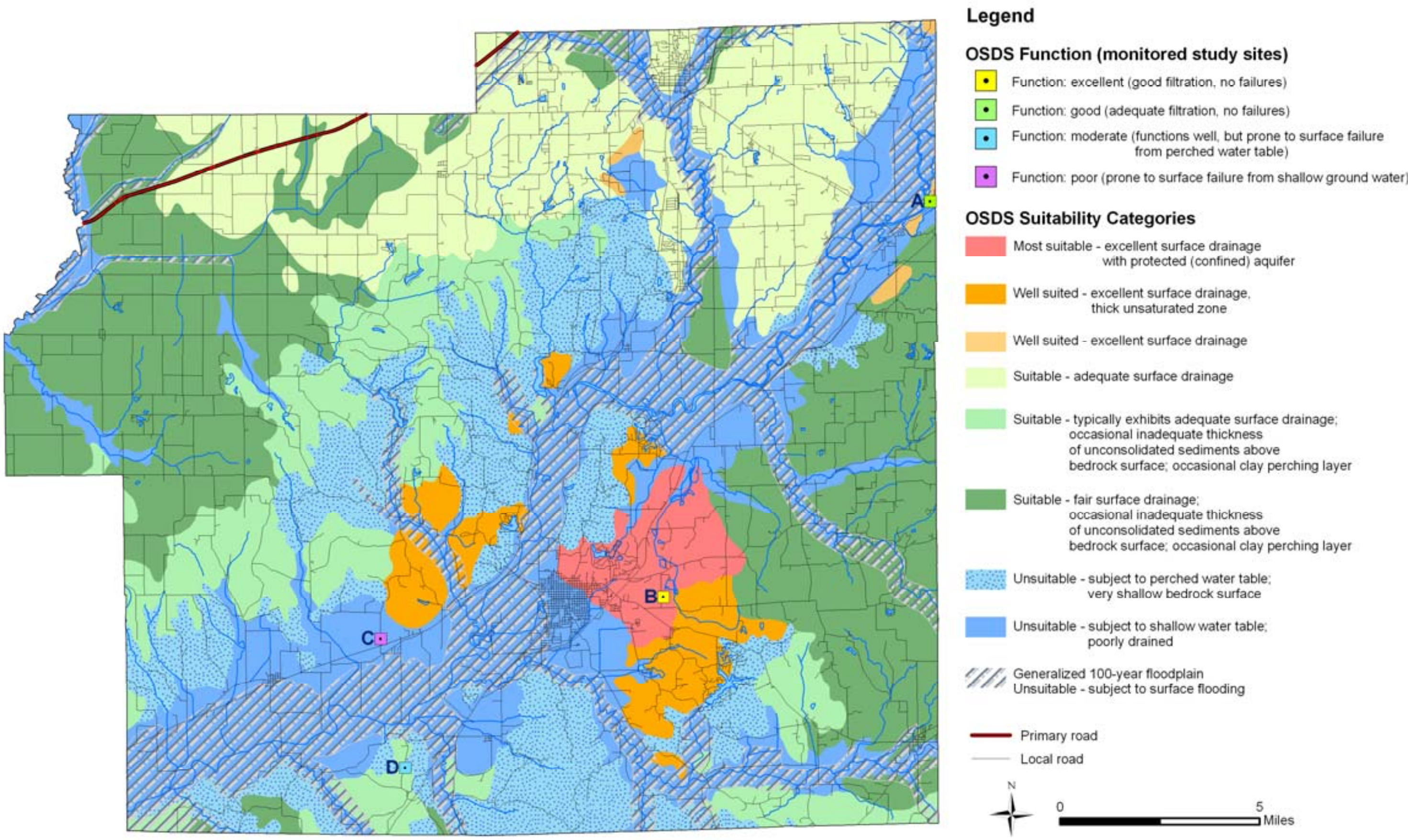

Figure 16. Map showing suitability analysis for on-site septic disposal systems (OSDS) in Morgan County, Indiana. Roads are shown for context. In addition, the locations and observed OSDS function are also shown on the map.

SUMMARY AND RECOMMENDATIONS

At each study site, sensors were installed to measure soil-water tension in the unsaturated zone, soil-moisture content, and water-table elevations. Aluminum access tubes were installed to allow measurements of soil-moisture profiles using a neutron soil-moisture gauge, and pressure-vacuum soil-water samplers were installed to allow water to be extracted from the unsaturated zone for chemical analysis. Measurements of precipitation were made at two of the sites. Each site was monitored for 10 months. Over the course of the study period, which commenced in late October 2004 and ended in late August 2005, samples of water were collected from the saturated or unsaturated zones or both at each of the four study sites on 16 separate occasions. Several of the samples were collected immediately after rain storms. All water samples were analyzed in the laboratories of the Indiana State Department of Health in Indianapolis. On all 16 occasions the water samples were analyzed for nitrogen (nitrate + nitrite). Other parameters were analyzed at other times (see Appendix 1).

Site A (glacial outwash): The highest concentrations of nitrogen at Site A occurred in late spring in association with stormy periods that triggered recharge events. The hydrochemical monitoring showed that nitrate levels moved downward with recharge-driven wetting fronts; however, the permeable sediments provided adequate filtration and elevated nitrate levels were not observed below the instruments located at 3 meters bgs. This site appeared to perform adequately during the period of monitoring.

Site B (interlayered clay, silt, and sand): Although high nitrate levels were observed in the shallow (1-m) observation depth, the topographic setting and geologic materials filtered the leachate to much lower levels with depth. This site appeared to perform well during the period of monitoring.

Site C (sand dune or glacial outwash): Site C had a higher concentration of nitrogen within the saturated zone than the other three study sites. However, the low values of nitrogen concentrations at 1-m and 2-m indicate that either minimal loading was occurring on site or that the nitrogen was readily flushing through the sandy soil and into the shallow zone of saturation. If the nitrogen was flushing into the saturated zone, the system was not functioning as designed. This site flooded twice during the period of monitoring, and both failures were because of water-table rises associated with river flooding.

Site D (loess or bedrock residuum): Nitrogen concentrations at Site D remained consistently low throughout the study. The nitrogen concentrations also decreased with depth, indicating that the nitrogen was being filtered out as the water percolated down through the soil. However, near the end of the study period a very intense rainstorm caused water to pond at the surface; this ponding eventually led to a water-table rise that flooded the OSDS.

The analysis indicated that four recharge periods (net downward flux through the profile) occurred at Site A, two recharge periods at Site B, three recharge periods at Site C, and six recharge periods at Site D. Based on these calculations total recharge was determined to be 5.15 cm/day at Site A, 4.82 cm/day at Site B, 8.34 cm/day at Site C, and 7.55 cm/day at Site D for the recharge period.

The information and understanding of processes gained from the intensive hydrochemical monitoring study described in this report were used in an analysis of on-site sewage disposal systems (OSDS) in Morgan County. Geographic information systems software was used to conduct an analysis of similar hydrogeologic settings that would yield an assessment of the suitability of installing on-site sewage disposal systems in different areas of Morgan County. In this analysis, the following parameters were considered: (1) depth to water table, (2) susceptibility of surface failure of OSDS, (3) permeability of geologic materials and soils, (4), thickness of unconsolidated materials (includes depth to bedrock), (5) topographic setting, and (6) observed function of septic systems studies.

All the available hydrogeological data layers were evaluated in conjunction with the results of the monitoring study, and the input data layers were analyzed to identify the most suitable and least suitable areas for OSDS in Morgan County, Indiana. The characteristics for the *most* suitable areas include:

- Well-drained surficial materials (typically glacial outwash gravel, or sand and gravel);
- Thick unconsolidated materials (> 15 meters);
- Moderately deep to deep water table (> 7.5 meters below ground surface);
- Protected aquifer (either confined aquifer or aquifer with protective capping materials).

Suitable areas for OSDS include similar characteristics, but are modified slightly:

- Well-drained surficial materials (typically glacial outwash gravel, or alluvial sands);
- Thick unconsolidated materials (> 15 meters);
- Moderately deep to deep water table (>7.5 meters below ground surface).

Less suitable areas for OSDS include the following characteristics:

- Poorly drained surficial materials (clays or silty clays);
- Thin unconsolidated materials (<7.5 meters);
- Shallow water table (<7.5 meters below ground surface).

The least suitable areas for OSDS include the following characteristics:

- Poorly drained surficial materials (clays or silty clays);
- Thin unconsolidated materials (<7.5 meters), shallow bedrock;
- Shallow water table (<7.5 meters below ground surface);
- Susceptible to surface failure from surface flooding (located in floodplain);
- Susceptible to surface failure from perched water table.

Recommendations for identifying suitable locations for installation of OSDS in Morgan County, Indiana, would include:

- Continue site-specific evaluation of potential OSDS locations;
- Attempt to assess the presence of adequate unconsolidated material thickness below the proposed OSDS;
- Attempt to assess the permeability of unconsolidated materials and soils at and below the proposed OSDS;
- Avoid locations where surface failures owing to perched water tables or surface flooding might occur.

ACKNOWLEDGEMENTS

Technical staff on this project included Jack Haddan, Matthew Reeder, and Jeff Olyphant, all staff of the Center for Geospatial Data Analysis, Indiana Geological Survey. This project was funded by the Indiana State Department of Health, Grant Number: ISDH PHB 200-11.

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Morgan County Chemistry

Site A	Notes
Location	High Terrace above the white river in northern section of county
Parent Material	Gravel
Well	Water table deeper than well (>23 meters bgs)
L1	Unsaturated zone, vacuum lysimeter at 1 meter bgs
L2	Unsaturated zone, vacuum lysimeter at 2 meters bgs
L3	Unsaturated zone, vacuum lysimeter at 3 meters bgs

Site B	Notes
Location	Upland underlain by ablation till in the east-central part of the county
Parent Material	Interlayered clay, silt, and sand
Well	Water table between 3.4 and 4 meters bgs
L1	Unsaturated zone, vacuum lysimeter at 1 meter bgs
L2	Unsaturated zone, vacuum lysimeter at 2 meters bgs
L3	Unsaturated zone, vacuum lysimeter at 3 meters bgs

Site C	Notes
Location	Low terrace adjacent to the White River in the southwestern part of the county
Parent Material	Sand
Well	Water table varies between 1.3 and 2.5 meters bgs
L1	Unsaturated zone, vacuum lysimeter at 3 foot depth (~ 1 meter bgs)
L2	Varies between saturated and unsaturated zone, vacuum lysimeter at 6 foot depth (~ 2 meters bgs)
L3	Saturated zone, vacuum lysimeter at 3 meters bgs

Site D	Notes
Location	Norman Upland in the south central part of the county
Parent Material	Loess and weathered siltstone
Well	Water table varies between 2.7 and 3 meters bgs
L1	Unsaturated zone, vacuum lysimeter at 1 meter bgs
L2	Unsaturated zone, vacuum lysimeter at 2 meters bgs
L3	Saturated zone, vacuum lysimeter at 3 meters bgs

ISDH lab results for Morgan Co Septic Project
Nitrogen- nitrate+nitrite, mg/L

Sample Date:	12/3/2004	12/16/2004	1/6/2005	1/20/2005	2/2/2005	2/16/2005	3/3/2005	3/17/2005
Site:								
Site A, well	dry	dry	dry	dry	dry	dry	N/A	N/A
Site A, L1	5.1	8.9	10.0	4.6	3.6	3.4	8.5	12.0
Site A, L2	2.6	3.8	4.1	6.8	5.2	4.9	6.5	7.2
Site A, L3	4.4	7.1	10.0	21.0	8.8	9.0	9.8	10.0
Site B, well	5.8	6.6	14.0	6.1	7.5	7.4	9.4	8.8
Site B, L1	54.0	60.0	63.0	60.0	47.0	40.0	38.0	34.0
Site B, L2	7.7	11.0	15.0	25.0	20.0	16.0	16.0	13.0
Site B, L3	6.6	6.6	8.8	6.3	5.9	4.6	8.1	7.2
Site C, well	2.0	30.0	3.6	6.7	9.0	16.0	14.0	15.0
Site C, L1	5.8	6.1	6.1	6.9	3.6	4.4	4.1	3.5
Site C, L2	5.3	5.9	5.8	5.5	4.3	4.0	4.1	4.5
Site C, L3	37.0	37.0	33.0	9.3	10.0	11.0	13.0	14.0
Site D, well	1.7	2.0	5.5	4.7	4.5	5.0	6.4	4.8
Site D, L1	4.5	7.1	7.2	10.0	8.2	7.5	8.3	9.9
Site D, L2	0.6	1.3	2.0	2.7	3.2	3.4	3.5	3.4
Site D, L3	0.5	0.7	0.8	0.9	1.0	0.9	1.1	1.2

Sample Date:	4/7/2005	4/15/2005	4/25/2005	5/3/2005	5/16/2005	5/18/2005	6/14/2005	6/29/2005
Site:								
Site A, well	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Site A, L1	14.0	25.0	29.0	26.0	18.0	12.0	12.0	7.6
Site A, L2	12.0	10.0	10.0	11.0	16.0	23.0	26.0	18.0
Site A, L3	10.0	8.3	8.9	8.1	8.2	7.7	8.2	9.0
Site B, well	9.0	8.2	7.7	6.6	5.6	6.3	8.3	8.8
Site B, L1	18.0	9.2	7.7	3.8	2.2	1.2	2.0	7.2
Site B, L2	13.0	12.0	12.0	13.0	12.0	12.0	12.0	10.0
Site B, L3	6.3	5.2	5.6	7.0	8.3	8.8	11.0	7.1
Site C, well	16.0	16.0	17.0	17.0	14.0	14.0	13.0	11.0
Site C, L1	3.2	1.0	0.5	0.2	< 0.1	< 0.1	0.6	< 0.1
Site C, L2	N/A	3.9	3.6	3.5	3.0	3.3	2.1	< 0.1
Site C, L3	13.0	16.0	16.0	16.0	18.0	17.0	14.0	9.2
Site D, well	4.3	4.6	4.1	3.8	9.5	8.3	12.0	7.1
Site D, L1	10.0	8.0	6.8	4.4	1.7	0.5	0.4	0.6
Site D, L2	3.3	2.7	2.4	2.2	2.2	2.0	1.7	2.1
Site D, L3	1.4	1.1	1.1	1.1	1.1	1.2	2.3	1.7

Nitrogen (nitrate+nitrite)

Site:	Average (mg/L)	max (mg/L)	min (mg/L)
Site A, well	NA	NA	NA
Site A, L1	12.5	29	3.4
Site A, L2	10.4	26	2.6
Site A, L3	9.3	21	4.4
Site B, well	7.9	14	5.6
Site B, L1	28.0	63	1.2
Site B, L2	13.7	25	7.7
Site B, L3	7.1	11	4.6
Site C, well	13.4	30	2
Site C, L1	3.5	6.9	0.2
Site C, L2	4.2	5.9	2.1
Site C, L3	17.7	37	9.2
Site D, well	5.5	12	1.7
Site D, L1	5.9	10	0.4
Site D, L2	2.4	3.5	0.6
Site D, L3	1.1	2.3	0.5

ISDH lab results for Morgan Co Septic Project
Nitrogen- ammonia, mg/L

Sample Date:	12/3/2004	12/16/2004	1/6/2005
Site:			
Site A, well			
Site A, L1	<0.1	<0.1	<0.1
Site A, L2	<0.1	<0.1	<0.1
Site A, L3	<0.1	<0.1	<0.1
Site B, well	<0.1	<.1	<.1
Site B, L1	<0.1	<.1	<.1
Site B, L2	<0.1	<.1	<.1
Site B, L3	1.0	0.5	<.1
Site C, well	<0.1	<0.1	0.3
Site C, L1	<0.1	<0.1	<0.1
Site C, L2	>0.1	<0.1	<0.1
Site C, L3	<0.1	<0.1	<0.1
Site D, well	0.7	0.5	1.4
Site D, L1	<0.1	<0.1	<0.1
Site D, L2	<0.1	<0.1	<0.1
Site D, L3	<0.1	<0.1	<0.1

ISDH lab results for Morgan Co Septic Project
Phosphorus-total mg/L

Sample Date:	12/3/2004	12/16/2004
Site:		
Site A, well		
Site A, L1	0.07	
Site A, L2	0.04	0.05
Site A, L3	0.07	0.07
Site B, well	3.28	1.73
Site B, L1	0.34	0.29
Site B, L2	0.40	0.36
Site B, L3	0.48	0.32
Site C, well	1.70	1.33
Site C, L1	0.13	0.12
Site C, L2	0.06	0.05
Site C, L3	0.06	0.05
Site D, well	0.25	0.17
Site D, L1	<0.03	<0.03
Site D, L2	<0.03	<0.03
Site D, L3	<0.03	<0.03

ISDH lab results for Morgan Co Septic Project
Chloride mg/L

Sample Date:	12/3/2004	12/16/2004	1/6/2005
Site:			
Site A, well			
Site A, L1			
Site A, L2			
Site A, L3			
Site B, well	2160.0	19.0	
Site B, L1			
Site B, L2			
Site B, L3			
Site C, well	1420.0	1230.0	
Site C, L1			
Site C, L2			
Site C, L3			
Site D, well	<5.0	<5.0	7.7
Site D, L1			
Site D, L2			
Site D, L3			

ISDH lab results for Morgan Co Septic Project
Solids-suspended mg/L

Sample Date:	12/3/2004	12/16/2004	1/6/2005
Site:			
Site A, well			
Site A, L1			
Site A, L2			
Site A, L3			
Site B, well	2160	1590	
Site B, L1			
Site B, L2			
Site B, L3			
Site C, well	940	426	
Site C, L1			
Site C, L2			
Site C, L3			
Site D, well	800	415	398
Site D, L1			
Site D, L2			
Site D, L3			

ISDH lab results for Morgan Co Septic Project
TKN mg/L

Sample Date:	12/3/2004	12/16/2004	1/6/2005
Site:			
Site A, well			
Site A, L1			0.5
Site A, L2		0.5	0.4
Site A, L3		0.3	0.2
Site B, well		3.1	0.5
Site B, L1		0.5	1.5
Site B, L2		1.0	0.7
Site B, L3		1.4	0.9
Site C, well		2.8	2.2
Site C, L1		1.5	1.4
Site C, L2		0.9	0.8
Site C, L3		0.1	0.3
Site D, well		0.1	6.7
Site D, L1		0.2	0.1
Site D, L2		0.2	0.2
Site D, L3		0.1	0.1

ISDH lab results for Morgan Co Septic Project
nitrite mg/L

Sample Date:	12/3/2004	12/16/2004	1/6/2005
Site:			
Site A, well			
Site A, L1			
Site A, L2			
Site A, L3			
Site B, well		<0.01	
Site B, L1			
Site B, L2			
Site B, L3			
Site C, well		<0.01	
Site C, L1			
Site C, L2			
Site C, L3			
Site D, well		0.26	
Site D, L1			
Site D, L2			
Site D, L3			

ISDH lab results for Morgan Co Septic Project
BOD-5 mg/L

Sample Date:	12/3/2004	12/16/2004	1/26/2005
Site:			
Site A, well			
Site A, L1			
Site A, L2			
Site A, L3			
Site B, well		<1.0	
Site B, L1			
Site B, L2			
Site B, L3			
Site C, well		<1.0	
Site C, L1			
Site C, L2			
Site C, L3			
Site D, well		<1.0	>26.0
Site D, L1			
Site D, L2			
Site D, L3			

The dilution range for BOD failed to capture the true value of the sample.
The results are therefore reported as >26mg/L

ISDH lab results for Morgan Co Septic Project
CBOD-5 mg/L

Sample Date:	12/3/2004	12/16/2004	1/6/2005
Site:			
Site A, well			
Site A, L1			
Site A, L2			
Site A, L3			
Site B, well		<1.0	
Site B, L1			
Site B, L2			
Site B, L3			
Site C, well		<1.0	
Site C, L1			
Site C, L2			
Site C, L3			
Site D, well		<1.0	
Site D, L1			
Site D, L2			
Site D, L3			

Morgan County Neutron Soil Moisture Measurements

Site A	**Notes**
Location	High Terrace above the white river in northern section of county
Parent Material	Gravel

Site B	**Notes**
Location	Upland underlain by ablation till in the east-central part of the county
Parent Material	Interlayered clay, silt, and sand

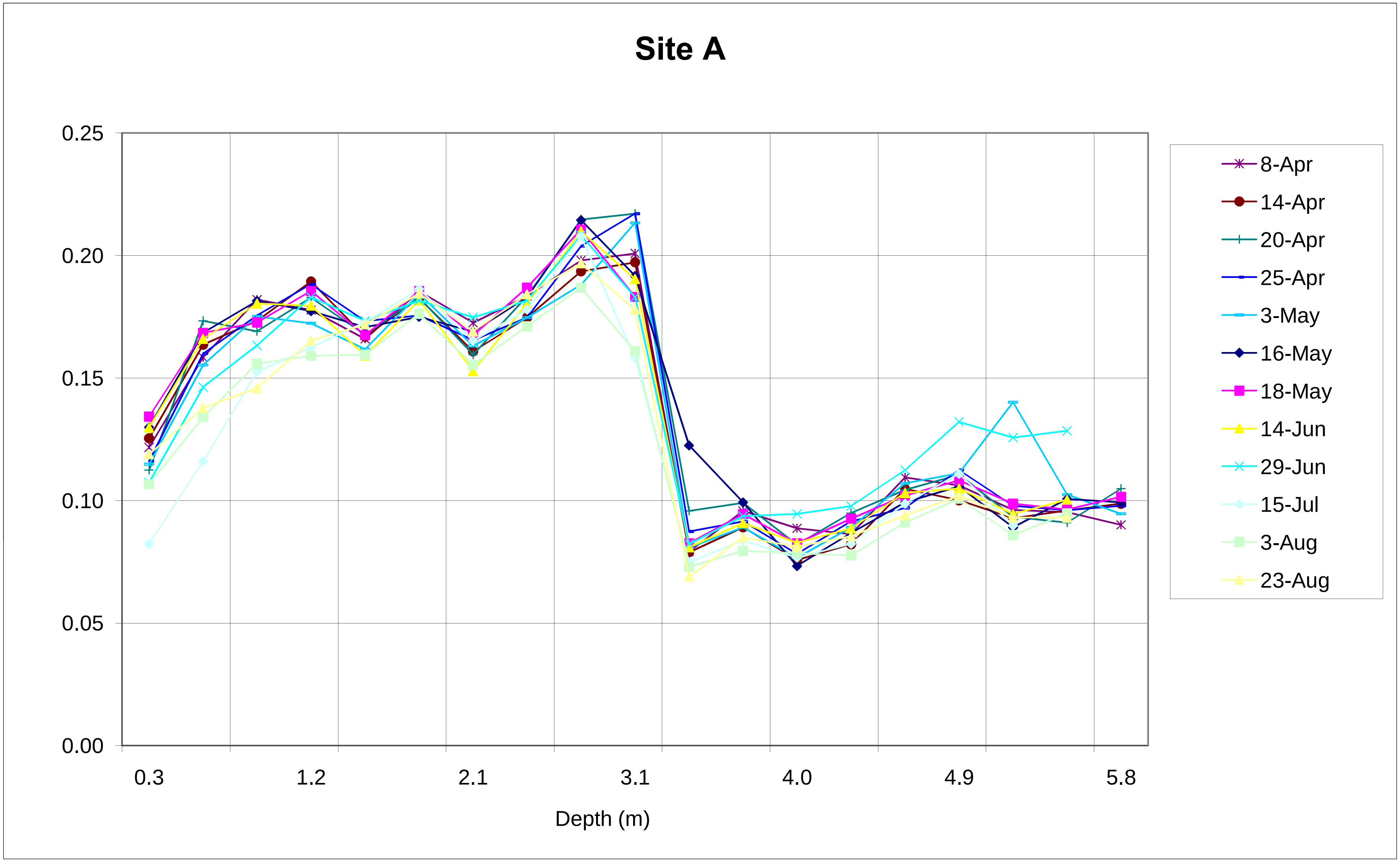
Site C	**Notes**
Location	Low terrace adjacent to the White River in the southwestern part of the county
Parent Material	Sand

Site D	**Notes**
Location	Norman Upland in the south central part of the county
Parent Material	Loess and weathered siltstone

Symbols:	θ	soil moisture fraction
	S	storage (cm)

SITE A

	Depth (m)	Depth (ft)	4/8/2005	4/14/2005	4/20/2005	4/25/2005	5/3/2005	05/16/05	05/18/05	06/14/05	06/29/05	07/15/05	08/03/05	08/23/05
Standard			873	894	865	901	894	886	868	910	898	879	889	872
Counts	0.305	1	283	298	261	280	275	305	308	313	260	201	256	277
	0.610	2	361	381	389	376	363	388	380	393	345	273	315	317
	0.915	3	411	402	380	410	406	416	389	425	382	351	362	334
	1.220	4	402	437	409	438	400	407	416	423	425	372	369	375
	1.525	5	377	388	377	405	377	393	378	378	404	394	370	389
	1.830	6	418	422	409	410	426	402	416	428	422	423	406	416
	2.135	7	391	375	360	388	380	389	378	364	407	378	361	383
	2.440	8	414	405	410	408	405	419	419	425	422	405	395	415
	2.745	9	445	446	476	472	434	487	469	490	480	469	429	442
	3.050	10	451	454	481	501	489	438	411	447	425	363	373	402
	3.355	11	193	197	226	217	201	289	199	205	205	185	183	171
	3.660	12	228	219	233	226	219	239	224	227	230	204	197	205
	3.965	13	213	190	197	197	192	183	199	209	232	189	195	197
	4.270	14	208	204	224	226	219	212	220	222	239	201	193	206
	4.575	15	257	253	244	238	258	239	240	254	271	236	222	224
	4.880	16	250	243	257	272	267	253	253	258	314	262	243	241
	5.185	17	229	227	221	240	330	217	233	235	300	217	211	222
	5.490	18	227	234	216	236	248	242	228	248	306		230	222
	5.795	19	216	240	245	240	231	239	239					
θ	0.305	1	0.122	0.125	0.112	0.116	0.115	0.130	0.134	0.130	0.107	0.082	0.107	0.119
	0.610	2	0.158	0.164	0.173	0.160	0.155	0.168	0.168	0.166	0.146	0.116	0.134	0.138
	0.915	3	0.182	0.173	0.169	0.176	0.175	0.181	0.173	0.180	0.163	0.153	0.156	0.146
	1.220	4	0.178	0.189	0.183	0.188	0.172	0.177	0.185	0.180	0.183	0.162	0.159	0.165
	1.525	5	0.166	0.167	0.168	0.173	0.162	0.171	0.167	0.159	0.173	0.173	0.160	0.172
	1.830	6	0.185	0.183	0.183	0.176	0.184	0.175	0.185	0.182	0.182	0.186	0.176	0.185
	2.135	7	0.173	0.161	0.160	0.165	0.163	0.169	0.167	0.153	0.175	0.165	0.155	0.169
	2.440	8	0.183	0.175	0.183	0.175	0.175	0.183	0.187	0.180	0.182	0.178	0.171	0.184
	2.745	9	0.198	0.194	0.215	0.204	0.188	0.214	0.211	0.210	0.208	0.208	0.187	0.197
	3.050	10	0.201	0.197	0.217	0.217	0.213	0.192	0.183	0.190	0.183	0.158	0.161	0.178
	3.355	11	0.079	0.079	0.096	0.087	0.081	0.123	0.083	0.081	0.082	0.075	0.073	0.069
	3.660	12	0.096	0.089	0.099	0.091	0.089	0.099	0.094	0.091	0.094	0.084	0.079	0.085
	3.965	13	0.089	0.076	0.082	0.078	0.077	0.073	0.083	0.083	0.095	0.077	0.079	0.081
	4.270	14	0.086	0.082	0.095	0.091	0.089	0.087	0.093	0.089	0.098	0.082	0.078	0.085
	4.575	15	0.109	0.105	0.104	0.097	0.107	0.099	0.102	0.103	0.112	0.099	0.091	0.094
	4.880	16	0.106	0.100	0.111	0.113	0.111	0.106	0.108	0.105	0.132	0.111	0.101	0.102
	5.185	17	0.096	0.093	0.093	0.098	0.140	0.089	0.099	0.095	0.126	0.090	0.086	0.093
	5.490	18	0.095	0.096	0.091	0.096	0.102	0.101	0.096	0.100	0.129		0.095	0.093
	5.795	19	0.090	0.099	0.105	0.098	0.095	0.099	0.102					
S	0.305	1	3.709	3.824	3.427	3.541	3.501	3.960	4.093	3.957	3.274	2.511	3.255	3.627
	0.610	2	4.829	4.988	5.283	4.877	4.736	5.135	5.134	5.060	4.461	3.538	4.087	4.202
	0.915	3	5.548	5.283	5.153	5.350	5.339	5.532	5.264	5.501	4.978	4.651	4.750	4.447
	1.220	4	5.418	5.774	5.573	5.740	5.255	5.404	5.654	5.473	5.579	4.951	4.849	5.037
	1.525	5	5.059	5.086	5.109	5.281	4.932	5.206	5.105	4.853	5.286	5.265	4.863	5.238
	1.830	6	5.648	5.563	5.573	5.350	5.619	5.334	5.654	5.542	5.537	5.679	5.371	5.626
	2.135	7	5.260	4.904	4.863	5.044	4.974	5.150	5.105	4.660	5.327	5.037	4.736	5.152
	2.440	8	5.591	5.325	5.588	5.322	5.325	5.574	5.697	5.501	5.537	5.422	5.216	5.612
	2.745	9	6.036	5.900	6.545	6.213	5.732	6.537	6.420	6.397	6.347	6.335	5.695	6.000
	3.050	10	6.122	6.012	6.617	6.617	6.503	5.843	5.582	5.804	5.579	4.822	4.905	5.425
	3.355	11	2.416	2.407	2.920	2.663	2.463	3.734	2.518	2.468	2.506	2.282	2.225	2.102
	3.660	12	2.918	2.715	3.021	2.789	2.715	3.026	2.879	2.771	2.855	2.554	2.422	2.591
	3.965	13	2.703	2.308	2.499	2.385	2.336	2.233	2.518	2.523	2.883	2.340	2.394	2.476
	4.270	14	2.631	2.505	2.891	2.789	2.715	2.644	2.822	2.703	2.981	2.511	2.366	2.606
	4.575	15	3.335	3.192	3.181	2.956	3.262	3.026	3.111	3.144	3.428	3.010	2.775	2.865
	4.880	16	3.235	3.052	3.369	3.429	3.389	3.224	3.299	3.199	4.028	3.381	3.071	3.109
	5.185	17	2.933	2.827	2.847	2.984	4.273	2.715	3.010	2.882	3.833	2.739	2.620	2.836
	5.490	18	2.904	2.926	2.775	2.928	3.122	3.069	2.937	3.061	3.917		2.888	2.836
	5.795	19	2.746	3.010	3.195	2.984	2.884	3.026	3.096					
		S total	79.042	77.601	80.430	79.242	79.074	80.373	79.898	75.496	78.337	67.027	68.486	71.788
Evap total (cm)				3.74	1.96	2.08	4.45	6.55	1.11	10.84	3.41	4.29	10.57	6.09
Precip (cm)				0.31	0.00	1.21								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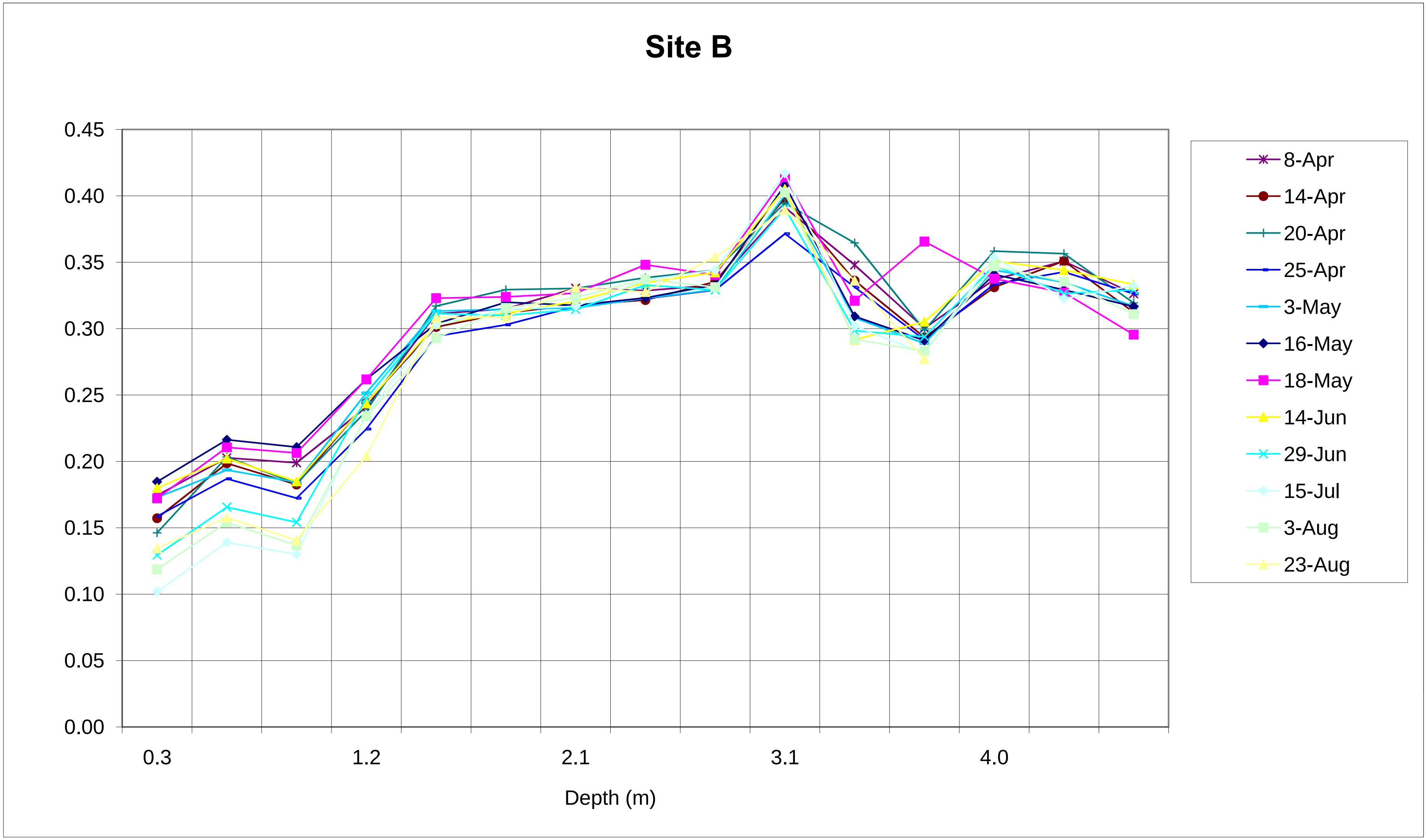
Depth (m)
8-Apr
14-Apr
20-Apr
25-Apr
3-May
16-May
18-May
14-Jun
29-Jun
15-Jul
3-Aug
23-Aug

SITE B

	Depth (m)	Depth (ft)	4/8/2005	4/14/2005	4/20/2005	4/25/2005	5/3/2005	05/16/05	05/18/05	06/14/05	06/29/05	07/15/05	08/03/05	08/23/05
Standard			873	894	865	901	894	886	868	910	898	879	889	872
Counts	0.305	1	395	367	332	373	401	423	388	424	308	243	282	310
	0.610	2	455	457	452	435	446	491	469	473	387	322	358	359
	0.915	3	447	422	410	403	426	479	460	435	362	303	321	323
	1.220	4	536	556	525	517	572	589	577	565	566	527	531	457
	1.525	5	685	680	691	670	706	679	706	697	705	672	658	678
	1.830	6	693	703	717	689	709	714	708	715	702	697	707	679
	2.135	7	726	716	719	719	711	709	714	735	712	702	724	726
	2.440	8	722	724	736	732	727	721	759	766	752	744	754	719
	2.745	9	731	754	748	746	741	742	743	783	744	760	741	775
	3.050	10	855	891	854	839	896	904	898	922	878	916	895	850
	3.355	11	763	756	791	751	695	691	702	671	677	670	656	737
	3.660	12	662	663	653	664	653	652	796	701	667	626	637	612
	3.965	13	740	745	778	756	773	759	737	802	784	781	775	
	4.270	14	769	788	774	776	753	734	715	787	738	714	750	
	4.575	15	717	704	696	740	714	707	648	763	744	735	697	
θ	0.305	1	0.174	0.157	0.146	0.159	0.173	0.185	0.172	0.180	0.129	0.102	0.119	0.135
	0.610	2	0.203	0.199	0.203	0.187	0.194	0.216	0.211	0.202	0.166	0.139	0.154	0.158
	0.915	3	0.199	0.183	0.183	0.172	0.184	0.211	0.206	0.185	0.154	0.130	0.137	0.141
	1.220	4	0.241	0.244	0.238	0.224	0.252	0.262	0.262	0.244	0.248	0.235	0.234	0.204
	1.525	5	0.311	0.301	0.317	0.294	0.313	0.304	0.323	0.303	0.311	0.303	0.293	0.308
	1.830	6	0.315	0.312	0.329	0.303	0.315	0.320	0.324	0.312	0.310	0.315	0.316	0.309
	2.135	7	0.331	0.318	0.330	0.317	0.316	0.318	0.327	0.321	0.315	0.317	0.323	0.331
	2.440	8	0.329	0.322	0.338	0.323	0.323	0.323	0.348	0.335	0.333	0.337	0.337	0.328
	2.745	9	0.333	0.335	0.344	0.329	0.329	0.333	0.341	0.342	0.329	0.344	0.331	0.354
	3.050	10	0.391	0.398	0.395	0.371	0.401	0.408	0.414	0.405	0.391	0.417	0.403	0.389
	3.355	11	0.348	0.336	0.365	0.331	0.308	0.309	0.321	0.292	0.299	0.302	0.292	0.336
	3.660	12	0.300	0.293	0.299	0.292	0.289	0.291	0.366	0.305	0.294	0.281	0.283	0.277
	3.965	13	0.337	0.331	0.358	0.334	0.344	0.341	0.338	0.351	0.348	0.354	0.347	
	4.270	14	0.351	0.351	0.357	0.343	0.335	0.329	0.327	0.344	0.326	0.323	0.335	
	4.575	15	0.326	0.312	0.319	0.326	0.317	0.317	0.295	0.333	0.329	0.332	0.311	
S	0.305	1	5.318	4.792	4.457	4.835	5.269	5.631	5.249	5.487	3.945	3.110	3.621	4.102
	0.610	2	6.180	6.054	6.197	5.698	5.900	6.594	6.420	6.162	5.048	4.237	4.694	4.807
	0.915	3	6.065	5.563	5.588	5.253	5.619	6.424	6.290	5.638	4.699	3.966	4.172	4.289
	1.220	4	7.344	7.443	7.255	6.840	7.668	7.981	7.981	7.430	7.548	7.163	7.135	6.216
	1.525	5	9.485	9.183	9.663	8.970	9.548	9.255	9.845	9.250	9.490	9.232	8.926	9.395
	1.830	6	9.599	9.506	10.040	9.234	9.590	9.751	9.874	9.498	9.448	9.589	9.618	9.410
	2.135	7	10.074	9.688	10.069	9.652	9.618	9.680	9.960	9.774	9.588	9.660	9.858	10.086
	2.440	8	10.016	9.801	10.315	9.833	9.843	9.850	10.611	10.201	10.146	10.259	10.281	9.985
	2.745	9	10.145	10.221	10.489	10.028	10.039	10.147	10.379	10.435	10.035	10.488	10.098	10.790
	3.050	10	11.927	12.144	12.026	11.323	12.214	12.441	12.619	12.351	11.906	12.714	12.270	11.869
	3.355	11	10.605	10.250	11.113	10.098	9.394	9.425	9.787	8.891	9.099	9.203	8.898	10.244
	3.660	12	9.154	8.945	9.112	8.886	8.804	8.873	11.145	9.305	8.959	8.575	8.630	8.446
	3.965	13	10.275	10.095	10.924	10.167	10.488	10.388	10.293	10.697	10.593	10.787	10.577	
	4.270	14	10.691	10.699	10.866	10.446	10.207	10.034	9.975	10.490	9.951	9.831	10.225	
	4.575	15	9.944	9.520	9.735	9.944	9.660	9.652	9.007	10.160	10.035	10.131	9.477	
		S total	136.823	133.904	137.848	131.207	133.862	136.124	139.434	135.770	130.490	128.946	128.479	99.638
Evap total (cm)				3.74	1.96	2.08	4.45	9.19	1.11	10.84	3.41	4.29	10.57	6.09
precip (cm)				0.31	0.00	1.21								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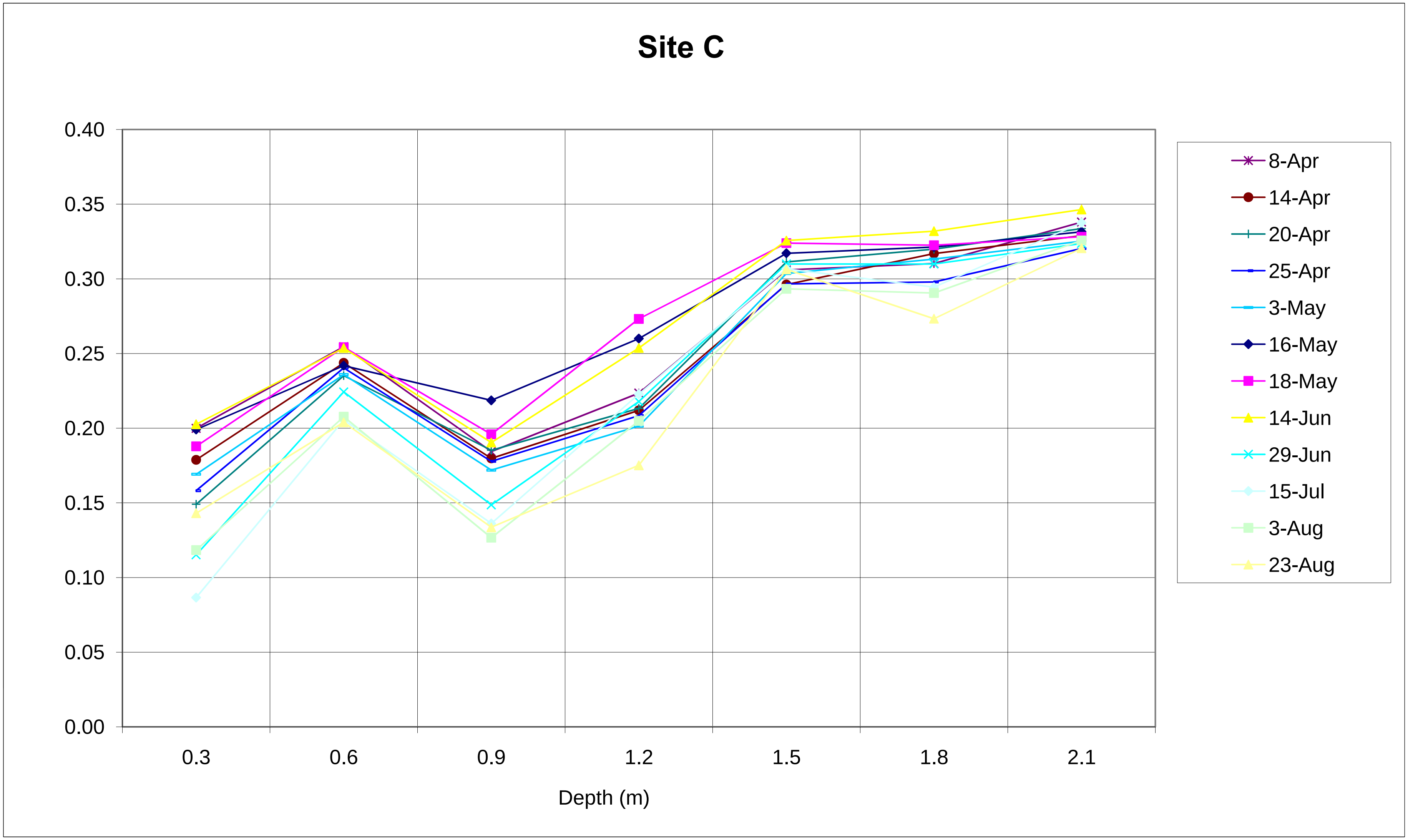
3.1
4.0
Depth (m)
8-Apr
14-Apr
20-Apr
25-Apr
3-May
16-May
18-May
14-Jun
29-Jun
15-Jul
3-Aug
23-Aug

SITE C

	Depth (m)	Depth (ft)	4/8/2005	4/14/2005	4/20/2005	4/25/2004	5/3/2005	05/16/05	05/18/05	06/14/05	06/29/05	07/15/05	08/03/05	08/23/05
Standard			873	894	865	901	894	886	868	910	898	879	889	872
Counts	0.305	1	449	414	338	372	393	454	421	474	277	210	281	328
	0.610	2	565	555	519	552	538	546	561	587	515	464	474	457
	0.915	3	416	416	414	415	399	496	438	447	350	316	299	308
	1.220	4	499	486	473	482	463	585	601	587	501	501	468	396
	1.525	5	674	669	679	675	685	708	708	746	702	680	659	674
	1.830	6	683	714	697	678	706	717	705	760	702	654	653	604
	2.135	7	742	740	726	727	732	739	717	792	732	746	729	704
θ	0.305	1	0.199925	0.179	0.149	0.158	0.169	0.199	0.188	0.203	0.115	0.087	0.118	0.143
	0.610	2	0.254606	0.244	0.235	0.240	0.236	0.242	0.254	0.254	0.224	0.206	0.208	0.204
	0.915	3	0.184369	0.180	0.185	0.178	0.172	0.219	0.196	0.190	0.149	0.136	0.127	0.134
	1.220	4	0.223495	0.212	0.213	0.208	0.201	0.260	0.273	0.254	0.218	0.223	0.205	0.175
	1.525	5	0.305988	0.296	0.311	0.297	0.304	0.317	0.324	0.326	0.310	0.307	0.293	0.306
	1.830	6	0.31023	0.317	0.320	0.298	0.313	0.321	0.323	0.332	0.310	0.294	0.291	0.273
	2.135	7	0.338042	0.329	0.334	0.320	0.325	0.332	0.328	0.346	0.324	0.338	0.326	0.321
S	0.305	1	6.093723	5.451	4.544	4.821	5.156	6.070	5.726	6.176	3.512	2.639	3.607	4.361
	0.610	2	7.760403	7.429	7.168	7.327	7.191	7.372	7.749	7.734	6.836	6.264	6.330	6.216
	0.915	3	5.619581	5.479	5.646	5.420	5.241	6.664	5.972	5.804	4.531	4.152	3.861	4.073
	1.220	4	6.81212	6.461	6.501	6.353	6.139	7.924	8.327	7.734	6.640	6.792	6.246	5.339
	1.525	5	9.326509	9.029	9.489	9.039	9.253	9.666	9.874	9.925	9.448	9.346	8.941	9.338
	1.830	6	9.45582	9.660	9.750	9.081	9.548	9.793	9.830	10.118	9.448	8.975	8.856	8.331
	2.135	7	10.30353	10.025	10.170	9.763	9.913	10.105	10.004	10.559	9.867	10.288	9.928	9.769
		S total	55.37168	53.535	53.268	51.805	52.441	57.595	57.482	58.050	50.282	48.455	47.769	47.426
Evap total (cm)				3.74	1.96	2.08	4.45	1.43	1.11	10.84	3.41	4.29	10.57	6.09
precip (cm)				0.32	0.00	0.78	0.00	0.00	0.00	0.00				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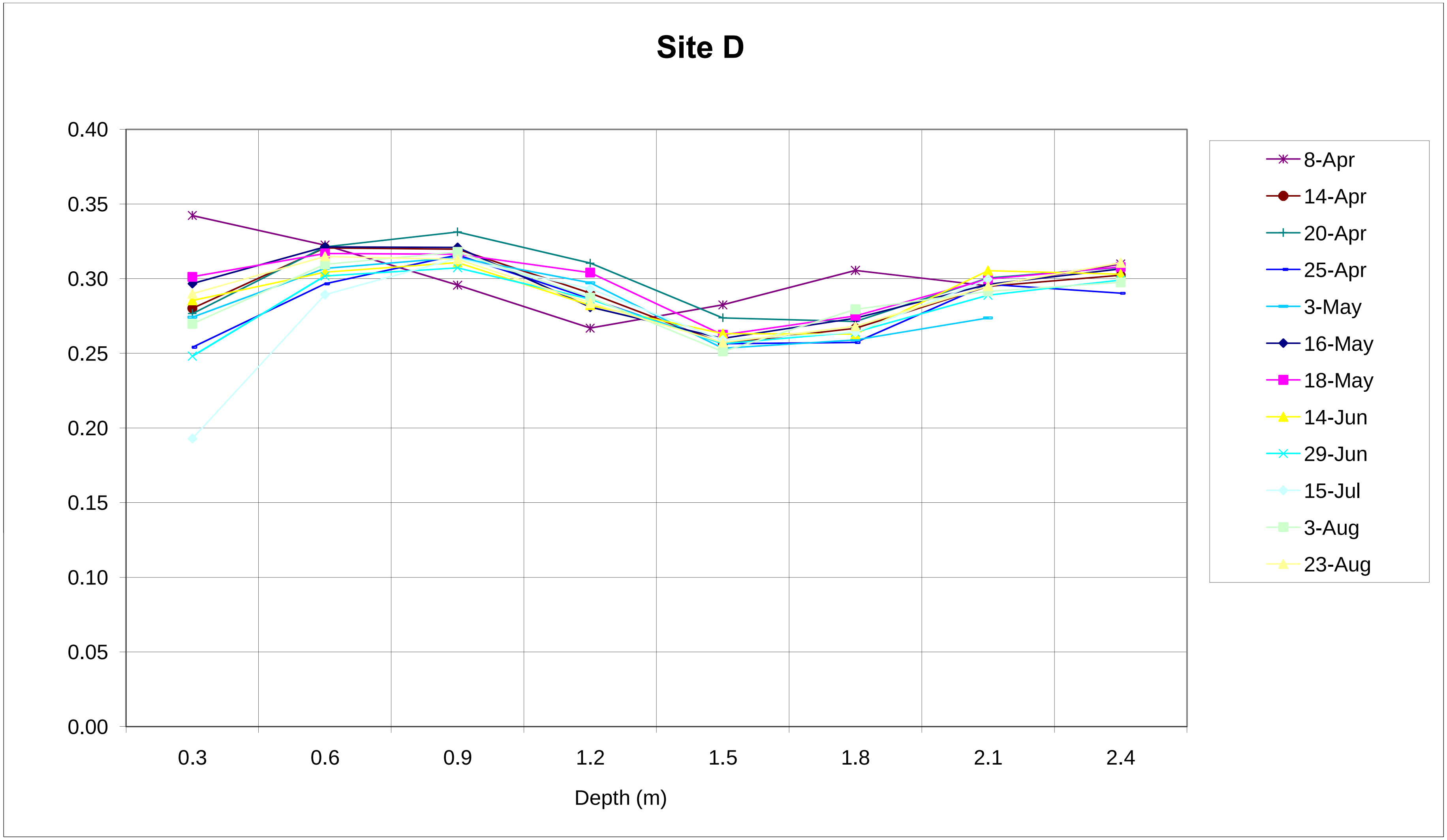
2.1
Depth (m)
8-Apr
14-Apr
20-Apr
25-Apr
3-May
16-May
18-May
14-Jun
29-Jun
15-Jul
3-Aug
23-Aug

SITE D

	Depth (m)	Depth (ft)	4/8/2005	4/14/2005	4/20/2005	4/25/2005	5/3/2005	05/16/05	05/18/05	06/14/05	06/29/05	07/15/05	08/03/05	08/23/05
Standard			873	894	865	901	894	886	868	910	898	879	889	872
Counts	0.305	1	751	634	606	582	621	664	660	657	567	437	608	639
	0.610	2	709	722	700	675	692	717	693	699	684	643	694	692
	0.915	3	652	720	721	717	708	716	692	713	696	695	712	688
	1.220	4	591	656	677	653	671	630	666	650	650	651	646	626
	1.525	5	624	583	600	587	576	585	578	608	585	578	568	570
	1.830	6	673	605	595	589	588	614	605	607	602	589	629	593
	2.135	7	651	666	656	674	620	663	657	701	656	665	655	650
	2.440	8	682	682	671	661		685	674	696	678		668	683
θ	0.305	1	0.342285	0.280	0.277	0.254	0.274	0.297	0.301	0.285	0.248	0.193	0.270	0.290
	0.610	2	0.322486	0.321	0.321	0.297	0.307	0.321	0.317	0.304	0.302	0.289	0.310	0.315
	0.915	3	0.295617	0.320	0.331	0.316	0.314	0.321	0.316	0.311	0.307	0.314	0.318	0.313
	1.220	4	0.266863	0.290	0.310	0.287	0.297	0.281	0.304	0.282	0.286	0.293	0.287	0.284
	1.525	5	0.282418	0.257	0.274	0.256	0.253	0.260	0.262	0.263	0.256	0.259	0.251	0.257
	1.830	6	0.305516	0.267	0.271	0.257	0.259	0.273	0.275	0.263	0.264	0.264	0.279	0.268
	2.135	7	0.295146	0.295	0.300	0.296	0.274	0.296	0.300	0.305	0.289	0.300	0.291	0.295
	2.440	8	0.309759	0.302	0.307	0.290		0.306	0.308	0.303	0.299		0.297	0.311
S	0.305	1	10.43284	8.538	8.430	7.745	8.355	9.043	9.180	8.698	7.562	5.878	8.221	8.834
	0.610	2	9.829387	9.772	9.793	9.039	9.352	9.793	9.657	9.277	9.197	8.818	9.434	9.597
	0.915	3	9.010414	9.744	10.098	9.624	9.576	9.779	9.642	9.470	9.364	9.560	9.688	9.539
	1.220	4	8.13397	8.846	9.460	8.733	9.057	8.562	9.267	8.602	8.722	8.932	8.757	8.647
	1.525	5	8.608112	7.822	8.343	7.814	7.724	7.924	7.995	8.023	7.814	7.890	7.657	7.842
	1.830	6	9.312141	8.131	8.271	7.842	7.892	8.335	8.385	8.009	8.051	8.047	8.517	8.172
	2.135	7	8.996046	8.987	9.155	9.026	8.341	9.029	9.137	9.305	8.805	9.132	8.884	8.992
	2.440	8	9.441452	9.211	9.373	8.845		9.340	9.382	9.236	9.113		9.068	9.467
		S total	73.76436	71.052	72.921	68.668	60.298	71.805	72.645	70.621	68.628	58.259	70.227	71.090
Evap total (cm)				3.74	1.96	2.08	4.45	5.70	1.11	10.84	3.41	4.29	10.57	6.09
Precip (cm)				0.32	0.00	0.78	0.00	0.00	0.00	0.00				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Depth (m)
8-Apr
14-Apr
20-Apr
25-Apr
3-May
16-May
18-May
14-Jun
29-Jun
15-Jul
3-Aug
23-Aug

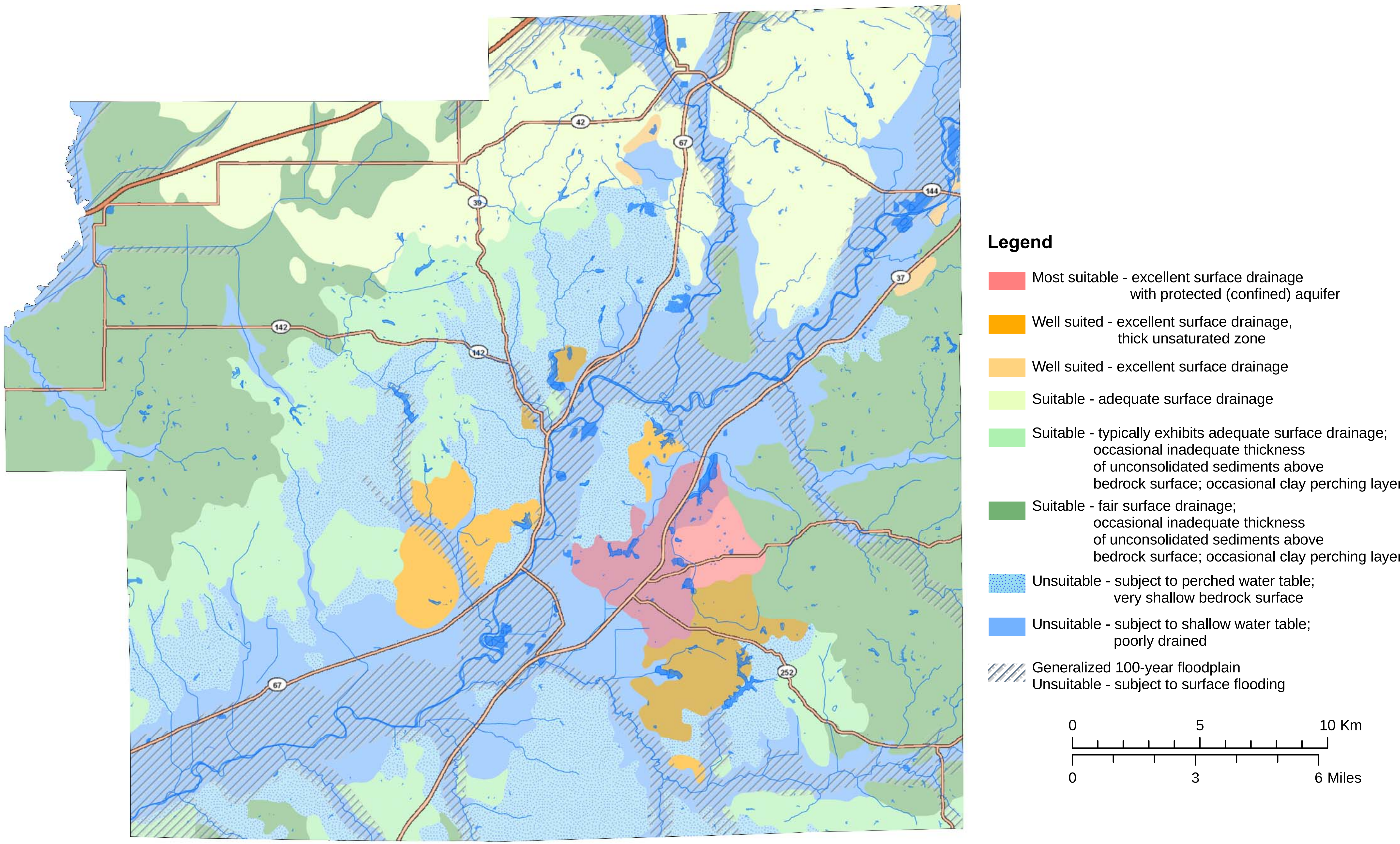

Plate 1. Map showing suitability analysis for on-site sewage disposal systems (OSDS) in Morgan County, Indiana.