Jim Doolittle
copies distributed 8/27/98

United States Department of Agriculture | Natural Resources Conservation Service | 5 Radnor Corporate Center, Suite 200 Radnor, PA 19087-4585

Subject: SOI -- Wet-Soils Monitoring Project -- Jasper County, Indiana

Date: 21 August 1998

To: Warren C. Lynn
Research Soil Scientist
NSSC, MS 41
USDA Natural Resources Conservation Service
100 Centennial Mall North, Room 152
Lincoln, Nebraska 68508-3866

Philip J. Schoeneberger
Research Soil Scientist
NSSC, MS 41
USDA Natural Resources Conservation Service
100 Centennial Mall North, Room 152
Lincoln, Nebraska 68508-3866

Purpose:
The purpose of this investigation was to provide data on water table depths. This study supports the Wet Soil Monitoring Project in Jasper County, Indiana.

Participants:
Jim Doolittle, Research Soil Scientist, USDA-NRCS, Radnor, PA
Byron Jenkinson, Research Assistant, Purdue U., Lafayette, IN

Activities:
All field activities were completed on 11 August 1998.

Equipment:
The radar unit was the Subsurface Interface Radar (SIR) System-2, manufactured by Geophysical Survey Systems, Inc.♣ The SIR System-2 consists of a digital control unit (DC-2) with keypad, VGA video screen, and connector panel. The system was powered by a 12-volt battery. This unit is backpack portable and requires two people to operate. A 200 mHz antenna was used in this study. A scanning time of 190 nanoseconds (ns) and a scanning rate of 32 scan/second were used in this survey.

Discussion:
At the time of this survey, the water table was moving downwards in the soils. Radar surveys were conducted by pulling the 200 mHz antenna by hand along all but two traverse lines. Two traverse

♣ Manufacturer's names are provided for specific information; use does not constitute endorsement.

lines were accessible by 4WD vehicle. These traverse lines were surveyed with the antenna towed behind the 4WD vehicle.

Water levels at sixteen monitoring wells were measured immediately following the radar survey. These depths were used to verify and scale the radar imagery, and to estimate water table depths across the study site. Radar traverses were conducted along the two lines containing the monitoring wells. The measured depths were compared with the interpreted depths to the water table. These data were used to confirm the dielectric permittivity and velocity of propagation of electromagnetic energy through the coarse-textured materials. This information was used to depth scale for the radar profiles and perdict water table depths at all observation points.

The measured and the scaled interpreted (from radar imagery) depths to the water table at the sixteen monitoring wells (two radar interpretations were made at well 7B) were compared. At these wells, the depth to the water table ranged from 0.78 to 9.28 meters. The coefficient of determination (r^2) between the measured depth and interpreted depth was 0.999. This relationship is unprecedented and is considered coincidental. At the sixteen wells, differences between measured and interpreted depths to the water table averaged 0.08 m, and ranged from -0.12 to 0.18 m.

Based on the averaged round-trip travel time to the water table, the velocity of propagation was estimated to be 0.1366 m/ns. The dielectric permittivity was estimated to be about 4.8.

The maximum depth of observation was estimated by the equation:

$$D = VT/2$$

Where D is the depth of observation, V is the velocity of propagation, and T is the two-way travel time of a radar pulse. According to this equation, with a scanning time of 190 ns and velocity of propagation of 0.1366 m/ns, the maximum, theoretical observation depth was about 12.98 m.

Six, ground-penetrating radar surveys of the Jasper County site have been completed. These surveys were completed in May, July, and September of 1997; and January, May, and August of 1998. Surveys were completed with a 300 mHz (May 1997), 200 mHz (July 1997, January, May, and August 1998), and 120 mHz antenna (September 1997). Velocity of signal propagation, resolution and penetration depth vary with antenna and time of year. At this site and for this application, the 200 mHz antenna provides the best balance of observation depth and resolution. This antenna will be used on all subsequent surveys.

Table 1

	# of WELL *OBSERVATIONS*	**MIN. *DEPTH***	**MAX. *DEPTH***	***R^2***	**MAXIMUM *DIFFERENCE***	**AVERAGE *VELOCITY***	**DIELECTRIC *PERMITTIVITY***
May 1997	7	0.00	9.73	0.993	0.43	0.1245	5.9
July 1997	15	0.75	9.22	0.995	0.22	0.1465	4.2
Sept. 1997	16	1.50	9.46	0.998	0.50	0.1190	6.6
Jan 1998	16	0.63	9.86	0.998	0.28	0.1410	4.6
May 1998	16	0.00	8.71	0.986	0.65	0.1242	5.8
Aug. 1998	16	0.78	9.28	0.999	0.18	0.1366	4.8

With each survey, the number of comparisons made between observed and interpreted water table depths has varied. The observed depths to the water table varied with the season. Minimum water table depths (0.0 m) were observed (in low-lying inter-dune areas) during the surveys conducted in May of each year. The maximum water table depth measured was 9.86 m. This measurement was recorded in January on the crest of a dune.

The correlations between observed and interpreted depths to the water table were high (r^2 ranged from 0.993 to 0.999). The strength of these correlations confirms the uniform velocity of signal propagation through these coarse-textured soils to the water table. The maximum difference between observed and interpreted depth to the water table was 0.65 m (May 1998).

Velocity of propagation varied with the time of the year and the antenna used. Velocities, though rather uniform, varied from 0.1190 to 0.1465 m/ns. Differences are principally dependent on changes in soil moisture contents. Within the study site, the dielectric permittivity of the sandy soil materials above the water table ranged from 4.2 to 6.6. These permittivities conform to tabled values for *dry sands*.

Radar Interpretations of water table:
On radar profiles collected within the Jasper County site, the water table appears as two, smooth and uniform lines. Typically, these lines are segmented into sections of varying amplitude. The amplitude of this interface varies from weak to strong. The strength (amplitude) of this reflection indicates the degree of contrast in dielectric properties across this interface. Differences in dielectric permittivity are due primarily to changes in soil moisture contents. The strength and interpretability of this interface are also influenced by the depth and presence of overlying, contrasting and/or conductive layers. System parameters, such as antenna and gain selections, also influence the strength and interpretability of the water table.

Within the Jasper County site, on radar profiles, the image of the water table is smooth and does not appear as irregular or chaotic as strata within the parent material. However, in areas of contrasting, inclined strata, the water table may appear disrupted and imbricated. In areas where the water table is perched, its image is smoother, less segmented and irregular than the underlying, restrictive layer.

Inclined strata that intercept and pass through the water table, are more discernible (higher signal amplitudes) immediately above this interface. The amplitudes of these strata become fainter at greater distances from the water table. At the water table, the images of these strata often end abruptly. These strata are believed to provide preferential flow paths for moisture through flow. Above the water table, these strata are believed to have a higher moisture content and therefore more expressed than adjacent, drier strata. Below the water table, all strata are saturated and differences caused by grain sizes are suppressed. In saturated materials, the lack of contrast in dielectric properties makes these strata indiscernible on radar profiles.

At the ranges needed to adequately profile the site, antennas were often unable to resolve the water table at shallow depths (less than 1 m). At depths of less than 1 meter, reflections from the water table were often masked by reflections from the soil surface, near surface soil horizons, wetting fronts, and features such as tree roots. The use of a higher frequency antenna with a lower range setting could improve the resolution of the water table at these shallow depths. However, the results do not appear to justify the added time and labor needed to perform multiple traverses with different antennas.

Summary:

1. All radar imageries have been stored on disc. At each observation point, the depth to the water table has been predicted from the radar imagery. Hard copies of the radar profile were prepared and given along with the data set to Byron Jenkinson.

2. In October, Byron Jenkinson will present the results of this study at the Annual Meeting of the American Society of Agronomy in Baltimore, Maryland.

3. The next radar survey will be conducted in October 1998.

With kind regards,

James A. Doolittle
Research Soil Scientist

cc:

J. Culver, Acting Director, USDA-NRCS, National Soil Survey Center, Federal Building, Room 152, 100 Centennial Mall North, Lincoln, NE 68508-3866

W. Hosteter, Assistant State Soil Scientist, USDA-NRCS, RR #2, Box 90, Frankfort, IN 46041

J. Kimble, Supervisory Soil Scientist, USDA-NRCS, National Soil Survey Center, Federal Building, Room 152, 100 Centennial Mall North, Lincoln, NE 68508-3866

B. Jenkinson, Graduate Student, Agronomy Department, Purdue University, West Lafayette, IN 47907

T. Neely, State Soil Scientist/MO Leader, USDA-NRCS, Indianapolis, IN

The following tables list the observation points, surface elevations, and depths to water table as predicted from interpretation of GPR records. All measurements are in meters. Tables are arranged by traverse lines.

The water table is not always discernible at shallow soil depths. In May 1997, the water table was not discernible within depths of 0.93 m of the surface. In July 1997, the water table was not discernible within depths of 0.96 m of the surface. In September 1997, the water table was observable at all observation points. In January 1998, the water table could not be seen within depths of 0.67 m of the soil surface. In May 1998, the water table could not be interpreted within depths of 0.38 m of the soil surface. Ponded conditions are represented as 0.02 m. In August 1998, the water table was observable at all observation points.

	ELEVATION	MAY-97 PREDICTED	JULY-97 PREDICTED	SEPT.-97 PREDICTED	JAN-98 PREDICTED	MAY-98 PREDICTED	AUG.-98 PREDICTED
Mid-Road							
South	214.89	0.93	1.08	1.89	1.23	0.38	1.25
	214.76	0.93	1.03	1.74	1.23	0.38	1.25
	214.81	0.93	1.03	1.74	1.31	0.38	1.32
	214.86	0.93	1.13	1.74	1.31	0.38	1.32
	215.43	0.93	1.11	1.99	1.31	0.50	1.44
	215.47	0.93	1.11	2.23	1.31	1.34	1.32
	215.96	1.32	1.84	2.43	2.28	0.98	2.33
	215.02	0.93	1.52	2.28	1.71	0.92	1.79
	215.04	0.93	1.31	1.99	1.63	0.38	1.63
	215.01	0.93	1.03	1.79	0.99	0.38	1.21
	214.92	0.93	0.96	2.03	0.91	0.38	1.09
	214.82	0.93	0.96	1.89	0.67	0.38	0.93
North	214.79	0.93	0.96	1.79	0.67	0.62	1.01
North Road							
East	215.41	.00	0.96	2.03	0.59	0.38	0.86
	216.26	1.85	2.20	3.31	2.32	1.40	2.57
	218.51	3.47	3.65	3.94	5.09	3.19	4.43
	218.15	3.15	3.12	4.48	4.61	2.89	4.20
	217.39	2.43	2.45	3.70	3.56	2.29	3.34
	215.95	1.58	1.64	2.52	1.55	1.16	1.63
	215.44	0.93	1.16	1.99	1.39	0.68	1.32
	215.59	1.00	1.54	2.13	1.55	0.74	1.59
	214.91	0.93	0.96	1.74	0.95	0.38	1.01
	214.72	0.93	0.96	1.79	0.71	0.38	0.93
	214.99	0.93	0.96	1.89	0.67	0.38	1.17
	214.89	0.93	0.96	1.79	0.67	0.38	1.01
	215.01	0.93	0.96	1.89	0.59	0.38	1.25
	214.89	0.93	0.96	1.89	0.71	0.38	1.09
	214.98	0.93	0.96	2.08	0.71	0.38	1.25
	214.88	0.93	0.96	1.74	0.71	0.38	1.25
	214.94	0.93	0.96	1.84	0.71	0.38	1.09
	214.90	0.93	0.96	1.79	0.67	0.38	1.17
	215.00	1.13	1.20	2.38	1.55	0.38	1.40
	217.53	1.78	1.99	3.75	4.45	2.71	2.88
	222.07	6.99	6.75	7.02	7.66	6.48	7.46
	223.03	7.78	7.79	8.15	8.47	7.37	8.01
	223.21	7.19	7.21	7.66	8.87	7.43	8.47
	222.89	6.15	6.12	6.49	8.55	6.00	7.85
	221.28	4.26	4.33	5.21	7.26	4.56	6.61
West	219.71	2.82	2.86	3.75	6.14	2.83	5.60

	ELEVATION	MAY-97 PREDICTED	JULY-97 PREDICTED	SEPT.-97 PREDICTED	JAN-98 PREDICTED	MAY-98 PREDICTED	AUG.-98 PREDICTED
West Road							
North	217.44	2.82	2.84	3.60	3.72	2.83	3.27
	218.61	3.87	3.75	4.58	4.69	3.79	4.82
	218.78	4.06	3.77	4.63	4.85		
	218.37	4.52	4.72	5.36	5.82	4.27	4.51
	218.90	5.56	6.19	6.73	7.42	5.64	5.29
	219.82	3.87	3.87	4.68	5.01	3.85	7.07
	218.08	2.56	2.68	3.45	3.56	2.53	4.59
	216.50	2.63	3.04	3.75	3.81	2.65	3.11
	216.76	1.13	1.84	2.52	2.04	1.16	3.58
	215.01	0.93	1.18	1.99	1.15	0.38	2.02
	214.25	0.93	1.20	2.03	0.91	0.38	1.25
	214.10	0.93	0.96	2.18	0.67	0.38	1.01
	214.11	0.93	0.96	1.99	6.30	0.38	1.09
	213.97	0.93	0.96	1.99	0.67	0.38	0.93
	214.07	0.93	0.96	1.99	0.67	0.38	0.93
South	213.84	0.93		1.99	0.67	0.38	0.78
South Road							
West	213.84	0.93	0.96	1.99	0.67	0.38	0.78
	214.26	0.93	0.96	1.74	0.91	0.38	1.17
	214.29	0.93	0.96	1.79	0.91	0.38	1.01
	214.71	0.93	1.36	2.28	1.31	0.38	1.56
	214.88	0.93	1.61	2.43	1.79	0.38	1.71
	215.28	1.58	1.92	2.67	2.20	1.34	2.49
	217.72	3.67	3.55	4.38	4.85	3.25	4.28
	217.78	3.54	3.85	4.72	5.09	3.13	4.59
	214.80	1.00	1.16	2.38	1.55	0.74	1.71
	214.66	0.93	1.16	2.08	1.31	0.38	1.40
	214.58	0.93	1.11	1.79	1.03	0.38	1.17
	214.60	0.93	1.06	1.84	0.95	0.38	1.17
	214.57	0.93	1.08	1.79	0.91	0.38	1.17
	214.72	0.93	1.08	1.89	1.23	0.38	1.25
	214.92	1.00	1.31	2.08	1.31	0.68	1.40
	215.75	1.45	1.82	2.62	2.12	1.40	2.02
	215.82	1.45	1.99	2.67	2.36	1.52	2.26
	217.45	3.08	3.12	3.89	3.89	2.89	3.65
	219.34	5.36	5.00	5.75	6.22	4.68	5.52
	220.97	6.99	7.00	7.37	7.99	6.78	7.38
	216.87	2.17	2.61	3.8	4.37	2.18	3.34
	215.90	1.52	2.12	2.87	2.60	1.58	2.64
	214.73	1.00	1.38	2.13	1.31	0.62	1.48
	214.34	0.93	0.96	1.99	0.99	0.38	0.93
	214.43	0.93	0.96	1.94	0.63	0.38	0.78
	214.31	0.93	0.96	1.89	0.59	0.38	0.78
East	214.50	0.93	0.96	1.74	0.59	0.80	0.78
East Road							
South	214.50	0.93	0.96	1.74	0.59	0.38	0.78
	214.29	0.93	0.96	1.79	0.67	0.38	0.86
	214.34	0.93	0.96	1.79	0.67	0.38	0.86
	214.59	0.93	1.01	1.89	0.67	0.38	0.78
	214.69	0.93	1.36	1.79	0.63	0.38	1.17
	214.64	0.93	0.96	1.79	0.67	0.38	0.93
	214.68	0.93	0.96	1.79	0.67	0.38	0.86
	214.72	0.93	0.96	1.74	0.67	0.38	0.86
	214.85	0.93	0.96	1.79	0.67	0.38	0.78
	214.71	0.00	0.96	1.84	0.67	0.02	0.86
	214.69	0.00	0.96	1.89	0.67	0.02	0.86
	214.77	0.00	0.96	1.89	0.67	0.02	0.78
	214.88	0.00	0.96	1.94	0.67	0.02	0.62
North	214.85	0.00	0.96	1.94	0.67	0.02	0.62

	ELEVATION	MAY-97 PREDICTED	JULY-97 PREDICTED	SEPT.-97 PREDICTED	JAN-98 PREDICTED	MAY-98 PREDICTED	AUG.-98 PREDICTED
Interior (north)							
East	214.85	0.93	0.96	2.72		2.23	3.5
	217.30	1.78	2.25	3.26	3.16	2.06	3.03
	216.94	1.52	1.97	2.82	3.40	1.88	2.88
	221.66	6.67	6.44	3.06	7.58	1.88	7.15
	223.22	8.04	7.87	6.88	8.47	7.07	7.85
	222.67	7.78	7.72	9.18	6.14	8.03	7.93
	220.03	4.71	4.51	7.85	4.37	7.37	5.60
	217.88	2.63	3.01	5.65	4.29	4.39	3.42
	218.37	2.95	3.19	4.09	3.89	2.18	3.89
	217.59	2.37	2.68	4.04	2.68	2.65	3.65
	216.87	1.71	2.20	3.89	1.96	2.12	2.49
	216.33	0.93	1.59	2.87	1.55	1.58	1.79
	215.21	0.93	1.52	2.28	1.23	1.10	1.94
	215.03	0.93	1.01	2.13	1.15	0.86	1.25
	214.91	0.93	1.03	1.74	1.03	0.38	0.86
	214.82	0.93	0.96	1.94	0.67	0.38	1.01
	214.72	0.93	0.96	2.08	0.67	0.38	1.01
	214.79	0.93	0.96	1.94	0.67	0.38	1.01
	214.80	0.93	0.96	1.74	0.67	0.38	0.78
	214.77	0.93	0.96	1.79	0.67	0.02	0.78
	214.81	0.93		1.74	0.67	0.38	0.86
	214.60	0.93		1.74	0.67	0.38	1.01
	214.58	0.93		1.74	0.67	0.38	1.01
West	216.50	2.63	3.04	2.18		2.53	0.86
Interior (south)							
West	214.10	0.93	0.96	1.99		0.20	
	214.69	0.93		2.13	0.67	0.38	0.86
	214.77	0.93	0.96	1.99	0.67	0.38	1.25
	214.76	0.93	0.96	2.33	0.75	0.38	1.01
	214.75	0.93	1.11	2.13	0.99	0.38	1.25
	215.47	1.06	1.56	2.43	1.71	0.92	1.87
	216.08	1.32	2.10	3.11	2.44	1.70	2.41
	215.01	0.93	0.96	1.84	1.07	0.38	1.32
	215.03	0.93	1.03	2.03	0.91	0.38	1.25
	215.03	0.93	1.01	2.03	1.07	0.38	1.17
	215.06	0.93	0.96	1.89	1.07	0.38	1.17
	215.08	0.93	0.96	1.79	1.27	0.38	1.17
	215.22	0.93	0.96	1.99	1.31	0.38	1.25
	215.39	0.93	0.96	1.99	1.39	0.38	1.17
	215.91	0.93	1.64	2.28	2.04	0.98	1.79
	218.43	3.41	3.52	5.51	5.17	3.07	5.99
	218.45	3.41	3.57	5.26	5.17	3.07	4.28
	218.64	3.60	3.85	4.77	5.33	3.13	4.51
	219.82	4.52	4.49	5.12	5.57	4.21	4.98
	223.16	8.36	8.25	8.15	9.43	7.79	8.47
	224.49	10.06	10.03	9.66	10.72	8.75	10.18
	224.26	9.73	9.93	9.52	10.4	8.87	10.03
	219.17	4.13	4.36	4.97	5.57	3.91	4.98
	215.06	0.93	0.96	2.03	0.75	0.38	0.93
	215.08	0.93	0.88	2.03	0.67	0.02	0.86
	215.38	0.93	0.83	2.18	0.67	0.38	0.78
East	214.68	0.93	0.96	1.79			