A National Database of Subgrade Soil-Water Characteristic Curves and Selected Soil Properties for Use with the MEPDG

DETAILS

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A NATIONAL DATABASE OF SUBGRADE SOIL-WATER CHARACTERISTIC CURVES AND SELECTED SOIL PROPERTIES FOR USE WITH THE MEPDG

This digest summarizes key findings from NCHRP Project 9-23A, "Implementing a National Catalog of Subgrade Soil-Water Characteristic Curve (SWCC) Default Inputs for Use with the MEPDG" conducted by Arizona State University, Tempe, AZ. The digest was prepared from the project final report authored by Claudia E. Zapata, Arizona State University. The final report and Appendices A through D are available on the TRB website (www.trb.org) as *NCHRP Web-Only Document 153.* The interactive National Database is available on a DVD from NCHRP upon request to eharriga@nas.edu.

CONTENTS

INTRODUCTION

The *Mechanistic-Empirical Pavement Design Guide* (MEPDG) was developed in NCHRP Project 1-37A to give pavement designers a tool to assess, for a specific design problem, the sensitivity of the critical parameters that influence pavement performance.

Within the MEPDG, the Enhanced Integrated Climatic Model (EICM) is the engine that handles the input, collection, characterization, and analysis of environmental and material properties that determine the stiffness or modulus of unbound materials. This stiffness, in turn, significantly influences the pavement distresses predicted by the MEPDG. The EICM requires two main categories of input parameters in order to accurately predict the environmental factors: climatic information and material properties for unbound (granular base, subbase, and subgrade) materials. The necessary climatic information is readily available to the pavement designer in the form of a database within the MEPDG that contains historical weather data from more than 800 stations of the U.S. National Weather Service, with hourly information that includes precipitation, temperature, wind speed, cloud cover, and relative humidity. The unbound material information required by the MEPDG, on the other hand, ranges from routine index properties, which are well known to pavement engineering practitioners and researchers and are used in design Levels 2 and 3, to a specialized set of moisture retention parameters (soil-water characteristic curves, SWCC) that are required for Level 1 designs and are fundamental to predicting the moisture content and soil stiffness of the subgrade and unbound pavement layers. SWCC are commonly used by the agricultural sciences and unsaturated soil mechanics communities, but are relatively unfamiliar to the pavement community.

The objective of NCHRP Project 9-23A was to create a national database of pedologic soil families that contains the soil properties for subgrade materials needed as input to the MEPDG. The database focuses upon the parameters describing the SWCC, which are key parameters in the implementation of MEPDG Level 1 environmental analysis, but also includes measured soil index properties needed by the EICM in all three hierarchical levels of pavement design.

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This Research Results Digest (RRD) summarizes the approach taken to create the national database of unbound material properties from soil properties directly measured in the field for agricultural and geotechnical (pavement) engineering purposes down to depths of 100 in. The soil properties are contained in a database available from the U.S. Department of Agriculture's (USDA) Natural Resources Conservation Service (NRCS, formerly the Soil Conservation Service) that comprises 31,100 soil units distributed in more than 9,800 soil profiles covering the continental United States, Hawaii and Alaska, and Puerto Rico. Data were downloaded from the NRCS database and manipulated in both tabular and spatial files. Tabulated data were organized by soil profiles, each of which comprises one or more soil units. The spatial data files were organized in 814 maps covering the entire United States and Puerto Rico that are searchable with a user-interface created in Microsoft Excel; this interface facilitates searching for specific locations within a state, using the maps created in the project.

This RRD was prepared from the project final report, which includes four appendices. Appendix A presents a comprehensive user guide to obtain and integrate the contents of the National Database. Appendix B includes 4 volumes presenting the National Atlas of Soil Units. Appendix C includes 10 volumes containing the tabular database. Appendix D is a concise summary of the technical fundamentals related to unsaturated moisture behavior and in particular, to the SWCC parameters. The project final report and Appendices A through D are available online as NCHRP *Web-Only Document 153* at http://www.trb.org/Main/Blurbs/163721.aspx. The interactive National Database is available on a DVD from NCHRP upon request.

INPUT PARAMETERS FOR UNBOUND MATERIALS REQUIRED BY THE EICM

The specific types of input parameters required by the EICM in order to accurately predict environmental factors are defined by the hierarchical level of MEPDG analysis selected for the pavement design. Generally, as the design level proceeds from Level 3 to Level 1, the number of input parameters and the scope and complexity of testing required to determine them substantially increase. Specifically:

- **For Level 3,** the designer inputs the AASHTO soil classification, grain-size distribution, and Atterberg limits of the unbound material. Though these properties are best measured by the designer, default values, based on AASHTO soil classification, are available within the EICM.
- **For Level 2,** the designer inputs the parameters required for a Level 3 design plus mass-volume properties including specific gravity of solids, maximum dry density, and optimum moisture content. Default values gathered from the published literature for specific gravity of solids are available within the EICM. In addition, default values based on AASHTO classification are also available for the compaction parameters, optimum moisture content, and maximum dry density. However, these values are derived by correlation with grain size distribution and consistency limits.
- **For Level 1,** the user is expected to input measured results for all the parameters required for Level 2, plus the SWCC parameters. The SWCC parameters are the least standardized and the most complicated set of inputs used in EICM analysis.

All three levels of analysis also require the groundwater table depth. This input parameter can be the best estimate of either the annual average depth or the seasonal average depth. For input to Level 1, the groundwater table depth can be determined from profile characterization borings prior to design. For input to Level 3, an estimate of the annual average value or the seasonal averages can be provided.

DEVELOPMENT OF THE NATIONAL DATABASE OF SOIL PROPERTIES FROM THE NRCS DATABASE

The NRCS has collected, stored, maintained, and distributed soil survey information in the United States since the last decade of the 19th century. It is an excellent source for determining the regional distribution and general characteristics of soils for urban and rural engineering projects. While the NRCS database was obviously intended for agricultural purposes, the USDA entered into an agreement with the then Bureau of Public Roads (BPR, predecessor to the Federal Highway Administration [FHWA]) to also measure key soil properties useful for highway engineering. Thus, the NRCS database contains numerous engineering properties of soil deposits needed as input to the MEPDG.

The NRCS information is divided among three soil geographic databases, which differ primarily in the scale used for mapping the different soil units. The three soil geographic databases are:

1. The Soil Survey Geographic (SSURGO) database,
2. The State Soil Geographic (STATSGO) database, and
3. The National Soil Geographic (NATSGO) database.

The components of map units in each database are different and correspond to a differing level of detail. The SSURGO database, for example, provides the most detailed level of information, while NATSGO has a somewhat lower level of detail and is primarily used for national and regional resource appraisal, planning, and monitoring. The source of information used in this initial national database is the NATSGO database.

Processing NRCS Raw Data

The NATSGO database was downloaded from the NRCS website (http://soildatamart.nrcs.usda.gov). The NATSGO database contains spatial and tabular files.

The tabular files provide engineering and agricultural soil properties in Microsoft Access format, facilitating manipulation of the immense volume of data found in the database. The tables are organized by attribute group according to the technological field; therefore, it is possible to classify and query the database.

The spatial files have information necessary to process the graphical expressions of the different soil units. They provide *shapefiles*, which allow the user to analyze spatial information, edit data, and create maps in a Geographic Information System (GIS)-based format.

The soil data (tabular and spatial) available from NRCS are shown in Figure 1. The database has information from both private and public sources, as NRCS combines survey information from several organizations including federal agencies. The dark and light green areas in Figure 1 correspond to soil survey areas for which digital data are available. The white areas are land areas where soil surveys either have not been conducted or do not exist in digital form (at the time of this research). Overall, the database provides information from 78,311 map units covering the 50 states and Puerto Rico.

The term *map unit* is defined as an area that represents a group of soil profiles with generally the same or similar characteristics. These map units contain information organized according to the schematic diagram shown in Figure 2. Each map unit is identified with a code called a Map Unit Key (Mukey). Each Mukey or map unit consists of several *components*, which are soil profiles with slightly different soil properties. The percentage of the area within the map unit that is covered by each component is available. For the purpose of this project, it was assumed that the component with the largest percentage of coverage was representative of the entire map unit. Each profile is typically comprised of 3 to 5 layers, with some profiles containing information from as many as 11 layers. The depth covered by the typical profile averages about 60 in., with some profiles approaching 100 in.

CREATING THE MASTER FILE

The files downloaded from the NRCS database were processed initially in the Microsoft Access *.mdb format. The master file created with the information extracted from NRCS contained data for 1,227,117 soils throughout the United States and Puerto Rico.

Properties and Characteristics of the Master File

Soil properties known to impact the structural engineering behavior of pavement systems were extracted from the NRCS database into a master file; the preliminary selection is shown in Table 1. Some of these properties are not required by the MEPDG software, but they were initially included because they either can be correlated to properties that are required or are needed in the estimation of these properties. Table 2 describes the soil properties that were eventually stored in the master file.

Missing Information in the Master File

Due to the enormous size of the master file, the information was initially stored in seven Microsoft Excel *.xls files, each capable of storing data for about 60,000 soils. Upon detailed review, 11.6% of the total number of soils mapped in the United States were found to have incomplete information. This percentage is considered remarkably low, given the

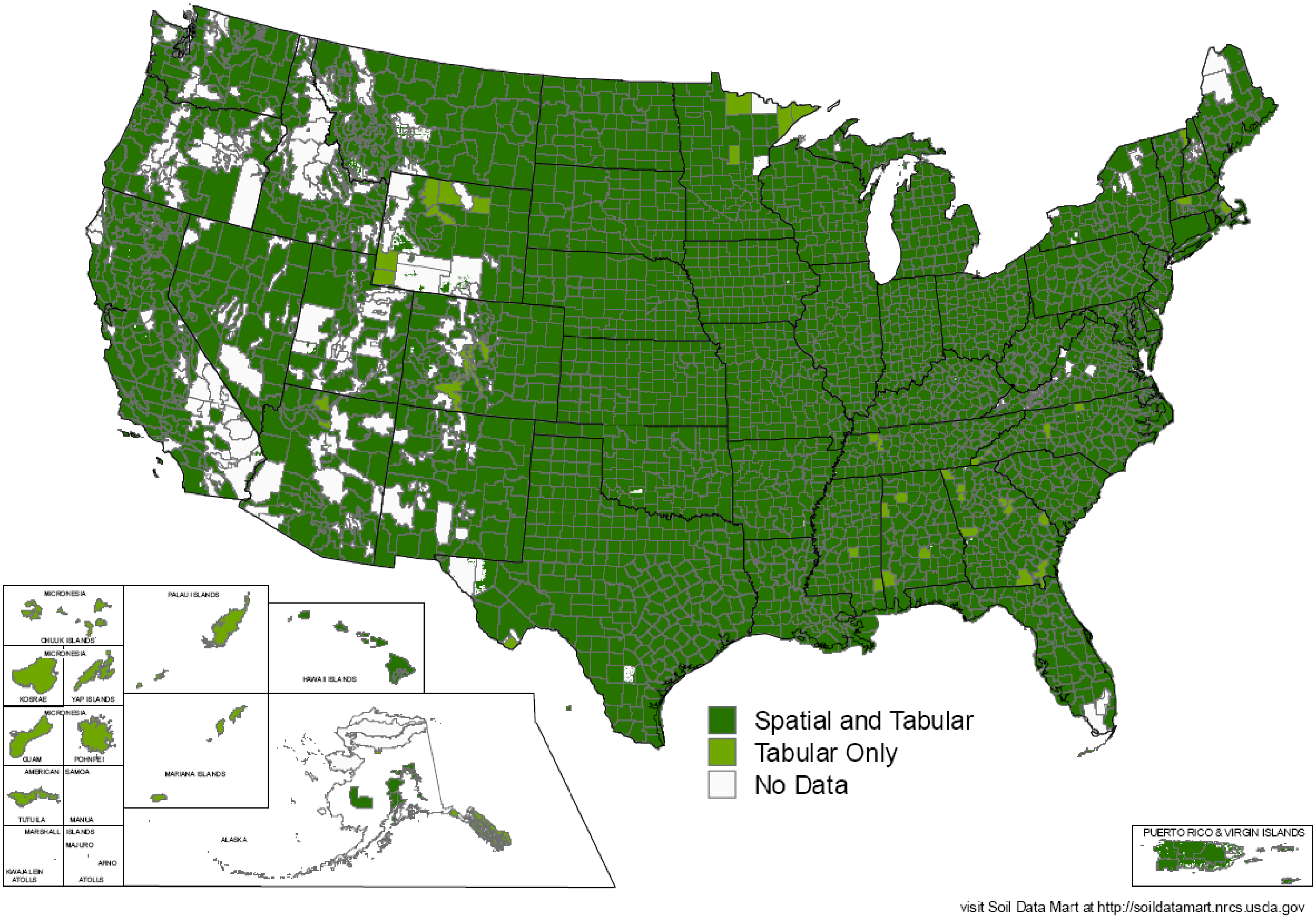


Figure 1 Soil survey available data.

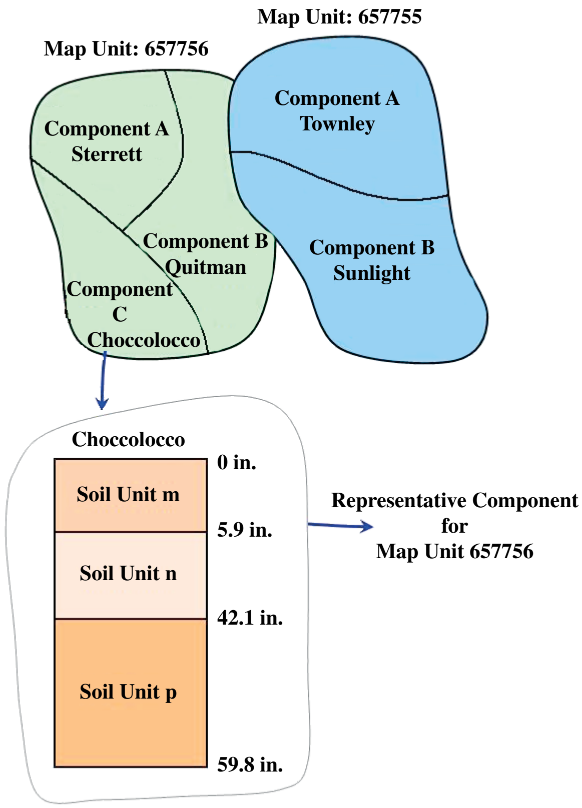


Figure 2 Schematic representation of map unit, component, and soil unit.

vast geographic area covered by the project. Table 3 presents the distribution by state of the soil units with missing information. As can be observed, three states have a significant percentage of missing information, viz., North Carolina (99.4%), North Dakota (68.3%), and Montana (57.0%). If these states are removed, the amount of missing information for the remainder of the United States and Puerto Rico is reduced to 5.3%.

PRELIMINARY REDUCTION OF SOIL UNIT DATA

Each soil type found in the database had information from several boring logs. In most cases, the information for each boring log was similar or very similar, allowing for an initial reduction of the master file. This process was carefully performed by choosing the boring log with the most complete information. In some cases, the information collected from two boring logs was complementary and was combined to produce a complete description of the soil. This process resulted in a reduced database that contained 291,216 soils. This reduction also allowed a switch to the use of Microsoft Excel as the primary database tool.

SELECTING THE PROPER COMPONENT TO REPRESENT THE MAP UNIT

As previously noted, the master file consisted of information for different components within each map unit. It was necessary to further reduce the master file to reflect only one set of soil properties per Mukey or map unit. For the purposes of this project, it was assumed that the component with the largest percentage of coverage was representative of the entire map unit. After this criterion was applied, the total number of soils was reduced to 31,100.

Table 4 shows an example of one map unit with several components. In this case, the map unit with Mukey 677056 is comprised of eight components or soil profiles with coverage ranging from 33% to 2% (see the column labeled *comppct*–Component percentage). The typical soil profile selected for this map unit corresponded to the component with greater coverage, that is, the one with 33%.

DATA SORTING BY MAP UNIT

Once each soil had been assigned a unique set of index properties, the final sorting effort consisted of organizing the data by map unit. Each map unit consists of several layers that need to be contained in a unique row. This approach was required in order to link the tabular database with the spatial data, which allows for the creation of the maps. This effort resulted in a final count of 9,827 map units.

PROPERTIES INCLUDED IN THE NATIONAL DATABASE

Table 5 presents the final selection of soil properties included in the National Database. The database contains the following data necessary for input to the MEPDG at the three design levels:

- **For Level 3 analysis,**
  - Grain-size distribution including percentage of clay
  - Plasticity properties (Atterberg limits)
  - AASHTO soil classification
  - Groundwater table depth
- **For Level 2 analysis,**
  - Saturated hydraulic conductivity
- **For Level 1 analysis,**
  - Data to estimate the Fredlund and Xing SWCC parameters

Table 1 Initial soil properties selected for the master database

Column Label	Column Name
Map Unit Symbol	musym
Map Unit Name	muname
Component Name	compname
AASHTO Classification	aashtocl
AASHTO Group Index—Representative Value	aashind_r
Unified	unifiedcl
Top Depth—Representative Value	hzdept_r
Bottom Depth—Representative Value	hzdepb_r
Thickness—Representative Value	hzthk_r
#4—Representative Value	sieveno4_r
#10—Representative Value	sieveno10_r
#40—Representative Value	sieveno40_r
#200—Representative Value	sieveno200_r
Total Clay—Representative Value	claytotal_r
LL—Representative Value	ll_r
PI—Representative Value	pi_r
Db 0.1 bar H2O—Representative Value	dbtenthbar_r
Db 0.33 bar H2O—Representative Value	dbthirdbar_r
Db 15 bar H2O—Representative Value	dbfifteenbar_r
Dp	partdensity
Ksat—Representative Value	ksat_r
0.1 bar H2O—Representative Value	wtenthbar_r
0.33 bar H2O—Representative Value	wthirdbar_r
15 bar H2O—Representative Value	wfifteenbar_r
Satiated H2O—Representative Value	wsatiated_r
LEP—Representative Value	lep_r
CaCO3—Representative Value	caco3_r
Gypsum—Representative Value	gypsum_r
CEC-7—Representative Value	cec7_r
Water Table Depth—Annual—Minimum	wtdepannmin
Water Table Depth—April—June—Minimum	wtdepaprjunmin
Bedrock Depth—Minimum	brockdepmin
Corrosion Concrete	corcon
Corrosion Steel	corsteel
EC—Representative Value	ec_r
Available Water Storage 0–150 cm	aws0150wta
SAR—Representative Value	sar_r
pH H2O—Representative Value	ph1to1h2o_r
Kw	kwfact
Kf	kffact
AWC—Representative Value	awc_r
Db oven dry—Representative Value	dbovendry_r
Comp %—Representative Value	comppct_r
Hydrologic Group	hydgrp
MAAT—Representative Value	airtempa_r
Elevation—Representative Value	elev_r
ENG—Local Roads and Streets	englrsdcd
Map Unit Key	mukey
Component Key	cokey
Chorizon Key	chkey
Chorizon AASHTO Key	chaashtokey
Chorizon Unified Key	chunifiedkey

Table 2 Soil properties of master database

Column Label	Description
Map Unit Symbol	The symbol used to uniquely identify the soil map unit in the soil survey.
Map Unit Name	Correlated name of the map unit (recommended name or field name for surveys in progress).
Component Name	Name assigned to a component based on its range of properties.
AASHTO Classification	A rating based on a system that classifies soils according to those properties that affect roadway construction and maintenance. Soils are classified into seven basic groups plus eight subgroups, for a total of fifteen for mineral soils. Another class for organic soils is used. The groups are based on determinations of particle-size distribution, liquid limit, and plasticity index. The group classification, including group index, is useful in determining the relative quality of the soil material for use in earthwork structures, particularly embankments, subgrades, subbases, and bases. (AASHTO)
AASHTO Group Index—Representative Value	The empirical group index formula devised for approximately within-group evaluation of the “clayey granular materials” and the “silty-clay materials.”
Unified	Unified Soil Classification System—A system for classifying mineral and organo-mineral soils for engineering purposes based on particle size characteristics, liquid limit, and plasticity index.
Top Depth—Representative Value	The distance from the top of the soil to the upper boundary of the soil horizon.
Bottom Depth—Representative Value	The distance from the top of the soil to the base of the soil horizon.
Thickness—Representative Value	A measurement from the top to bottom of a soil horizon throughout its areal extent.
#4—Representative Value	Soil fraction passing a number 4 sieve (4.70-mm-square opening) as a weight percentage of the less than 3 in. (76.4 mm) fraction.
#10—Representative Value	Soil fraction passing a number 10 sieve (2.00-mm-square opening) as a weight percentage of the less than 3 in. (76.4 mm) fraction.
#40—Representative Value	Soil fraction passing a number 40 sieve (0.42-mm-square opening) as a weight percentage of the less than 3 in. (76.4 mm) fraction.
#200—Representative Value	Soil fraction passing a number 200 sieve (0.074-mm-square opening) as a weight percentage of the less than 3 in. (76.4 mm) fraction.
Total Clay—Representative Value	Mineral particles less than 0.002 mm in equivalent diameter as a weight percentage of the less than 2.0 mm fraction.
LL—Representative Value	The water content of the soil at the change between the liquid and plastic states.
PI—Representative Value	The numerical difference between the liquid limit and plastic limit.

(*continued on next page*)

Table 2 (Continued)

Column Label	Description
Db 0.1 bar H2O—Representative Value	The oven dried weight of the less than 2 mm soil material per unit volume of soil at a water tension of 1⁄10 bar.
Db 0.33 bar H2O—Representative Value	The oven dry weight of the less than 2 mm soil material per unit volume of soil at a water tension of 1⁄3 bar.
Db 15 bar H2O—Representative Value	The oven dry weight of the less than 2 mm soil material per unit volume of soil at a water tension of 15 bars.
Dp	Mass per unit of volume (not including pore space) of the solid soil particle either mineral or organic. Also known as specific gravity.
Ksat—Representative Value	The amount of water that would move vertically through a unit area of saturated soil in unit time under unit hydraulic gradient.
0.1 bar H2O—Representative Value	The volumetric content of soil water retained at a tension of 1/10 bar (10 kPa), expressed as a percentage of the whole soil.
0.33 bar H2O—Representative Value	The volumetric content of soil water retained at a tension of 1/3 bar (33 kPa), expressed as a percentage of the whole soil.
15 bar H2O—Representative Value	The volumetric content of soil water retained at a tension of 15 bars (1500 kPa), expressed as a percentage of the whole soil.
Satiated H2O—Representative Value	The estimated volumetric soil water content at or near zero bar tension, expressed as a percentage of the whole soil.
LEP—Representative Value	The linear expression of the volume difference of natural soil fabric at 1/3 or 1/10 bar water content and oven dryness. The volume change is reported as percent change for the whole soil.
CaCO3—Representative Value	The quantity of Carbonate (CO3) in the soil expressed as CaCO3 and as a weight percentage of the less than 2-mm size fraction.
Gypsum—Representative Value	The percent by weight of hydrated calcium sulfate in the less than 20 mm fraction of soil.
CEC-7—Representative Value	The amount of readily exchangeable cations that can be electrically absorbed to negative charges in the soil, soil constituent, or other material, at pH 7.0, as estimated by the ammonium acetate method.
Water Table Depth—Annual—Minimum	The shallowest depth to a wet soil layer (water table) at any time during the year expressed as centimeters from the soil surface, for components whose composition in the map unit is equal to or exceeds 15%.
Water Table Depth—April—June—Minimum	The shallowest depth to a wet soil layer (water table) during the months of April through June expressed in centimeters from the soil surface for components whose composition in the map unit is equal to or exceeds 15%.
Bedrock Depth—Minimum	The distance from the soil surface to the top of a bedrock layer, expressed as a shallowest depth of components whose composition in the map unit is equal to or exceeds 15%.

Corrosion Concrete	Susceptibility of concrete to corrosion when in contact with the soil.
Corrosion Steel	Susceptibility of uncoated steel to corrosion when in contact with the soil.
EC—Representative Value	The electrical conductivity of an extract from saturated soil paste.
Available Water Storage 0–150 cm	Available water storage (AWS). The volume of water that the soil, to a depth of 150 centimeters, can store that is available to plants. It is reported as the weighted average of all components in the map unit, and is expressed as centimeters of water. AWS is calculated from available water capacity (AWC) which is commonly estimated as the difference between the water contents at 1/10 or 1/3 bar (field capacity) and 15 bars (permanent wilting point) tension, and adjusted for salinity and fragments.
SAR—Representative Value	A measure of the amount of Sodium (Na) relative to Calcium (Ca) and Magnesium (Mg) in the water extract from saturated soil paste.
pH H2O—Representative Value	The negative logarithm to the base 10, of the hydrogen ion activity in the soil using the 1:1 soil-water ratio method. A numerical expression of the relative acidity or alkalinity of a soil sample.
Kw	An erodibility factor which quantifies the susceptibility of soil particles to detachment and movement by water. This factor is adjusted for the effect of rock fragments.
Kf	An erodibility factor which quantifies the susceptibility of soil particles to detachment by water.
AWC—Representative Value	The amount of water that an increment of soil depth, inclusive of fragments, can store that is available to plants. AWC is expressed as a volume fraction, and is commonly estimated as the difference between the water contents at 1/10 or 1/3 bar (field capacity) and 15 bars (permanent wilting point) tension, and adjusted for salinity and fragments.
Db oven dry—Representative Value	The oven dry weight of the less than 2 mm soil material per unit volume of soil exclusive of the desiccation cracks, measured on a coated clod.
Comp %—Representative Value	The percentage of the component of the map unit.
Hydrologic Group	A group of soils having similar runoff potential under similar storm and cover conditions. Examples are A and A/D.
MAAT—Representative Value	The arithmetic average of the daily maximum and minimum temperatures for a calendar year taken over the standard “normal” period, 1961 to 1990.
Elevation—Representative Value	The vertical distance from mean sea level to a point on the earth’s surface.
ENG—Local Roads and Streets	The rating of the map unit as a site for local roads and streets, expressed as the dominant rating class for the map unit, based on composition percentage of each map unit component.
Map Unit Key	A non-connotative string of characters used to uniquely identify a record in the map unit table.
Component Key	The unique identifier of a record in the Component table. Use this column to join the Horizon table to the Component table.
Chorizon Key	A non-connotative string of characters used to uniquely identify a record in the Horizon table.

Table 3 Soil units with missing information

State	Name	Map Units	Map Units without Information
1	Alabama	1394	30
2	Alaska	1818	115
4	Arizona	1229	15
5	Arkansas	1073	38
6	California	4203	182
8	Colorado	2013	121
9	Connecticut	354	10
0	Delaware	43	0
12	Florida	2984	272
13	Georgia	2722	21
0	Hawaii	378	0
16	Idaho	1506	45
17	Illinois	1344	28
18	Indiana	1372	18
19	Iowa	1954	33
20	Kansas	1116	33
21	Kentucky	607	6
22	Louisiana	2259	127
23	Maine	1236	172
24	Maryland	568	79
25	Massachusetts	465	56
26	Michigan	2218	63
27	Minnesota	2400	199
28	Mississippi	1255	20
29	Missouri	904	25
30	Montana	4284	2443
31	Nebraska	2332	419
32	Nevada	2898	24
33	New Hampshire	385	42
34	New Jersey	363	13
35	New Mexico	1985	37
36	New York	3253	314
37	North Carolina	1371	1363
38	North Dakota	2291	1564
39	Ohio	1022	22
40	Oklahoma	1714	74
41	Oregon	1252	76
42	Pennsylvania	1228	25
72	Puerto Rico	217	13
44	Rhode Island	110	4
45	South Carolina	825	101
46	South Dakota	1589	241
47	Tennessee	1402	35
48	Texas	3892	136
49	Utah	1471	61
50	Vermont	273	5
51	Virginia	940	82
53	Washington	2350	83
54	West Virginia	362	8
55	Wisconsin	1220	84
56	Wyoming	1131	49
	No State Designation	736	59
		78311	9085
		% Map Units without Soil Information . . .	11.6

Table 4 Example of component by map unit

muname	mukey	aashtocl	layer	hzdept	hzdepb	hzthk	comppct	sieve10	sieve40	sieve200	ll	pi
Rogert-Rock outcrop	677056	A-2	1	0	10	10	33	62.5	42.5	30	30	2.5
Rogert-Rock outcrop	677056	A-1	2	10	36	26	33	35	25	12.5		0
Rogert-Rock outcrop	677056	A-2	1	0	8	8	17	62.5	50	30		0
Rogert-Rock outcrop	677056	A-2	2	8	25	17	17	62.5	42.5	35	27.5	7.5
Rogert-Rock outcrop	677056	A-1	3	25	48	23	17	20	14	7.5		0
Rogert-Rock outcrop	677056	A-2-4	1	0	8	8	10	95	70	30	22.5	2.5
Rogert-Rock outcrop	677056	A-6	2	8	30	22	10	80	62.5	45	35	15
Rogert-Rock outcrop	677056	A-6	3	30	51	21	10	65	52.5	35	35	12.5
Rogert-Rock outcrop	677056	A-2-6	4	51	84	33	10	37.5	25	17.5	35	12.5
Rogert-Rock outcrop	677056	A-2	1	0	18	18	6	82.5	55	35		0
Rogert-Rock outcrop	677056	A-2	2	18	25	7	6	62.5	42.5	30	25	10
Rogert-Rock outcrop	677056	A-6	3	25	36	11	6	80	60	45	32.5	12.5
Rogert-Rock outcrop	677056	A-1	1	0	25	25	6	92.5	55	25		0
Rogert-Rock outcrop	677056	A-2	2	25	66	41	6	65	35	27.5	35	12.5
Rogert-Rock outcrop	677056	A-1	1	13	30	17	3	42.5	32.5	25	20	2.5
Rogert-Rock outcrop	677056	A-1	2	30	48	18	3	22.5	17.5	10	20	2.5
Rogert-Rock outcrop	677056	A-1	1	0	25	25	3	62.5	40	20		0
Rogert-Rock outcrop	677056	A-2	2	25	71	46	3	35	27.5	17.5	25	10
Rogert-Rock outcrop	677056	A-4	1	0	8	8	2	95	87.5	65	30	2.5
Rogert-Rock outcrop	677056	A-4	2	8	152	144	2	95	87.5	72.5	30	10

Table 5 Soil Properties Included in the National Database

Column Label	Parameter	Description	Units
MapChar	Map Chart Key	Key to identify the number of map.	
MapunitSym	Map Unit Symbol	The symbol used to uniquely identify the soil map unit in the soil survey.	
MapUnitNam_01	Map Unit Name	Recommended name or field name for surveys in progress for each map unit.	
Mukey_01	Map Unit Key	A non-connotative string of characters used to uniquely identify a record in the Map unit table.	
Compname_01	Component Name	Name assigned to a component based on its range of properties. Most predominant soil unit within the map unit.	
AASHTO_01	AASHTO Classification	A rating based on a system that classifies soils according to those properties that affect roadway construction and maintenance. Soils are classified into seven basic groups plus eight subgroups, for a total of fifteen for mineral soils. The groups are based on determinations of particle-size distribution, liquid limit, and plasticity index.	
GroupIndex_01	AASHTO Group Index	The empirical group index formula devised for approximately within-group evaluation of the "clayey granular materials" and the "silty-clay materials." The group classification, including group index, is useful in determining the relative quality of the soil material for use in earthwork structures, particularly embankments, subgrades, subbases, and bases.	
TopDepth_01	Top Depth of Layer	The distance from the top of the soil to the upper boundary of the soil horizon.	In.
BottDepth_01	Bottom Depth of Layer	The distance from the top of the soil to the base of the soil horizon.	In.
Thickness_01	Thickness of the Layer	A measurement from the top to bottom of a soil horizon throughout its areal extent.	In.
Pass#4_01	Passing # 4	Soil fraction passing a number 4 sieve (4.70-mm-square opening) as a weight percentage of the less than 3 in. (76.4 mm) fraction.	%

Pass#10_01	Passing # 10	Soil fraction passing a number 10 sieve (2.00-mm-square opening) as a weight percentage of the less than 3 in. (76.4 mm) fraction.	%
Pass#40_01	Passing # 40	Soil fraction passing a number 40 sieve (0.42-mm-square opening) as a weight percentage of the less than 3 in. (76.4 mm) fraction.	%
Pass#200_01	Passing # 200	Soil fraction passing a number 200 sieve (0.074-mm-square opening) as a weight percentage of the less than 3 in. (76.4 mm) fraction.	%
Clay0.002_01	Passing Sieve 0.002 mm	Clay as a soil separate consists of mineral soil particles that are less than 0.002 mm in diameter. The estimated clay content of each soil layer is given as a percentage, by weight, of the soil material that is less than 2 mm in diameter.	%
LL_01	Liquid Limit	Liquid limit (LL) is one of the standard Atterberg limits used to indicate the plasticity characteristics of a soil. It is the water content, on a percent by weight basis, of the soil (passing #40 sieve) at which the soil changes from a plastic to a liquid.	%
PI_01	Plasticity Index	Plasticity index (PI) is one of the standard Atterberg limits used to indicate the plasticity characteristics of a soil. It is defined as the numerical difference between the liquid limit and plastic limit of the soil.	%
Ksat_01	Sat'd Hydraulic Conductivity	The amount of water that would move vertically through a unit area of saturated soil in unit time under unit hydraulic gradient.	ft/hr
Wsatiated_01	Satiated H2O	The estimated volumetric soil water content at or near zero bar tension, expressed as a percentage of the whole soil; also known as saturated volumetric water content or porosity.	%
af_01	A	Soil-Water Characteristic Curve fitting parameter	Psi
nf_01	N	Soil-Water Characteristic Curve fitting parameter	
mf_01	M	Soil-Water Characteristic Curve fitting parameter	
hr_01	Hr	Soil-Water Characteristic Curve fitting parameter	Psi

(*continued on next page*)

Table 5 (Continued)

Column Label	Parameter	Description	Units
CBR_FROM_PI_01	California Bearing Ratio	Measured pressure required to penetrate a soil sample with a plunger of standard area. The measured pressure is then divided by the pressure required to achieve an equal penetration on a standard crushed rock material. CBR data were estimated from simple index properties: $wPI = \frac{P_{200} * PI}{100}$ $CBR = \frac{75}{1+0.728(wPI)} \quad wPI > 0$ $CBR = 28.09 * (D_{60})^{0.358} \quad wPI = 0$	%
MR_FROM_PI_01	Resilient Modulus	It is defined as the ratio between the repeated axial stress to the recoverable axial strain. Resilient modulus was calculated based on CBR values: $M_R(psi) = 2555 * (CBR)^{0.64}$	Psi
Elev_01	Elevation	The vertical distance from mean sea level to a point on the earth's surface.	M
Comppct_01	Comp %	The percentage of the component of the map unit.	%
BedroDepth_01	Bedrock Depth—Minimum	The distance from the soil surface to the top of a bedrock layer, expressed as a shallowest depth of components whose composition in the map unit is equal to or exceeds 15%.	Ft
wtdepannmin_01	Water Table Depth—Annual—Minimum	The shallowest depth to a wet soil layer (water table) at any time during the year expressed as centimeters from the soil surface, for components whose composition in the map unit is equal to or exceeds 15%.	Ft
wtdepaprjunmin_01	Water Table Depth—April—June—Minimum	The shallowest depth to a wet soil layer (water table) during the months of April through June from the soil surface for components whose composition in the map unit is equal to or exceeds 15%.	Ft

In addition to the SWCC parameters necessary for the MEPDG, many other relevant MEPDG soil parameters were also computed, checked, and incorporated in the database. The following additional engineering properties were estimated based on the original database information and then incorporated into the National Database:

- Group index
- Layer thickness
- D_{60},
- Weighted Plasticity Index (wPI)
- California Bearing Ratio (CBR), and
- Resilient modulus (M_R), computed from estimated CBR.

Table 6 summarizes the percentage of data available for each soil engineering variable considered in the database. For example, there are 31,100 soil units in the database, but only 66% of these have enough information to compute SWCC parameters. The soil properties needed to estimate the SWCC parameters include the volumetric water content at 0.1, 0.33, and 15 bars, and the saturated volumetric water content (i.e., satiated water content or porosity).

Computed Parameters

AASHTO Group Index

The group index is an engineering concept developed by AASHTO that categorizes the probable

Table 6 Summary of available engineering data

Soil Properties	Total	Data in Surveys	Percentage
Map Unit Symbol	31,100	31,100	100
Map Unit Key	31,100	31,100	100
Map Unit Name	31,100	31,100	100
Component Name	31,100	31,100	100
AASHTO Classification	31,100	31,100	100
AASHTO Group Index	31,100	31,100	100
Top Depth of Layer	31,100	31,101	100
Bottom Depth of Layer	31,100	31,101	100
Thickness of the Layer	31,100	31,101	100
Passing # 4	31,100	30,796	99
Passing # 10	31,100	30,796	99
Passing # 40	31,100	30,794	99
Passing # 200	31,100	30,793	99
Passing Sieve 0.002 mm	31,100	1,127	4
Liquid Limit	31,100	27,409	88
Plasticity Index	31,100	30,800	99
Oven dried weight per unit volume at H2O tension of 0.1 bar	31,100	3	0
Oven dried weight per unit volume at H2O tension of 0.33 bar	31,100	29,684	95
Oven dried weight per unit volume at H2O tension of 15 bars	31,100	265	1
Saturated Hydraulic Conductivity (Ksat)	31,100	31,090	100
Volumetric water content at 0.1 bar H2O	31,100	2,151	7
Volumetric water content at 0.33 bar H2O	31,100	20,497	66
Volumetric water content at 15 bars H2O	31,100	20,497	66
Satiated H2O	31,100	20,588	66
SWCC parameter: a	31,100	31,101	100
SWCC parameter: n	31,100	31,100	100
SWCC parameter: m	31,100	31,100	100
SWCC parameter: hr	31,100	31,101	100
California Bearing Ratio (CBR) from Index Properties	31,100	31,101	100
Resilient Modulus from Index Properties	31,100	31,101	100
Elevation	31,100	21,988	71
Comp %	31,100	31,101	100
Water Table Depth—Annual—Minimum	31,100	10,024	32
Water Table Depth—April—June—Minimum	31,100	9,058	29

"service performance" of the soil, particularly when it is used as a highway pavement subgrade. The group index can be calculated by the empirical equation given in AASHTO M145-91, *Standard Specification for Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes:*

$$GI = (P_{200} - 35)[0.2 + 0.005(LL - 40)] + 0.01(P_{200} - 15)(PI - 10) \quad (1)$$

Where: P_{200} = Passing the No. 200 sieve
LL = Liquid Limit
PI = Plasticity Index

Note that the first term in equation (1) is related to the liquid limit and the second to the plasticity index. The final GI value is based on the following qualifications:

- If the GI calculated is negative, it is taken to be zero.
- The GI calculated is rounded to the nearest whole number.
- There is no upper limit.
- The GI for the following soils must be taken as zero: A-1-a, A-1-b, A-2-4, A-2-5, and A-3.
- For soils A-2-6 and A-2-7, the GI must be calculated by the equation:

$$GI = 0.01(P_{200} - 15)(PI - 10) \quad (2)$$

Soil-Water Characteristic Curve Parameters

The SWCC is defined as the relationship between soil water content and soil matric suction (Fredlund, 2006). The water content refers to either the volumetric water content (ratio of volume of water to the volume of solids) or the degree of saturation (percentage of voids filled with water), depending upon the intended use of the SWCC relationship. The soil suction corresponds to the matric suction ($u_a - u_w$), which is the difference between the pore-air pressure and the pore-water pressure.

Several researchers have proposed models to define the SWCC. The model implemented in the MEPDG is that of Fredlund & Xing (Fredlund & Xing, 1994). This model is represented as a sigmoidal function with four fitting parameters. In terms of degree of saturation and English units, the equation reads:

$$S = C(\psi) \times \left[\frac{1}{\left\{ \ln\left[e + \left(\frac{h}{a_f} \right)^{b_f} \right] \right\}^{c_f}} \right] \quad (3)$$

$$C(\psi) = 1 - \frac{\ln\left(1 + \frac{h}{h_r}\right)}{\ln\left[1 + \left(\frac{1.45 \times 10^5}{h_r}\right)\right]} \quad (4)$$

Where: S = Degree of saturation, in %
h = Soil matric suction, in psi
a_f = Soil fitting parameter which is related to the air entry value of the soil, in psi
b_f = Soil fitting parameter which is related to the rate of water extraction of the soil after exceeding the air entry value
c_f = Soil fitting parameter which is related to the residual water content of the soil
h_r = Soil fitting parameter which is related to the suction value at which the residual water content occurs, in psi

This particular equation sets the maximum suction value (zero moisture content) at 1.45×10^5 psi (1,000,000 kPa), which is very convenient when incorporated in numerical analysis because it eliminates the possibility of indeterminate results when the moisture content approaches zero.

In order to find the four fitting parameters for the 31,100 soils, a macro was created to repeat the computation required for each soil. Figure 3 shows an example of the computations needed for one soil. The "Solver" function in Microsoft Excel was used to optimize the nonlinear relationship, by finding the least squared error between the measured and predicted moisture content data available at each suction value. Two or three measured suction values were consistently available in the database. In addition, the saturated volumetric water content (soil porosity) was available, which corresponded to a suction equal to zero. The fourth point was set to one million kPa (145,000 psi) of suction at zero moisture content.

California Bearing Ratio (CBR) and Resilient Modulus (M_R)

The CBR is an empirical soil property that characterizes the strength of subgrade and unbound

Suction (Bar)	Suction (kPa)	Dry Density (gm/cc)	Note	Vol. Water Content (%)	Sat Vol. Water Content (%)	Sat
0.1	10		N/A		39.0	
0.33	33.33		Not reliable	25.8		66.2
15	1500		N/A	14.2		36.4

SWCC Parameters		
	Final	Initial
af	1.1972	10
bf	1.4156	1
cf	0.4969	2
hr	3,000.0	3000

Objective Function
1.05642E-09

xe Suction (psi)	Vol. Water Content (%)	ye Sat	yp	Constraints
0.0001	39.0	100.0	100.0	0.000
4.8309	25.8	66.2	66.2	0.000
217.3913	14.2	36.4	36.4	0.000

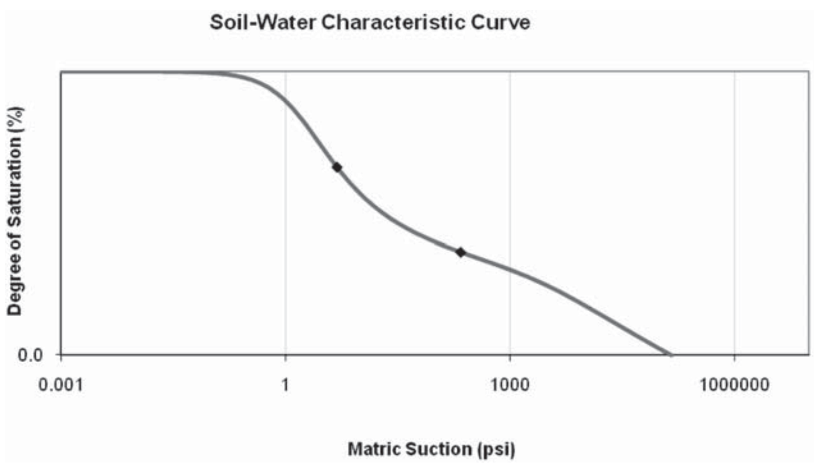


Figure 3 Spreadsheet with the Soil-Water Characteristic Curve parameter calculations.

materials. The resilient modulus can then be estimated from the CBR by using the expression:

$$M_R(psi) = 2555 \times CBR^{0.64} \quad (5)$$

that is used in the MEPDG (Witczak et al., 2001). CBR values can also be estimated from index soil properties like grain size distribution and Atterberg limits. U.S. Geological Survey (USGS) and AASHTO classification are correlated to estimate typical CBR and M_R values. However, another practical way is to use the grain size distribution. First, grain size distribution parameters as the D_{60}, Passing 200, and Plasticity Index are used to estimate the weighted plasticity index (wPI) by the expression:

$$wPI = \frac{P_{200} \times PI}{100} \quad (6)$$

The value of wPI will depend on the type of soil being considered. For coarse soils, wPI = 0; for soils with more than 12 percent of fines, wPI > 0.

For coarse soils (with wPI = 0), the CBR value is related to the grain diameter at which 60% of the grain size distribution passes (D_{60}), in millimeters. The equation in this case is:

$$CBR = 28.09\left(D_{60}\right)^{0.358} \quad (7)$$

This equation has two limitations: for soils with D_{60} less than 0.01 mm, CBR = 5 is used and for soils with D_{60} greater than 30 mm, CBR = 95 is used. For fine soils (with wPI > 0), the expression that is used is:

$$CBR = \frac{75}{1+0.728\left(wPI\right)} \quad (8)$$

It should be recognized that all of these conditions are approximations to the real measured laboratory value for either CBR or M_R. Their use should be confined to Level 3 applications of the MEPDG.

GIS AND CARTOGRAPHIC PROCESS

A series of maps was created to allow the user of the MEPDG to visually identify the specific geographic region of interest. Each soil unit depicted in these maps was uniquely identified to allow for a search of the material properties in the National Database.

The procedures used to create these maps are described next.

Software

All GIS and cartographic work was performed using ESRI's ArcGIS 9.2, Microsoft Excel 2007, and Microsoft Access 2007.

Data Collection

The first step in the map creation involved collecting the necessary elements of the map. The soil unit boundaries and related tabular data were downloaded from the NRCS NATSGO database. The spatial boundaries are in the form of a shapefile, to be used with the GIS software, and the tabular data were stored as Microsoft Access files. Both the spatial and tabular files contained data for the 50 U.S. states and Puerto Rico.

Boundary files for the 50 states and Puerto Rico were downloaded as shapefiles from the U.S. Census Bureau website. These files, known as TIGER files, are free and readily available to the public. In addition to state boundaries, shapefiles of the main interstate road network were also downloaded from the U.S. Census Bureau.

Data Preparation

Road Shapefiles

After downloading all of the data from the Census Bureau, some shapefiles needed modification before they could be used. In particular, the road files from the Census Bureau were greatly altered before use. These road files are organized by county, so the first step involved combining the numerous county files by state, using ArcGIS 9.2. Once these files were reduced to one shapefile per state, a query was performed to identify only the interstates in the highway network. The Census Bureau uses Census Feature Class Codes (CFCC) to identify the various types of roads, and these classification codes are included in the data table for all road shapefiles. Using these tables in ArcGIS 9.2, roads with a CFCC of "A1" or "A2," which indicate interstates and other major highways, were selected. Once selected, these roads were exported to a separate file. As a result, 50 new shapefiles were created that held data for the major highways in each state. These smaller files allowed for quicker data processing and mapping.

Map Unit Keys and Map Characteristics

Like the road files, the map unit boundary shapefile (and its associated data table) required additional analysis before mapping could begin. First, the state boundary shapefile and the map unit boundary shapefile were combined using a spatial join in ArcGIS 9.2 to reveal the number of map units in each state at the level of detail for the NATSGO data. Then this new shapefile was used to draft a state map, which revealed areas of missing data.

Furthermore, a summary function was applied to the Mukey column in the data table of the map unit boundary file. The summary function allowed for the creation of a new table that showed the number of times each unique Mukey appeared in the table and the overall number of unique Mukeys.

After identifying each unique Mukey, a Map Character was assigned to each one; each Mukey was assigned a three-character alpha-numeric code. Since each Mukey is at least six characters long, use of the Map Character substantially reduced the space required in the database for labeling purposes. Map Characters are the key labels that allow the user of the database to easily search for the unbound material information needed to run the MEPDG.

Map Projection and Coordinate System

All of the original data were downloaded as unprojected shapefiles within the Geographic Coordinate System (GCS) North American 1983 coordinate system. Following common practice, these data were re-projected to a more appropriate projection and coordinate system to reduce distortion. It is important to note that all two-dimensional maps of the globe contain some distortion, due to the process of representing a three-dimensional surface on a two-dimensional plane. Regardless of the type of projection, some distortion of area, shape, direction, or distance occurs. In order to reduce distortion, each state was treated as a separate set of maps, and the State Plane Coordinate System (SPCS) was employed.

According to Stem (1989), the SPCS was developed by the U.S. Coast and Geodetic Survey in the 1930s and uses three different projections, depending on the orientation of the state or zone. The SPCS is commonly used to reduce distortion in large-scale maps, generally at the county level or below. For each state, the zone that covers the largest region was used as the projection and coordinate system for that state's maps, which resulted in an atlas of maps with a minimum of distortion.

User Interface

To minimize any difficulties in the search of a particular soil profile corresponding to a specific project location, a simple user interface was developed. This interface is an extraction tool that facilitates the use, analysis, and reporting of the data and maps implemented in the National Database. It contains links to the maps that allow the user to choose the soil unit of interest and extract, in a printable report, all the information available for that particular unit.

The interface was developed using Microsoft Excel and Adobe Acrobat. The maps are provided as Adobe PDF files, while Excel is used for the database and the interface.

USING THE NATIONAL DATABASE

The steps required to extract the desired subgrade SWCC and soil properties at a selected site using the Microsoft Excel interface follow:

1. Choose the state map.
    a. The state map is divided with a numbered grid, which allows the user to narrow the search to a smaller region within the state. The map for Louisiana is presented as an example in Figure 4.
2. Select the region number of interest from the state grid map.
    a. Maps are created for each region within each state. There are 814 maps available. The map of Region 14 in Louisiana is presented as an example in Figure 5.
3. Select the map unit desired to extract the relevant soil property data from the region map and note the map unit number (Mapchar number).
4. Input the Mapchar number in the Microsoft Excel file interface.
5. Display and, if desired, print a report of the soil properties for that particular map unit.
    a. Figure 6 shows an example of a printable report.

SUMMARY

The National Database developed in this project provides an easy, efficient access to Level 3 unbound material properties required for input to the MEPDG for Level 3 designs. Besides a full set of Level 3 data, the database also provides most information required for Levels 1 and 2 designs, including SWCC parameters and saturated hydraulic conductivity. In addition, the information in the database permits predictions of typical resilient modulus and CBR values based on soil index properties. This information is organized in GIS Soil Unit Maps for the entire United States and Puerto Rico.

The National Database provides transportation agencies with a tool to design better-performing and more cost-effective pavements through the use of

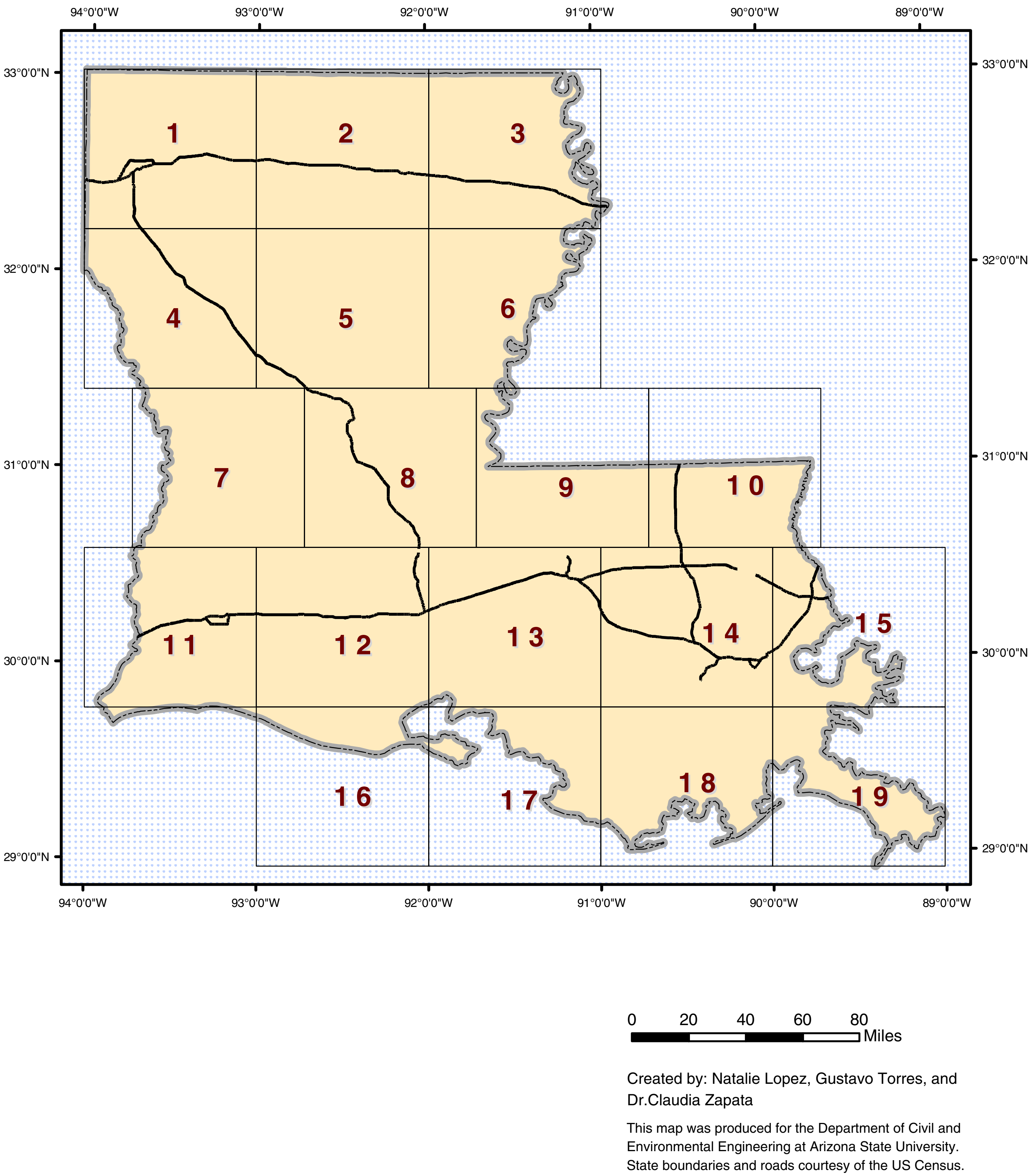
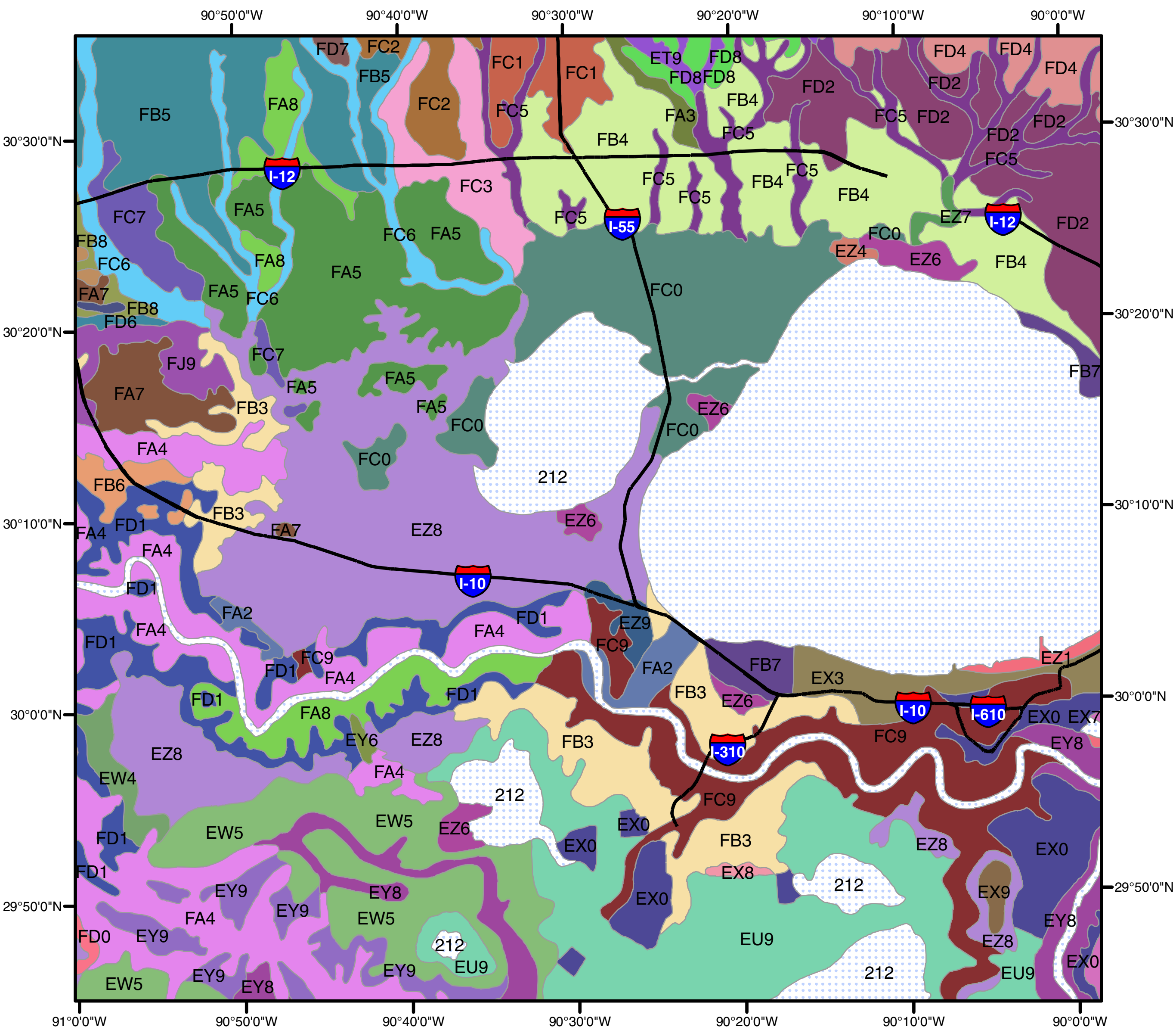
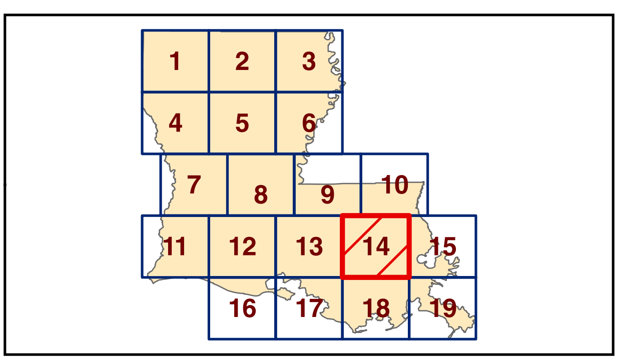


Figure 4 State of Louisiana map with region grid.





0 5 10 15 20 Miles

Created by: Natalie Lopez
Data by: Gustavo Torres, Claudia Zapata

Date: 8/11/09
Projected Coordinate System: NAD 1983, State Plane, Louisiana North, FIPS 1701
Projection: Lambert Conformal Conic

This map was produced for the Department of Civil and Environmental Engineering at Arizona State University. Soil unit data was downloaded from the USDA NRCS. State boundaries and roads courtesy of the US Census.

Figure 5 Region 14 soil unit map for the state of Louisiana.

National Catalogue of Natural Subgrade Properties Needed for the MEPDG Input

Map Char	**FA5**
Mapunit Key	**667683**
Mapunit Name	**Springfield-Natalbany-Encrow-Colyell (s2864)**
Component Name	**Colyell**

	Top Layer	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6	Layer 7	Layer 8	Layer 9
AASHTO Classification	A-4	A-4	A-7-6	A-7-6					
AASHTO Group Index	6	5	32	19					
Top Depth (in.)	0.0	3.1	11.8	39.0					
Bottom Depth (in.)	3.1	11.8	39.0	59.8					
Thickness (in.)	3.1	8.7	27.2	20.9					
% Component	25	25	25	25					
Water Table Depth - Annual Min (ft)	0.8	0.8	0.8	0.8					
Depth to Bedrock (ft)	N/A								

STRENGTH PROPERTIES

CBR from Index Properties	11	13	4	5					
Resilient Modulus from Index Properties (psi)	11,621	12,908	5,730	7,558					

INDEX PROPERTIES

Passing #4 (%)	100.0	100.0	100.0	100.0					
Passing #10 (%)	100.0	100.0	100.0	100.0					
Passing #40 (%)	100.0	100.0	100.0	100.0					
Passing #200 (%)	97.5	97.5	97.5	97.5					
Passing 0.002 mm (%)	7.0	12.5	47.0	29.0					
Liquid Limit (%)	22.0	23.5	55.0	41.0					
Plasticity Index (%)	8.5	7.0	28.5	18.0					
Saturated Volumetric Water CONTENT (%)	43.0	44.0	44.0	40.0					
Saturated Hydraulic Conductivity Ksat (ft/hr)	0.11	0.11	0.01	0.03					

SOIL-WATER CHARACTERISTIC CURVE PARAMETERS

Parameter af (psi)	9.5142	8.8036	0.5313	10.7499					
Parameter bf	0.9430	0.9069	1.0255	1.0082					
Parameter cf	1.0789	1.0745	0.2021	0.4163					
Parameter hr (psi)	3000.00	3000.00	3000.20	2999.99					

Figure 6 Example of a printable report displayed in the Excel Interface.

measured materials properties rather than empirical relationships.

The database will greatly assist pavement designers using the MEPDG and other pavement design methods. The SWCC parameters contained in the database represent the largest collection of this type of information available in the world. This database will also allow further analyses to estimate better default parameters for Level 3 designs. Parameters such as the group index, the complete soil gradation, and the Atterberg limits can be used to further subdivide soil classifications and improve the default parameters used as MEPDG inputs. Finally, and as importantly, researchers can use the database to revise and update the SWCC models currently available in the MEPDG.

REFERENCES

Fredlund, D. G. (2006). "Unsaturated Soil Mechanics in Engineering Practice," *Journal of Geotechnical and Geoenvironmental Engineering,* Vol. 132, No. 3, pp. 286–321.

Fredlund, D. G. and Xing, A. (l994). "Equations for the soil-water characteristic curve," *Canadian Geotechnical Journal,* Vol. 31, pp. 521–532.

Stem, J. E. (1989). "State Plane Coordinate System of 1983." NOAA Manual NOS NGS 5. U.S. Government Printing Office, Washington, D.C.

Witczak, M. W., Houston, W. N., and Zapata, C. E. (2001). *Correlation of CBR Values with Soil Index Properties.* Development of the 2002 Guide for the Design of New and Rehabilitated Pavement Structures—Technical Report. NCHRP Project 1-37A, Transportation Research Board of the National Academies.

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