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PREDICTIVE SOIL MAPPING TO IMPROVE THE PHYSICAL BASIS OF DISTRIBUTED ECOHYDROLOGICAL MODELS IN ARID ENVIRONMENTS

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Colby W. Brungard Mikayla J. Allan



Excavated soil profile showing soils and vegetation common in the study area. The soil in this picture was excavated until a root restricting petrocalcic horizon was encountered.

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By

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ABSTRACT

Spatial patterns in soil properties such as particle size and soil depth significantly affect hydrological and ecological processes. Finely spatially resolved information about the spatial distribution of soil properties is needed for hydrological and ecohydrological modeling. This information is not currently provided by existing small-scale soil maps. This research uses geostatistical methods to interpolate soil depth as well as sand and clay concentrations at four harmonized depth increments (0-5, 5-15, 15-30, and 30-60 cm) within a single alluvial landform surrounding a small, heavily instrumented watershed at the Jornada Experimental Range in southern New Mexico. Soil depth and sand and clay concentration observations were obtained from two sampling campaigns. Each variable was analyzed for anisotropy and statistically significant relationships with nine terrain variables to account for non-stationarity. Spherical, circular, and exponential variogram models were fitted to all sand and clay concentrations and soil depth and compared using root-mean-square-error (RMSE) derived from leave-one-out cross validation. RMSE ranged between 4.8 and 5.9% for sand and between 1.3 and 1.9% for clay. RMSE for soil depth was 37.7 cm. In general, sand had a shorter range of spatial autocorrelation and a smaller nugget than did clay at all depths. The range of spatial autocorrelation for sand was between 150 and 225 m, while clay had a much more variable range of values between 90 and 3206 m. In general, nugget values were relatively low because of the sampling design that had a minimum distance of 3 m, which appears to have captured most of the small-scale variability. Spatial prediction was done using Kriging with External Drift. Uncertainty in sand and clay concentration predictions were low while the uncertainty of soil depth predictions was greater. Interpolated variables and the associated prediction uncertainty will be used to improve the parameterization of future ecohydrological modeling applications.

Keywords: soils, ecohydrological models, soil maps, Jornada Experimental Range, spatial patterns

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INTRODUCTION

Spatial patterns in soil properties such as soil particle size and soil depth significantly affect ecohydrological patterns and processes such as soil moisture, runoff generation, subsurface and groundwater flow (Freer et al., 2002; Stieglitz et al., 2003; Gribb et al., 2009) as well as vegetation community composition (English et al., 2005; Gremer et al., 2015). Finely spatially resolved information regarding the spatial distribution of soil properties is needed for improving ecohydrological models (Tesfa et al., 2009; Wood et al., 2011). Within the United States, the Natural Resource Conservation Service (NRCS) national soils database (SSURGO) has been the main source for soil property information used for ecohydrological modeling (Anderson et al., 2006). This information is provided in mapping units delineated with sharp boundaries. In arid western USA rangelands, these mapping units are often composed of multiple soil components, which often are not spatially represented. This representation of soils is discrete, highly generalized, and is often unsuited to work with other landscape data (Tesfa et al., 2009). Although a soil survey is an excellent tool to optimize land use and management, it was designed for county-level land management and does not provide detailed information required for environmental modeling or site-specific management (Moore et al., 1993; Duffera et al., 2007).

Spatially explicit soil information, specifically particle size and depth, at spatial resolutions finer than that provided by SSURGO, is needed to refine and constrain the parametrization of distributed ecohydrological models (Méndez-Barroso et al., 2016). The purpose of this study was to model soil particle size and soil depth for a small, heavily instrumented watershed with the ultimate goal of incorporating the resulting information into spatially distributed ecohydrological models. This study utilized geostatistics and Kriging with External Drift to produce this information.

METHODS

Site Information

The study area was co-located with the Tromble Weir Watershed (TWW, 32°35'4.62" N, 106°36'8.815 W) in the northern part of the Chihuahuan Desert, 37 km northeast of Las Cruces, New Mexico at the Jornada Experimental Range. The TWW is a small experimental watershed (4.7 ha) on the bajada of the San Andres Mountains (Templeton et al., 2014). Vegetation in the TWW is a mixed shrubland that has undergone historical changes in plant dominance throughout time. Throughout the TWW, hydrological instruments including an eddy covariance tower, flumes, and multiple soil moisture sensors were installed (Anderson and Vivoni, 2016). To capture soil spatial variability while avoiding excessive soil disturbance, soil sampling was performed across the entire ballena surrounding the TWW (Figure 1). A ballena (*sp. whale*) is a remnant of fan alluvium that is distinctly round-topped and occurs along mountain fronts as groups of semiparallel ridges that reflect the incision of parallel drainageways (Peterson, 1981). This ballena was identified by selecting the map unit delineation from an existing NRCS soil survey, which adequately captured the entire landform.

Climate in this area is typical of the northern Chihuahuan Desert, with a mean annual precipitation of 247 mm, 53% of which occurs between July 1 and September 30 (Gibbens and Beck, 1987; Wainwright, 2006). Summer precipitation is mostly from short-duration high-intensity convective storms over small areas, while winter precipitation is mostly associated with low-intensity frontal storms over broad areas (Wainwright, 2006). Vegetative composition at the TWW includes four dominant plant communities being black grama grassland (*Bouteloua eriopoda*), creosotebush (*Larrea tridentate*), honey mesquite (*Prosopis glandulosa*), and tarbush (*Flourensia cernua*) (Anderson and Vivoni, 2016).

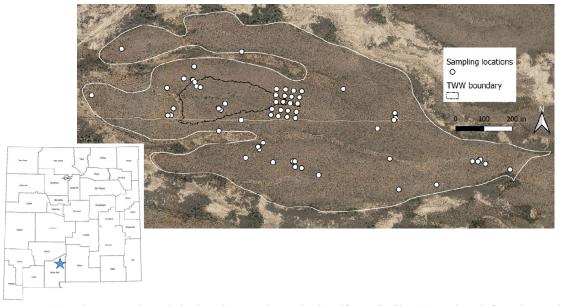


Figure 1. Study area. The solid white line outlines the landform (ballena) used to define the study area. The Tromble Weir Watershed (TWW) boundary is the black line inside the larger study area. The circles are sampling locations. The star on the inset map shows the location of the study area in southern NM.

Typical soils within the Jornada basin consist of Entisols and Aridisols. Within the study area, Aridisols were the dominant soil order. The soil map unit delineation used to define the study area boundary was a Doña Ana-Chutman Complex, with 1 to 10% slopes (Soil Survey Staff, 2017). This complex is comprised of the Doña Ana (fine-loamy, mixed, superactive, thermic Typic Calciargids) and the Chutman (fine-loamy, mixed, superactive, thermic Typic Calciargids) and the Chutman (fine-loamy, mixed, superactive, thermic Typic Haplocalcids) series (Soil Survey Staff, 2017). Doña Ana soils (65% of the map unit) occur on fan piedmonts with alluvium parent material. Typical textures are sandy loam and sandy clay loam. Chutman soil (35% of the map unit) occur in drainageways and toeslopes of fan piedmonts and also contains alluvial parent material (Soil Survey Staff, 2017). Textures range from silt loam to clay loam. Diagnostic features for the soil series include an ochric epipedon (A and Bw horizons), cambic (Bw horizon), and calcic (Bk1 and Bk2 horizons) horizons (Soil Survey Staff, 2017).

Data Collection and Laboratory Analysis

Sampling locations were generated using a modified balanced multi-stage sampling design (Webster et al., 2006). The concept behind this method is to hierarchically subdivide sampling distances using multiple stages to capture accurately enough observations to compute a semi-variogram with modest effort (Webster et al., 2006) This approach chooses several starting nodes and chooses subsequent nodes at set decreasing intervals in random directions (Figure 2). Soil sampling is then performed at the location of each sampling stage.

Starting nodes were generated by extracting centroids of seven spatially compact clusters (Walvoort et al., 2010) Seven levels of subsequent sampling locations were then chosen by decreasing distances by a factor of three from an initial sampling distance of 800 m. This resulted in sampling locations separated by the following distances: 800 m, 267 m, 89 m, 30 m, 10 m, and 3 m. An initial distance of 800 m was chosen as it was approximately one-half the length of the longest axis of the study area. This resulted in 49 sampling locations (seven levels with seven samples at each level). Implementation of this balanced hierarchical sampling algorithm was done using a custom script written in R (R Core Team, 2018), which is included in Appendix A.

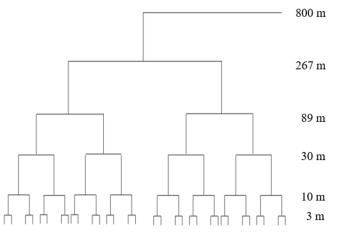


Figure 2. A schematic of the modified balanced nested sampling design used to identify sampling locations. Numbers indicate the physical distance between hierarchical stages. Adapted from Webster et al. (2006).

All 49 sampling locations were visited and sampled in June 2017. Sampling locations were navigated to by GPS, and physical soil sampling was located within a 3-m radius of the generated point according to estimated GPS accuracy. All sampling was done in intershrub areas. At each sampling location, general site information including slope, aspect, surface ground cover, and slope shape were collected. Soil profiles were then excavated (30-50 cm wide) to a depth of either 150 cm or to a root restrictive petrocalcic horizon. If a root restrictive horizon was not reached after approximately 100 cm, an auger was used to excavate from 100-150 cm.

After each sampling location was excavated, 100-200 g soil samples were collected by genetic horizons (~2-4 horizons per soil sampling location) and soil profiles were described according to Schoeneberger et al. (2012). Soil profile descriptions included horizon depth and designation, rock fragments (percent, type, size), structure (grade, size, type), carbonate development stage, hand texture (textural class and clay percentage), and ped and void surface features (percent, distinction, continuity, kind, location). Field data descriptions are included in Appendix B.

After samples from each soil horizon were collected, air dried, and sieved to < 2 mm, soil particle size distribution (i.e., sand, silt, and clay concentration) was measured by the hydrometer method. Briefly, 100 g of air-dry soil was mixed in a blender cup with 10 ml 5% Sodium Hexametaphosphate and deionized water for five minutes. The mixture was quantitatively transferred to a graduated cylinder and the cylinder was then filled to 1000 ml. A stirring plunger was used to mix the sample for ~30 strokes, the hydrometer was inserted, and readings taken at 40 seconds, and again after six hours. With each set of measurements, the temperature of the hydrometer samples was recorded, and a blank was used to adjust for any differences found between actual readings and the blank.

In addition to the soil information collected at the 49 sampling locations, sand, silt, and clay concentrations from an exisiting dataset of 20 locations within the TWW were also included (Anderson, 2013). These samples were collected in June 2013 during the installation of soil moisture and temperature probes from the depth ranges of 0-7, 7-17, and 17-27 cm using a split-tube corer (AMS, 2"x12" Signature Split Soil Core Sampler) except for the depth range of 17-27 cm at one location, where excessively rocky soil prevented deep sampling (Anderson, 2013). Sand, silt, and clay was determined for each depth increment using the hydrometer method (Anderson, 2013). Because of the relatively shallow sampling depth, these additional 20 samples were used only for sand and clay predictions from the top three depth increments and were not included in the analysis of the 30-60 cm increment or for predicting soil depth. All numerical data used for analysis are included in Appendix C.

Analysis

Measurements of sand, silt, and clay concentrations at each sampling location were standardized to the following depth increments by depth weighted median to facilitate interpolation: 0-5 cm, 5-15 cm, 15-30 cm, 30-60 cm (Beaudette et al., 2013; Science Committee, 2015). Observations at depths below 60 cm were not included in the analysis because there were too few for robust analysis, and because soil moisture does not often infiltrate past this depth in this system (Schreiner-Mcgraw and Vivoni, 2018). Soil depth was defined as the distance to a root restricting horizon (e.g., petrocalcic or bedrock). If a root restricting horizon was not encountered before reaching the excavation depth of 150 cm, the soil depth was recorded as 150 cm.

Measured values at standardized depth increments were compared against estimated values of sand, silt, clay, and soil depth from the soil survey. Estimated values for the soil map unit delineation used to define the study area boundary were obtained from the Soil Survey Geographic (SSURGO) database for "White Sands Missile Range, New Mexico, Parts of Doña Ana, Lincoln, Otero, Sierra and Socorro Counties." (Soil Survey Staff, 2017). This data is created during soil survey by estimating low, representative, and high values of texture values (and other physical and chemical properties) for each component. Multiple components often exist in a single map unit. Component horizon values were standardized by weighted median to the same depth intervals as the measured data and used to calculate a weighted average for each depth interval using the proportion of the components in the map unit (65% Doña Ana, 30% Chutum).

Measured sand and clay were analyzed separately by depth interval. Silt was not analyzed as it could be calculated from the sum of sand + clay. Spatial non-stationarity, a key assumption of geostatistics, was evaluated by linear regression between soil texture fractions and soil depth and nine terrain variables. Terrain variables were derived from a 5-m digital elevation model using SAGA-GIS and are listed in Table 1 (Conrad et al., 2015). Each variable was regressed against sand, clay, and depth one at a time. Significant variables (p < 0.01) were included in the kriging equation to remove any trend. If multiple variables were significant, the variables were used in a multiple-linear regression. Any non-significant variables (p < 0.01) in the multiple-linear regression were removed and the process repeated until all variables were significant. Multiple-liner regression was only used in the analysis of sand at the 30-60 cm. Anisotropy was found to exist and was included in each model at 120 degrees, which was approximately the longitudinal direction of the landform.

Spherical, circular, and exponential variogram models were fit to sand and clay concentrations and soil depth and compared using root-mean-square-error (RMSE) derived from leave-one-out cross validation. The model that returned the lowest RMSE was selected for each variable. If variogram models did not converge, 'bin' sizes equal to the distances used in the sampling design were used over which average semivariance was calculated.

Spatial prediction was done using Kriging with External Drift, which specifically accounts for correlations with auxiliary variables (i.e., terrain variables) (Hengl, 2007). Interpolated variables and the associated standard deviation (a measure of prediction uncertainty) were produced and are the digital soil mapping outputs that are intended for inclusion in future ecohydrological applications. Standard deviation was calculated as: $\sqrt{kriging} variance$.

All analysis was performed using RStudio (RStudio Team, 2016) and the following packages: aqp (Beaudette et al., 2013); car (Fox and Weisberg, 2011); dplyr (Wickham et al., 2018); e1071 (Meyer et al., 2019); ggplot2 (Wickham, 2016); gstat (Pebesma, 2004); openxlsx (Walker, 2018); plyr (Wickham, 2011); raster (Hijmans, 2014); RColorBrewer (Neuwirth, 2014); and rgdal and sp (Bivand et al., 2018). R code used for the geostatistical analysis of sand and clay concentrations are included in Appendix D. R code use for the geostatistical analysis of depth are included in Appendix E.

Terrain Variable	units	Interpretation
Northness [*]	degrees	Direction from north that the slope is facing
Convergence Index	unitless	Flow convergence and divergence
Cross-sectional Curvature	unitless	Flow convergence and divergence
Elevation	meters	Vertical distance above mean sea level
Flow Accumulation	m^2	Size of upslope area
Longitudinal Curvature	unitless	Flow convergence and divergence
Slope	degrees	Slope steepness
Topographic Wetness Index	unitless	Potential wetness
Valley Depth	meters	Elevation below the nearest ridge

Table 1. Terrain variables, unit, and interpretation of the variables.

* Northness calculated as: cosine(aspect)

RESULTS AND DISCUSSION

Summary statistics of measured sand and clay concentrations by standardized depth increment and total soil depth are presented in Table 2. Sand concentrations ranged between 35% and 84%. Clay concentrations ranged between 3% and 19% (Table 3). Clay concentrations were about one-half as variable as were sand concentrations as quantified by the standard deviations of each harmonized horizon, but the variability was $\leq 8\%$ for both sand and clay. Average depth to restrictive horizon was 77 cm, but this is calculated including ten observations that stopped at 150 cm because of limitations in the depth of excavation, which results in biased summary statistics. Summary statistics of estimated sand and clay concentrations by standardized depth increment and total soil depth from soil survey are also presented in Table 2. Although soil survey underestimated sand and overestimated clay at all most all depth increments when compared with the measured values, both measured and estimated values are similar. The maximum absolute difference between measured and estimated values is 19% clay at the 30-60 cm depth increment. The minimum absolute difference between measured and estimated values is 2% sand at the 5-15 cm. However, total depth is poorly approximated by soil survey likely because of the spatial variability of total soil depth.

Table 2. Summary statistics of sand and clay concentrations and soil depth for both measured values from field sampling and estimated values from soil survey. All values are in percent except for soil depth which is given in cm. SD = standard deviation. n = number of observations.

		Ν	leasure	d values fr	om field	l sampli	ng	Estimated	values from	soil survey
	Depth	n	Min.	Median	Mean	Max.	SD	Low	RV	High
	0-5	67	35	64	64	80	6	39	58	75
Sand	5-15	67	46	64	63	77	5	35	58	75
Sanu	15-30	67	46	63	64	84	6	36	58	75
	30-60	41	39	61	61	78	8	34	56	75
	0-5	67	3	8	8	15	3	8	17	22
Class	5-15	67	4	8	8	16	3	8	19	23
Clay	15-30	67	3	8	8	16	3	9	20	24
	30-60	41	3	9	9	19	3	21	28	35
Depth	_	47	22	58	77	150	44	-	150+	-

Sand and clay values are in percent. Depth values are in cm

Statistically significant linear relationships between sand and clay concentrations by harmonized depth increment and total soil depth are presented in Table 3. Elevation, topographic wetness index, valley depth, and cross-sectional curvature were linearly related with sand and clay concentrations and soil depth. The relationships are generally weak ($R^2 < 0.3$ for most variables), which is expected given the relatively small size of the study area and the general uniformity of the soil in this single landform. The relatively weak linear relationships may also be a result of the 5-m resolution of the digital elevation model used to derive terrain parameters. It is possible that stronger relationships may have been found had terrain derivatives been calculated using a DEM with a finer resolution (e.g., <1 m) because such resolution could potentially capture variability in micro-relief between shrubs and inter-plant spaces that likely govern soil redistribution. The resolution of the DEM may also explain the generally increasing strength of the linear relationships between soil texture fractions with increasing depth. We assume that soil texture fractions become less related to surface features that redistribute soil particles, as the depth increases and internal pedological processes become more dominant. However, any interpretation of these relationships must be treated with caution as the range in sand and clay fractions was relatively narrow and the amount of variance explained by each variable was generally low.

Table 3. Terrain variables with statistically significant linear relationships between sand and clay at standard soil depths and soil depth. Multiple linear regression used if multiple variables significant.

	Depth Interval	Terrain Variable	<i>p</i> -value	[*] Multiple-R ²
Sand	0-5	Elevation	0.005	0.113
	5-15	Elevation	0.006	0.109
	15-30	Topographic Wetness Index	0.001	0.169
	30-60	Elevation	0.000	0.555
		Longitudinal Curvature	0.002	0.555
Clay	0-5	Valley Depth	0.001	0.165
	5-15	Valley Depth	0.000	0.279
	15-30	Valley Depth	0.000	0.272
	30-60	Cross-sectional Curvature	0.011	0.184
Depth	-	Elevation	0.008	0.145
Depth	15-30	Valley Depth Cross-sectional Curvature	0.000 0.011	0.272 0.184

 R^{2} is the coefficient of determination and indicates the variance explained

Variogram parameters are reported in Table 4. The RMSE is a measure of model performance, with lower values indicating a better model fit. In general, the RMSE values for sand are larger than RMSE values for clay, which is likely because observed clay concentrations were less variable than sand concentrations (Table 2). However, the RMSE for both sand and clay was relatively low indicating a good model fit and was approximately within the estimated accuracy of the hydrometer method used to measure the soil texture fractions. The RMSE for both sand and clay was similar to the range of measured values for each horizon (compare tables 2 and 4).

	Depth cm	Model	RMSE %	Range m	Nugget C ₀	Partial Sill C	Sill C ₀ +C	Nugget-to-Sill ratio $C_0 / (C_0 + C)$
	0-5 cm	Cir	5.8	185.1	10.7	27.5	38.2	0.3
Sand	5-15 cm	Cir	4.8	152.0	18.7	7.7	26.4	0.7
Sanu	15-30 cm	Cir	5.9	35.0	5.7	30.4	36.1	0.2
	30-60 cm	Sph	5.1	225.6	15.8	8.9	24.6	0.6
	0-5 cm	Cir	1.9	3206.5	1.3	33.5	34.9	0.0
Clay	5-15 cm	Sph	1.3	521.7	0.6	4.0	4.6	0.1
Clay	15-30 cm	Cir	1.4	500.3	0.9	5.0	6.0	0.2
	30-60 cm	Cir	1.5	90.4	0.3	1.7	2.0	0.1
Depth	-	Sph	37.7*	50.9	610.6	1067.8	1678.4	0.4

Table 4. Variogram model parameters for geostatistical modeling of sand and clay concentrations and soil depth.

*Soil depth RMSE, nuggest and sill reported in cm

The RMSE for soil depth was 37.7 cm (Table 3). This RMSE value is very similar to the values reported by Tesfa et al. (2009) who modeled soil depth in a semi-arid environment using machine learning and Liu et al. (2013), who modeled soil depth in a humid area using an analytical terrain evolution model. Based on these results it may be that \sim 35 cm is the average error that can be expected in soil depth predictions. This suggests that soil depth is rather difficult to accurately model. This is most likely because soil depth is controlled by processes such as deposition and weathering that are currently not approximated with terrain derivatives. However, the difficulty in dealing with observations where the soil is deeper than the excavation depth (e.g., > 150 cm in this study) is a problem that needs to be resolved. One possible approach may be to use maximum likelihood regression combined with kriging (Knotters et al., 1995). However, if soil depth estimates are required with greater than about 30 cm precision, geophysical methods such as ground penetrating radar may be more suited to estimating soil depth (Sucre et al., 2011).

In general, sand had a shorter range of spatial autocorrelation and a smaller nugget than did clay at all depths (Table 4). Semi-variogram ranges are interpreted as the range of spatial correlation. Samples separated by distances shorter than the range are spatially correlated and contribute to kriging predictions (Cambardella et al., 1994). Excluding the variogram models for sand 15-30 cm and clay 5-15 cm, which required separate bin sizes for stable model fit, the range of spatial autocorrelation for sand was between 150 and 225 m, while clay had a much more variable range of values between 90 and 3206 m. The discrepancy in variogram ranges between sand and clay is a bit surprising, particularly the range of clay 0-5 cm. We are unsure of the exact mechanism that would cause such differences, but it is likely related to the general paucity of clay in this landform and the sparseness of the sampling design. The variogram range of soil depth was much less than that of sand or clay and should be used to set the maximum distance between nodes in any subsequent grid sampling of this area.

The nugget value is the semivariance at separation distance equal to zero and can be interpreted as variability that is undetectable at the resolution of mapping (Cambardella et al., 1994). In general, nugget values were relatively low because of the sampling design that had a minimum distance of 3 m, which appears to have captured most of the small-scale variability. The nugget-to-sill ratio is an indicator of the strength of spatial dependency (Cambardella et al., 1994). Smaller ratios indicate stronger spatial dependence structure of Cambardella et al. (1994), all soil properties had moderate to high spatial dependence.

Figures 3, 4, and 5 plot each variogram model. The wide dispersion of points around the lines in each figure is a result of the relatively few observations used to build the variograms. In general, 150-200 observations are recommended for a robust variogram model, which is considerably more than were available in this study; and we acknowledge that if more observations were available for fitting each model, variograms would be more robust (Webster and Oliver, 2007). However, because this study occurred in an area that is part of ongoing hydrologic investigations, options for more intensive sampling may require the use of geophysical instruments that minimize sampling disturbance to produce enough observations for robust variogram modeling.

Figures 6, 7, and 8 show the kriging predictions and prediction uncertainty. The spatial patterns in Figs. 6E, 6G, and 7G (sand 15-30 cm and 30-60 cm and clay 30-60 cm predictions) are a result of the correlation with the terrain variables. The linear patterns in these predictions generally show a decrease in sand and an increase in clay concentrations. These patterns can be explained by the presense of shallow gullies in these locations where erosion has removed the overlying coarser textured soils and lowered the land surface closer to the siltier formation that underlies this area (the whitebottom surface; Gile et al., 1981). The gradient of soil depth (Fig. 8A, shallower in the west and gradually deepening to the east) is a result of the relationship between elevation and soil depth. Soils are generally shallower in the west where decreasing elevation exposes the relatively planar petrocalcic horizons that run throughout the landform. The spotty nature of soil depth predictions and uncertainty (Fig. 8B in particular) is a result of the range of autocorrelation (~ 50 m). Although not as visually obvious, all predictions (Figs. 6, 7, and 8) show the effect of including elevation as a variable.

Uncertainty in sand and clay concentration predictions were low, while the uncertainty of soil depth predictions was fairly large (compare areas of low vs. high uncertainty in Figures 6, 7, and 8). A sampling grid with nodes ~ 50 m apart (less than the range of the soil depth variogram) would be required to reduce the uncertainty in soil depth predictions. These outputs are in a GIS-ready format and could be used as input to future distributed ecohydrological modeling efforts on the Tromble Weir Watershed.

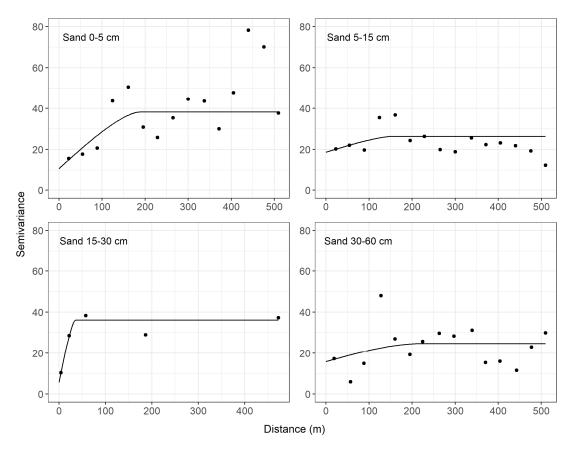


Figure 3. Variogram models of sand concentration. The variogram model for 15-30 cm is visually different than the other variogram models because stable model fit required established 'bin' sizes over which average semivariance values were calculated. Bin sizes were set to equal distances between the sampling levels as defined in the sample design.

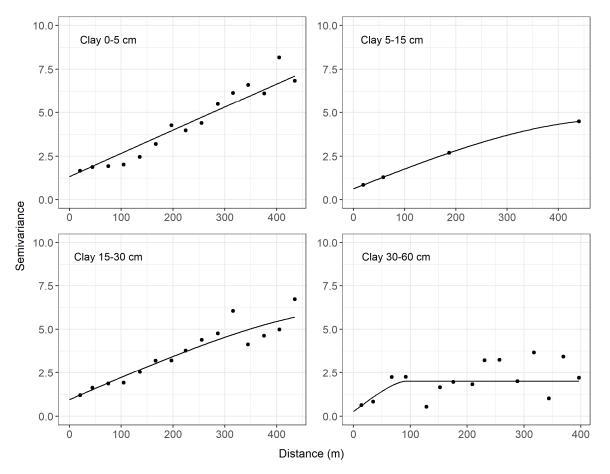


Figure 4. Variogram models of clay concentration. The variogram model for 5-15 cm is visually different than the other variogram models because stable model fit required established 'bin' sizes over which average semivariance values were calculated. Bin sizes were set to equal distances between the sampling levels as defined in the sample design.

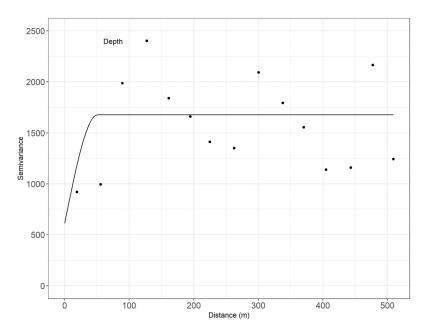


Figure 5. Variogram model of soil depth.

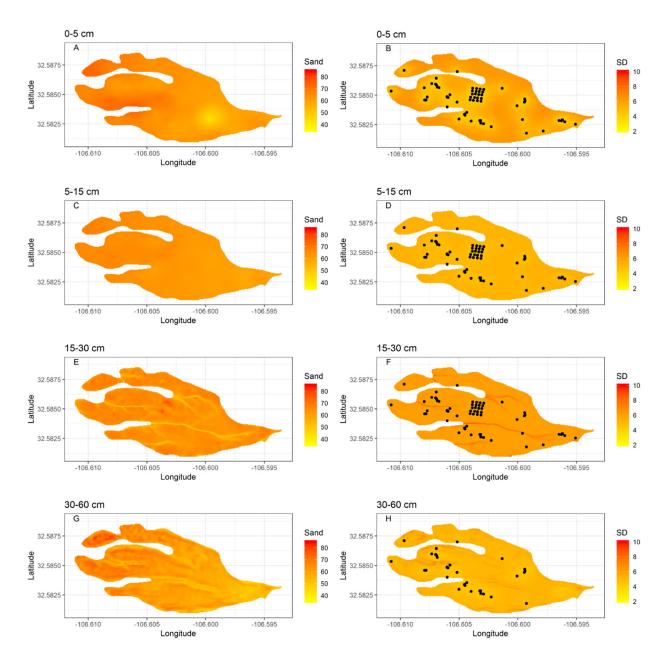


Figure 6. Sand concentration (%) predictions and prediction uncertainty. Left hand figures are the predictions of sand concentration at 0-5 cm (A), 5-15 cm (C), 15-30 cm (E), and 30-60 cm (G). Right hand figures are prediction uncertainty (SD = standard deviation of kriging variance) at 0-5 cm (B), 5-15 cm (D), 15-30 cm (F), and 30-60 cm (H). Filled circles on right hand figures are the sampling locations.

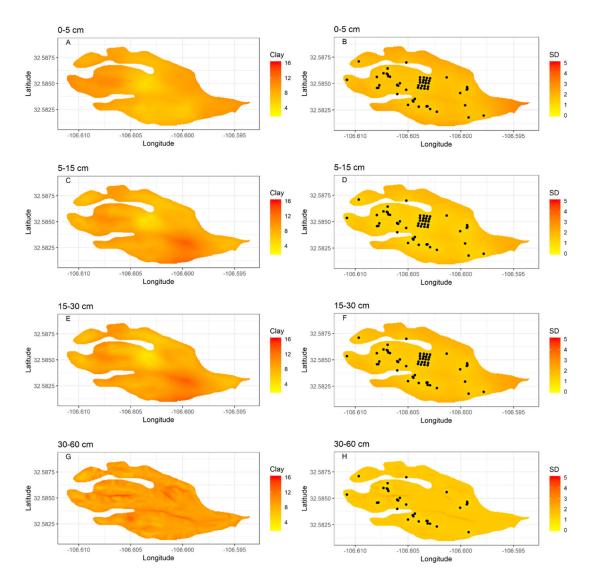


Figure 7. Clay concentration (%) predictions and prediction uncertainty. Left hand figures are the predictions of sand concentration at 0-5 cm (A), 5-15 cm (C), 15-30 cm (E), and 30-60 cm (G). Right hand figures are prediction uncertainty (SD = standard deviation of kriging variance) at 0-5 cm (B), 5-15 cm (D), 15-30 cm (F), and 30-60 cm (H). Filled circles on right hand figures are the sampling locations.

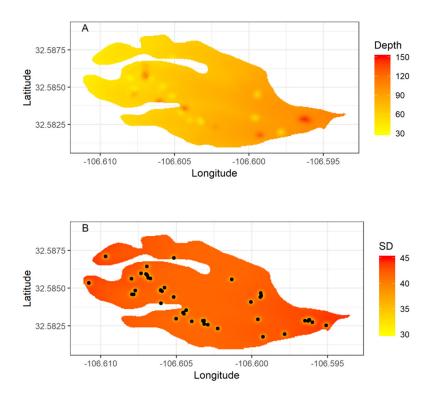


Figure 8. Soil depth predictions and prediction uncertainty. Top figure (A) is prediction. Bottom figure (B) is prediction uncertainty (SD = standard deviation of the kriging variance). Filled circles on bottom figure are the sampling locations.

CONCLUSIONS

Sand and clay at four standardized depth intervals and soil depth were measured in the alluvial landform surrounding the Tromble Weir Watershed in southern New Mexico. Measured values were compared to estimated values from soil survey. Sand and clay were similar between measured and estimated values, while soil depth was overestimated by soil survey and much more variable in measured values. Geostatistical models were fit to observed data. In general, the accuracy of sand and clay concentration models were within the measurement accuracy and predictions are reliable. Soil depth models were less accurate than sand and clay models and had greater uncertainty. Denser observations of soil depth from a grid sampling effort or from geophysical methods are needed to reduce the uncertainty in soil depth predictions. Spatial predictions of sand, clay, and soil depth, and their accompanying uncertainty, may be used to test the effect of more finely resolved soil property values on distributed ecohydrological models and to explore patterns in vegetation density, structure, and distribution.

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APPENDIX A CODE FOR NESTED SPATIAL SAMPLING

The following can be copied and pasted into an R script

Nested Spatial Sampling

This code implements a modified version of nested sampling in Webster et al., 2006. This code is implemented as follows: first, a polygon representing the study area is loaded, second the user creates a vector of the desired decreasing distances between sample points, thirdly the nestsamp function generates a series of initial sample points (the first level of hierarchy) by extracting centroids of compact clusters. Compact geographic clusters are created using the spcosa packages. Subsequent hierarchical levels are then created from each centroid while being restricted to remain inside the study area boundary.

Required arguments for the nestsamp function:

poly = polygon to sample in

n = number of samples at each level

dists = distances between each hierarchical level. Define before running function.

cellSize = cellSize of grid used in spcosa. Start with 50 or greater (i.e., 50 meters) to quickly run, then set smaller to get a grid with higher fidelity to the original polygon.

hlevels = number of hierarchical levels to be run. Should match the number of desired hierarchical levels. e.g., if you want 7 levels then this should be 7.

#The number of resulting points will be n*hlevels.

Note, this code does not exactly follow the Webster et al. paper. Instead of choosing a random vector of length h-1, this code simply samples the point and chooses the next point.

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#Citation

#' @article{WEBSTER20061320,

#' title = "Estimating the spatial scales of regionalized variables by nested sampling, hierarchical analysis of variance and residual maximum likelihood",

- #' journal = "Computers & Geosciences",
- #' volume = "32",
- #' number = "9",
- #' pages = "1320 1333",
- #' year = "2006",
- #' note = "",
- #' issn = "0098-3004",
- #' doi = "http://dx.doi.org/10.1016/j.cageo.2005.12.002",
- #' url = "http://www.sciencedirect.com/science/article/pii/S0098300405002761",
- #' author = "R. Webster and S.J. Welham and J.M. Potts and M.A. Oliver",
- #' keywords = "Nested sampling",
- #' keywords = "Analysis of variance",
- #' keywords = "Variance components",
- #' keywords = "Variogram",
- #' keywords = "Balance",
- #' keywords = ""

#' }

#Begin

```
# Load necessary packages
```

library(sp)

library(rgdal)

library(spcosa)

library(plyr)

```
# Set working directory
setwd(".")
```

1. Read in polygon. It is easiest if this is in a projection with meters, e.g., UTM

poly <- readOGR(dsn = ".", layer = "SoilMU26")</pre>

2. Geographic distances between each subsequent hierarchy level. This should match the number of hierarchical levels you want minus one. e.g., if you want 7 levels then you should have six distances, because the first level is created using spcosa centroids. All subsequent hierarchical levels will be based off of this first level.

Inelegant way to get distances by decreasing factor of 3. One could also set these manually if a nonexponential decrease was desired.

I chose 800 m because it seemed like a good idea and because it was approximatley 1/2 the length of the longest axis of the soil map unit that I was interested in.

dists <- vector() dists[1] <- 800 dists[2] <- dists[1]/3 dists[3] <- dists[2]/3 dists[4] <- dists[3]/3 dists[5] <- dists[4]/3 dists[6] <- dists[5]/3

To do an imbalanced sample I could just run the following balanced sampling for the number of desired balanced levels, then re-run for the following levels with 1/2 of the sample points selected randomly.

3. Function to apply modified version of fully balanced nested spatial sampling based on Webster et al. 2006

nestsamp <- function(poly, n, dists, cellSize, hlevels) {</pre>

poly = polygon to sample in

n = number of samples at each level

dists = distances between each hierarchical level. Define before running function.

cellSize = cellSize of grid used in spcosa. Start with 50 (i.e., 50 meters) to quickly run, then set smaller to get a grid with higher fidelity to the original polygon.

hlevels = number of hierarchical levels to be run. Should match the number of desired hierarchical levels. e.g., if you want 7 levels then this should be 7.

#The number of resulting points will be n*hlevels.

Define initial sample points (first level of hierarchy) by extracting centroids of compact clusters using spcosa. One could also use spsample to generate random points in the polygon, but I like this idea of spreading the initial sample points across the area by compact clusters.

poly2 <- SpatialPolygons(poly@polygons)
strat <- stratify(poly2, nStrata = n, nTry = 5, cellSize = cellSize)</pre>

Centroids in dataframe format
samp <- as(spsample(strat), "data.frame")
names(samp) <- c('X1', 'X2')</pre>

Identify sampling locations for all hierarchical levels past the first level. hsamps <- list(samp)</p>

-1 since the first hierarchical level is already done
for(k in 1:(hlevels-1)){

Generate samples with in each hierarchical level newSampX <- vector() newSampY <- vector() samps2 <- data.frame(matrix(ncol = 2, nrow = nrow(samp)))</pre>

for (i in 1:nrow(samp)){

Generation of random direction
dir <- runif(1, min = 0, max = 360)</pre>

```
# Generation of new point
dx <- dists[k] * sin(dir)
dy <- dists[k] * cos(dir)</pre>
```

```
newSampX <- hsamps[[k]][i,1] + (dists[k] * sin(dir))
21
```

newSampY <- hsamps[[k]][i,2] + (dists[k] * cos(dir))

Convert new points to spatialpointsdataframe and assign projection to use the over function newSamp <- data.frame(cbind(newSampX, newSampY)) coordinates(newSamp) <- ~ newSampX + newSampY proj4string(newSamp) = proj4string(poly)

Is the new point in the boundaries of the polygon? If not, choose another point that is inside the boundaries. inPoly <- !is.na(over(newSamp, poly))[1,1]</p>

while(inPoly != TRUE) {

Generation of random direction
dir <- runif(1, min = 0, max = 360)</pre>

Generation of new point
dx <- dists[k] * sin(dir)
dy <- dists[k] * cos(dir)</pre>

newSampX <- hsamps[[k]][i,1] + (dists[k] * sin(dir))
newSampY <- hsamps[[k]][i,2] + (dists[k] * cos(dir))</pre>

Convert new points to spatialpointsdataframe and assign projection to use the over function
newSamp <- data.frame(cbind(newSampX, newSampY))
coordinates(newSamp) <- ~ newSampX + newSampY
proj4string(newSamp) = proj4string(poly)</pre>

Is the new point in the boundaries of the polygon? inPoly <- !is.na(over(newSamp, poly))[1,1]</pre>

} # end while

samps2[i,] <- data.frame(newSamp)</pre>

}# end inner for loop

```
# Join all samples into a list
hsamps[[k+1]] <- samps2</pre>
```

```
} # end outer for loop
return(hsamps)
}
```

4. Run nested samplingtry1 <- nestsamp(poly = poly, n = 7, dists = dists, cellSize = 5, hlevels = 7)

```
plot(poly)

points(try1[[1]], col = 'red', pch = 19)

points(try1[[2]], col = 'blue', pch = 19)

points(try1[[3]], col = 'black', pch = 19)

points(try1[[4]], col = 'green', pch = 19)

points(try1[[5]], col = 'orange', pch = 19)

points(try1[[6]], col = 'purple', pch = 19)

points(try1[[7]], col = 'grey', pch = 19)
```

#Name each plot

try1[[1]]\$level <- rep('Level1', nrow(try1[[1]]))
try1[[2]]\$level <- rep('Level2', nrow(try1[[2]]))
try1[[3]]\$level <- rep('Level3', nrow(try1[[3]]))</pre>

try1[[4]]\$level <- rep('Level4', nrow(try1[[4]])) try1[[5]]\$level <- rep('Level5', nrow(try1[[5]])) try1[[6]]\$level <- rep('Level6', nrow(try1[[6]])) try1[[7]]\$level <- rep('Level7', nrow(try1[[7]]))

Collapse to dataframe, add unique identifier, and write to csv.

dat <- ldply(try1, data.frame)</pre>

dat\$id <- paste0(0,seq(01,nrow(dat)))

write.csv(dat, "./SamplingPoints.csv", row.names = FALSE)

Convert to other file formats as needed in qgis as it is easier.

#I imported the .csv file, assigned the right projection (same as SOILMU26.shp - WGS84 UTM 13N), then saved as .gpx and .kml in WGS84 lat/long geographic coordinates. I also saved these in WGS 84 UTM13N projection as a shapefile

#End

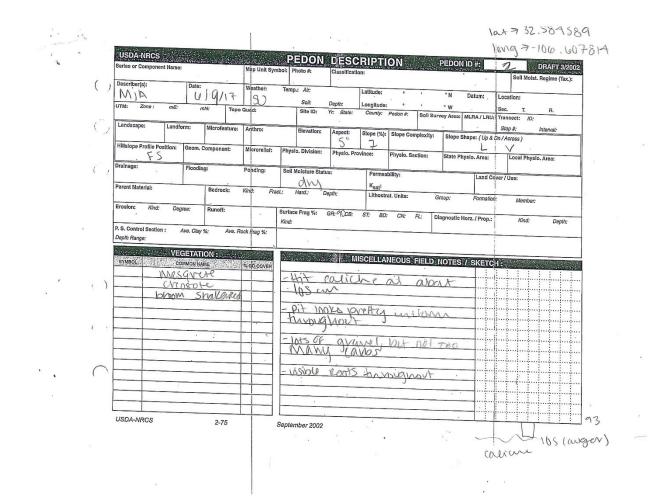
APPENDIX B SOIL PROFILE DESCRIPTIONS

The following paired images are the field data sheets collected by Mikalya Allan during her field sampling campaign. Each image pair consists of the front and back of one field sheet.

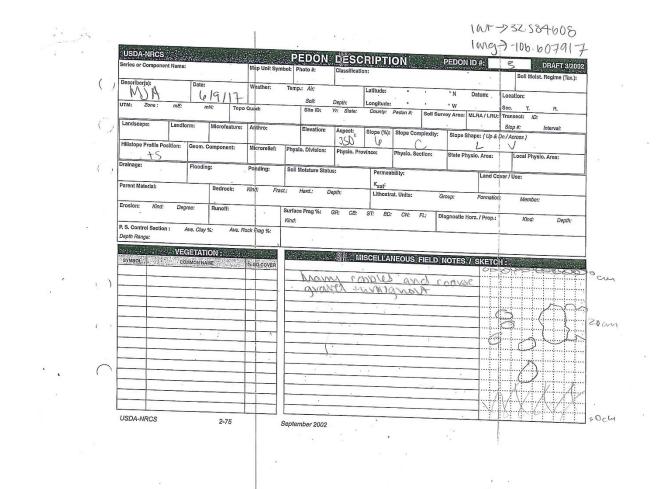
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	4		01-1	LHU.	VSF				8	C: Stagett
\frown	5	J.~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~						and the state of t		
	6									
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8 e.	8			1.0		2				
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t a	9						USDA-NRCS		2-76	September 200
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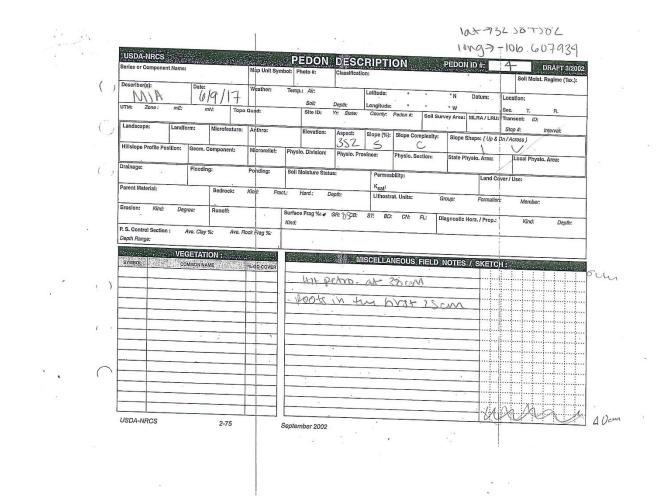


	Depth								it Sýmbol:					Date:	
Obser. Method	(in) (cm)	Horizon	Bno		Noist	Texture	Rock Frac	s	Structure		Consis	tence		Mottleex	Col Mst Sp. Loc
	0-6	A.	W		12-121-12-12-12-12-12-12-12-12-12-12-12-	VFSL	35 MXR 20/ MXR	160 1	SG	UN	MSL	Stk	Plan	% Sz-Cn	Col Mst Sp Loc
2	6-53	BK					2% MXR 2% MXR 5% MXR	FG							
	53-8Z	BKZ				VESL	3% NXE	62	FSBR						
	82-105		T	+			15 MXR	172	1						•
		BKK	-				Town	11	SG						
	105+	BILKM	1-												
-	147	Ky-10	-					_							
				-											
Red	oximorphic Features		l c	oncentrations		Ped / V. Surfa	ce Features	Roots	Pores	1 50	Effor	Clay	COL	1.2.4.5.NG 5735	Notes
% Sz (On Hd Sp Kd Loc B	d Col % s	Sz Cn	Hd Sp Kd Loc	Bd Col %	Dat Cont K	d Loc Col		oc Qty Sz Shp	(meth)	(agent)	%	COL	and and a star	a state the second state of
2		2.		14-2	NE	FFF	CAF					8			
-		2	20	CAN	C	D FF	CAF					6			t
3	(2.4	- ce	CAN		DAF	CAF					6			 +
3	ć		- ce									10		~	I H
3		4	- ce	CAN							,	6 10 12			H H H
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3 4 5 6		4	- ce	CAN								10			
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3 4 5 6 7 8		4	- ce	CAN							,	10			

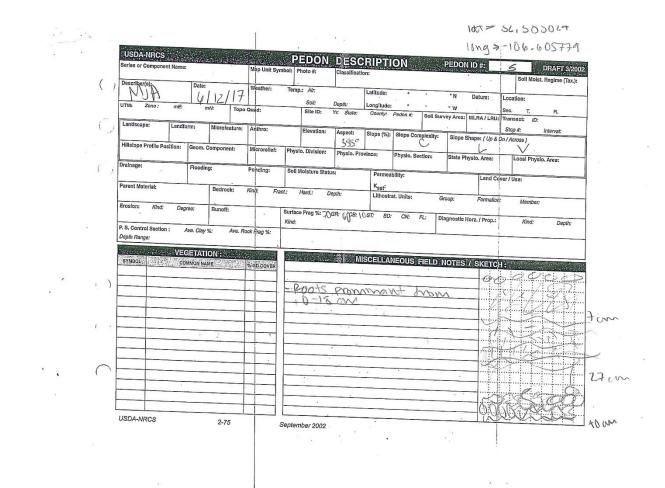


Ohser	C Depth	Horizon	Name: Bnd	Ma	HIN COLOR	A MARGARIAN	and Consecting over series	Map		Sýmbol:				_	Date:	-
Method	(in) (cm)		, ono		Moist	Texture	Knd % Br	nd Sz	Grac	Structure de Sz Type	Dry	Consisi Mst	tence Stk	Pla	Mottles % Sz-Cn. (Col Mit S
	6-7	NB:	5			VESL	MXR22	F.F.	1	SG			CALCULATION PARTY		and the second second	
2	7-22	BK	S			VER	MXR 3		1	VESBE	-					
3	22-47	BKK	T			FSL	CACILAN	FG	1.	VESBE				-		
4	47+	BELLAM	W				Cherina			1.505						
5								3	+							
6						1			1							
7												-	-	-		
8						1		-	1			-				
9									-			-	-	-		
0								-	+				-			
Rec	oximorphic Features	s (State)	Cor	centrations	22200	"Ped / V. Surl	ace Features	l' Roc	Is	Pores	1.00	Ettor	Clay	COT	a with the second	. other start H
% Sz	Cri Hd Sp Kd Loc	Bd Col % s	Sz Cn H	ld Sp Kd Lo	Bd Col	% Dst Cont				Oly Sz Shp	(meth)	(agent)	%. (COE	山北部 网络小子门的 浅	otės
2					3	000	CAF RF						7			
3				· · ·		3.DCI	CAFRF						6		II	
4					E	3 PC	CAF LL/FF								· [[]	
5				84											TV	
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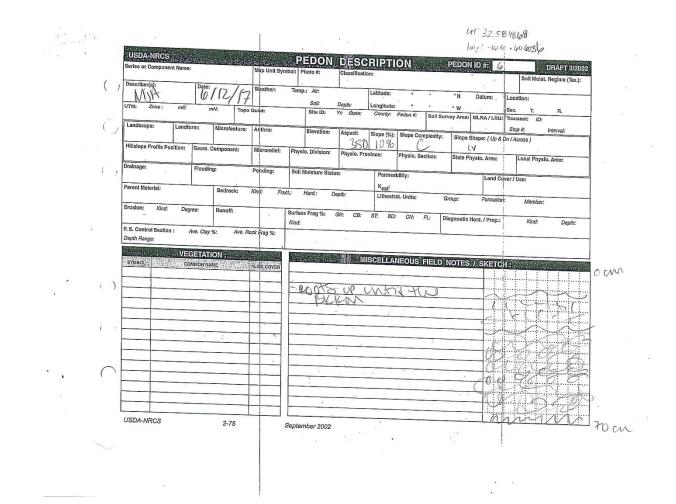
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Obser.	C.	pinponent N							Map L	Jnit	Symbol:			-		Date:	-	
Method,	Depth (in) (cm)	Horizon	Bnd	Ma Dry	Itrix Color Mois	Te	xture	Rock Fr	ags		Structure le Sz Type		Consis	tence	- Poort	Mottles		
		h a	1	and a start of the second	10 Min 19 Min 19					Grac		Dry	Mst	Stk	Pls	% Sz 0	n Col N	ist Sp Loc
	6-4	AB.	5				JL.	3 FG)	36							
	6-22	BK	5			. S.	11	3FG		1	SBK							
	22-38	BUK	W			51	ン	SPAF	1	1	SA							
	38+	BICKM	W						1	1	/			-	-			
								-	-	+		-		-	-			
									-	+								0
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										1	1							
Redo	ximorphic Features	1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 -	Con	centrations	940-2016-2016	Ped /	V Surfar	- Fasturae	i Post			T. Sec. 1		Los William		1		
% Sz Cr	ximorphic Features 1 Hd Sp. Kd. Loc. B	d Col % S	z Cn H	centrations d. Sp. Kd. Li VF. CA.F. ⁴	C Bd Col	% Dst		ce Features d. Loc : Col	City Sz		Pores Oly Szi Shp	pH (meth)	Effer (agent)	ctay %	CCE	(1	Notes	
	n Hd Sp Kd Loc B	d Col % S	z Cn H	d Sp Kd L	C Bd Col	% Dst						pH (meth)	Effer (agent)	1D	CCE		Notes	
% Sz Cr	n Hd Sp Kd Loc B	d Col % S	z Cn H	d Sp Kd L	C Bd Col	% Dst						PH (meth)	Effer (agent)	26 10 12	CCE		Notes,	
	n Hd Sp Kd Loc B	d Col % S	z Cn H		C Bd Col	% Dst						pH (meth)	Effer (agent)	1D	CCE		Notes,	
	n Hd Sp Kd Loc B	d Col % S	z Cn H	d Sp Kd L	C Bd Col	% Dst						pH (meth)	Effer (agent)	26 10 12	CCE		Notes I I I I	
% Sz Cr	n Hd Sp Kd Loc B	d Col % S	z Cn H	d Sp Kd L	C Bd Col	% Dst						(meth)	Effer (agent)	26 10 12	CCE		I I I I	
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% Sz Cr	n Hd Sp Kd Loc B	d Col % S	z Cn H	d Sp Kd L	C Bd Col	% Dst						pH (meth)	Effer (agent)	26 10 12	CCE		I I I I I I	
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% Sz G	n Hd Sp Kd Loc B	d Col % S	z Cn H	d Sp Kd L	C Bd Col	% Dst						(meth)	(egent)	26 10 12	CCE		Nötös I I I I I I I	
% Sz G	n Hd Sp Kd Loc B	d Col % S	z Cn H	d Sp Kd L	C Bd Col	% Dst						(meth)	(agent)	26 10 12	CCE		I I I I I I I I I I I I I I I I I I I	



	Depth	omponent N			Automation and	and all the second second			it Symbol:	445.7			1	Date:		
(Obser. Method)	(in) (cm)	Horizon			trix Color Mois		Rock Frag		Structure	125105.303	Consist Mst	100001-0000-01		Mottles		
	6-2	AR.		999-1928-6, -12 <u>9</u> -1	5 (25) YOU	VECI	3% M/2	64 1	(Dry	Mst	Stk	Play	% Sz-Cn	Col Mst	SpiriLoc
1	7 - 71	Bre			-	1640	3% MXIZ F	66 (SG	-			_			
	7 - 24		×			YFSL	250 MXR	-/	11 30		_		-			
	-1 -1	BLYM				FSL	3% MXR	6 0	VESD			_				
	36+	BXXM	2													
				-												
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				100 at 100											~ ~ ~ ~ ~ ~	
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(Compression)																
Red % Sz 0	oximorphic Feature On Hid Sp Kd Loc I	s Bd Col % S	Conce	Sn Kd Lo	R BR Coll	Ped / V. Surfa	Contraction of the second	Roots	Pores oc. Qty Sz. Shr			Clay C	CE		Notes	
1				terlette terlette	in the order									State Ballet and	A Man Philip	
						a second me		uty SZ L			(agent)	1	GRANN D	140700-000-000-000	T	
2						FDDC	AFILE	JUV SZ L			(agent)	12	999999	tall to de Donnad	I	
_						FDDC	AF RE/C	, ,			(agent)	E		1473: 40.00 - 33	I H	
3			-			FDDC	AF RE/C				(agent)	6			THE	
3						FDDC	AF RE/C	/			(agent);	E		<i>антоны ист. 43</i>	THE	
2 3 4 5						FDDC	AF RE/C				(agent)	E			H H H	
3						FDDC	AF RE/C	/				E		1.	H H H	
3 4 5 6						FDDC	AF RE/C	/				E			I H H	
3						FDDC	AF RE/C	200/527L			(agenty)	E		, ,	I H H	
3 4 5 6 7						FDDC	AF RE/C				(agenty)	E		, ,	I H H	
3 4 5 6 7 8						FDDC	AF RE/C					E		1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	I H H	



Obser.	Depth	Horizon	Bnd	Ma	2401112-002-0000	navari stanova		S Ma	ip Un	it Sýmbol:	-				Date:		
Method	(in). (cm)	1 IIIII ZOII	Dna	Dry	Mols	Text		Rock Frags		Structure ade Sz Type		Consist		and the second	Mottles		
	0-5	AB.		a design and the state	STORE THE OWNER		2/2	XNX2 Cr		1	Dry	Mst	Stk	Pls	% Sz Cn	Col Ms	Sp. Loc
	0					- FS	シレシ	Y MYR-CG	10	SA		1.1					
	5-201	BKF	35			FS	L 3	% MXRFC	7 1	VF SBK	-						
	101-105	BEEM				56	3	CA CA	10				-	-			
	in L		-				- 4	PLACME	0	SG		-					
	ust	BKRM	-					1									
								1									
									-	1	-						
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					1												1
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	ximorphic Features			centrations		Ped / V.			Roots	Pores	pĤ	Effer	Clay	CCE		Notes	alan ker
	ximorphic Features n Hd Sp Kd: Loc E			centrations d Sp Kd Lo		% Dst G	ont Kd I	oc Col Oty		Pores oc Oty Sz Shi				CCE		Notes	
% Sz C							ont Kd I	oc Col Oty						CCE		Notes	
						% Dist G	ont kd i) CAF	ioc Col jaiy					%	CCE		Notes,	
% Sz C				d Sp Kd Lo	ic Bd Col	FDI CDT	ont ka t D CAF D CAF	ioc Col Cally REF REF/CC					%	CCE		Notes	
% Sz C				d Sp Kd Lo	ic Bd Col	% Dist G	ont ka t D CAF D CAF	ioc Col Cally REF REF/CC					%	CCE		Notes ー ー ー ー ー ー ー ー ー ー ー ー ー	
% Sz C				d Sp Kd Lo	ic Bd Col	FDI CDT	ont ka t D CAF D CAF	ioc Col Cally REF REF/CC					7; 7; 9	CCE		Notes:	
% Sz C				d Sp Kd La	ic Bd Col	FDI CDT	ont ka t D CAF D CAF	ioc Col Cally REF REF/CC					7; 7; 9	CCE		Notes	
% Sz C				d Sp Kd Lo	ic Bd Col	FDI CDT VMDC	ont ka t D CAF D CAF	ioc Col Cally REF REF/CC					7; 7; 9	CCE		Notes	
% Sz G				d Sp Kd La	ic Bd Col	FDI CDT	ont ka t D CAF D CAF	ioc Col Cally REF REF/CC					7; 7; 9	CCE		で世正亿	
% Sz G				d Sp Kd La	ic Bd Col	FDI CDT VMDC	ont ka t D CAF D CAF	ioc Col Cally REF REF/CC					7; 7; 9	CCE		Notes	
% Sz G				d Sp Kd La	ic Bd Col	FDI CDT VMDC	ont ka t D CAF D CAF	ioc Col Cally REF REF/CC					7; 7; 9	CCE		Notions	
% Sz Q				d Sp Kd La	ic Bd Col	FDI CDT VMDC	ont ka t D CAF D CAF	ioc Col Cally REF REF/CC					7; 7; 9	CCE		Notes 士 士 工 工	
% Sz Q				d Sp Kd La	ic Bd Col	FDI CDT VMDC	ont ka t D CAF D CAF	ioc Col Cally REF REF/CC					7; 7; 9	CCE		Notes 士 士 工 工	
% Sz Q				d Sp Kd La	ic Bd Col	FDI CDT VMDC	ont ka t D CAF D CAF	ioc Col Cally REF REF/CC					7; 7; 9	CCE		Notes	

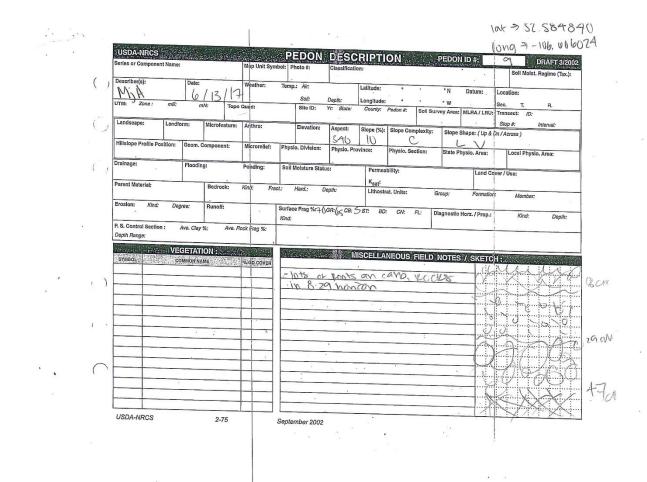
		9		1		8.2							
		USDA-NRCS Series or Component Name		Map Unit Symbol	PEDON	DESC	RIPTI	ON	l.	PEDONI	D#: 7		DRAFT 3/2002
	(Describer(s):	Date:		Photo #:	Classificati	on:					and the strength of a second s	Regime (Tax.):
		MJA	Date:	Weather: Te	emp.: Air:		Latitude:	•	1	" N	Datum:	Location:	
		UTM: Zone : mE:	, mN: Top	o Quad:	Soil: Site ID:	Depth: Yr: State:	Longitude: County:		Soll Surv	" W		Sec. T. Transect: ID:	R.
	()	Landscape: Landfo	orm: Microfeature:	Anthro:	Elevation:	Aspect:	Diana (at)	1	1			Stop #:	Interval:
		Hillslope Profile Position:	Geom. Component:	Microrellef: P		350°	Slope (%):	Slope Com	plexity:	Slope Shi	ape: (Up & C	n / Across)	
		Drainage:			nysio. Division:	Physio, Pro	ovince:	Physic. Sec	tion:	State Phys		Local Physio	Area:
	()	- Johanage:	Flooding:	Ponding: S	oil Moisture Sta	tus:	Permea	bility:			Land Co	rer / Use:	
		Parent Material:	Bedrock:	Kind: Fract.:	Hard.:	Depth:	K _{sat} :	at. Units:					
		Eroslon: Kind: Deg	ree: Runoff:	Sui	face Frag %:					oup:	Formation:	Member:	
		P. S. Control Section :		Kir		GR: CB:	ST: BD:	CN: I	L: Dia	gnostic Ho	rz. / Prop.:	Kind:	Depth:
		Depth Range:	Ave. Clay %: Ave. F	Rock Frag %:		2							
		VE	GETATION :			NA NA	SCELLA	NEQUO					
		SYMBOL: CO	MMON NAME	% GD,COVER		and a literation		NEOUS		OTES /	SKETC	8	ALCONT OF A
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Obser.	Depth	Horizon		Degrate the day of the later	1.41.11.2.11.1.1.1.1.1.	and the second work of	selection of the second second	Wap	Unit	Sýmbol:					Date:	
Method	(in) (cm)	Horizon	Bnd	M: Dry	atrix Color Moist	Texture		rags	Gra	Structure		Consis	tence	1.540	Mottles % Sz Cn. Col Mi	N A DE
	0-4	AR				VESL	2% WAN	RFM			(ECOLOR)		SIK	CHIST	No. Szech. Col. Me	Sp. Loc
	4-74	BXXI				VESL	21/ MX		0	SG		1.8				
	24 - 57	BKKM	_				1 CVAR			SBK		-				
	871		,			SiL	7%CAR	. CG	0	SG						
	041	BERM									_					
14	5	V pl. a vice		-		_										
-			_	-		_										
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						-		1				. 1	-	-		
Redo	ximorphic Features	1998 - Dager	Co	centrations	PROPERTY.	Ped / V. Surf.	ice Features	Bo	ots	Pores		Effor	Clay	COL	Notes	Carrie Ga
% Sz Cr	i Hd Sp Kd Loc I	Bd Col % s	z Cn I	ld Sp Kd L	oc Bd Col	% Dst Cont				c Oty Sz Shp	(meth) (agent), %,		in the second	i da 117. Altera Alt
						VED DCA	FRF	-					5		2	
_						FODCA	F PF/C	c.				4	6		II	
							anner manner filmer	-	- 1							
						NEDDII	AF RFIL	9					8		· Stt	
						NEDDII	AF RFIL	1					8		· III	
				-		NEDDI	AF PF/	<u>(</u>					8		TH I	
						NEDD (1	AF PF/	<u> </u>					8		TH I	
						NEDD (I	AF PF//						8		11- 112 2	
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	USDA-NRCS	in trick	Sec. Cal	12.7.1	W. Mr. Carl		and station of the	***** * ****** Z				10101	3-106
	Series or Componen	t Name:	and the second		Map Unit Sy	mbol: Photo #:	Classification		ON	PEDON	ID #:	B	DRAFT 3/20
()	Describer(s): M/N		Date: 0/13	5/17	Weather:	Temp.: Alr:		Latitude:	• i	*N	Datum:	Location:	st. Regime (tax.):
	UTM: Zone :	mE:	mN:		Quad:	Soil: Site ID:	Depth: Yr: State:	Longitude: County:		" W Survey Area:	MLBA/LBU	Sec. T. Transect: ID:	R.
C)	Landscape:	Landform	: Micr	ofeature;	Anthro:	Elevation:	Aspect:	Slope (%):	Slope Complex!			Stop #: Dn / Across)	Interval:
	Hillslope Profile Pos	ition: G	eom. Compo	onent:	Microrellef:	Physio. Division:	170° Physio, Pro	vince:	S Physio. Section:		L /sio. Area:	Local Phys	In Areas
C y	Drainage:	F	looding:		Ponding:	Soll Moisture Stat	tus:	Permea	bility:			over / Use:	sio. Area:
	Parent Material:		Bed	lrock:	Kind: Fr	act.: Hard.: I	Depth:	K _{sat} :	at. Units:			ļ	
	Erosion: Kind:	Degree	e Run	off:		Surface Frag %: 7	GRICE CRI			Group:	Formation	: Member	:
						Kind:	6000.(031. 80	GN: FL:	Diagnostic H	orz. / Prop.:	Kind:	Depth:
15	P. S. Control Section	: Ave	. Clay %:	Ave. R	ock Frag %:								
	Depth Range:				ock Frag %:								
	Depth Range:	VEGE	TATION	Same					Neous Fiel	D NOTES	/ SKETC	H:	
,)	Depth Range:	VEGE	TATION	Same						d notes	/ SKETC	H:	
·)	Depth Range:	VEGE	TATION	Same							/ SKETC	H	
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	Depth Range:	VEGE	TATION	Same							/ SKETC		
	Depth Range:	VEGE	TATION :	Same									
	Depth Range:	VEGE	TATION :	Same			ALU						
	Depth Range:	VEGE	TATION :	Same			ALU	- hi		Szum			
	Depth Range:	VEGE					ALUC	- hi		SZ M			
	Depth Range:	VEGE		Same			ALUC	- hi		SZ M			
	Depth Range:	VEGE					ALUC	- hi		SZ M			

Obser.	Depth	Horizon	Bnd	Ma	Inc. Acture	weeks 19 19 12 29	-Theodorean				Sýmbol:					Date:	
Method	(in) (cm)	Horizon	Bna	Dry			xture	Rock F			Structure e' Sz Type		Consis	tence	Ariant Alfa	Mottles % Sz. Ch. Cc	
	0-7	AB.	S			Contract of the second	56	1% NX6	2.46	1		C.Dry.	Wist	SIK	PISA	sz ch ici	ol Mst Sp Loc
	7.17	BV	W		-			ZYONX	- SIA	1	SG		10				
	17-32	100						3% CAR	CED	1	VESBE	-	_				
		BUK	W			82	s	15% CAC	65	0	SA		_				
	32+	BULM	S	R					1								
			-						1								
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Transfer of the									1	1							
% Sz C	n Hd Sp Kd Loc I	3d Col % s	Con Con H	centrations	Bd Coll	Ped /	V. Surfa	ce Features	Root		Pores Oty Sz Shp	рĤ	Effer	Clay	Sec. 1	in a which a start of	tes
								FRF	July Sc.	LUC	Joly 52 Shp	, (intern)	(agent	2	<u>. Nilória</u>	t t	arranta da
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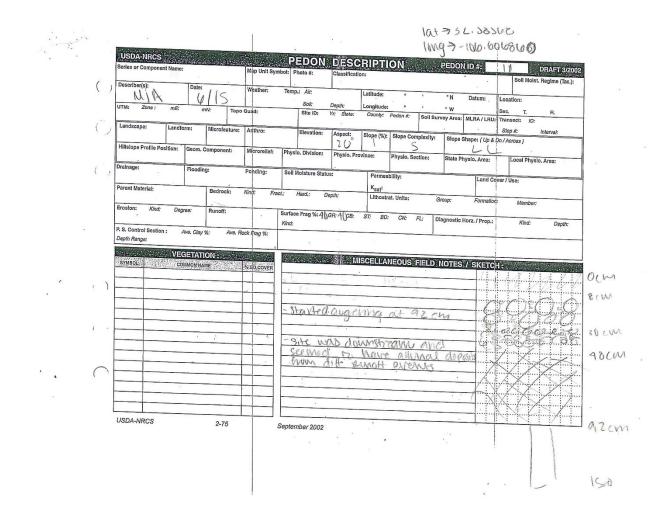
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(Obsei	Depth	omponent l		A	Sinte Portage	10 Mar 10 10	Contraction Carrier	di certaine anno cris		nit Sýmb						Date:		
Metho	d (in) (cm)	a line line line line line line line line	, one	Diry	Mole		Texture	Rock Fi	ags	Structi	ire		Consis	tence	1.000 1.000	Mottles	A.C. Star	
	0-8	AB.	5		- Saltra	- Max	FSZ	2% MX	255		1.000	Dry	Mst	Stk	Pls	% Sz.(Dn. Col	Mst Sp.
	8-29	BKH	-		-	-				1	36							
	29-47	BKK2				-	JF8L		LCh 1		SBK							
	477					-	1881	3% CA &	65 0) 5	5							
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()	Landscape:	Landform:	Microfeature:	Anthro:	Elevation:	Aspect:	Slope (%):	Slope Compl	exity: Slo	e Shape:	(Up & D	Stop #: n / Across)	Interval:	
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(7	Drainage:	Floodi	ng:	Ponding:	Soll Moisture Sta	tus:	Permeabi	lity:		ļ.	and Cov	er / Use:		
	Parent Material:		Bedrock:	Kind: Fra	nct.: Hard.:	Depth:	K _{sat} : Lithostrat	. Units:	Group:	Fc	ormation:	Membe	<i>ar:</i>	
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2	0-8	A			168	sl	1/mare	FG	0	SG							
3	8-30	BK1	1		S:	L	30/MXEF	SA	1	NESBE							
4	30 - 48	BUI			5	L	3% MXI	55		WSBL	•						
5	48-150	BEIL			Si	L	15 MXX	1 11	2	MSBK							
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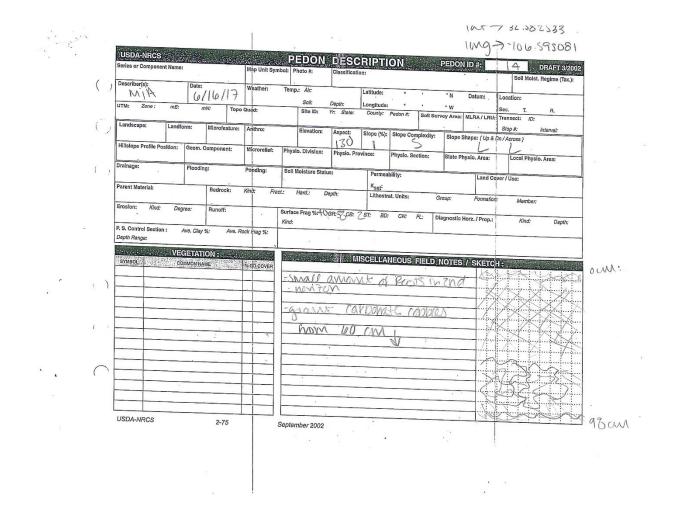
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		USDA-NRCS Series or Component Name:		PEDON D		ION	PEDON ID #:	2 DRAFT 3/2002
	()	Describer(s): Date:	Weather:	4	assification:			Soll Moist. Regime (Tax.):
	× /	MIA G/ISIT		Temp.: Air: Soll: Dep			"N Datum:	Location: Sec. T. B.
	(°)	Landscape: Landform: Microfeature:	Quad:		State: County:		vey Area: MLRA/LRU	Sec. T. R. : Transect: ID: Stop #: Interval;
	1	Hillslope Profile Position: Geom. Component:	Microrellef:		331 Slope (%	5): Slope Complexity:	Slope Shape: (Up &	
	1	Drainage: Flooding:	Ponding:		iysio. Province:	Physic. Section:	State Physio. Area:	Local Physio. Area:
	1 1	Parent Material: Bedrock:		Soll Moisture Status:	K _{sat} :	eability:	Land C	over / Use:
		Erosion: Kind: Degree: Runoff:	Kind: Fi	ract.: Hard.: Depth:	Lithos	strat. Units: G	roup: Formatio	n: Member:
				Surface Frag %: GR: Kind:	CB: ST: E	ID: CN: FL: D	agnostic Horz. / Prop.:	Kind: Depth:
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		USDA-NRCS 2-75		September 2002				
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Obser.	Depth	Horizon		Des est or Landston	No S. C.S. Samera	and the second second second			it Sýmbo					Date:		
Method	(if) (cm)		Bnd	Dry.	trix Color Moist	Texture	Rock Frags Knd % Rnd							Mottles % Sz Cn		
1	0-7	A.		Contraction Section		NFSU	2% MXR FM		1			Stk	Pls	Sz. Cn	Col Mst	Sp. Loc
2	7-32	BTK			-	1882	3% MXL MI 3% DAV2 FT 3% DAV2 FT		1	6		-	-			
	32-80	BYKN	-			10880	3% CAR FE	7	VFSB	NL I		-	-			
	50 +	BRIAN	-				1% CAR FF	7				-	_			
	30 1	DEMMI	1					-								
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	doxImorphic Features		Co	ncentrations		Ped / V. Surfa	ce Features	Roots	Por	es pi	Effer	Clay	COF	tall and	Notes	arra tara
% Sz:	Cn Hd Sp Kd Loc I	Bd Col % s	Sz Cn I	Hd Sp Kd Lo	c Bd Col	% Dst Cont K				Shp (me				a de la	Notes	an Norga Wardha
2						FDDC	AFRF				•	4			T	
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	USDA-NRCS Series or Component Name:	PEDON DESCRIPTIO	N PEDON ID #: DRAFT 3/2002
() Describer(s): Date: Mik 6/15	Weather: Temp.: Air: Latitude: Soli: Depth: Longitude:	Soli Moist. Regime (Tax.): N Datum: Location:
(UTM: Zone: mE: mN: To Landscape: Landform: Microfeature	ppo Quad: Site ID: Yr: State: County: Pe	Stop #: Interval
	Hillslope Profile Position: Geom. Component:	Microrelleft Division Slope (%): S	Hope Complexity: Slope Shape: (Up & Dn / Across)
(Drainage: Flooding:	Pohding: Soil Molsture Status: Permeabili	
	Parent Material: Bedrock: Erosion: Kind: Degree: Runoff:	Kind: Fract.: Hard.: Depth: Lithostrat.	Group. Pormailon: Member:
	P. S. Control Section : Ave. Clay %: Ave. Depth Range:	. Surface Frag %: GR: CB: ST: BD: Kind:	CN: FL: Diagnostic Horz. / Prop.: Kind: Depth:
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	USDA-NRCS 2-75		
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	Contraction Co					The local sector			t Symbol:					Date:	
/Obser. Method	Depth (in) (cm)	Horizon	Bnd	Mat Drv	rix Color Moist	Texture	Rock Frags					tence Stk		Mottles % Sz Cn Col Mst	
	0-9	AB	terror (Calo		CONTRACTOR OF	VESL	2 % NXE FG	, D		, ory	Mat	SIK	PIS	Sz Ch. Col Mst	Sp. Loc
	9-32	BY				VESL	3X CAR FE	7					-		1
	32-75	BUN	1			Sil	2% CAP FO	16	FOOR			-	-		
	FSt	BKILM	+				WWOAP CG	-		-					
	101	OPIN	-			-		+				-	_		
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% Sz.C	oximorphic Features In Hd Sp Kd Loc E	d Col % S	l Co z Cn	ncentrations Hd Sp Kd Lo	c Bd Col	Ped / V. Surfa % Dst Cont I		oots :	Pores			Clay	CCE	Notes	5677
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	· ·	· · ·				NED DCI	AF RF	94, 14	oc (Qiy Sz Shr	(meth)) (agent)	8 D		T.	
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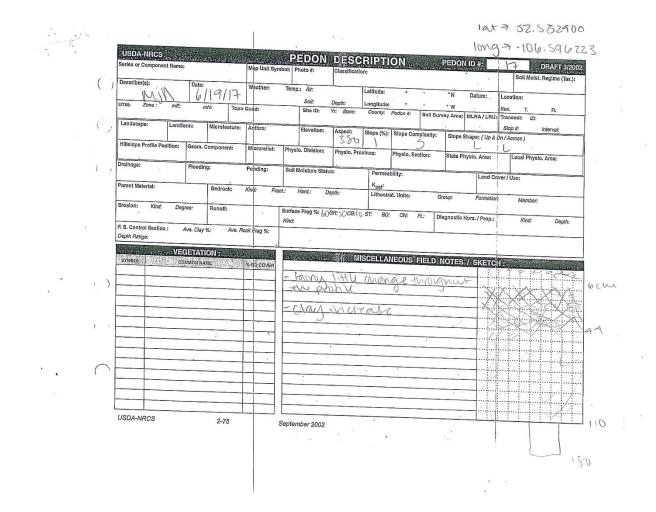
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2	5-26	BKY	IN			SiL	34/ MX2	CG	1	VE SBX			_		
3	210-70	BUG				Sil	ASCAR	16	6	95					
4	70-98	BRIGN				Cal	35 MXP	CG	0	Sh					
5	10 10		1			2	EL-OKE	(4							
6												+			
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		USDA-NRCS Series or Componen	t Name:	inice an		11:00	Map Unit S	ymbol:	EDON	DESC		ON		PEDON	I ID #:	15		DRAFT 3/2
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		UTM: Zone :	mE:	mi	N:	Topo C	luad:		Soil: Site ID:	Depth: Yr: State:	Longitude: County:	° Pedon II:	Soil Sun	" W /ey Area:	MLRA / LRU	Sec.	T.	R.
(1	Landscape:	Landfor	m:	Microfe	ature:	Anthro:		Elevation:	Aspect:	Slope (%):	Slope Com			Shape: (Up &	Stop #	e	Interval:
		Hillslope Profile Pos	ition:	Geom. C	ompone	nt:	Microrellet	: Phys	sio. Division:	260 Physio. Pro		S	5		L	iL		
7		Drainage:	_	Flooding			Dah II	5			vince:	Physio. See	otion:	State P	hysio. Area:	Lo	cal Phys	lo. Area:
(1			· roounig	4.		Ponding:	Soil	Moisture State	us:	Permea	bility:			Land C	Cover / Us	:	
		Parent Material:			Bedroo	ck: /	lind:	Fract.:	Hard.: D	Depth:	K _{sat} : Lithostr	at. Units:	G	roup:	Formatio	on:	Member	
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		Erosion: Kind:	Degr	ee:	Runoff:			Surfa	ce Frag %:	GR: CB:		CAL	GI - DI			+		
		P. S. Control Section Depth Range:	: A	ve. Clay 9	%:	Ave. Roo	k Frag %:	Kind:		<u>anke</u>	ST: BD.				Horz. / Prop.:		Kind:	Depth:
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)	P. S. Control Section Depth Range:	· A	ve. Clay 9	«: ON:	Ave. Roo		Kind:		<u>anke</u>							Kind:	Depth:
t î)	P. S. Control Section Depth Range:	· A	ve. Clay 9	«: ON:	Ave. Roo		Kind:		<u>anke</u>							Kind:	
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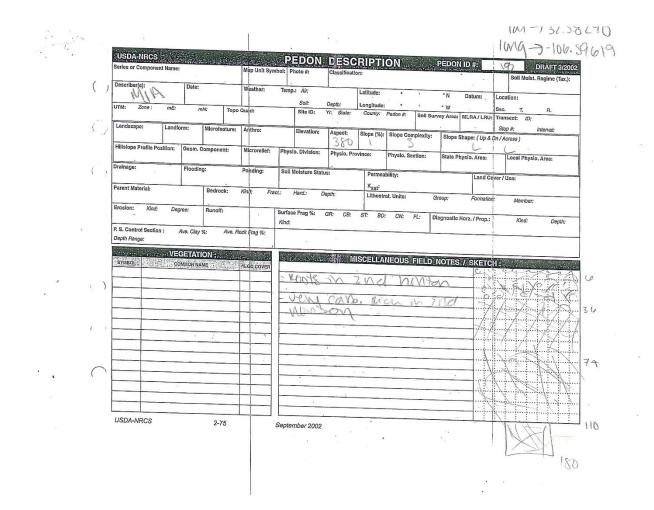
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	32- (00	BWKI				51	67 MX	K PH	1	VESBE	•						
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							ingolo. Division.	Physio, Pro	ovince:	Physic. Section:	State Physi	io. Area:	Local Physic.	Area:
	()	Drainage:		Flooding:		Ponding:	Soil Moisture Sta	tus;	Permea	bility:		Land Co	ver / Use:	
		Parent Material:		Т	Bedrock:	Kind: Fra	ict.; Hard.;		K _{sat} :					
						Inno. Pra	ict.: Hard.:	Depth:	Lithostr	at. Units:	Group:	Formation	: Member:	
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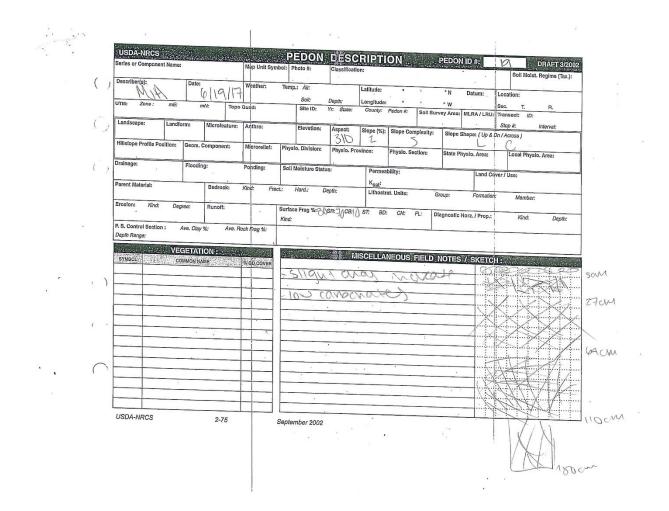
	Depth	omponent I Horizon		A CARLEN CO	Ciber west	No. 2 Construction of			it Sýmbol:					Date:	6/16	7772
/Obser. Method/	(in) (cm))		Matrix C		Texture	Rock Fr	ags	Structure		Consisi Mst			Mottles		
1	0-9	RO				1.	24 MX0	-66		Dry	SOMSLES	Stk	Pls	∿%! Sz⊍Cn	Col Mst	Sp. Loc
2	9-80	BIL				C. 1	STO. CAY	LFG .	1							-1
	SD-181	atk			-	DID	2% MXX	266		-		_		_		
	000	121.					29-MXX	-(6)		-		_				
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Redo % Sz C	oximorphic Features In Hd Sp Kd Loo E	d Col % s	Concentra	itions Kd Loc Bd			ice Features Kd Loc Col	Roots			Effer	Clay	CCE	19 A. (17)	Notes	590.2%
1					E		AFIF	Nory OZ. L	ec Qty Szi Shr	(mein)	(agent)	B	9600-0 <u>1</u>	na de la composición br>La composición de la c	A GENERAL	din Un
2				9 G		12	AF RF/a					9			T	
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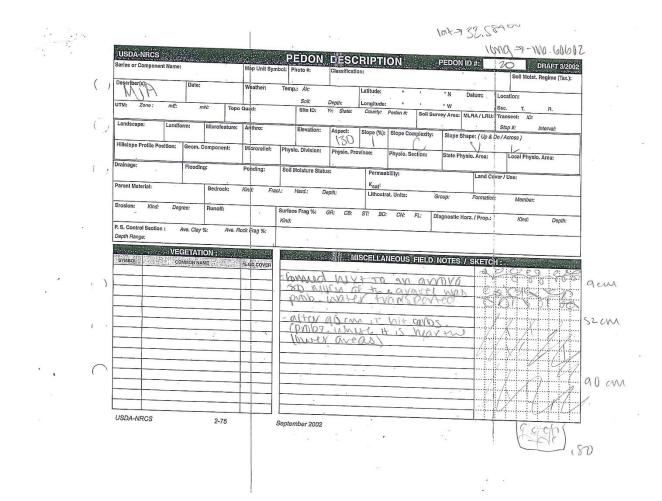
	Obser.	Depth	omponent l Horizon	Bind		rix Color	Texture	No. of the second second	Map	Uni	t Sýmbol:				Date:		
1000	Method	(in) ((cm))	Horizon	Bna	Dry	Moist		Rock F			Structure ide Sz Type	Cons	Istence	Pla	Mottles % Sz Cn		
1		0-6	AB.	5			VESZ	1 % MX2 3% MX2 2% MX2	64	0	YG.		- COIN	1025183	- tes dzoon	COLMAN	op. i
2		10-AA	BTK	S			SiL	3% CAR 3% CAR	Fh				-	-			-
3		44-180	Bt	C			Sil	1- 5 NXX	LFH	-	VF SBIL					- Vietle	
4		11 100	Par-	-)			210			2	FSBK						
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8		-							1								
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10									1								
	Red	oximorphic Feature		Co	ncentrations		Ped / V. Surf	ace Features	Ro	ots	Pores	pH Effe	r Clay	CCE	e an	Notes	t _a a
1	% Sz (On Hd Sp Kd Loc	Bd Col %	Sz Cn	Hd Sp Kd Lo	c Bd Col	Dst Cont	Kd Loc Col	Oty S	Sz Lo	c Qty Sz Shp						
2							FDD		-	_		1	7				
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3	1					V	FDDa	AFRF					15				
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Obser.	Depth	imponent N		The of the officer				Map Un						1	Date:		1
Method	(in) (cm)	Horizon	Bnd	Mat Dry	rix Color Moist	Texture	Rock Frag	s c	Stri	ucture	0			S. Mr.	Mottles		en de la compañía de Compañía de la compañía
	0-6	A			Solution	VFSL	4 CMARI	61.			Ury	MSL	Sik	Pls	% Sz Cr	Col·M	it Sp. Loc
	10-36	BAK	1			5:1	ST MXLC SK CAR F	60	1	SA							
	36.74	BHI	-			Sil	JOS MXRA	4	1	SBK			_	-			
	74-187	B+7	-			Sil	ZEMXE	CC	F	SUF			_	_			x
	11100	PIC				Sil	ZKMXKA	18 2	F	SBK			-	-			
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% Sz.C	loximorphic Features Cn Hd Sp Kd Loc B	d Col % s	Cor Z Cn H	centrations	Bd Col	Ped / V. Surf. % Dst Cont I		Roots	oc C	Pores Ny Sz Shp			Clay C %	CE	ala je Doba z	Notes	
% Sz (Cn Hd Sp Kd Loo B	d Col % s	I Cor	centrations Id Sp Kd Lo		% Dist Cont 1	Ke Loo Col .C		oc C					CE :	si di c	Notes,	
% Sz 0	Cn Hd Sp Kd Loc B	d Col % s	I Cor	ld Sp Kd Lo	-	VEDD VEDD	Ke Loo Col R CAF RF AF RF//C					agent),	7	CE		Notes	
% Sz 0	San Hd Sp Kd Loc B	d Cal % s	I Cor	ld Sp Kd Lo	-	VEDD VEDD	Ke Loo Col .C					agent); ((26 7) 7	CE		Notes	
% Sz 0	San Hd Sp. Kd Loc B	d Cal % s	I Cor	d Sp Kd Lo	-	VEDD VEDD	Ke Loo Col R CAF RF AF RF//C					agent); ((7	:CE		Notes	
% Sz C	San Hd Sp. Kd Loc B	d Col % s	I Cor	d Sp Kd Lo	-	VEDD VEDD	Ke Loo Col R CAF RF AF RF//C					agent); ((26 7) 7			Notes	
% Sz C	an Hd Sp, Kd Lbe B	d Col % s	I Cor	d Sp Kd Lo	-	VEDD VEDD	Ke Loo Col R CAF RF AF RF//C					agent); ((26 7) 7	·CE		Notes	
2 2	on Ho Sp Kd Loo B	d Col % s	i Cor	a Sp Ka Lo	-	VEDD VEDD	Ke Loo Col R CAF RF AF RF//C					agent); ((26 7) 7			Notes T T T	
% \$2:0 2	Can Ho Sp Kd Loo B		I Cor	d Sp Kd Lo	-	VEDD VEDD	Ke Loo Col R CAF RF AF RF//C					agent); ((26 7) 7	CE		Notes	
% Sz: 2	Chi Hd Sp Kd Loo B		I Cor	a Sp Ka Lo	-	VEDD VEDD	Ke Loo Col R CAF RF AF RF//C					agent); ((26 7) 7	CE		Notes	
% Sz: 2	Gn Hd Sp Kd Loc B		z Cn F	a Sp Ka Lo	-	VEDD VEDD	Ke 1.00 Con X CAF 121 AF 21/1C AF 227	Dity Sz La		ity Sz Shp		agent); ((7 7 1 7			TI X LI	
HEG HEG 2 2 3 3 0 0	Gn Hd Sp Kd Loc B		z Cn F	a Sp Ka Lo	-	VEDD VEDD	Ke 1.00 Con X CAF 121 AF 21/1C AF 227	Dity Sz La				agent); ((26 7) 7			TI X LI	mber 2002
% Sz: 2	Gn Hd Sp Kd Loc B		z Cn F	a Sp Ka Lo	-	VEDD VEDD	Ke 1.00 Con X CAF 121 AF 21/1C AF 227	Dity Sz La		ity Sz Shp		agent); ((7 7 1 7			TI X III	mber 2002
% \$z::C 1 2 8 6 7 3	Gn Hd Sp Kd Loc B		z Cn F	a Sp Ka Lo	-	VEDD VEDD	Ke 1.00 Con X CAF 121 AF 21/1C AF 227	Dity Sz La		ity Sz Shp		agent); ((7 7 1 7			TI X III	mber 2002



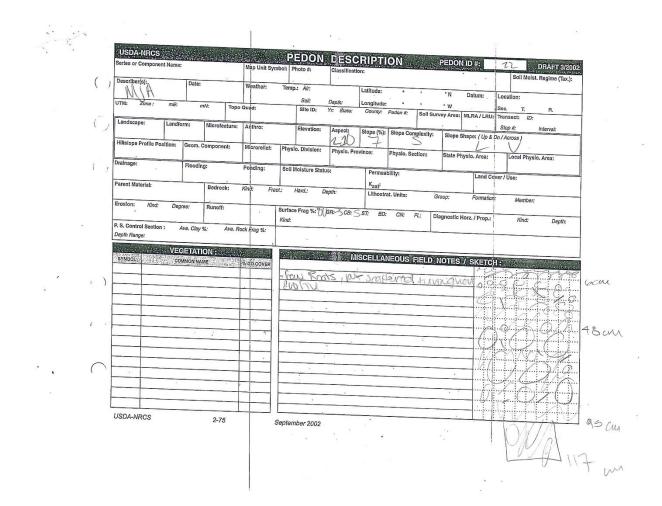
Obser.	Depth	omponent N Horizon		Ma	Sale Cales	Text	Sector Converter			t Sýmbol:					Date:		
Method	(in) (cm)		1	Dry			STATISTICS.	ock Frags		Structure		Consis			Mottles		
	0-5	AB				VFS	1 4%	MXRECE	TA		Dry	MSL	Stk	Pls	% Sz⊍Cr	Col Ms	t Sp. Loc
	5-27	1011				VI	3%	MXRCA	iU	<u>\$6</u>		1.1					
_		Bit			-	511	24	HAR M	31	NESPIC							
	27-6A	BYI				Sil	- 11k	WXBEE	12	FSBL	•						
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Redo	ximorphic Features	3d Col. % e) Con	centrations		Ped / V.	Surface Feat		Roots	Pores	pH	Effer	Clay	CCE		Notes	3.00.777
Redo % Sz: C	xxImorphic Features n. Hd. Sp. Kd. Loc. F	3 30 Col % S) Con z Cn H	centrations d. Sp. Kd. Li	oc .Bd .Col!	% Dst G	ont Kd Loc	Col Ot		Pores	.pH (meth)	Effer (agent)	Clay	CCE		Notes	in the second
¹ Redo % Sz: G	ximorphic Features n Hd Sp Kd Loc F	3d Col % S) Con z Cn H	centrations d. Sp. Kd. Li	oc Bd Col	% Dst G	ont kd Loc > (FA)	Col jat			pH (meth)	Effer (agent)	Cláý 1%	11. 11. 11. 11.		Notes	2910
% Sz C	iximorphic Features n Hd Sp Kd Loc F	Sd Col % S) Con z Cn H	d Sp Kd L	oc.Bd Col	% Dst G	ont kd Loc > (FA)	Col Ot			pH (meth)	Effer (agent)	70			'Notes	
% Sz C	ximorphic Features n Hd Sp Kd Loc F	od Col: % S) Con z Cn H	d Sp Kd L	oc .Bd .Col	% Dst G	ont kd Loc > (FA)	Col Jan RF IJ/U			.pH (meth)	Effer (agent);	70			Notes T	
% Sz C	iximorphic Features n Hd Sp Kd Loo E	d Col % S) Con z Cn H	d Sp Kd L	oc.Bq.Col	VFDT VFDT	ont kd Loc 2 (EAF 2 (AF) 1 D MF F	Col Jan RF V/U F			pH (meth)	Effer (agent)	7013			Notes T	
% Sz C	ximorphic Features n Ho Sp Ka Loc F	3d, Col: 5% S) Con z Cn H	d Sp Kd L	oc.Bq.Col	VFDT VFDT	ont kd Loc D GAL C CAL 1	Col Jan RF V/U F			pH (meth)	Effer (agent)	70			Notes.	
% Sz C	Xinorphic Features n. Ho. Sp. Kd. Loc. F	Be Col % S	l Con z Cn H	d Sp Kd L	oc.Bq.Col	VFDT VFDT	ont kd Loc 2 (EAF 2 (AF) 1 D MF F	Col Jan RF V/U F			(meth)	Effer	7013			Notés F	
% Sz C	Ximorphic Features	Str. Col- %, s	l Con z Cn H	d Sp Kd L	oc.Bq.Col	VFDT VFDT	ont kd Loc 2 (EAF 2 (AF) 1 D MF F	Col Jan RF V/U F			pH (meth)	Effer (agent)	7013		- -	'Notes,	
% Sz C	Ximorphia Features	8 8d, Col: %, S) Con z Cn H	d Sp Kd L	oc.Bq.Col	VFDT VFDT	ont kd Loc 2 (EAF 2 (AF) 1 D MF F	Col Jan RF V/U F			pH (meth)	Effer (agent)	7013			T	
% Sz C	ximorphia Features n Ha Sp Ka Loe F	8 8d, Col: %, S) Con z Cn H	d Sp Kd L	oc.Bq.Col	VFDT VFDT	ont kd Loc 2 (EAF 2 (AF) 1 D MF F	Col Jan RF V/U F			(meth)	Effer (agent)	7013		-	F	
% Sz C	ximorphic Features	33 Col: %, S) Con z Qn H	d Sp Kd L	oc.Bq.Col	VFDT VFDT	ont kd Loc 2 (EAF 2 (AF) 1 D MF F	Col Jan RF V/U F			pH (meth)	Effer	7013			T	
% Sz C	ximorphic Features	39. Col: %, S) Con	d Sp Kd L	oc.Bq.Col	VFDT VFDT	ont kd Loc 2 (EAF 2 (AF) 1 D MF F	Col Jan RF V/U F			pH (meth)	Effer	7013			T	



Obser.	Depth	Horizon		Ma	Ply Caller	Texture		Map U				to B leads to B us		Date:	
Method	(in) (cm)		, one	Dry	Moist		Rock Fr		Struct			onsistenci Mei Su		Mottles % Sz Cn Col M	
	1.9	AB	N			VESU	SY MX	efh A	1	SA	- City		Constant States	Sz Ch Col A	Ast Sp. Loc.
2	9-52	BW	N			1	214 WX				-				
	52.90	2.1	N		· · ·		198MXX		180	5456			-		
	90-15D	DIN				SiL	1		1	BK	_	_	_		
	-10 100	BWK	V	-		JIL	2 0/ MX0 3 5/ CAR	MA	WFJ	BR	_				
						-	1	_							
										_					
								2							
									1						
1	On Hd Sp Kd Loc I	Bd Col % :	Sz Cn H	ld Sp: Kd Lo		% Dist Cont	AFRF	Qty Sz	Lec Qty	Sz Shp		Effer Cla agent) %		Notes	
2				2			2110 1-3								
з						RDDC	AFRF					2			
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() Describer(e): M A UTM Zon Landscape: Hillstope Prof Parent Materia	e: mE: mN: To	po Quad: e: Arithro:	Elevation: As	State: County:		"N Datum: "W ey Area: MLRA / LR	Soli Moist. Re Location: Sec. T.	Pgime (Tax.):
Landscape: Hillslope Prof	Landform: Microfeature	e: Anithro:	Site ID: Yr: Elevation: As	State: County:			Sec. T.	R.
Hillslope Prof	Ille Position: Geom. Component:		10	mante Law			U: Iransect: ID:	
Drainage:		Microrellef: Phys		_10 Slope (%):	Slope Complexity:	Slope Shape: (Up	Stop #: Int & Dn / Across)	terval:
	Flooding:		io. Division: Ph	ysio. Province:	Physio. Section:	State Physio. Area:	Local Physic, A	irea:
Farent materia		Ponding: Soll	Moisture Status:	Permea K _{sat} :	bility:	Land	Cover / Use:	
Erosion:	Bedrock:	Kind: Fract.:	Hard.: Depth:		at. Units: Gr	oup: Format	on: Member:	
P. S. Control S	Kind: Degree: Runoff:	Surfac Kind;	e Frag %: 60GA:	SCB: S ST: BD	CN: FL: Dia	gnostic Horz. / Prop	: Kind:	Depth:
				and at	NEOUS FIELDIN TP} CWI Mg A+ 2 WARDY	OR ASAM		101 8 101 25 10 64

Obser.	Depth	Horizon	Bnd		rix Color",		ture				t Sýmbol:					Date:	
Method	(in) (cm)	Hunzon	Bna		Moist	lext	2010/2012	Rock			Structure de Sz Type			tence. Stk	Ple	Mottles % Sz Cn. Col. Mst	So Loc
	6-8	A.	S			VIFS		1% MY			SF+				0.0011252.00		00.100
2	8-25	BKI	W			040	SL.	4% MX	lih	. 1	VESBIC						
	25-6A	BVK	5			VES	1	SHCAP	FG	0	SG						
L	10A-117	BKI	W			1002		3% CAN	-64	1							
1	1177	BUVW	00			-		140 (14	FIG	1	FSBK			-			
		1.50 + 10.								$\left \right $					-		
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		and the second s											÷				
Rec	doximorphic Features Cn. Hd. Sp. Kd. Loc. E	3d Col % S	l Con	centrations Id Sp :Kd Ld	c .Bd Col	Ped/V. % Dst G	. Surfac	e Features	l' Re	125-51	Pores	pĤ		Clay	CCE	Notos	
Rec	doximorphic Features Cn. Hd :Sp. Kd. Loc. E	id Col: % S	l Con z Cn H	centrations Id Sp::Kd Lo	c Bd Col	% Dst C	Cont Ko	e Features 1 Los Col AF BG	Qty d	125-51	ALD ALD ALD ALS	pĤ		%	CCE	Notes	54735 194735
Rec % Sz	Joximorphic Features Cn. Hd. Sp. Kd. Loc. E	3d Col % S) Con sz Cn H	icentrations Id Sp Kd Ld	c Bd Col	% Dst G	Sont Ke	AF BF	Qty :	125-51		pĤ			CCE	Notes.	
* Rec % Sz	JoxImorphic Features Cn. Hd Sp. Kd. Loc E	id: Col. %, S	Con Z Cn H	id Sp Kd Lo		% Dst G UFD CD T	Sont Ke	AF EG	Qty :	125-51		pĤ		55	CCE	Notes J E T	
Rec % Sz 1 2	Joximorphic Features Cn Hd Sp Kd, Loc E	1d: Col: % S	l Con iz Cn H	id Sp Kd Lo		<u>x Dst c</u> KD LD (JD (DCP	AF EG AF EG AF EG AF EG/A	Qty :	125-51		pĤ		5554	CCE	Notes	
Rec % Sz 1 2 3	JoxImorphic Features Gn. Hd. Sp. Kd. Loc /	rd Col. % S	Con Z Cn H	id Sp Kd Lo		<u>x Dst c</u> KD LD (JD (DCP	AF EG	Qty :	125-51		pĤ		55	CCE		
Rec % Sz 1 2 3 4	JoxImorphie Feature Cri. Hd.3p. Ko. too E	2d Col. % S	l'Con	id Sp Kd Lo		<u>x Dst c</u> KD LD (JD (DCP	AF EG AF EG AF EG AF EG/A	Qty :	125-51		pĤ		5554	CCE	T T T T T T T	
Rec % Sz 1 2 3 4 5	oximorphic Feature Cri. Hd 39 Ko. too E	2d Col %, S	Z Cn H	id Sp Kd Lo		<u>x Dst c</u> KD LD (JD (DCP	AF EG AF EG AF EG AF EG/A	Qty :	125-51		pĤ		5554	CCE		
Rec % Sz 1 2 3 4 5 6	loximorphic Features Cri, Hd Sp, Kd, Loo E	id, Col: %, S	I Con	id Sp Kd Lo		<u>x Dst c</u> KD LD (JD (DCP	AF EG AF EG AF EG AF EG/A	Qty :	125-51		pĤ		5554	CCE		
Rec % Sz 1 2 3 4 5 6 7 8	Joximorphić Features Cn. Hd Sp. Kd. Loc I:	3d Col: %, S	Con Z Cn H	id Sp Kd Lo		<u>x Dst c</u> KD LD (JD (DCP	AF EG AF EG AF EG AF EG/A	Qty :	125-51		pĤ		5554	CCE		
Rec % Sz 1 2 3 4 5 6 7	Joximorphi6 Features Cn. Hd Sp. Kd. Loo IS	id Gol: %, s	l Con	id Sp Kd Lo		<u>x Dst c</u> KD LD (JD (DCP	AF EG AF EG AF EG AF EG/A	Qty :	125-51		pĤ		5554	CCE		

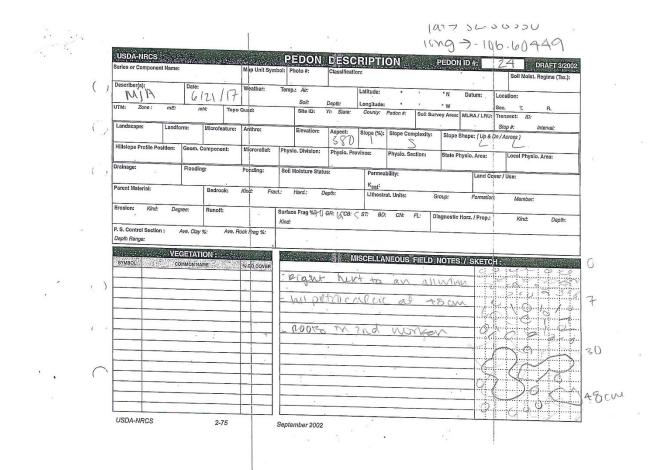


Obser,	Depth	Horizon		and contraction		1 Mini Market Minister			it Sýmbol:	1				Date:		1 (m) (m)
Method.	(in) (cm)	Horizon	Bnd	Mat Dry	Moist	Texture	Rock Frags	Sz Gr	Structure	Dry	Consis Mst	tence. Stk	Pls	Mottles	Col Mst	Sp. Loc
	0-6	RO	5			VESL	34 MX20	80	561					and the second second		<u>ad is in</u> mente
	10-48	BK	W			VESL	6% CARE FO		FSBL				-			
	48-117	BKK	S			N88L	SECALE	51	VESBE							
	1174	BKKW	15										-			
	(1											_				
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								-								
Red	oximorphic Features) Cor	ncentrations		Ped / V. Surla		Roots	Pores	pH	Effer	Clay	CCE	and the second	Notes	Can Pri
% SZ C	n Hd Sp Kd Loc I	3d Col- % 5	Sz Cn I	Hd Sp Kd Lo		6 Dst Cont k	1	ty Sz: L	oc Oty Sz Shr	(meth	(agent)	%	Number Number	1.2.265 C	a da andara 	
					t		LAF RF			-		9			+	
3							CAF PF/12					a			tr	
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			USDA-NRCS	States			PE	DON	DESC	RIPTI	ÓŇ	-	EDON	ID #:	22	L DOG D	DRAFT 3/2002
		5	Series or Component Name	9:	,	Map Unit Syr	nbol: Pho	oto #:	Classificati			an one successively an	1921 24 (4231) -		Intel in such	and the second	Regime (Tax.):
	(2	Describer(s):	Date:	11014	Weather:	Temp.:	Àir:		Latitude:			" N	Datum:	Locatio		6
			JTM: Zone: mE:	6	10011	Quad:		Soil:	Depth:	Longitude:			" w		Sec.	т.	R.
		-				Guad:		Site ID:	Yr: State:	County:	Pedon #:	Soll Surve	ey Area:	MLRA/LRU:			
	(1	Landscape: Land	form:	Microfeature:	Anthro:		Elevation:	Aspect:		Slope Cor	nplexity:	Slope S	hape: (Up &	Stop #		Interval:
			Hillslope Profile Position:	Geom. 0	Component:	Microrellef:	Physio	. Division:	Z2O Physio. Pr	()	Physio. Se	<u> </u>		V	L		
			Drainage:							oviniou.	Filysio. at	etton:	State Ph	ysio. Area:	Lo	ical Physic	Area:
	(1	·	Floodin	g:	Ponding:	Soll M	oisture Sta	tus:	Permea	bility:			Land Co	ver/Us	0:	
			Parent Material:		Bedrock:	Kind: Fr	act.: H	lard.:	Depth:	K _{sat} : Lithost	at. Units:	Gn	oup:	Formation		Member:	
		ŀ	Erosion: Kind: D	egree:	Runoff:		Curfage	From BLO /	an miler	0						wember;	
							Kind:	riag vary) GR: - У СВ:	SST: BC	: CN:	FL: Dia	ignostic H	lorz. / Prop.:	1	Kind:	Depth:
			P. S. Control Section : Depth Range:	Ave. Clay	%: Ave. F	Rock Frag %:									1		
		- 5	View V	EGETAT		6. B. C.	201050	ar de arte te				~					
					ME 1	% GD, COVER			л	ISCELLA	NEOUS	FIELD N	IOTES.	/ SKETC	18.	ale provinciale ale provinciale	and the states of the
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			USDA-NRCS		2-75		Septer	nber 2003	2				245				
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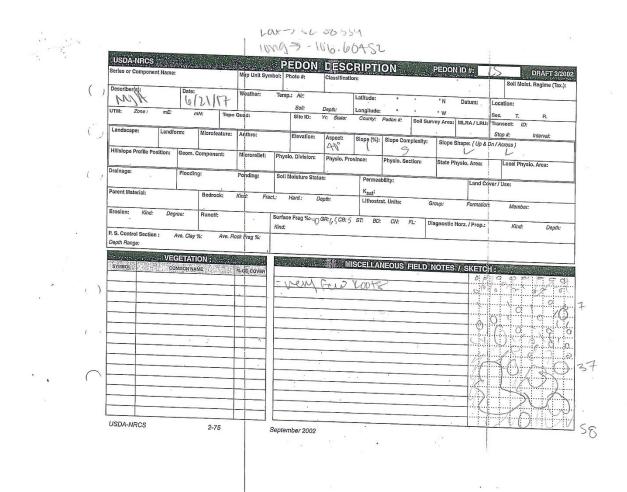
	Obse Meth	Depth	Horizon	Bnd	Matri	x Color	Texture		Map Un	it Sýmbol:			Date:	
	Meth		W I	5 12	Dry	Moist	- Texture	Knd % R	id Sz G	Structure	Cons	Istence	Mottles	Col Mst Sp Loc
		0-5	AB.	5			UFSL	2%.MXV	-95/	SEI	ivis	SIK P	Sal 76 Szorn	Col Mst Sp Loc
	2	5-27	BK	S			UESI		2951	VESBK		+	_	
	3	27-90	BKP	W			Sil	STOP.	LEG	VESISIE		+		
	4	9/0+	BYKW	-			SIL	75KOAT	LCC				_	
	5		DIE											
	6			+										
	7													
	8													
	9								1					
	10													
									1					
	Re % Sz	doximorphic Feature Cn Hd Sp Kd Loc		Con	centrátions		Ped / V. Surfa	ce Features	Roots		pH Effe	Clay CCI	द्वार्थ स्थल व्यापन	Notes
	1			SZ GR H	d Sp Kd Loc	Bd Col %	Dst Cont k		Qty Sz Lo	c Qty Sz Shp	(melh) (ager	ŧĴ, %		
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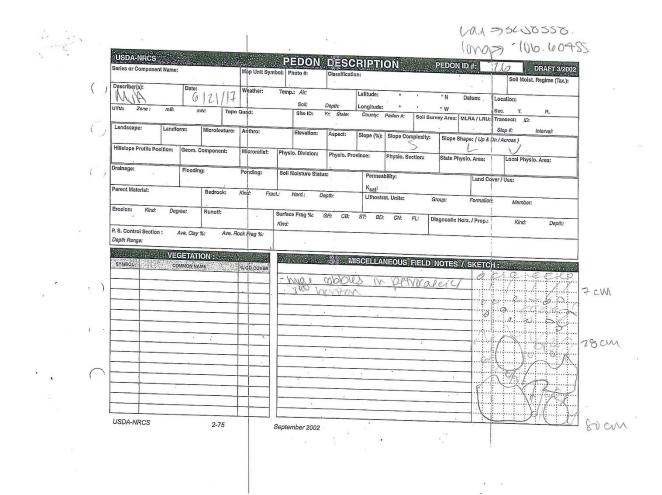


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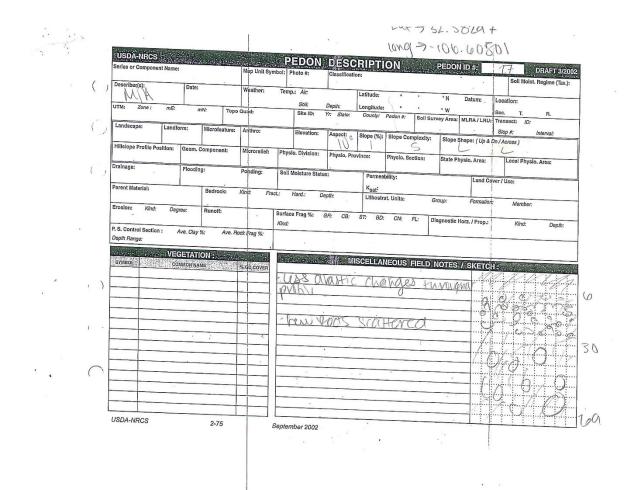
Obser.	Depth	omponent N		the second second	Tagen Cross Concerns			Map Un	nit Symbol:					Date:		
Method	(in) (cm)		Bnd	Ma Dry		Texture	Rock Fra	a 0	Structure			tence		Mottles		
	0-7	AB.	S			VESL	3% CARE	50	Sh	Dry	Mst	Sik	Pls	% Sz C	n Col M	ist Sp. Loc
	7-30	Part	S			VICEL	A 1/0 MAL	661	VEJBK		-					-
	30-48	BXHM	W			Sil	A % CAL	61	UFSYBK							
	ABT -	1000	N			010	69- MARL	5	01310	-		-				
					-											
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1.1.02	oximorphic Features	1. 28. 1.20		centrations			1									
									oc Oty Sz Shp	(meth)			2 10 Mar 10 10 10 10 10	Tat South St. o	a la Mar	THE CONTRACT AND A
2						DDE	AFRE					5		har contraction of	T	142 x 10 x 104 x 14 x 14
-	-				C	DCC	AF REF			•		7			T A	1472/03/2000 - 1277
					C		AF REF					7			THT	-
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					C	DCC	AF REF					7			日日	-
					C	DCC	AF REF					7			THT	-
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					C	DCC	AF KF AF KF/A F cc					77				
					C	DCC	AF KF AF KF/A F cc	. USE	2A-NRCS			7	76		日日	
					C	DCC	AF KF AF KF/A F cc	. USE				77	76		日日	
					C	DCC	AF KF AF KF/A F cc	. USE				77	76		日日	
					C	DCC	AF KF AF KF/A F cc	. USE				77	76		日日	



Obser.	Depth	imponent N Horizon		Mat	Set Solution of	of the 2 gas westerney on		Map Un	it Sýmbol:					Date:		1 11
Method,	(in) (cm)	Horizon	Bnd		Moist	Texture	Rock Frac Knd % Rnd		Structure		Consiste	ence:	i sant Sant	Mottles % Sz Cn		
	0-7	AB				VESL	2% NXR	IG N	86	e hory a	wsi	SIK	Plś.,	≫ Sz⊲cn	Gol Ms	Sp. Loc
	1-37	DAVY				NICEL	16. LAVE	6	<u> </u>			-	-+			1
	37-58	RYNM	-			VESV	3 CACANE CI	201	VESKEX	-		-	-			
	1998	Derry				VESL	37 MAR C	Ball	SA							
	58+											_				
													1			
									1				+			
Redo % Sz C	oximorphic Features In Holisp Kol Locie	id Col- % S	Con Cn H	centrations Id Sp:Kd Lo	s Bid Col s	FDDC	NF RF	Roots	Pores oc. Oty Sz Sh			6	CCE		Notes,	
% Sz C	oximorphic Features m Hd Sp Kd Loc B	d Col % s	Con	ld Sp Kd Lo		6 Dat Cont K FDDC DCO	Kd Loc Col	aly Sz L				%	CCE		Notes T	
% Sz C	oximorphic Features in Hd Sp Kd Loc B	id Col % S	Con Cn H	ld Sp Kd Lo		6 Dat Cont K FDDC DCO	Ke Loo Cor MF RF NF H/N	aly Sz L				6	CCE		Notes	
% Sz C	oximorphic Features in Hd Sp Kd Loc B	d Col % S	Con	d Sp Kd Lo		6 Dat Cont K FDDC DCO	Ke Loo Cor MF RF NF H/N	aly Sz L				6	CE		Notes T T T T	
% Sz C	oximorphic Features	d Col % S	l Con	d Sp Kd Lo		6 Dat Cont K FDDC DCO	Ke Loo Cor MF RF NF H/N	aly Sz L				6	CE		Notes T	
% Sz C	oximorphic Features	d Col % S	l Con	d Sp Kd Lo		6 Dat Cont K FDDC DCO	Ke Loo Cor MF RF NF H/N	aly Sz L				6	CCE		Notes T T T T T T T	-
% Sz C	oximorphic Features	d Col %, 5	I Con F	d Sp Kd Lo		6 Dat Cont K FDDC DCO	Ke Loo Cor MF RF NF H/N	aly Sz L				6	CCE		Notes T T T T T T T T T	
% Sz C	oximorphic Festures	d Col % 5	Con F	a Sp. Ka Lo		6 Dat Cont K FDDC DCO	Ke Loo Cor MF RF NF H/N	aly Sz L				6			Notes T T T T T T	
1% Sz C	oximorphic Features	d Col. % s) Con	a Sp. Ka Lo		6 Dat Cont K FDDC DCO	Ke Loo Cor MF RF NF H/N	aly Sz L				6			Notes T T T T T T T T	
% S2 C	in Hai Spi Kdi Loo B	d Col. % S	2 <u>Cn</u> H	a Sp. Ka Lo		6 Dat Cont K FDDC DCO	Ke Loo Cor MF RF NF H/N	2 y Sz L				6			T T T T T	nber 2002
% S2 C	in Hai Spi Kdi Loo B		2 <u>Cn</u> H	a Sp.Ka Lo		6 Dat Cont K FDDC DCO	Ke Loo Cor MF RF NF H/N	2 y Sz L				- 36 6 0			T T T T T	nber 2002
% S2 C	in Hai Spi Kdi Loo B	d, Col. %, S	2 <u>Cn</u> H	a Sp.Ka Lo		6 Dat Cont K FDDC DCO	Ke Loo Cor MF RF NF H/N	2 y Sz L				- 36 6 0			T T T T T	nber 2002
% S2 C	in Hai Spi Kdi Loo B	<u>d</u> Col: <u>%</u> S	2 <u>Cn</u> H	a Sp.Ka Lo		6 Dat Cont K FDDC DCO	Ke Loo Cor MF RF NF H/N	2 y Sz L				- 36 6 0			T T T T T	

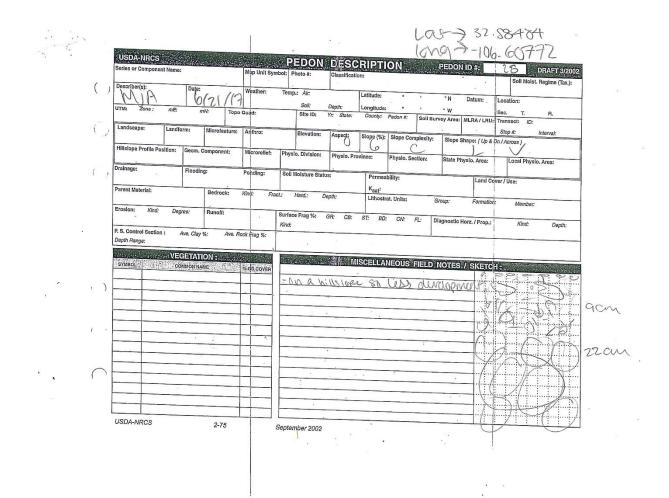


Obser,	Depth	mporient N		towns whereas	1427 - 6 1015 A. DOV				nit Sýmbol:					Date:		
Method	(in) (cm)	Horizon	Bnd	Ma Dry	Moist		Rock Fra	igs	Structure		Consis	tence	Sec.	Mottles		
	0.7	A	and recar	na na kata	in the second second	and the particular states	2 % MUNAK	16 0	rade Sz Ty		Mst	Sik	Pls	% Sz G	n Col M	st Sp. Loc
	7-29	PXK				VESL	356 CAR	(G (J SF	1			-			
			-			VESC	TROAL	CALL	NESR)e						
	28.80	BARAN				VESL	3 CARE I	BI	SA							
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Redo	oximorphic Features	a 041 44 4	Con	centrations		Ped / V. Surf		Roots			Effer		CCE	1. A. S. S.	Notes	6.246.245
% Sz C	oximorphic Features In Hd Sp Kd Loc B	d Col % S	Con Z Cn H	centrations d Sp Kd Lo	c Bd Col	Ped / V. Surfa % Dst Cont 1	Kd Loc Col		Pores .oc. Oty Sz S				CCE		Notes	
% Sz C	n Hd Sp Kd Loc B	id Col: % S	Con z Cn H	centrations d Sp Kd Lo	c Bd Col	% Dist Cont 1	KO LOO COI						CCE			
% Sz C	n Hd Sp Kd Loc B	id Col: % S) Con z Cn H	d Sp Kd Lo	c Bd Col	<u>* Dist Cont</u> VFDD CDC(Kd Loc Col						CCE			(jan) Nata N
% Sz C	n Hd Sp Kd Loc B	id Col: % S) Con z Cn H	d Sp Kd Lo	c Bd Col	WEDD VEDD CDC(KO LOO COI					7	CCE			
% Sz C	n Hd Sp Kd Loc B	d Col: <u>% S</u>) Coh z Cn H	d Sp Kd Lo	c Bd Col	WEDD VEDD CDC(KO LOO COI CAFRF MF CC				(agent)	7	CCE			(1946) (1946)
% Sz C	n Hd Sp Kd Loc B	d Col % S) Con H	d Sp Kd Lo	c Bd Col	WEDD VEDD CDC(KO LOO COI CAFRF MF CC				(agent)	7	CCE			
% SZ C	n Hd Sp Kd Loc B	id Col % S) Con z <u>C</u> n H	d Sp Kd Ld	c Bd Col	WEDD VEDD CDC(KO LOO COI CAFRF MF CC				(agent)	7	CCE			
% Sz C	n Hd Sp Kd Loc B	id Col % S) Con z Cn H	d Sp Kd Ld	c Bd Col	WEDD VEDD CDC(KO LOO COI CAFRF MF CC				(agent)	7	CCE			
% S2 C	n Hd Sp Kd Loc B	d Col %. S) Con z Cn H	d Sp Kd Ld	c Bd Col	WEDD VEDD CDC(KO LOO COI CAFRF MF CC				(agent)	7	CCE			
% Sz C	n Hd Sp Kd Loc B	d Col %, s) Con z Cn H	d Sp Kd Ld	c Bd Col	WEDD VEDD CDC(KO LOO COI CAFRF MF CC				(agent)	7	CCE			
	in He Sp. Kd. Loc B	d Col %, s	z <u>Cn</u> H	d Sp Kd Ld	c Bd Col	WEDD VEDD CDC(KO LOO COI CAFRF MF CC				(agent)	7	CCE	· · · ·		· · · ·
Hedg % S2 C 2 3 3 3 3 3 3	n Hd Sp Kd Loc B	d'Col' %, s) Con z On H	d Sp Kd Ld	c Bd Col	WEDD VEDD CDC(KO LOO COI CAFRF MF CC				(agent)	7	CCE			· · · ·
% S2 C	in He Sp. Kd. Loc B	d'Col %, s	z <u>Cn</u> H	d Sp Kd Ld	c Bd Col	WEDD VEDD CDC(KO LOO COI CAFRF MF CC	Ohy Sz L			(agent)	7			T T	mber 200:

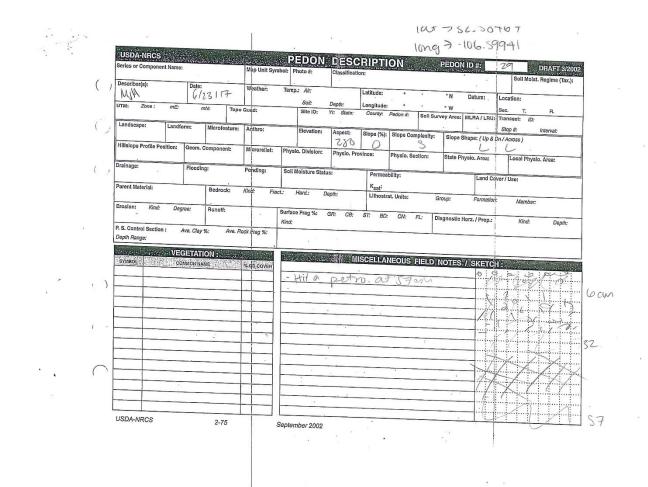


	CONTRACTOR OF CONTRACTOR	mponent N		Second contract of the	and the state of the second				it Sýmbol:				Date:		
Obser. Method	Depth (in) (cm)		Bnd		rix Color Moist	Texture			Structure		nsistence Ast Stk		Mottles % Sz Cn		
	0-6	AB.				NEXT	AN MXP	FAI	562	2002000000	GIN	<u>ROFIA</u>		COI MIL	30. 200
	6-50	BK				VEST	AP6CAR STOCAR	FGI	VESBK		-	-			
	311-69	BAYER				Sil	79% CAIL		VFSBA			-	1.1		
	1094	BREW	-			0.0	TT UNP	CAL	1.30			-			
	0					1	1	-	1		-				
									1	+		-			
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								1	8			-			
								<u>.</u>			_				
% Sz: 0	oximorphic Features Ch. Hd :Sp. Kd. Loc I	Bd Col % S	z Gn I	ncentrations Hd 'Sp Kd Lo	c Bd Col	% Dst Cont	-	Roots Oty Sz I	Pores				at para da 1	Notes	
% Sz (Cn Hd Sp Kd Loc I	3d Col % s	z Gn I	ncentrations Hd. Sp. Kd. Lo	c Bd Col	Dist Cont	KC LOC COL	1	- ALL AND AND DESCRIPTION		gent), %			Notes:	
% Sz (On Hd Sp Kd. Loc (3d Col % s	z Gn I	Hd Sp Kd Lo		NO DEL CONT	Kd Loc Col	1	- ALL AND AND ADDRESS		gent) <u>, %</u> 5 7	- -		INOTES;	
% Sz (1 2	On Hd Sp Kd Loc I	3d Col. % s	z Gn I	Hd Sp Kd Lo		NO DEL CONT	ke Loë Col CAE VF AF (C	1	- ALL AND AND ADDRESS		gent), %	- -		Notes T F T	
% Sz (1 2 3	Zn Hd Sp Kd Loc S	30 Col % s	z Gn I	Hd Sp Kd La		NO DEL CONT	ke Loë Col CAE VF AF (C	1	- ALL AND AND ADDRESS		gent) <u>, %</u> . 5 7	- -		Notes	
% Sz (1 2 3 4 5	2n Hd Sp Kd Loo S	30 Col % S	z Gn I	Hd Sp Kd La		NO DEL CONT	ke Loë Col CAE VF AF (C	1	- ALL AND AND ADDRESS		gent) <u>, %</u> . 5 7	- -		Notes, T F T	
% Sz (1 2 3 4	on HallSp Koll Loo I	30 Col: % s	z Gn I	Hd Sp Kd La		NO DEL CONT	ke Loë Col CAE VF AF (C	1	- ALL AND AND ADDRESS		gent) <u>, %</u> . 5 7	- -		IL I	
% Sz: 0 1 2 3 4 5 6	Э́і (на Зр Ка́ (Loō)	3d Col: <u>% S</u>	z Gn I	Hd Sp Kd La		NO DEL CONT	ke Loë Col CAE VF AF (C	1	- ALL AND AND ADDRESS		gent) <u>, %</u> . 5 7	- -		F T	
% S2: 0 1 2 3 4 5 6 7	Э́і (на Зр Ка́) (сё)	Sd Col: % S	z Gn I	Hd Sp Kd La		NO DEL CONT	ke Loë Col CAE VF AF (C	1	- ALL AND AND ADDRESS		gent) <u>, %</u> . 5 7	- -		F III	
% S2:0 1 2 3 4 5 6 7 8	54" Hot Sp Kot Loo B	Sd Col: % S	z on i	Hd Sp Kd La		NO DEL CONT	ke Loë Col CAE VF AF (C	1	- ALL AND AND ADDRESS		gent) <u>, %</u> . 5 7	- -		F III	
% S2:0 1 2 33 4 5 6 7 8 9	271 Hd 35p Kd Loo 9	24) Col: 4% S		Hd Sp Kd La		NO DEL CONT	ke Loë Col CAE VF AF (C	City, Sz. 1	- ALL AND AND ADDRESS		gent), 36 5 7 15	- -		THAT	nber 200:
% S2:0 1 2 33 4 5 6 7 8 9	271 Hd 35p Kd Loo 9	20, Col: 4% S		Hd Sp Kd La		NO DEL CONT	ke Loë Col CAE VF AF (C	City, Sz. 1			gent), 36 5 7 15	-)		THAT	nber 200;
% SZ: 0 1 2 33 4 5 6 7 8 9	271 Hd 35p Kd Loo 9			Hd Sp Kd La		NO DEL CONT	ke Loë Col CAE VF AF (C	City, Sz. 1			gent), 36 5 7 15	-)		THAT	nber 200:

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Obser.	Depth	nponent N Horizon		Nax and participants	all the state	increase.	1977 - 2010 - Highland				Sýmbol:		100			Date:		
Method	(in) (cm)	Horizon	Bnd		Matrix Cold		Texture				Structure le Sz Type	Drv	Consis Met	tence	Ple	Mottles	Col.	Met So
	0-9	AB	L				NIPSL	39 MX	086	1	SG	2277A2484		- Olive	a statem		001	Wet Ob to
	9-22	RICK	w				VESL	4 % OAR 30% OAR	651	1	VFSBK	-	-		-			
	278	BRUM					10000	SCOUNC	197 1		Vr JBC	10						
		- Uptit								1		-		-	-			
			-			-		-	-	+				-				
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Redo % Sz C	oximorphic Features On Hd Sp Kd Loc I	3d Col % s	Cor	d Sn Kd	ns	01 %	Ped / V. Sur	ace Features	Roots		Pores Oty Sz Shp			Clay	CCE		Note	s.
1				id op itd	LUCIBU: C	F	DDO		Jory OZ. I			(meth)	(agent	8	5-1497 s	s theodol	T	i nata ila n
1				10,109,110		F	DDO	CAF EF	July SZ.			(meth)		8		s mainte	I I I	
2						F	DDO		July 32.1			(meth)		8)		T	-
3		•			1	F	DDO	CAF EF	JARY 02.1					8)	* ************************************	THT	Ē
1 2 3 4					1	F	DDO	CAF EF				. (meth)		8)		T T T T T	Ē
1 2 3 4 5					1	F	DDO	CAF EF	juny 02.1					8)		TTT	Ē
1 2 3 4 5 6					1	F	DDO	CAF EF	1 1					8)		THI	Ē
1 2 3 3 4 5 6 6 7					1	F	DDO	CAF EF	1 1			. (meth)		8)		THT	Ē
1 2 3 4 5 6 7 8					1	F	DDO	CAF EF	(JACKY) (52. 1					8)		THI	
1 2 3 3 4 4 5 6 6 7 8 8 9					1	F	DDO	CAF EF						8)		THU	Ē
1 2 2 3 3 4 4 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5					1	F	DDO	CAF EF						8				
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1 2 3 4 4 5 6 7 8 9 9					1	F	DDO	CAF EF						8			1 1 1 50	plember 2

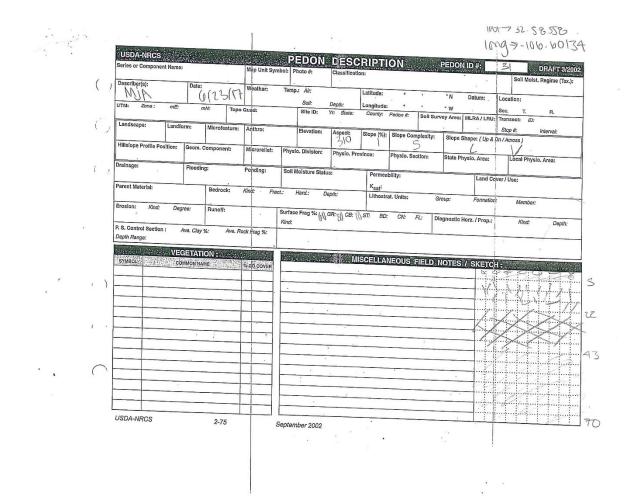


(in) (cm)) - (0 0 - 32	AB	Bnd S	Dry	Mols		Texture	Rock I			Structure	1.1.1.1.1.1	Consiste	10.10	1.20	Mottles	S. Jose Colat	ALC: NO
0-32		S							-	de Sz Type	Dry	Mst	Stk	Pls	% Sz⊍Cn	Col M	st Sp. Loc
	10.5 4				U	FSL	290 047	MG	0	SCY							
	BK	5			. 5	Sil	3% CAY	2 GA	1	UFSBR							
2-57	BAR	W			S	iL	7%OKY	285	0	SG							
7+	BKKM	W						ţ.									
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				1943					USI	DA-NRCS			2-	76	5	Septe	ember 2002
	d Sp Kd Lee 5	d Sp Kd Loc Bd Col % e	d 35p Kd Los 8d Col 44 82 Con 1	d 35p Kd Loo Bd Col 34 Sz Gn Hd Sp Kd 1		d 35p Kd Loo Bd Col 34 Sz Con Hd Sp Kd Loo BS Col 34 Dz C T M D M D	d Sp Kd Lee Bd Col & Sz Cn Hd Sp Kd Lee Bd Col & Dai Cent CD C CD C MD C N	d SP Kd Loo Bd Cal % Sz Gn Hd Sp Kd Loo Bd Car & Dai Cont Kd Loo Go CD C (NE PS) CD C (NE PS) MD C (AF CC	disp Kd i loo Bd Cal K Si Con Ha Sp Kd Loo Bd Cal Si Dai Cont Kd Loo Cal Du CD C (NF. R.J.(I MD C (AF R.S.) 	d SB Kd Loo Bd Cal & Sz Con Hd Sp Kd Loo Bd Cal & Da Com Kd Loo Cou Day Sz Lo CD C (MF. 25/11 CD C (MF. 25/11 MD C (AF) CC	d 35p Kd 100 Bd Cal % Sz On Hd Sp Kd Lae Bd Cal % Dat Cont Kd Lae Cal by Sz Lae Cdy Sz Shp C D C (MF.P.J/// C D C (MF.P.J/// MD C (AF P.CC)	d 35p Kd Loo Bd Cal 14 Sz Cn Ha Sp Kd Loo Bd Cal 14 Dat Cân Kd Loo Cal Day Sz Bhp Imen C D C (NF PE//(C D C (NF PE//(MD C (A F CC)	d SP Md Loe Bd Cal % Sz Cn Hd Sp Kd Loe Bd Cal % Dai Cont Kd Loe Cal Divise Loe Cdy Sz Shp (meth)(agen), CD C (NF DJ/() CD C (NF DJ/() MD C (AF CC	d 35p Kd 100 Bd Cat % 5z Cn Hd 5p Kd Loc 20 Cat % Dat Can Kd Loc Cat C D C (NF 25/// 7 C D C (NF 25/// 7 C D C (NF 26/// 7 MD C (NF 26// 16 16 16 16 16 16 16 16 16 16	d 35p Kd 100 Bd Cal % 5z Cn Ha Sp Kd Loc Bd Cal % Dai Cont Kd Loc Cal Dry Sz Loc Dry Sz Shp (metry)(egen), % C D C (NF 25/11) C D C (NF 25/11) M D C (AF 25/11)	C D C (NF P6/m) 7 C D C (NF P6/m) 7 C D C (NF P6/m) 7 C D C (NF P6/m) 8 MD C (AF P6/m) 8	C D C (NF.25/ll) 7 7 C D C (NF.25/ll) 7 7 C D C (NF.25/ll) 7 7 MD C (NF.02/ll) 8 11

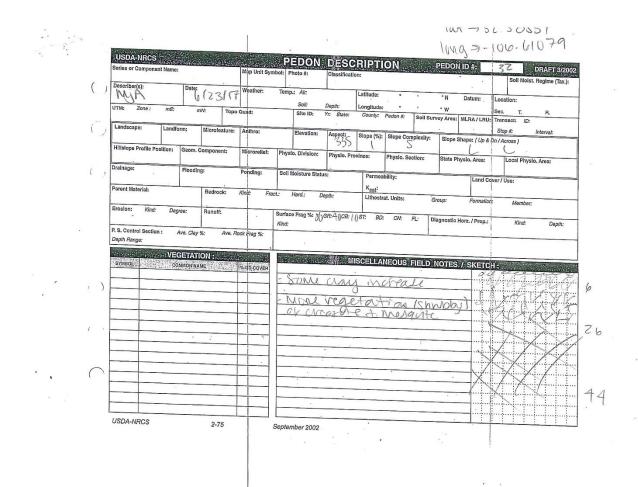
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	Parent Material:		Bedrock:	Kind: Frac	t.: Hard.: D	epth:	K _{sat} :			Cand Cov	er/Use:	×.,
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	7-28	BV	5			SiL	A chora	LG	1	VF SBIC	-			-			<u>.</u>
	28-46	BULL	W			SIL	ZY.CAR SYCAR SYCAR	EG	1	56							
	ALAT	BUUM	[4]			010	DUCHIC	5	4	261		-		-			
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Obser. Method	Depth (in) (cm)	Horizon	Bnd	Ma Dry	trix Color Moist	Texture	· · · · · · · · · · · · · · · · · · ·	6.0	Structure	De	Consis	tence		Mottles		
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	5-22	BK	5			VESL	4 % CKR FE	21	FSB							
	22-43	Excl	w			Sil	490 CAN F	51			-	-				
	43-70	BARYCH	W			Sil	77. CAR FO	5	NESBA		1					·
	7114					0,	THE RECE	<u>, ,</u>	1 3.0	-	-				17	
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Red	loximorphic Features Cn Hd Sp Kd Loc E					Ped/V. Surf		Roots	a service set as			Clay			Notes	
Red % Sz C 1 2	loximorphic Features Ch. Hd.;Sp. Kd.: Loc.:E			id Sp Kd L	56",B8 (Col	SPed/V.Surf % Dst Cont こ D D こ わ こ	Ke Loc Col C	0.0 . Oak	Pores						Notès I	
Red % Sz C 1 2 3				ld Sp Kd L	56" Bill (Col	NO CI	Ke Loe Cot K CAF & Ma CAF (L DAF (L	0.0 . Oak	a service set as						Notès I I	
/Red % Sz c 1 2 3 4				id Sp Kd L	oc Bd Col	NO CI	KO LOG COI C CAFEFICI CAFECC	0.0 . Oak	a service set as						Notes I I I	
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Bed % S2 C 1 2 3 4 5 6				id Sp Kd L	oc Bd Col	NO CI	Ke Loe Cot K CAF & Ma CAF (L DAF (L	0.0 . Oak	a service set as					-	Notes I I I	
Bed % S2 0 1 2 3 4 5 6 7				id Sp Kd L	oc Bd Col	NO CI	Ke Loe Cot K CAF & Ma CAF (L DAF (L	0.0 . Oak	a service set as						Notes I I I	
% Sz: C 1 2 3 4 5 6 7 8				id Sp Kd L	oc Bd Col	NO CI	Ke Loe Cot K CAF & Ma CAF (L DAF (L	0.0 . Oak	a service set as						Notes I I I	
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Method,	(in) (cm)	Horizon	Bna .	Dry	Moist	Texture	Knd % Rnd	Sz Gr	Structure	Dry	Consis Mst	tence.	Pls	Mottles % Sz Cn	Col Mst Sp L
	0-4	A	5			VESL	2% MXXFR	160	00				0.001.07.01	and construction	
2	6-26	BYK	S			. V881	A CLEAKE FE			-					
	7.6-9A	BKK	W			Sil	STANDAR FOR	10	SG						
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Red	oximorphic Feature	1	Cor	centrations	1999 (1997) 1999 (1997)	Ped / V. Sur	ace Eesturee	Roots	Pores	all and	Effer	10180	1000	1.5	Notes
% Sz 0	n Hd Sp Kd Loc	Bd Col % s	Sz Cn H	ld Sp Kd Lo	c Bd Col	% Dst Cont	Kd Loc Col Q		oc Oty Sz Shp				CCE		Notes
2	•						CAF REF.					7	1		
3						CDC	CAFVILL					(0)		-	T
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()	MJA UTM: Zone: m		27/17	Weather:	Temp.: Àir: Soil:	Depth:	Latitude: Longitude			" N " W	Datum:	Location:	
6		dform:	Microfeature:	Quad:	Site ID:	Yr: State:		Pedon II:	Soll Surv		MLRA/LRU	Sec. T Transect: Stop #:	ID:
1	Hillslope Profile Position		Component:	Microrelief:	Elevation:	Aspect: 175	Slope (%):		nplexity:	Slope Sh	nape: (Up &	Dn / Across)	Interval:
(.	Drainage:	Floodin		Ponding:	Physic. Division:	Physio. Pr		Physlo. Se	ction:	State Phy	vsio. Area:	Local	hysio. Area:
()	Parent Material:		Bedrock:		Soll Moisture Stat		Permea K _{sat} :				Land Co	over / Use:	
	Erosion: Kind: I	Degree:	Runoff:			Depth:		rat. Units:	Gro	oup:	Formation	h: Men	ber:
	-	-			Surface Frag %:75 Kind:	GR: AD CB: <	ς ST: BD	: CN:	FL: Dia	gnostic Ho	orz. / Prop.:	Kin	d: Depth
	P. S. Control Section :	Aug Clau	or. Aug D	and to at									
	P. S. Control Section : Depth Range:	Ave. Clay		ock Frag %:									
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.)	Depth Range:	EGETAT	ION :			<u>š</u> ř. n	NSCELLA	NEOUS	FIELD N	otes /	SKETC	1:	
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Method	(in) (cm)	нонгон	Bna	Dry	Moist	Texture	Knd %	nd Sz		Structure de Sz Type	Dry	Consis Msi	tence Stk	Pis	Mottles % Sz⊍Cn	Col Mst	Sn Loc
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2	10-27	BK				VEN	2% CAR 2% CAR	EG.		VESBL							
3	79-37	BKK				VESI	RYCAR 74 CAR	FG	0	SG							
4						100	11 cmp	(1)	-	001	-		-				
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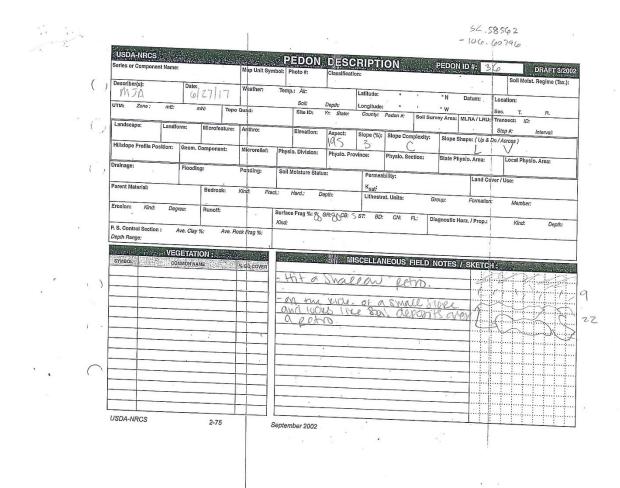
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		Map Unit Syn	nbol: Photo #:	Classificatio	on:	and in the second			Soll Moist. Regime (Tax.):	2
()	Describer(s); MUR 012717	Weather:	Temp.: Air:	1	Latitude: •		"N Date			
	UTAN ZOSAL Z	Quad:	Soil: Site ID:	Depth:	Longitude: °		" W .	Se	ocation: ac. T. R.	
1	[Lord		ane iD;	Yr: State:	County: Pedon #:	Soll Surve	ey Area: MLR/	A/LRU: Tr	ansect: ID:	-
1	and the second s	Anthro:	Elevation:	Aspect:	Slope (%): Slope C	omplexity:	Slope Shape:		Stop #: Interval: (Across)	-
	Hilislope Profile Position: Geom. Component:	Microrellef:	Physio. Division:	PIU Physio. Pro		Section		VI	L.	
([*] ,	Drainage: Flooding:	Ponding:	Soll Moisture State			section,	State Physic.	Area:	Local Physio. Area:	1.1
* <i>*</i>	Parent Material: Rodensiu		Con moisture stat	us:	Permeability: K _{sat} :			and Cover	/ Use:	4
	Bedrock:	Kind: Fra	ict.: Hard.: D	Depth:	Lithostrat. Units:	Gro	up: F	ormation:	Member:	-
	Erosion: Kind: Degree: Runoff:		Surface Frag %: 1	GR: 1. CB: 1	()ST: BD: CN:	FL: Dia			meniodi.	
	P. S. Control Section : Ave. Clay %: Ave. F	Rock Frag %:	Kind:	00 /1	0 0/1	v Li Diag	gnostic Horz. /	Prop.:	Kind: Depth:	
	Depth Range:									1
	VEGETATION :	16.	All South and	NI.	ISCELLANEOUS	EIELD M	OTES / SI	1		
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Obser. Method	(in) (cm)		Bnd		Moist	Texture	Rock Frags		Structure		Consis	tence		Mottles		
	1-90	AB.	etta Dea	A REPORT AND A DECISION	ACCESS MODEL	VFSL	IZCL MYV.	6	in an and the second se	Dry	Mst	Stk	Pls	SZ-C	n Col Mi	st Sp. Loc
	9-76	BUI	-			1	25-MX2 (1)	70	1		1					
	20.70	BUMM	-			VFR	AKNYRC	31	VESBE	-						
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% Sz (oximorphic Features On Hd Sp Kd Loc E	s Bd Col % s	Col Iz Cn I	ncentrations Hd Sp Kd Lo	c Bd Col	Ped / V. Surfi 6 Dst Cont 1		Roots y Sz L	Pores oc. Oty Sz. Shi		Effer) (agent			12 St (25 10 67 41	Notes	
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	10ng ->-106.60733
USDA-NRCS PEDON DESCRIPTION PEDON ID #	
Series or Component Name: Map Unit Symbol: Photo #: Classification:	Soll Molst. Regime (Tax.):
() Describer(s): Date: Veather: Temp: Air: Latitude: • • • N Datu	
UTM: Zone: m ^{Er} with an Soil: Depth: Longitude: "W	N: Location: Sec. T. R.
Sile ID: Yr: Stale: County: Pedon II: Soll Survey Area: MLRA	LRU: Transect: ID:
Landscape: Landform: Microfeature: Arithro: Elevation: Aspect: Slope (%): Slope Complexity: Slope Shape:	Up & Dn / Across)
Hillslope Profile Position: Geom. Component: Microrelleft. Physica Division Component:	
	rea: Local Physio. Area:
Permeability: L	and Cover / Use:
Parent Material: Bedrock: Kind: Fract.: Hard.: Depth: Lithostrat. Units: Group: Fo	mation: Member:
Erosion: Kind: Degree: Runoff: Surface Env 9(.0) on 7(0)	montor.
	Prop.: Kind: Depth:
P. S. Control Seotion : Ave. Clay %: Ave. Rock Frag %: Depth Range:	
VEGETATION : MISCELLANEOUS FIELD NOTES / SK	
SYMBOL: COMMON NAME & COCOVER	
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Obser.	Depth	omponent N Horizon	Matri	x Color	Text	ure	Rock F	Map			nbol: cture	-	Consis	tanca	-19 Samt	Date:	CROSSER AND ALL THE
Method,	(in) (cm)			Molst		-) K	nd % R	nd Sz								% Sz\Gn Col	Mst Sp. Loc
	0.9	KB				72	1. MXV	CG	1	VE	SBK						
	9-22	BKK				1	2% CAN	LCH	1	JF	SBK						
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Obser,	Depth			Steel swap ont Symbol:									1	Date:			
Method	(in) (cm)	TIOTZON	Bna	Dry	Moist	Texture	Rock Fr Knd % Rr	rags 1d S7 C	Stri	icture Sz. Turos	Dny	Consist	ence		Mottloe		openi Non-Jud
	0-6	NB.			9°	L	1% MX G	286	6	SG		mar	OIK	SC 18 33	szoon.	Gol Mst	Sp. Loc
	6-49	BHI	+			1.	2% MXY	156-	INA								
	44-115	Bt2				Sil											
	115-180	Bty				S1	st CIAN	06/1		SIBK			-	-			
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Rec % Sz	doxImorphic Features Cn Hd Sp Kd Loc B	id Col % s) Con iz Cn H	centrations d Sp:Kd Lo	c Bd Col	Ped/V.Surf % Dst Cont	Kd Loc Col	Root: Oly Sz		Pores Dty Szi Shp	pH (meth	Effer (agent)	%	CCE		Notes	
% Sz.	daximorphilo Features On Hol.Sp. Kol. Loo B		I Con	ld Sp Kd La	e Bd Col	VFDD VFDD VFDD VFDD	ace Features Kid Loc Col CAF RS CAF RS CAF R CAF R MF C				pH (meth) (agent)	ciay % 12 2 9	11 M		1. 1996	
% Sz. 1 2 3	doximorphic Features On Hd Sp Kd Loc B	id Col: % s	I Con	ld Sp Kd La	e Bd Col	VFDD VFDD VFDD VFDD	Ka Loe Col CAF RS CAF RF CAF RF				pH (meth) (agent)	26 12 5 9	11 M			
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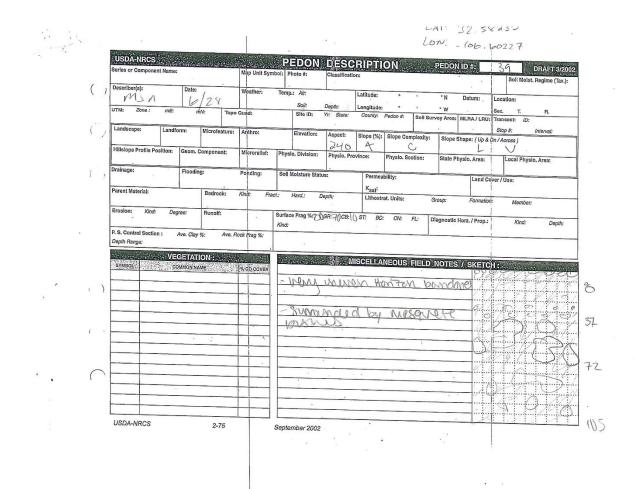
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	1	Landscape:	Landform:						. Statu.	County.	Pedon #:	Soll Sur	vey Area:	MLRA/LRU				1
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		Hillslope Profile Pos	ition: Geon	n. Component	t: M	crorellef:	Physio. Div	Ision:	Physio. Pr	ovince:	Physio. S	otion			1			
	1	Drainage:	Floor	dino:	Pa	hding:						ienon:	State Phy	/sio. Area:	Local	Physio, Area		
	()				PU	nung:	Soll Moistu	ire Status		2 mar	ability:			Land Co	ver / Use:			
		Parent Material:		Bedrock	: Kin	d: Fra	nct.: Hard.:	Dep	oth:	K _{sat} : Lithos	trat. Units;	G	oup:	Formation				
		Erosion: Kind:	Degree:	Runoff:			Surface Frag		R: CB:	1					Me	mber:		
							Kind:	, /e. (3)	R: CB:	ST: B	D: CN:	FL: DI	agnostic Ho	orz. / Prop.:	K	ind:	Depth:	
		P. S. Control Section : Depth Range:	Ave. Cla	ay%: A	ve. Rock I	Frag %:												
		Street Land	VEOFT		A DO	1												
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· •		USDA-NRCS	and the second	Constraint by	and the street of				100	101-6 1	0150210
		Series or Component Name	01 01	ann an the	Man Unit Co	PEDO	N DESC			PEDON ID #:	
(Describer(s):			map Unit Sy	mbol: Photo #:	Classification	on:	an manifestration and and for the staticity	Constantine of the	Soll Molst. Regime (Tax.):
(.)	MIA	Date:	128/17	Weather:	Temp.: Air:		Latitude:		"N Datum	1
		UTM: Zone : mE:			o Quad:	Soil: Site ID:	Depth:	Longitude		"N Datum: , "W	Location:
1		Landscape: Landf				Site ID:	Yr: State:	County:	Pedon #: Soll Sur	vey Area: MLRA / LR	Sec. T. R. J: Transect: ID:
i	2	Land	form:	Microfeature:	Anthro:	Elevatio		Stope (%):	Slope Complexity:	Siona Shanay (1)	Stop #: Interval:
		Hillstope Profile Position:	Geom.	Component:	Microrelief:	Physio. Divisio	200	0	5	Slope Shape: (Up a	(Dn/Across)
7	4	Drainage:	Floodin					vince:	Physio, Section:	State Physio. Area:	Local Physio. Area:
7	- 2	,	1 loouli	ig.	Ponding:	Soll Moisture S	Status:	Permea	billty:	Land C	Cover / Use:
		Parent Material:		Bedrock:	Kind: Fra	ict.: Hard.:	Depth:	Ksat:			
		Erosion: Kind: Dec	gree:	Runoff:	_			Litnostr	at. Units: G	roup: Formatio	on: Member:
			g.co.	nunon:		Surface Frag %: Kind:	GR: CB:	ST: BD.	CN: FL: DI	agnostic Horz. / Prop.:	Kind: Depth:
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		SYMBOL VE	GETATI	ION :	6.2.2.1	2000	M	SCELLA	NEOUS FIELD (Contraction of the second second second second second second second second second second second second second s	
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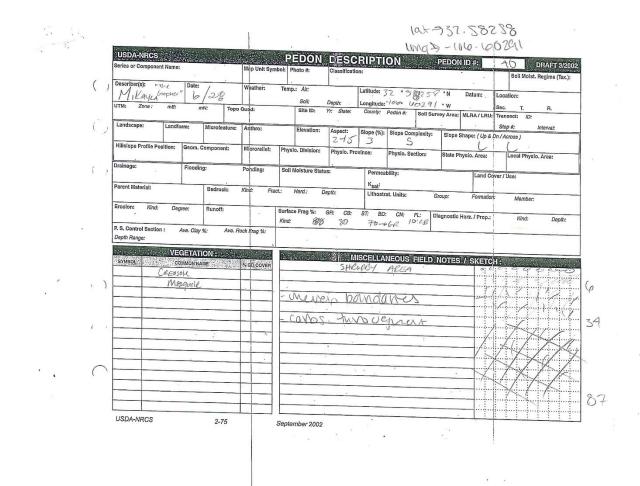
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Obser. Method	Depth	Horizon		Ma			Rock Fr	gs	nit Sýmbol: Structure rade Sz Typ		Consist			Date: Mottles		
2017.075.29	A-17	AB	8 6 6 J 6 6 6	Diy	MOIS	SiL			- FSB		Mst	Stk	PISA	76 . SZ-0	n: Col-A	Ast Sp. Loc
	A-44	BTI				h.1			MSBK		-	-	-			
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% Sz: 1 2 3			2 Co Sz Cn	ncentrátions Hd. Sp. Kd. L	oc Bd Col	- % Dst Cont."	Kd Loc Col					12	CCE		Notes	
% Sz. 1 2 3 4			2 Co Sz Cn	ncentrátions Hd. Sp. Kd. L	oc Bd Col		Kd Loc Col					12)		Notes	
% SZ: 1 2 3 4 5			Sz Cn	ncentrations Hig. Sp. KoʻL	oc Bd Col	- % Dst Cont."	Kd Loc Col					12 17 20)		Notes	
% Sz. 1 2 3 4			Sz Cn	ncentrátions Id. Sp. Ko L	oc Bd Col	- % Dst Cont."	Kd Loc Col					12 17 20)		Notës	
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% Sz :- 1 2 3 4 5 6			Sz Cn	neentailans ia Sp Ka L	oc Bd Col	- % Dst Cont."	Kd Loc Col					12 17 20)		Notès	
% Sz 1 2 3 4 5 6 7			Co Sz Sn 1	icentrátions 18. Sp. Ka L	oc Bd Col	- % Dst Cont."	Kd Loc Col					12 17 20)			

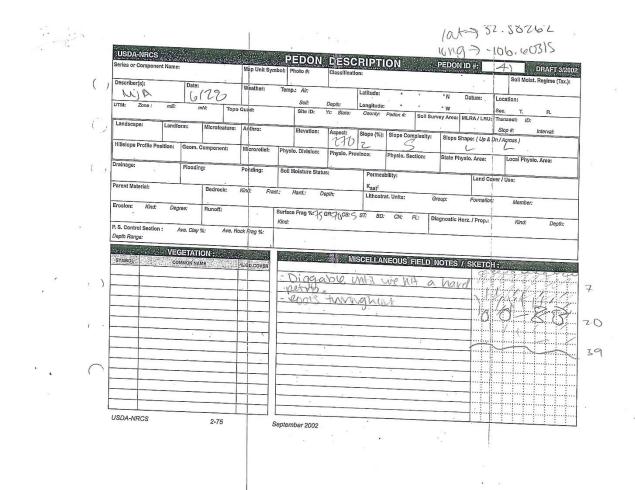
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Obser.	Depth	Horizon	Bnd	Sector Constant	atrix Color	Marcent Marian Week	the second second second		it Sýmbol:				Date:		
Method	(in) (cm)	- Hunzon	БПО		Moi			rags	Structure	Day	Consister Mst		Mottles s. % Sz		
	0-8	AB.	S			VESL	APMX	LIGO	0.0	105030		PIKSONER	s	On Col M	st Sp. Lo
	8-37	BAK	5			VF8	0.11	2.1.17	FSBK				-		· · · ·
	37-72	BKKI	W			FSU	34 46 600	256 0	100				+		
	72-105	BUUZ	I			Sil	12704	249	SE	-	-+-	-			•
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Bed	oximorphic Features	10 19 19 19 19 19 19 19 19 19 19 19 19 19		2 March 10	200 PT 1999	1		1							
% Sz C	on Hd Sp Kd Loo E	id Col % S	z Cn H	centrations d Sp Kd L	oc Bd Col	Ped / V. S % Dst Con	urface Features I. Kd. Loc. Col	City Sz 1	Pores	pH (meth)	Effer C	ay CCE		Notes	iya N
			1			VEDO	CAPES	1			. 2		194 M.S. 2005	Contraction of the	dana Ro
						FDC	CARRE				11			T	
					1		CAK CC				0			+	
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				н				. USD	JA-NRCS					Septe	mber 200
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Oheor	Depth 🖉	Horizon		light of the Local State	And the second second	the second second second		Map Ur	nit Sýmbol:	1000			-	Date:		
'Obser. Method/	(in) (cm)	Horizon	Bnd	Dry	trix Color Mole			rags	Structure		Consis	tence		Monthese	Class	
1	0.4	AB		C. Hard Same Providence	101010101010	VESL			rade Sz Ty	pe Dry	Mst	Stk	Pls	% Sz C	n Col I	Ast Sp. Loc
2	6.34	BK				VSS	1 76/42									
	34.87	BKK	-			. V82	54 (m)	ra	1							
		ispt	-			DIL	- 8% CAR	MG								
			-					-		-						
			-													
								4					-			
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									1	-			-			
Redo	ximorphic Features	1988 - Saga) Con	centrations	NEWS IN	Ped / V. St	Inface Features	Roots	Pores	and the second		Clay	Calgar 1	1		
% Sz C	n Hd Sp Kd Loc B	d Col % S	z Cn H	d Sp Kd Lo	c Bd Col	% Dst Cont	Kd Loc Col		oc Oty Sz S	hp (meth	ener (agent)		CCE	ta ya di Malakara	Notes	
0						FDD	CAFRF				. (6		And the second second	T	
							CAFEF	E.			· (6			T	
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3						CDC	CAREGU				· (1			1 1 1 1 1 1 1 1	
3 4 5						CDC	CAREGU				· (1			T T T T T	
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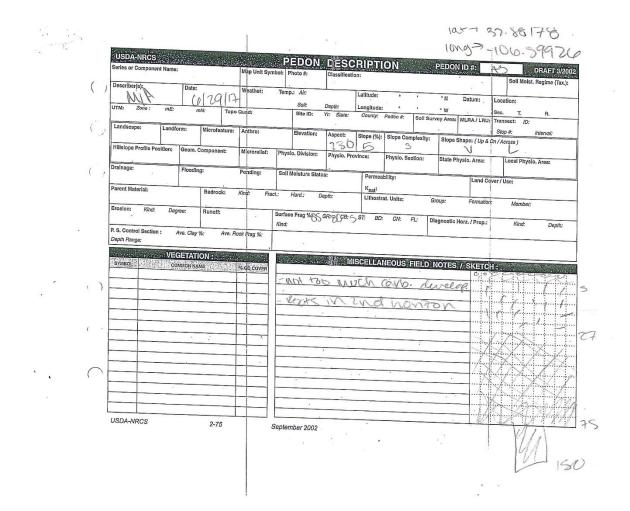


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Obser. Method	Depth (in) (cm)	Horizon	Bnd .		olor Molst	Texture		rags		Structure de Sz Type	Dev	Consisi Met	tence	Ple		Col. Met	
	0-7	AB	electric d'Anna d'Alladarciae			NESL	A % MY	REG	0	SG	- City -	mau	OIK		32001	GOLAWST	apcoc
	2-20	BU				LICSI.	3% (AR 4% (AR		- 1	NESBE		-		-			
	70-39	BICK				VFSL	ST CAYE	FA	0	SA	•						
		JIFF				VISC	1275 CM	-CB	V	34		-					
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Red	oximorphic Features	21. Tel	Concentra		e. 1751	Ped / V. Surf	UAL 4201000	i Gilena	1000	A Distance of the	Provence				1.000.000		
% Sz: 0	Cn Hd Sp Kd Loc E		Sz Cn Hd Sp	Kd Loc Bo	Col	% Dst Cont				Pores ic. Qty Sz Shp		Effer) (agent	Clay	CCE		Notes	an the second second second second second second second second second second second second second second second
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		USDA-NRCS Series or Component Name:		PEDON	DESCR	IPTI	ON	PEDON I	Area de Stati	P.D.C.W.	DRAFT 3/2002
	1		Map Unit Symb	ol: Photo #:	Classification:					Section of the section of Section Sect	Regime (Tax.):
	()	Describer(s): Date:	7 Weather:	Temp.: Air:	La	atitude:	• •	*N [Datum:	Location:	
		UTM: Zane: mE: mN: To	po Quad:	Soil: Site ID:		ongitude: County:	Pedon #: Soll Su	" W Irvey Area: M		Sec. T.	R.
	(Ē.,	Landscape: Landform: Microfeatur	Anthro:	Elevation:	11 C	1				Stop #:	interval:
		Hillslope Profile Position: Geom. Component:			190 s	lope (%):	Slope Complexity:	Slope Sha	ape:(Up & l	On / Across)	
			Microrelief:	Physio. Division:	Physio. Provin	ice:	Physio. Section:	State Phys	io. Area:	Local Physio.	Area:
	()	Drainage: Flooding:	Ponding:	Soll Moisture State	JS:	Permeal	bility:		Land Co	ver / Use:	
		Parent Material: Bedrock:	Kind: Fract.	: Hard.: D	lepth:	K _{sat} : Lithostra	at Unito.				
		Eroslon: Kind: Degree: Runoff:						Group:	Formation	: Member;	
				Surface Frag %:75 Kind:	GR: ()CB: 5 S	T: BD;	CN: FL:	Diagnostic Ho	rz. / Prop.:	Kind:	Depth:
		P. S. Control Section : Ave. Clay %: Ave Depth Range:	Rock Frag %:			1					
		VEGETATION :	Mar 2 Sel	and the second	MIS	CELLA	NEOUS FIELD	Norroll		To - Sills Marsans Subs	
		SYMBOL: COMMON NAME	% GD COVER					NOTES /			<u> </u>
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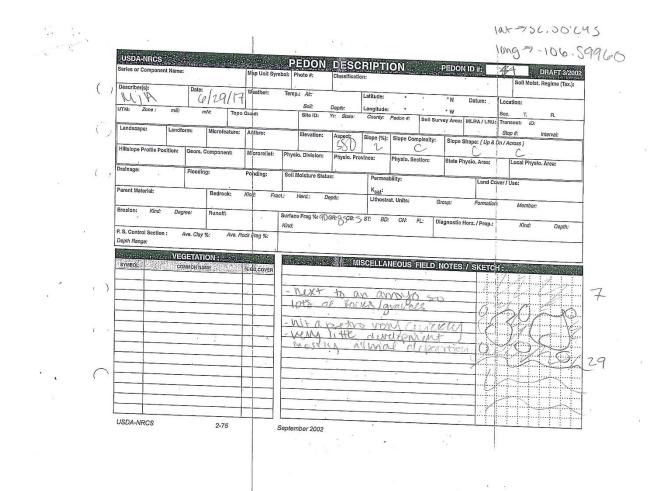
Obser. Method		Horizon		Ma	trix Color	Texture	BockEr	Wap U	nit	Sýmbol:	1000000	40.000	t Storage	Districts a	Date:	-	1
1	a starte starte	all all and		Dry	Moist		Knd % Rn	J Sz C	Srac	Structure de Sz Type	Dry	Mst	tence Stk	Pis	Mottles % Sz Cr	i. Col M	st Sp. Lo
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2	6-17	BK					4% CH12 2% CA12	FG	1	VF SBK		-	-				1.00
3	17+	FXKM					- (nic	1010-1	Ť	01 0-1				-			
4								-	+		-	-	-				
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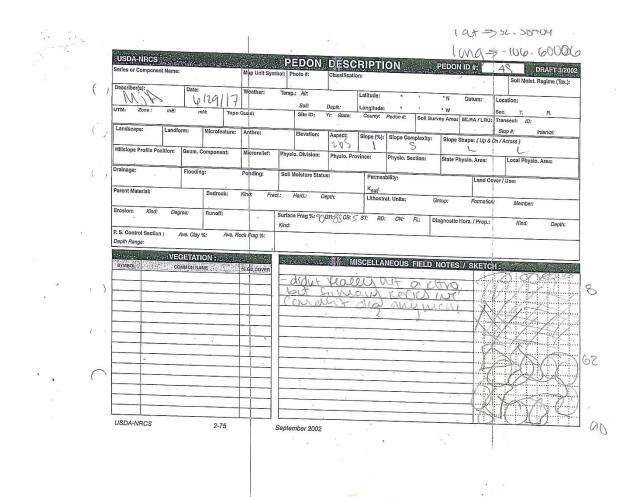


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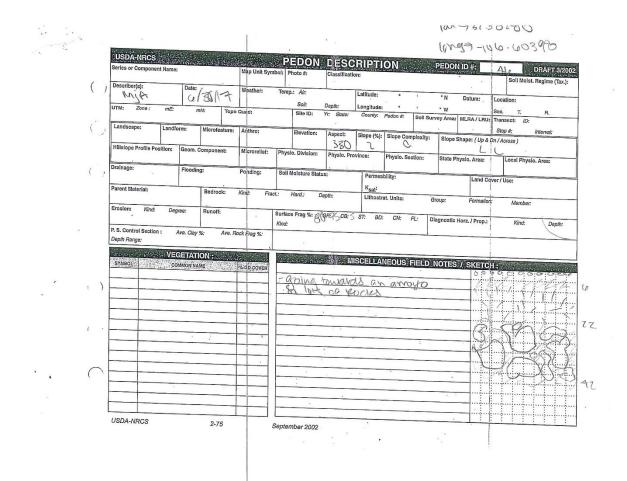


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		Permeability: Land Cover / Use:
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APPENDIX C DATA USED FOR GEOSTATISTICAL ANALYSIS

Soil observations used for analysis. Table C.1 is sand, silt, and clay concentrations (measured by hydrometer) as sampled from 49 sample locations by genetic horizon. Table C.2 is the location of each of the 49 pedons in Table C.1. Table C.3 is the sand, silt, and clay concentrations (measured by hydrometer) as sampled at 20 locations by standardized depth increment. Table C.4 is the location of each of the 20 observations in Table C.3. Data in tables C.3 and C.4 extracted from Cody Anderson's thesis.

Table C.1. Data used for analysis. PedonID is a unique identifier for each distinct sampling location. Designation is the horizon master and suffix designations used to describe each horizon. A combination of PedonID and Designation can be used as a unique identifier for each horizon. HZ top is the top of the horizon in cm. HZ Bottom is the bottom of the horizon in cm. Sand, Silt, and Clay are concentrations by genetic horizon in percent.

Pedon			HZ			
ID	Designation	HZ Top	Bottom	Sand	Silt	Clay
1	AB	0	6	76	17	7
1	Bk	6	32	73	20	6
1	Bkk	32	52	78	17	6
2	А	0	6	77	15	9
2	Bk1	6	53	77	13	10
2	Bk2	53	82	76	14	10
2	Bkk	82	105	74	14	13
3	AB	0	7	82	9	9
3	Bk	7	22	78	15	7
3	Bkk	22	47	81	11	9
4	AB	0	6	75	15	10
4	Bk	6	22	70	22	9
4	Bkk	22	38	63	28	9
5	AB	0	7	65	28	8
5	Bk	7	27	65	25	10
5	Bkkm	27	36	74	15	11
6	AB	0	5	68	21	11
6	Bkk	5	29	68	24	8
6	Bkkm	29	65	67	26	7
7	AB	0	4	66	25	9
7	Bkk	4	24	65	27	8
7	Bkkm	24	52	65	26	9
8	AB	0	7	72	21	7
8	Bk	7	17	71	20	9
8	Bkk	17	32	70	21	9
9	AB	0	8	68	22	10
9	Bkk1	8	29	65	26	9
9	Bkk2	29	47	63	29	8
10	AB	0	4	66	24	10
10	Bk	4	28	62	30	8

10	Bkk1	28	62	64	26	10
10	Bkk2	62	89	59	31	10
10	A	0	8	62	28	10
11	Bk1	8	30	6 <u>9</u>	23	8
11	Bk2	30	48	72	19	9
11	Btk	48	150	61	28	11
12	А	0	7	61	30	9
12	Btkk	7	32	60	33	7
12	Bkkm	32	50	60	31	9
13	AB	0	9	59	31	10
13	Bk	9	32	61	32	7
13	Bkk	32	75	65	32	3
14	AB	0	5	64	22	14
14	Bkk1	5	26	66	24	10
14	Bkk2	26	70	59	22	19
14	Bkkm	70	98	56	31	13
15	AB	0	7	67	22	12
15	Bk	7	32	66	23	11
15	Bwk1	32	60	49	47	4
15	Bwk2	60	150	39	58	3
16	AB	0	9	64	24	12
16	Bk	9	50	46	50	4
16	Btk	50	150	61	28	11
17	AB	0	6	61	25	14
17	Btk	6	44	63	25	12
17	Bt	44	150	39	58	3
18	Α	0	6	60	26	14
18	Btkk	6	36	58	26	16
18	Bt1	36	74	48	49	3
18	Bt2	74	150	39	58	3
19	AB	0	5	60	25	15
19	Btk	5	27	57	28	15
19	Bt1	27	64	52	45	3
19	Bt2	64	150	39	57	4
20	AB	0	9	80	13	7
20	Bw1	9	52	61	30	9
20	Bw2	52	90	62	26	12
20	Bwk	90	150	51	31	18
21	AB	0	8	64	28	8
21	Bk1	8	25	64	29	7
21	Bkk	25	64	62	29	9
21	Bk2	64	117	64	30	7

22	AD	0	6	63	27	11
	AB				27	11
22	Bk	6	48	64	29	8
22	Bkk	48	117	63	33	5
23	AB	0	5	65	28	8
23	Bk	5	27	65	29	6
23	Bkk	27	96	61	33	7
24	AB	0	7	64	28	9
24	Bkk	7	30	62	30	8
24	Bkkm	30	48	57	32	11
25	AB	0	7	70	22	8
25	Bkk	7	27	57	32	11
25	Bkkm	37	58	56	34	10
26	AB	0	7	64	28	8
26	Bkk	7	28	58	33	9
26	Bkkm	28	50	55	34	11
27	AB	0	6	65	26	9
27	Bk	6	30	61	31	8
27	Btkk	30	69	57	29	14
28	AB	0	9	61	28	11
28	Bkk	9	28	59	32	9
29	AB	0	6	61	30	9
29	Bk	6	32	58	34	8
29	Bkk	32	57	57	33	10
30	AB	0	7	57	33	10
30	Bk	7	28	57	35	8
30	Bkk	28	46	56	35	9
31	AB	0	5	61	30	9
31	Bk	5	22	58	34	8
31	Bkkm	22	43	61	29	10
31	Btkk	43	70	56	32	12
32	А	0	6	64	25	11
32	Btk	6	26	63	29	8
32	Bkk	26	44	63	29	8
33	A	0	10	64	28	8
33	Bk	10	27	61	30	9
33	Bkk	27	37	61	31	8
34	AB	0	8	58	32	10
34	Bk	8	20	65	25	10
34	Bkkm	20	30	62	30	8
35	AB	0	9	61	30	9
35	Bk	9	28	62	27	11
35	Bkkm	28	47	60	32	8
55	DIVINI	20	- - /	00	52	0

36	AB	0	9	61	29	10
36	Bkk	9	22	62	28	10
37	AB Dt1	0	6	58	33	9
37	Bt1	6	44	52	38	10
37	Bt2	44	115	55	35	10
37	Btk	115	150	54	34	12
38	AB	0	17	53	28	19
38	Bt1	17	44	35	51	14
38	Bt2	44	73	39	37	24
38	Btk	73	150	56	28	16
39	AB	0	8	61	31	8
39	Btk	8	37	62	30	8
39	Bkk1	37	72	60	33	7
39	Bkk2	72	105	61	31	8
40	AB	0	6	53	43	4
40	Bk	6	34	65	26	9
40	Bkk	34	87	64	29	7
41	AB	0	7	62	26	12
41	Bk	7	20	62	25	13
41	Bkk	20	39	61	30	9
42	AB	0	6	57	33	10
42	Bk	6	24	63	28	9
43	AB	0	5	64	29	7
43	Bk	5	27	60	28	12
43	Bkk	27	75	62	29	9
43	Bt	75	150	52	44	4
44	AB	0	7	35	61	4
44	Bwk	7	28	59	27	14
45	AB	0	8	58	33	9
45	Bkk	8	62	59	31	10
45	Bkkm	62	90	60	30	10
46	AB	0	6	61	36	3
46	Bk	6	22	62	29	9
46	Bkk	22	42	59	33	8
47	AB	0	7	77	18	5
47	Bw	7	24	69	24	7
48	AB	0	7	63	26	11
48	Bk	7	26	64	29	7
48	Bkk	26	50	63	27	10
49	AB	0	5	64	28	8
49	Bk1	5	47	61	30	9
49	Bk2	47	84	52	35	13

Table C.2. PedonID is a unique identifier for each sampling location and can be used to link sampling locations with horizon level data contained in Table C.1. Latitude and Longitude are GPS coordinates for each location. Coordinates are in WGS84 decimal degrees.

Pedon Latitude Longitude 1 32.5870910 -106.6096710 2 32.5845890 -106.6078140 3 32.5884608 -106.6079170 4 32.5845820 -106.6079340 5 32.5850240 -106.6057790 6 32.5847900 -106.6057790 6 32.5847900 -106.6059400 8 32.5844060 -106.6059400 8 32.584400 -106.6069420 10 32.5864240 -106.6068600 12 32.5845080 -106.5093850 13 32.5844800 -106.5993800 14 32.5825330 -106.5960000 16 32.5829000 -106.5962230 17 32.5829000 -106.5962230 18 32.5829000 -106.6069200 20 32.5859300 -106.6069200 21 32.5859300 -106.6069200 22 32.5859200 -106.6069200 23 32.5859200 -106.6069200 <t< th=""><th>Deden</th><th></th><th></th></t<>	Deden		
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3132.5855800-106.60134003232.5853400-106.61079003332.5869900-106.60516003432.5856400-106.60671003532.5859700-106.60733003632.5856200-106.6079600	29	32.5846700	-106.5994100
3232.5853400-106.61079003332.5869900-106.60516003432.5856400-106.60671003532.5859700-106.60733003632.5856200-106.6079600	30	32.5844100	-106.5994400
3332.5869900-106.60516003432.5856400-106.60671003532.5859700-106.60733003632.5856200-106.6079600	31	32.5855800	-106.6013400
3432.5856400-106.60671003532.5859700-106.60733003632.5856200-106.6079600	32	32.5853400	-106.6107900
35 32.5859700 -106.6073300 36 32.5856200 -106.6079600	33	32.5869900	-106.6051600
36 32.5856200 -106.6079600	34	32.5856400	-106.6067100
	35	32.5859700	-106.6073300
37 32.5835400 -106.6043500	36	32.5856200	-106.6079600
	37	32.5835400	-106.6043500

38	32.5809500	-106.6021600
39	32.5823200	-106.6022700
40	32.5825800	-106.6029100
41	32.5826200	-106.6031500
42	32.5819600	-106.5978400
43	32.5817800	-106.5992600
44	32.5829300	-106.5996000
45	32.5840900	-106.6000600
46	32.5828000	-106.6039800
47	32.5828100	-106.6032300
48	32.5828400	-106.6032400
49	32.5828400	-106.6031600

Table C.3. Sand, Silt, Clay concentrations in percent by equal depth sampling interval. Data extracted from Cody Anderson's thesis available at: <u>https://repository.asu.edu/items/21017</u>. Additional details can be found in the thesis.

		% Marse	% medium	% fine gravel	% very	% Coarse	% medium	% fine sand	% very fine	% silt 7-53mm	
		gravel	3	gravu 2-		sand	sand	106-	sand	IIInfoc-7	% clay
Profile	Depth [cm]	>19mm	_	4.75mm		0.5- 1mm	250- 500um	250µm	53- 106um		mµ2>
JER1	0-7	6.40	15.28	3.74	0.89	0.87	1.49	12.07	15.67	36.71	6.88
JER1	7-17	0.00	14.91	4.99	1.17	0.82	1.74	12.85	17.17	38.41	7.94
JER1	17-27	3.64	21.37	8.50	1.30	1.19	1.88	9.90	14.09	33.39	4.73
JER2	0-7	0.00	16.61	6.54	2.26	1.73	2.44	14.53	17.27	32.63	5.98
JER2	7-17	9.81	22.18	7.53	2.02	1.09	1.58	9.28	12.39	30.17	3.95
JER2	17-27	18.60	11.93	7.77	2.43	1.55	1.95	9.99	13.63	28.08	4.06
JER3	0-7	0.00	20.55	6.72	2.29	2.72	1.99	12.71	17.72	30.43	4.86
JER3	7-17	9.90	17.23	7.98	1.80	1.31	1.87	9.03	14.71	32.57	3.60
JER3	17-27	0.00	20.52	12.02	3.10	1.82	2.23	8.78	13.51	33.71	4.32
JER4	0-7	4.94	14.39	7.75	2.58	2.01	3.25	18.44	18.84	24.24	3.56
JER4	7-17	0.00	16.79	8.30	2.38	2.09	3.38	16.63	16.81	29.24	4.39
JER4	17-27	9.15	17.51	11.57	3.62	3.62	3.40	11.25	11.01	23.74	5.13
JER5	0-7	0.00	18.67	7.71	2.55	2.18	3.59	19.37	17.21	22.84	5.89
JER5	7-17	0.00	21.71	7.95	2.35	1.78	2.63	13.74	14.37	29.61	5.85
JER5	17-27	0.00	11.80	9.19	2.65	2.97	3.37	14.63	15.48	33.54	6.37
JER6	0-7	0.00	18.83	7.47	2.21	1.52	1.96	12.67	18.65	31.62	5.07
JER6	7-17	3.42	19.08	11.43	1.77	1.09	1.50	7.95	12.97	35.31	5.48
JER6	17-27	25.46	27.83	9.40	3.65	2.14	1.78	4.36	5.75	16.38	3.26
JER7	0-7	7.29	12.46	7.46	2.99	2.16	2.59	15.50	19.44	26.46	3.66
JER7	7-17	15.40	10.10	6.04	1.97	1.52	2.32	13.12	16.56	28.52	4.45
JER7	17-27	0.00	24.20	6.80	2.13	1.76	2.24	11.87	15.72	31.34	3.94
JER8	0-7	0.00	6.94	6.43	2.78	2.00	3.02	19.28	24.70	31.08	3.77
JER8	7-17	23.15	12.33	5.47	2.08	1.22	1.62	10.32	14.54	25.41	3.88
JER8	17-27	4.58	21.18	10.26	2.58	1.66	1.81	9.77	14.49	29.22	4.44
JER9	0-7	6.15	19.90	6.47	2.13	1.97	3.11	15.53	15.77	24.05	4.93
JER9	7-17	34.89	12.66	8.69	2.06	0.99	1.31	6.58	8.57	19.80	4.46

3.62	4.03 5.58	8.77	5.62	4.33	3.32	6.58	5.47	5.07	4.44	4.88	4.88	4.64	5.36	5.20	5.14	4.36	3.83	4.31	3.82	4.09	5.20	2.79	7.66	5.36	6.46	4.41	5.03	4.68	5.90	5.33	4.90
12.86	22.78 28.77	26.23	30.17	22.76	14.56	30.38	31.98	26.70	24.81	30.68	33.07	29.03	30.40	28.51	28.30	31.06	26.68	29.88	24.79	35.23	34.61	20.12	29.39	30.16	34.13	27.95	28.53	29.59	26.91	30.19	28.89
5.14	15.27 15.97	9.94	14.92	8.22	4.44	16.97	12.84	9.93	19.45	16.11	14.00	19.08	13.42	10.79	15.40	14.03	10.55	15.96	7.25	20.55	13.09	5.86	14.05	11.56	13.21	18.17	12.83	12.32	14.70	13.62	6.75
4.52	12.02 15.43	9.69	12.09	5.75	3.85	12.54	8.19	7.10	16.41	12.26	10.31	18.38	10.93	8.33	15.66	11.67	9.06	13.60	5.74	16.48	9.05	4.07	11.78	7.34	9.01	14.89	10.15	8.96	14.43	13.69	5.82
1.61	5.14 2.74	2.94	2.66	1.43	1.99	2.24	1.53	2.22	3.14	2.45	2.35	3.57	1.93	1.88	3.87	2.69	2.88	3.24	1.50	3.30	1.63	1.10	2.14	1.49	2.01	3.02	2.00	1.87	3.61	3.26	2.31
2.11	1.80 1.80	2.15	2.10	1.15	2.85	1.73	1.26	2.43	2.13	1.73	2.03	2.23	1.37	1.50	2.67	2.08	2.80	2.57	1.44	2.17	1.16	1.06	1.44	1.25	1.80	1.95	1.48	1.43	2.29	2.28	3.08
3.58	2.78 2.49	2.88	2.20	1.48	3.95	2.15	1.61	3.14	2.61	2.56	3.00	2.77	2.29	2.73	2.59	2.40	2.22	2.95	2.16	2.65	2.14	1.52	1.78	1.86	2.65	2.37	2.01	1.87	2.89	2.94	3.26
8.68	0.45 8.85	10.52	6.88	4.63	10.05	5.52	8.78	10.54	7.75	10.35	9.55	6.29	5.80	10.33	7.84	10.85	9.01	6.76	9.63	5.62	7.56	5.55	6.21	7.32	9.77	8.13	6.54	6.40	9.22	13.31	13.19
31.03	18.37	19.93	23.36	11.69	25.31	13.43	14.83	15.91	15.25	18.99	14.48	14.02	12.22	12.94	16.36	20.86	6.84	20.71	19.18	9.92	21.62	11.11	22.92	14.63	16.18	16.85	21.71	16.61	15.25	15.37	31.79
26.84	0.00	6.95	0.00	38.56	29.67	8.47	13.52	16.96	4.02	0.00	6.33	0.00	16.26	17.79	2.17	0.00	26.14	0.00	24.49	0.00	3.93	46.83	2.63	19.04	4.77	2.25	9.73	16.26	4.81	0.00	0.00
17-27	0-7 7-17	17-27	<i>L</i> -0	7-17	17-27	0-7	7-17	17-27	0-7	7-17	17-27	<i>L</i> -0	7-17	17-27	0-7	7-17	17-27	<i>L</i> -0	7-17	0-7	7-17	17-27	<i>L</i> -0	7-17	17-27	<i>L</i> -0	7-17	17-27	0-7	7-17	17-27
JER9	JER10 JER10	JER10	JER11	JER11	JER11	JER12	JER12	JER12	JER13	JER13	JER13	JER14	JER14	JER14	JER15	JER15	JER15	JER16	JER16	JER17	JER17	JER17	JER18	JER18	JER18	JER19	JER19	JER19	JER20	JER20	JER20

Table C.4. Location information for the texture fraction measurments in table C.3. Northing and Easting are given in UTM Zone 13N NAD83. ProfileID is a unique identifier that can be used to link tables C.3 and C.4. Data extracted from Cody Anderson's thesi available at: <u>https://repository.asu.edu/items/21017</u>.

JER	UTM Z Location	one 13	Vegetation cover						
Profile ID	Northing	Easting	Primary cover	Secondary cover	Coverage class				
JER1	3606481.0	349470.1	BA		BA				
JER2	3606454.7	349467.3	BM	BA	GR				
JER3	3606426.7	349467.8	BA		BA				
JER4	3606396.8	349452.7	BA	CR	BA				
JER5	3606372.7	349448.5	ТВ	BA	OS				
JER6	3606478.3	349502.3	CR/BM	BA	CR				
JER7	3606451.0	349498.6	CR	BA	CR				
JER8	3606426.8	349492.7	MQ	BA,BM/CR	MQ				
JER9	3606392.4	349484.1	BM/CR	BA	GR				
JER10	3606366.8	349474.9	BA		BA				
JER11	3606472.7	349530.2	BM/TB	BA	GR				
JER12	3606447.3	349522.7	BA	TB,MQ,CR	BA				
JER13	3606420.2	349517.9	CR	BA	CR				
JER14	3606389.4	349508.8	TB/BM	BA,MQ	OS				
JER15	3606362.6	349506.1	MQ/BM	BA	MQ				
JER16	3606469.5	349558.7	MA/BM/CR	BA	OS				
JER17	3606444.6	349550.9	MQ/TB	BM,BA	MQ				
JER18	3606418.4	349543.2	BA		BA				
JER19	3606383.5	349538.8	CR/PP	BA	CR				
JER20	3606357.9	349535.0	MA	TB,BA	OS				

APPENDIX D CODE USED FOR GEOSTATISTICAL MODELING OF SAND AND CLAY

R code used for geostatistical modeling of texture fraction (i.e., sand and clay).

#Geostatistical modeling of sand and clay by global maps standardized depth in the Tromble Weir Watershed

Colby Brungard, PhD

Load libraries library(aqp) library(sp) library(rgdal) library(rgdal) library(raster) library(gstat) library(ggplot2) library(openxlsx) library(openxlsx) library(plyr) library(dplyr) library(reshape2) library(RColorBrewer) library(e1071) library(ggpubr)

set working directory
setwd("D:/Tromble Weir")

#1. Data preprocessing

#1.1 Mikayla's sampling

mdat <- read.csv("./Mikayla Data/R_Pit_Data_cwb.csv")
mloc <- read.csv("./Mikayla Data/R_Pit_Site_Data.csv")</pre>

Reproject coordinates to UTM Zone 13N
coordinates(mloc) <- ~ Longitude + Latitude</pre>

proj4string(mloc) <- '+proj=longlat +ellps=WGS84 +datum=WGS84 +no defs +towgs84=0,0,0'

mloc <- spTransform(mloc, CRS('+proj=utm +zone=13 +ellps=GRS80 +datum=NAD83 +units=m +no defs'))

mloc <- as.data.frame(mloc)</pre>

names(mloc)[2:3] <- c('Easting', 'Northing')

Points 3 and 38 were located outside of the study area in a different parent material. Remove them. Because they are far away they are unlikely to have much impact. Points 20 & 37 may also be in a different landform, but are likely not in different enough parent material to affect matters. Interesingly though, when I tested removing these two points I did get slightly better X-validation fits.

mdat <- mdat[mdat\$Pedon.ID != 3 & mdat\$Pedon.ID != 38,]

mloc <- mloc[mloc\$Pedon.ID != 3 & mloc\$Pedon.ID != 38,]

#1.2 Sampling by Cody Anderson

Tables from his thesis

adat <- readWorkbook("./Enriques Data/Anderson asu Thesis TableB2.xlsx")

Get horizon top and bottom depths

adat\$HZ.Top <- sapply(strsplit(adat\$`Depth.[cm]`,"-"), `[`, 1)</pre>

adat\$HZ.Bottom <- sapply(strsplit(adat\$`Depth.[cm]`,"-"), `[`, 2)

Combine all gravel and sand percentages into only sand. Unfortunately it appears that Cody somehow divided gravel and sand values instead of dividing the coarse fraction from the fine earth fraction. I have decided to combine the gravel and sand values into a single 'Sand' column based on the following observations. 1) (Gravel+Sand)+Clay exactly equals Silt values. Since silt is calculated as 100 -(sand+clay) I'm reasonably confident that these values are correct. 2) The summary statistics of Gravel+Sand almost exactly match the summary statistics of sand values for the rest of the observation made by Mikayla. 3) The clay values appear correct. This assumption negates the use of the course fraction in any subsequent analysis. I have contacted Enrique about this data but have not gotten a response.

adatSand <- apply(adat[,c(3:10)], 1, sum)

adat\$Silt <- adat\$`%.silt.2-53µm` # Give silt a better name

adat\$Clay <- adat\$`%.clay.<2µm` #Give clay a better name

Create psuedo horizon names (needed for AQP) and make factor

adat1 <- ddply(adat, .(Profile), mutate, Designation = seq_along(HZ.Top))

adat1\$Designation <- as.factor(as.character(adat1\$Designation))

Subset for relevant variables and name columns to match Mikayla's data

adat2 <- adat1[,c(1,18,13:17)] names(adat2)[1] <- 'Pedon.ID'

Location information
aloc <- readWorkbook("./Enriques Data/Anderson_asu_Thesis-Table2.xlsx", rows=c(25:45), cols = c(1:3))
names(aloc)[1] <- 'Pedon.ID'
aloc2 <- aloc[,c(1,3,2)]</pre>

1.3 Join both datasets and format as needed
Pedon data
dat <- rbind(mdat, adat2)
dat\$HZ.Bottom <- as.numeric(dat\$HZ.Bottom)
dat\$HZ.Top <- as.numeric(dat\$HZ.Top)
Site data
sdat <- rbind(mloc, aloc2)</pre>

#2. Convert to SPC and convert to standard depth intervals.

depths(dat) <- Pedon.ID ~ HZ.Top + HZ.Bottom

Global soil map standard depth intervals: 0-5 cm, 5-15 cm, 15-30 cm, 30-60 cm, 60-100, & 100-200 cm. The following code modified from: https://ncss-tech.github.io/AQP/aqp/aqp-intro.html. However, many of these soils are < 100 cm deep. Because I have so few samples I am only going to map soil texture to 60 cm.

Use the slice and slab functions in AQP to average over these depths

s1 <- aqp::slice(dat, fm=0:100 ~Sand + Silt + Clay)

Subset to GSM depths and calculate weighted mean values (I'm pretty sure that this does a weighted mean).

gsm.depths <- c(0, 5, 15, 30, 60, 100)

d.gsm <- slab(s1, fm=Pedon.ID ~ Sand + Silt + Clay, slab.structure = gsm.depths, slab.fun = median, na.rm=TRUE)

reshape to wide format, convert to SPC, and make new hz names

gsmpedons <- dcast(d.gsm, Pedon.ID + top + bottom ~ variable, value.var = 'value')

depths(gsmpedons) <- Pedon.ID ~ top + bottom

gsmpedons\$hzname <- profileApply(gsmpedons, function(i) {paste0('GSM-', 1:nrow(i))})

Note: Use new gsmpedons with caution. It is very likely that values > 60 cm were calculated with very few observtions.

- # 2 Prepare for exploratory data analysis
- # Convert to SpatialPointsDataframe, and reproject
- site(gsmpedons) <- sdat #This automatically joins by id (cool!)
- coordinates(gsmpedons) <- ~ Easting + Northing

proj4string(gsmpedons) <- '+proj=utm +zone=13 +ellps=GRS80 +datum=NAD83 +units=m +no_defs'

Subset by GSM depth interval,

- $d1 \leq gsmpedons[, 1]$
- $d2 \leq gsmpedons[, 2]$
- $d3 \leq gsmpedons[, 3]$
- d4 <- gsmpedons[, 4]

Remove missing values (no data) from lower horizons

- d4 <- as.data.frame(d4)
- d4 <- d4[complete.cases(d4),]
- $coordinates(d4) \leq \sim Easting + Northing$

proj4string(d4) <- '+proj=utm +zone=13 +ellps=GRS80 +datum=NAD83 +units=m +no defs'

Load all rasters. Rasters created from 5m ifsar DEM using geoprocess_by_area.bat. See readme file in tw folder.

brk <- do.call(brick, lapply(list.files(path = "./Terrain_derivatives/TD_5m", pattern = ".*tif", full.names = TRUE), raster))

Reproject rasters to points (if needed)

brk2 <- projectRaster(brk, crs="+proj=utm +zone=13 +ellps=GRS80 +datum=NAD83 +units=m +no_defs +towgs84=0,0,0")

Mask to study area, then crop extent (significantly reduces processing time).

studyarea <- readOGR("./NestedSampllingExample", "SoilMU26")</pre>

brk3 <- mask(brk2, mask = studyarea)

brk4 <- crop(brk3, studyarea)

Extract covariate values ec <- raster::extract(brk4, y = d1) ec4<- raster::extract(brk4, y = d4) # Join covariate values to soil depth data de1 <- cbind(d1, ec) de2 <- cbind(d2, ec) de3 <- cbind(d3, ec) de4 <- cbind(d4, ec4)</pre>

Kriging and gaussian simulation requires a very fine underlying grid on which to predict.
Use rasters to create prediction grid
sgdf <- as(brk4, 'SpatialGridDataFrame')

3 Sand.

3.1 0-5 cm.

Summary stats. Webster and Oliver suggest the transformation be applied if the skewness is > 0.5.
 summary(d1\$Sand) # Median is close to mean so appears normally distributed.
 skewness(d1\$Sand) # -0.87

Histograms. This appears quite 'normal' hist(d1\$Sand, col = "lightblue", border = "red") rug(d1\$Sand) # Check for obvious spatial patterns
spplot(d1, zcol = 'Sand', col.regions=brewer.pal(5, "Set1"))

Look for spatial outliers
s1.sel = plot(variogram(Sand ~ 1, d1, cloud = TRUE), col = 'blue', pch = 19, digitize = TRUE)
plot(s1.sel, d1)

Fit linear models between Sand and covariates

Significance only shows that the relationship is not-zero.

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

summary($lm(Sand \sim Aspect$, de1))

summary(lm(Sand ~ ConvergenceIndex , de1))

summary(lm(Sand ~ CrossSectionalCurvature, de1))

summary(lm(Sand ~ DEM_5_utm , de1)) #** Adj. R2: 0.099

summary(lm(Sand ~ FlowAccumulation , de1))

summary(lm(Sand ~ LongitudinalCurvature , de1))

summary(lm(Sand ~ LSfactor , de1))

summary($lm(Sand \sim Slope$, de1))

summary(lm(Sand ~ TopographicWetnessIndex, de1))

summary(lm(Sand ~ ValleyDepth , de1))

Only elevation is significant

 $plot(Sand \sim DEM_5_utm, data = de1)$

#There isn't a very strong relationship, but it do need to account for this trend.

Check for Anisotropy. 120 seems best plot(variogram(Sand ~ 1, d1, alpha = c(0, 15, 30, 45, 60, 75, 90, 105, 120, 135, 155, 180)))

h-scatterplots. These are plots of z(x) against z(x+h) for each lag interval and show the distribution of pairs of points for that interval. The closer the points lie to the diagional line, the stronger the correlation

and the smaller the semivariance. These distances were chosen because these are the distances that I used for the nested sampling.

hscat(Sand ~ 1, data = de1, c(3, 9, 29, 88, 266, 800), variogram.alpha=120)

Most correlated (has the lowest semivariance) below ~ 30 m

Empirical (experimental or sample) variogram. It makes sense to use the distances over which I designed the sampling [boundaries = c(3, 9, 29, 88, 266, 800)], but when I do this I have a great deal of trouble fiting a variogram model (most of the time I get a singular model or no convergence), so I decided not to implement this.

svg1 <- variogram(Sand ~ DEM 5 utm, de1, alpha=120)

plot(svg1, plot.nu = FALSE)

svg1

Variogram modeling

The experimental variogram is basically just two columns of numbers: distance and semivariance. To use this for predictions, we need to fit a model (like a regression line) to the variogram. Because the variogram modeling is a numerical optimization we need to provide starting values. psill is the partial sill which is the sill-nugget.

```
svgm1.s <- fit.variogram(object=svg1, model = vgm(nugget = 10, psill = 20, range= 300, model = 'Sph'))
svgm1.c <- fit.variogram(object=svg1, model = vgm(nugget = 10, psill = 20, range= 300, model = 'Cir'))
svgm1.e <- fit.variogram(object=svg1, model = vgm(nugget = 10, psill = 20, range= 300, model = 'Exp'))</pre>
```

svgm1.s

svgm1.c

svgm1.e

plot(svg1, svgm1.s, pch = 19)

plot(svg1, svgm1.c, pch = 19)

plot(svg1, svgm1.e, pch = 19)

Leave-one-out cross validation

scv1.s = krige.cv(Sand ~ DEM_5_utm, de1, model = svgm1.s)

- scv1.c = krige.cv(Sand ~ DEM_5_utm, de1, model = svgm1.c)
- scv1.e = krige.cv(Sand ~ DEM_5_utm, de1, model = svgm1.e)

MPE. Mean prediction error (predicted-observed) = bias. Positive = under prediction, negative = over prediction

mean(scv1.s\$residual) # -0.10
mean(scv1.c\$residual) # -0.19
mean(scv1.e\$residual) # -0.07

MSE. Mean squared error measures on average how different predictions are from observations.

The MSE will be small if the predicted responses are very close to the true responses, and will be large if for some of the observations, the predicted and true responses differ substantially (ISL sixth printing).

mean(scv1.s\$residual^2) # 34.0

mean(scv1.c\$residual^2) # 33.2

mean(scv1.e\$residual^2) # 34.1

RMSE (take the square root to get units in original units)

sqrt(mean(scv1.s\$residual^2)) # 5.8 %

sqrt(mean(scv1.c\$residual^2)) # 5.8

sqrt(mean(scv1.e\$residual^2)) # 5.8

What is the spatial distribution of the residuals? bubble(scv1.s, "residual", main = "Sand 0-5 cm Spherical") bubble(scv1.c, "residual", main = "Sand 0-5 cm Circular") bubble(scv1.e, "residual", main = "Sand 0-5 cm Exponential")

Kriging + uncertainty. Because I use elevation as a covariate then this is Kriging with an External Drift, rather than universal kriging (which is only if I use the coordinates as variables).

sk1.s <- krige(Sand ~ DEM_5_utm, de1, model = svgm1.s, newdata = sgdf)
sk1.c <- krige(Sand ~ DEM_5_utm, de1, model = svgm1.c, newdata = sgdf)
sk1.e <- krige(Sand ~ DEM_5_utm, de1, model = svgm1.e, newdata = sgdf)</pre>

Plotting. sqrt(var1.var) returns the standard deviation rather than the variance. sk1.s %>% as.data.frame %>% ggplot(aes(x=s1, y=s2)) + geom_tile(aes(fill=sqrt(var1.var))) + coord_equal() +
scale_fill_gradient(low = "yellow", high="red", limits = c(2,8)) + ggtitle('Spherical') + theme_bw()

sk1.c %>% as.data.frame %>%

ggplot(aes(x=s1, y=s2)) + geom_tile(aes(fill=sqrt(var1.var))) + coord_equal() +
scale_fill_gradient(low = "yellow", high="red", limits = c(2,8)) + ggtitle('Circular') + theme_bw()

sk1.e %>% as.data.frame %>%

ggplot(aes(x=s1, y=s2)) + geom_tile(aes(fill=sqrt(var1.var))) + coord_equal() +
scale_fill_gradient(low = "yellow", high="red", limits = c(2,8)) + ggtitle('Exponential') + theme_bw()

None of these models seemed to have much different prediction patterns or much different uncertainty than another, so I choose Circular because it had slightly lower MSE. Publication quality plotting and writing to raster are done below.

3.2 5-15 cm

Summary stats. Appear fairly normal, no need to transform based on skewness

summary(d2\$Sand)

skewness(d2\$Sand) # -0.115

Histograms. Very normally distributed hist(d2\$Sand, col = "lightblue", border = "red") rug(d2\$Sand)

Plots to check for obvious spatial patterns
spplot(d2, zcol = 'Sand', col.regions=brewer.pal(5, "Set1"))

Look for spatial outliers. Nothing obvious

s2.sel = plot(variogram(Sand ~ 1, d2, cloud = TRUE), col = 'blue', pch = 19, digitize = TRUE)
plot(s2.sel, d1)

Fit linear models summary(lm(Sand ~ Aspect , de2)) summary(lm(Sand ~ ConvergenceIndex , de2)) #* Adj. R2 0.06 summary(lm(Sand ~ CrossSectionalCurvature, de2)) #* Adj. R2 0.08 summary($lm(Sand \sim DEM 5 utm)$, de2)) #** Adj. R2 0.09 summary(lm(Sand ~ FlowAccumulation , de2)) #* Adj. R2 0.05 summary(lm(Sand ~ LongitudinalCurvature , de2)) #** Adj. R2 0.004 , de2)) summary(lm(Sand ~ LSfactor summary($lm(Sand \sim Slope$, de2)) summary(lm(Sand ~ TopographicWetnessIndex, de2)) #** Adj. R2 0.14 summary(lm(Sand ~ ValleyDepth , de2))

plot(Sand ~ TopographicWetnessIndex, de2)

 $plot(Sand \sim DEM_5_utm, de2)$

plot(Sand ~ LongitudinalCurvature, data = de2)

Hmmm, only TWI and elevation seem to have a strong relationship with Sand. I suspect that the strength (if it can be considered strong) of the relationship between sand and TWI is due to the few points located in areas with higher TWI values and that the relationship may not be as 'strong' if these points were removed. I'm still going to go with elevation as it seems less spurious.

Check for Anisotropy. 120 seems best and agreed with the direction of the landform.

plot(variogram(Sand ~ 1, d2, alpha = c(0, 15, 30, 45, 60, 75, 90, 105, 120, 135, 155, 180)))

h-scatterplots. Strongest correlation at < 30 m.

hscat(Sand ~ 1, data = de2, c(3, 9, 29, 88, 266, 800), variogram.alpha=120)

Empirical (experimental or sample) variogram. When I include boundaries = c(3, 9, 29, 88, 266, 800) I am able to still get a model to fit, but it strongly reduces the range thus the prediction uncertainity is only concentrated around the sample locations and RMSE slightly increased, so I am not taking this approach.

```
svg2 <- variogram(Sand ~ DEM_5_utm, de2, alpha=120)</pre>
```

plot(svg2, plot.nu = FALSE)

svg2

Variogram modeling

svgm2.s <- fit.variogram(object=svg2, model = vgm(nugget = 20, psill = 1, range= 100, model = 'Sph'))
svgm2.c <- fit.variogram(object=svg2, model = vgm(nugget = 20, psill = 1, range= 100, model = 'Cir'))
svgm2.e <- fit.variogram(object=svg2, model = vgm(nugget = 20, psill = 1, range= 100, model = 'Exp'))</pre>

svgm2.s

svgm2.c

svgm2.e

plot(svg2, svgm2.s, pch = 19)
plot(svg2, svgm2.c, pch = 19)
plot(svg2, svgm2.e, pch = 19)

Leave-one-out cross validation
scv2.s = krige.cv(Sand ~ DEM_5_utm, de2, model = svgm2.s)

scv2.c = krige.cv(Sand ~ DEM_5_utm, de2, model = svgm2.c)

scv2.e = krige.cv(Sand ~ DEM_5_utm, de2, model = svgm2.e)

MPE. Mean prediction error (predicted-observed) = bias. Positive = under prediction, negative = over prediction

mean(scv2.s\$residual) # -0.02

mean(scv2.c\$residual) # -0.02

mean(scv2.e\$residual) # -0.02

MSE. Mean squared error mean(scv2.s\$residual^2) # 23.0

mean(scv2.c\$residual^2) # 23.2

mean(scv2.e\$residual^2) # 23.5

RMSE (take the square root to get units in original units)

sqrt(mean(scv2.s\$residual^2)) # 4.79
sqrt(mean(scv2.c\$residual^2)) # 4.82
sqrt(mean(scv2.e\$residual^2)) # 4.84

What is the spatial distribution of the residuals? bubble(scv2.s, "residual", main = "Sand 5-15 cm Spherical") bubble(scv2.c, "residual", main = "Sand 5-15 cm Circular") bubble(scv2.e, "residual", main = "Sand 5-15 cm Exponential")

Kriging + uncertainty. Because I use elevation as a covariate, then this is Kriging with an External Drift, rather than universal kriging (which is only if I use the coordinates as variables).

sk2.s <- krige(Sand ~ DEM_5_utm, de2, model = svgm2.s, newdata = sgdf)
sk2.c <- krige(Sand ~ DEM_5_utm, de2, model = svgm2.c, newdata = sgdf)
sk2.e <- krige(Sand ~ DEM_5_utm, de2, model = svgm2.e, newdata = sgdf)</pre>

Plotting. sqrt(var1.var) returns the standard deviation rather than the variance.

sk2.s %>% as.data.frame %>%

ggplot(aes(x=s1, y=s2)) + geom tile(aes(fill=sqrt(var1.var))) + coord equal() +

 $scale_fill_gradient(low = "yellow", high="red", limits = c(4,6)) + ggtitle('Spherical') + theme_bw()$

sk2.c %>% as.data.frame %>%
ggplot(aes(x=s1, y=s2)) + geom_tile(aes(fill=sqrt(var1.var))) + coord_equal() +
scale_fill_gradient(low = "yellow", high="red", limits = c(4,6)) + ggtitle('Circular') + theme_bw()

sk2.e %>% as.data.frame %>%

ggplot(aes(x=s1, y=s2)) + geom_tile(aes(fill=sqrt(var1.var))) + coord_equal() +
scale_fill_gradient(low = "yellow", high="red", limits = c(4,6)) + ggtitle('Exponential') + theme_bw()

Little difference between the models. Chose to use a circular model to be consistent with the 0-5 cm layer and had slightly larger areas of lower uncertainty

3.3 15-30 cm

Summary stats. Not much variability. Maybe I could just assume a mean value for this depth.

summary(d3\$Sand)

skewness(d3\$Sand) # 0.763

Log transform makes < 0.5; skewness(log(d3\$Sand)); but based on my attempts at back transform this doesn't make much difference and only complicates analysis.

Histograms. Not quite as 'normal' as the first two depths, but still pretty close. hist(log(d3\$Sand), col = "lightblue", border = "red")

rug(log(d3\$Sand))

Plots to check for obvious spatial patterns

spplot(d3, zcol = 'Sand', col.regions=brewer.pal(5, "Set1"))

Look for spatial outliers. Nothing obvious

s3.sel = plot(variogram(Sand ~ 1, d3, cloud = TRUE), col = 'blue', pch = 19, digitize = TRUE)

Fit linear models summary($lm(Sand \sim Aspect)$, de3)) summary(lm(Sand ~ ConvergenceIndex , de3)) #* Adj. R2 0.05 summary(lm(Sand ~ CrossSectionalCurvature, de3)) #** Adj. R2 0.09 summary($lm(Sand \sim DEM 5 utm)$, de3)) summary(lm(Sand ~ FlowAccumulation , de3)) #* Adj. R2 0.05 summary(lm(Sand ~ LongitudinalCurvature, de3)) #** Adj. R2 0.14 summary(lm(Sand ~ LSfactor , de3)) , de3)) #* Adj. R2 0.05 summary($lm(Sand \sim Slope$) summary(lm(Sand ~ TopographicWetnessIndex, de3)) #*** Adj. R2 0.16 summary($lm(Sand \sim ValleyDepth$, de3))

plot(Sand ~ LongitudinalCurvature, de3)
plot(Sand ~ TopographicWetnessIndex, de3)

#Hmmm, I suspect that the 'strength' of these relationships is due to the few points located in areas with higher LongCurv and TWI values and that the relationship may not be as 'strong' if these points were removed. I tried removing what I thought were these points (Points 20 & 37 see data cleaning notes in section 1), but this didn't fully remove these points or change the relationships.

 $summary(lm(Sand ~ LongitudinalCurvature+TopographicWetnessIndex, de3)) \ \# \ only \ TWI \ significant when run together. I'm going to use topographic wetness as the 'trend'$

Check for Anisotropy. Again 120 seems appropriate.

plot(variogram(Sand ~ 1, d3, alpha = c(0, 15, 30, 45, 60, 75, 90, 105, 120, 135, 155, 180)))

h-scatterplots. Not much correlation beyond ~ 30 m.

hscat(Sand ~ 1, data = de3, c(3, 9, 29, 88, 266, 800), variogram.alpha=120)

Empirical (experimental or sample) variogram.

For this depth interval I included the distances over which I designed the sampling [boundaries = c(3, 9, 29, 88, 266, 800)], because I got singular variogram models if I didn't.

svg3 <- variogram (Sand ~ TopographicWetnessIndex, de3, boundaries = c(3, 9, 29, 88, 266, 800), alpha=120) #

plot(svg3, plot.nu = FALSE)

svg3

Variogram modeling

svgm3.s <- fit.variogram(object=svg3, model = vgm(nugget = 5, psill = 30, range= 50, model = 'Sph'))
svgm3.c <- fit.variogram(object=svg3, model = vgm(nugget = 5, psill = 30, range= 50, model = 'Cir'))
svgm3.e <- fit.variogram(object=svg3, model = vgm(nugget = 5, psill = 30, range= 50, model = 'Exp'))</pre>

svgm3.s

svgm3.c

svgm3.e

```
plot(svg3, svgm3.s, pch = 19)
plot(svg3, svgm3.c, pch = 19)
```

plot(svg3, svgm3.e, pch = 19)

Leave-one-out cross validation

scv3.s = krige.cv(Sand ~ TopographicWetnessIndex, de3, model = svgm3.s)
scv3.c = krige.cv(Sand ~ TopographicWetnessIndex, de3, model = svgm3.c)
scv3.e = krige.cv(Sand ~ TopographicWetnessIndex, de3, model = svgm3.e)

MPE. Mean prediction error (predicted-observed) = bias. Positive = under prediction, negative = over prediction mean(scv3.s\$residual) # -0.07 mean(scv3.c\$residual) # -0.05 mean(scv3.e\$residual) # -0.11

MSE. Mean squared error mean(scv3.s\$residual^2) # 34.1 mean(scv3.c\$residual^2) # 34.7 mean(scv3.e\$residual^2) # 32.2

RMSE. Removing topographicwetnessindex as a covariate results in an ~0.5% RMSE increase. sqrt(mean(scv3.s\$residual^2)) # 5.84 sqrt(mean(scv3.c\$residual^2)) # 5.90 sqrt(mean(scv3.e\$residual^2)) # 5.67

What is the spatial distribution of the residuals? bubble(scv3.s, "residual", main = "Sand 15-30 cm Spherical") bubble(scv3.c, "residual", main = "Sand 15-30 cm Circular") bubble(scv3.e, "residual", main = "Sand 15-30 cm Exponential")

Kriging + uncertainty. Because I use elevation as a covariate then this is Kriging with an External Drift, rather than universal kriging (which is only if I use the coordinates as variables).
sk3.s <- krige(Sand ~ TopographicWetnessIndex, de3, model = svgm3.s, newdata = sgdf)
sk3.c <- krige(Sand ~ TopographicWetnessIndex, de3, model = svgm3.c, newdata = sgdf)

sk3.e <- krige(Sand ~ TopographicWetnessIndex, de3, model = svgm3.e, newdata = sgdf)

Plotting. sqrt(var1.var) returns the standard deviation rather than the variance. sk3.s %>% as.data.frame %>% ggplot(aes(x=s1, y=s2)) + geom_tile(aes(fill=sqrt(var1.var))) + coord_equal() + scale fill gradient(low = "yellow", high="red", limits = c(2,12)) + ggtitle('Spherical') + theme bw()

sk3.c %>% as.data.frame %>%
ggplot(aes(x=s1, y=s2)) + geom_tile(aes(fill=sqrt(var1.var))) + coord_equal() +
scale_fill_gradient(low = "yellow", high="red", limits = c(2,12)) + ggtitle('Circular') + theme_bw()

sk3.e %>% as.data.frame %>%
ggplot(aes(x=s1, y=s2)) + geom_tile(aes(fill=sqrt(var1.var))) + coord_equal() +
scale_fill_gradient(low = "yellow", high="red", limits = c(2,12)) + ggtitle('Exponential') + theme_bw()

I choose a circular model because it was the only model that returned a non-zero nugget.

3.4 30-60 cm
Summary stats. Appears normally distributed and no need to transform.
summary(d4\$Sand)
skewness(d4\$Sand) # -0.14

Histograms
hist(d4\$Sand, col = "lightblue", border = "red")
rug(d4\$Sand)

Plots to check for obvious spatial patterns
spplot(d4, zcol = 'Sand', col.regions=brewer.pal(5, "Set1"))
It appears that the values around the Tromble Weir itself are a bit sandier

Fit Linear models summary($lm(Sand \sim Aspect)$, de4)) summary(lm(Sand ~ ConvergenceIndex , de4)) #* Adj. R2 = 0.12summary(lm(Sand ~ CrossSectionalCurvature, de4)) #** Adj. R2 = 0.15 summary($lm(Sand \sim DEM 5 utm)$, de4)) $\#^{***}$ Adj. R2 = 0.42 summary(lm(Sand ~ FlowAccumulation , de4)) summary(lm(Sand ~ LongitudinalCurvature , de4)) $#^*$ Adj. R2 = 0.22 , de4)) $\#^{**}$ Adj. R2 = 0.14 summary(lm(Sand ~ LSfactor summary($lm(Sand \sim Slope$, de4)) $\#^{***}$ Adj. R2 = 0.25 summary(lm(Sand ~ TopographicWetnessIndex, de4)) #* Adj. R2 = 0.13summary(lm(Sand ~ ValleyDepth , de4))

This is rather interesting. Perhaps the significance with more variables as depth increases suggests that the surface is affected by other variables that control erosion and deposition, and that these covariates don't become important until below the surface. The surface horizon of most pedons was ~ 6 cm. In any case, I believe that this shows a trend in the data that I will need to account for. However, I am uncertain of the physical significance of these since I am using weighted average values.

summary(lm(Sand ~
DEM_5_utm+Slope+LongitudinalCurvature+CrossSectionalCurvature+LSfactor+TopographicWetnessIn
dex, de4)) # This reveals that only elevation (DEM_5_utm) is significant (***) when taken together.

Only the three variables with largest Adj. R2 values summary(lm(Sand ~ DEM_5_utm+Slope+LongitudinalCurvature, de4)) # Only elevation and longCurvature is significant

Elevation and slope

summary(lm(Sand ~ DEM_5_utm+Slope, de4))# Both significant Adj. R2 = 0.46

Elevation and LongCurvature

summary(lm(Sand ~ DEM_5_utm+LongitudinalCurvature, de4)) # Both significant Adj. R2 = 0.53

I am going to use elevation and longitudinal curvature.

Check for Anisotropy. 120 is probably best, but 135 could also work

plot(variogram(Sand ~ 1, d4, alpha = c(0, 15, 30, 45, 60, 75, 90, 105, 120, 135, 155, 180)))

h-scatterplots. These show equivalent correlations between 120 and 135. So I chose 120 to be consistent. hscat(Sand ~ 1, data = de4, c(3, 9, 29, 88, 266, 800), variogram.alpha=120) hscat(Sand ~ 1, data = de4, c(3, 9, 29, 88, 266, 800), variogram.alpha=135)

Empirical (experimental or sample) variogram. Leaving out longitudinalCurvature increases RMSE by \sim 0.4 so I left it in.

svg4 <- variogram(Sand ~ DEM 5 utm+LongitudinalCurvature, de4, alpha=120)

plot(svg4, plot.nu = FALSE)

svg4

Variogram modeling. The exponential model doesn't converge, but the values are realistic and stable (even with different values) so I will include the model.

svgm4.s <- fit.variogram(object=svg4, model = vgm(nugget = 10, psill = 20, range= 300, model = 'Sph'))
svgm4.c <- fit.variogram(object=svg4, model = vgm(nugget = 10, psill = 20, range= 300, model = 'Cir'))
svgm4.e <- fit.variogram(object=svg4, model = vgm(nugget = 10, psill = 20, range= 300, model = 'Exp'))</pre>

svgm4.s

svgm4.c

svgm4.e

plot(svg4, svgm4.s, pch = 19)
plot(svg4, svgm4.c, pch = 19)
plot(svg4, svgm4.e, pch = 19)

Leave-one-out cross validation

scv4.s = krige.cv(Sand ~ DEM_5_utm+LongitudinalCurvature, de4, model = svgm4.s)
scv4.c = krige.cv(Sand ~ DEM_5_utm+LongitudinalCurvature, de4, model = svgm4.c)
scv4.e = krige.cv(Sand ~ DEM_5_utm+LongitudinalCurvature, de4, model = svgm4.e)

MPE. Mean prediction error (predicted-observed) = bias. Positive = under prediction, negative = over prediction

mean(scv4.s\$residual) # 0.19
mean(scv4.c\$residual) # 0.19
mean(scv4.e\$residual) # 0.19

MSE. Mean squared error mean(scv4.s\$residual^2) # 26.25 mean(scv4.c\$residual^2) # 26.42 mean(scv4.e\$residual^2) # 27.70

RMSE (take the square root to get units in original units)
sqrt(mean(scv4.s\$residual^2)) # 5.12
sqrt(mean(scv4.c\$residual^2)) # 5.14
sqrt(mean(scv4.e\$residual^2)) # 5.26

What is the spatial distribution of the residuals? bubble(scv4.s, "residual", main = "Sand 30-60 cm Spherical") bubble(scv4.c, "residual", main = "Sand 30-60 cm Circular") bubble(scv4.e, "residual", main = "Sand 30-60 cm Exponential")

Kriging + uncertainty. Because I use elevation as a covariate then this is Kriging with an External Drift, rather than universal kriging (which is only if I use the coordinates as variables).
sk4.s <- krige(Sand ~ DEM_5_utm+LongitudinalCurvature, de4, model = svgm4.s, newdata = sgdf)</p>
sk4.c <- krige(Sand ~ DEM_5_utm+LongitudinalCurvature, de4, model = svgm4.c, newdata = sgdf)</p>
sk4.e <- krige(Sand ~ DEM_5_utm+LongitudinalCurvature, de4, model = svgm4.c, newdata = sgdf)</p>

Plotting. sqrt(var1.var) returns the standard deviation rather than the variance. sk4.s %>% as.data.frame %>% ggplot(aes(x=s1, y=s2)) + geom tile(aes(fill=sqrt(var1.var))) + coord equal() +

scale fill gradient(low = "yellow", high="red", limits = c(2,12)) + ggtitle('Spherical') + theme bw()

sk4.c %>% as.data.frame %>%

ggplot(aes(x=s1, y=s2)) + geom_tile(aes(fill=sqrt(var1.var))) + coord_equal() +
scale_fill_gradient(low = "yellow", high="red", limits = c(2,12)) + ggtitle('Circular') + theme_bw()

sk4.e %>% as.data.frame %>%

ggplot(aes(x=s1, y=s2)) + geom_tile(aes(fill=sqrt(var1.var))) + coord_equal() +
scale_fill_gradient(low = "yellow", high="red", limits = c(2,12)) + ggtitle('Exponential') + theme_bw()

Based on RMSE and review of spatial predictions I choose the spherical model

#-----

#4. Clay

Remove PedonID's 14:19 and 41. (possibly 48)
d1s <- d1[!(d1\$Pedon.ID %in% c(14:19,41)),]
de1s <- de1[!(de1\$Pedon.ID %in% c(14:19,41)),]</pre>

4.1 0-5 cm.

Summary stats. Webster and Oliver suggest the transformation be applied if the skewness is > 0.5. summary(d1s\$Clay) # Median is close to mean so appears normally distributed. skewness(d1s\$Clay) # -0.19

Histograms. This appears quite 'normal' hist(d1s\$Clay, col = "lightblue", border = "red") rug(d1s\$Clay)

Check for obvious spatial patterns. Cody's values appear a bit low compared to Mikayla's sampling.

spplot(d1s, zcol = 'Clay', col.regions=brewer.pal(5, "Set1"))

Look for spatial outliers. Maybe a few outliers.

c1.sel = plot(variogram(Clay ~ 1, de1s, cloud = TRUE), col = 'blue', pch = 19, digitize = TRUE)
plot(c1.sel, d1s)

Fit linear models between Clay and covariates

Significance only shows that the relationship is not-zero.

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

summary($lm(Clay \sim Aspect$, de1s))

summary($lm(Clay \sim ConvergenceIndex , de1s)$)

summary(lm(Clay ~ CrossSectionalCurvature, de1s))

summary(lm(Clay ~ DEM_5_utm , de1s)) #* Adj. R2 0.07

summary(lm(Clay ~ FlowAccumulation , de1s))

summary(lm(Clay ~ LongitudinalCurvature , de1s))

 $summary(lm(Clay \sim LSfactor , dels))$

summary($lm(Clay \sim Slope$, de1s))

summary(lm(Clay ~ TopographicWetnessIndex, dels))

summary(lm(Clay ~ ValleyDepth , de1s)) #** Adj. R2 0.15

Only Convergence index is significant

plot(Clay ~ ValleyDepth, data = de1s)

abline(lm(Clay ~ ValleyDepth, de1s))

Check for Anisotropy. 120 seems best
plot(variogram(Clay ~ ValleyDepth, de1s, alpha = c(105, 120, 135, 155, 180)))

h-scatterplots. Correlation out to ~ 270 m.
hscat(Clay ~ ValleyDepth, data = de1, c(3, 9, 29, 88, 266, 800), variogram.alpha=120)

Empirical (experimental or sample) variogram. Including boundaries does not help with model fitting.

cvg1 <- variogram(Clay ~ ValleyDepth, de1s, alpha=155)
plot(cvg1)
cvg1</pre>

Variogram modeling (also tried Pentaspherical and Matern, but they didn't fit either didn't work)
cvgm1.s <- fit.variogram(object=cvg1, model = vgm(nugget = 1, psill = 5, range= 300, model = 'Sph'))</p>
cvgm1.c <- fit.variogram(object=cvg1, model = vgm(nugget = 1, psill = 5, range= 300, model = 'Cir'))</p>
cvgm1.e <- fit.variogram(object=cvg1, model = vgm(nugget = 1, psill = 5, range= 300, model = 'Exp'))</p>

plot(cvg1, cvgm1.s, pch = 19)
plot(cvg1, cvgm1.c, pch = 19)
plot(cvg1, cvgm1.e, pch = 19)

cvgm1.s cvgm1.c

8-----

cvgm1.e

Leave-one-out cross validation ccv1.s = krige.cv(Clay ~ ValleyDepth, de1s, model = cvgm1.s) ccv1.c = krige.cv(Clay ~ ValleyDepth, de1s, model = cvgm1.c) ccv1.e = krige.cv(Clay ~ ValleyDepth, de1s, model = cvgm1.e)

MPE. Mean prediction error (predicted-observed) = bias. Positive = under prediction, negative = over prediction

mean(ccv1.s\$residual) # -0.03

mean(ccv1.c\$residual) # -0.03

mean(ccv1.e\$residual) # -0.03

MSE. Mean squared error measures on average how different predictions are from observations.

The MSE will be small if the predicted responses are very close to the true responses, and will be large if for some of the observations, the predicted and true responses differ substantially (ISL sixth printing).

mean(ccv1.s\$residual^2) # 3.45

mean(ccv1.c\$residual^2) # 3.45
mean(ccv1.e\$residual^2) # 3.44

RMSE (take the square root to get units in original units)
sqrt(mean(ccv1.s\$residual^2)) # 1.86
sqrt(mean(ccv1.c\$residual^2)) # 1.87
sqrt(mean(ccv1.e\$residual^2)) # 1.85

What is the spatial distribution of the residuals? bubble(ccv1.s, "residual", main = "Clay 0-5 cm Spherical") bubble(ccv1.c, "residual", main = "Clay 0-5 cm Circular") bubble(ccv1.e, "residual", main = "Clay 0-5 cm Exponential")

Kriging + uncertainty. Because I use elevation as a covariate then this is Kriging with an External Drift, rather than universal kriging (which is only if I use the coordinates as variables).

ck1.s <- krige(Clay ~ ValleyDepth, de1s, model = cvgm1.s, newdata = sgdf) ck1.c <- krige(Clay ~ ValleyDepth, de1s, model = cvgm1.c, newdata = sgdf) ck1.e <- krige(Clay ~ ValleyDepth, de1s, model = cvgm1.e, newdata = sgdf)

Plotting. sqrt(var1.var) returns the standard deviation rather than the variance.

ck1.s %>% as.data.frame %>%

ggplot(aes(x=s1, y=s2)) + geom_tile(aes(fill=sqrt(var1.var))) + coord_equal() +

 $scale_fill_gradient(low = "yellow", high="red", limits = c(0,4)) + ggtitle('Spherical') + theme_bw()$

ck1.c %>% as.data.frame %>%

ggplot(aes(x=s1, y=s2)) + geom_tile(aes(fill=sqrt(var1.var))) + coord_equal() +

 $scale_fill_gradient(low = "yellow", high="red", limits = c(1,3)) + ggtitle('Circular') + theme_bw()$

```
ck1.e %>% as.data.frame %>%
```

ggplot(aes(x=s1, y=s2)) + geom_tile(aes(fill=sqrt(var1.var))) + coord_equal() +

 $scale_fill_gradient(low = "yellow", high="red", limits = c(1,3)) + ggtitle('Exponential') + theme_bw()$

I choose circular model because the model appeared to fit the data slightly better than the other models. Still, I'm not very happy with this data.

3.2 5-15 cm

Remove PedonID's 14:19. Also remove 41 as it is an outlier and keeping it results in models that do not converge.

d2s <- d2[!(d2\$Pedon.ID %in% c(14:19,41)),] de2s <- de2[!(de2\$Pedon.ID %in% c(14:19,41)),]

Summary stats. Appear fairly normal, skewness suggests some need to transform, but not a lot

summary(d2s\$Clay)
skewness(d2s\$Clay) # 0.21

Histograms. Very normally distributed hist(d2s\$Clay, col = "lightblue", border = "red") rug(d2s\$Clay)

Plots to check for obvious spatial patterns
spplot(d2s, zcol = 'Clay', col.regions=brewer.pal(5, "Set1"))

Look for spatial outliers. Nothing obvious.
c2.sel = plot(variogram(Clay ~ 1, d2s, cloud = TRUE), col = 'blue', pch = 19, digitize = TRUE)
plot(c2.sel, d2)

Fit linear models
summary(lm(Clay ~ Aspect , de2s))
summary(lm(Clay ~ ConvergenceIndex , de2s)) #* Adj. R2 0.08
summary(lm(Clay ~ CrossSectionalCurvature, de2s)) #* Adj. R2 0.07
summary(lm(Clay ~ DEM_5_utm , de2s))
summary(lm(Clay ~ FlowAccumulation , de2s)) #* Adj. R2 0.06

summary(lm(Clay ~ LongitudinalCurvature , de2s)) summary(lm(Clay ~ LSfactor , de2s)) summary(lm(Clay ~ Slope , de2s)) summary(lm(Clay ~ TopographicWetnessIndex, de2s)) summary(lm(Clay ~ ValleyDepth , de2s)) #*** Adj. R2 0.21

summary(lm(Clay ~ CrossSectionalCurvature+ConvergenceIndex+ValleyDepth, de2s)) #ValleyDepth significant summary(lm(Clay ~ ConvergenceIndex+ValleyDepth, de2s)) # ValleyDepth significant summary(lm(Clay ~ CrossSectionalCurvature+ValleyDepth, de2s)) # ValleyDepty significant

plot(Clay ~ ConvergenceIndex, de2s)

abline(lm(Clay ~ ConvergenceIndex, de2s))

plot(Clay ~ CrossSectionalCurvature, de2s)

abline(lm(Clay ~ CrossSectionalCurvature, de2s))

plot(Clay ~ ValleyDepth, de2s)

abline(lm(Clay ~ ValleyDepth, de2s))

I'm choosing valley depth because it has the strongest correlation and because it makes sense to me.

Check for Anisotropy. 135 seems best and agreed with the direction of the landform. $plot(variogram(Clay \sim ValleyDepth, de2s, alpha = c(105, 120, 135, 155, 180)))$

h-scatterplots. Not much correlation beyone 90 m.

hscat(Clay ~ ValleyDepth, data = de2, c(3, 9, 29, 88, 266, 800), variogram.alpha=120)

Empirical (experimental or sample) variogram. When I include boundaries = c(3, 9, 29, 88, 266, 800) I am able to still get a model to fit, but it strongly reduces the range thus the prediction uncertainity is only concentrated around the sample locations and RMSE slightly increased, so I am not taking this approach. ConvergenceIndex+ValleyDepth

cvg2 <- variogram(Clay ~ ValleyDepth, boundaries = c(29, 88, 266, 800), de2s, alpha = 135) plot(cvg2) cvg2

Variogram modeling. Gaussian, Power, Log, Matern, none fit.

cvgm2.s <- fit.variogram(object=cvg2, model = vgm(nugget = 1, psill = 5, range= 300, model = 'Sph'))
cvgm2.c <- fit.variogram(object=cvg2, model = vgm(nugget = 1, psill = 5, range= 300, model = 'Cir'))
cvgm2.e <- fit.variogram(object=cvg2, model = vgm(nugget = 1, psill = 5, range= 300, model = 'Exp'))</pre>

plot(cvg2, cvgm2.s, pch = 19)
plot(cvg2, cvgm2.c, pch = 19)
plot(cvg2, cvgm2.e, pch = 19)

cvgm2.s

cvgm2.c

cvgm2.e

Leave-one-out cross validation

ccv2.s = krige.cv(Clay ~ ValleyDepth, de2s, model = cvgm2.s) ccv2.c = krige.cv(Clay ~ ValleyDepth, de2s, model = cvgm2.c) ccv2.e = krige.cv(Clay ~ ValleyDepth, de2s, model = cvgm2.e)

MPE. Mean prediction error (predicted-observed) = bias. Positive = under prediction, negative = over prediction

mean(ccv2.s\$residual) # 0.02

mean(ccv2.c\$residual) # 0.03

mean(ccv2.e\$residual) # 0.03

MSE. Mean squared error

mean(ccv2.s\$residual^2) # 1.81

mean(ccv2.c\$residual^2) # 1.88

mean(ccv2.e\$residual^2) # 1.88

RMSE (take the square root to get units in original units)
sqrt(mean(ccv2.s\$residual^2)) # 1.35
sqrt(mean(ccv2.c\$residual^2)) # 1.37
sqrt(mean(ccv2.e\$residual^2)) # 1.37

What is the spatial distribution of the residuals? bubble(ccv2.s, "residual", main = "Clay 5-15 cm Spherical") bubble(ccv2.c, "residual", main = "Clay 5-15 cm Circular") bubble(ccv2.e, "residual", main = "Clay 5-15 cm Exponential")

Kriging + uncertainty. Because I use elevation as a covariate then this is Kriging with an External Drift, rather than universal kriging (which is only if I use the coordinates as variables).

ck2.s <- krige(Clay ~ ValleyDepth, de2s, model = cvgm2.s, newdata = sgdf) ck2.c <- krige(Clay ~ ValleyDepth, de2s, model = cvgm2.c, newdata = sgdf) ck2.e <- krige(Clay ~ ValleyDepth, de2s, model = cvgm2.e, newdata = sgdf)

Plotting. sqrt(var1.var) returns the standard deviation rather than the variance.

ck2.s %>% as.data.frame %>%

ggplot(aes(x=s1, y=s2)) + geom_tile(aes(fill=sqrt(var1.var))) + coord_equal() +
scale fill gradient(low = "yellow", high="red", limits = c(0,3)) + ggtitle('Spherical') + theme bw()

ck2.c %>% as.data.frame %>%

ggplot(aes(x=s1, y=s2)) + geom_tile(aes(fill=sqrt(var1.var))) + coord_equal() +
scale_fill_gradient(low = "yellow", high="red", limits = c(0,3)) + ggtitle('Circular') + theme_bw()

ck2.e %>% as.data.frame %>% ggplot(aes(x=s1, y=s2)) + geom_tile(aes(fill=sqrt(var1.var))) + coord_equal() + scale_fill_gradient(low = "yellow", high="red", limits = c(0,3)) + ggtitle('Exponential') + theme_bw()

Little difference between the models. Chose to use a spherical model as it had slighly lower RMSE

3.3 15-30 cm

Remove pedons 13:19. See explanation for 0-5 cm. d3s <- d3[!(d3\$Pedon.ID %in% c(14:19)),] de3s <- de3[!(de3\$Pedon.ID %in% c(14:19)),]</pre>

Summary stats. Not much variability. No need to transform. summary(d3s\$Clay) skewness(d3s\$Clay) # -0.0007

Histograms. Not quite as 'normal' as the first two depths, but still pretty close. hist(d3s\$Clay, col = "lightblue", border = "red") rug(d3s\$Clay)

Plots to check for obvious spatial patterns
spplot(d3s, zcol = 'Clay', col.regions=brewer.pal(5, "Set1"))

Look for spatial outliers. No outliers
c3.sel = plot(variogram(Clay ~ 1, d3, cloud = TRUE), col = 'blue', pch = 19, digitize = TRUE)
plot(c3.sel, d3)

Fit linear models summary(lm(Clay ~ Aspect , de3s)) , de3s)) #* Adj. R2 0.06 summary(lm(Clay ~ ConvergenceIndex summary(lm(Clay ~ CrossSectionalCurvature, de3s)) #* Adj. R2 0.07 summary($lm(Clay \sim DEM 5 \text{ utm})$, de3s)) #* Adj. R2 0.07 summary(lm(Clay ~ FlowAccumulation , de3s)) #* Adj. R2 0.06 summary(lm(Clay ~ LongitudinalCurvature , de3s)) #* Adj. R2 0.08 summary($lm(Clay \sim LSfactor)$, de3s)) summary($lm(Clay \sim Slope$, de3s)) summary(lm(Clay ~ TopographicWetnessIndex, de3s))

summary(lm(Clay ~ ValleyDepth , de3s)) #*** Adj. R2 0.26

plot(Clay ~ ConvergenceIndex, de3s) abline(lm(Clay ~ ConvergenceIndex, de3s)) plot(Clay ~ CrossSectionalCurvature, de3s) abline(lm(Clay ~ CrossSectionalCurvature, de3s)) plot(Clay ~ LongitudinalCurvature, de3s) abline(lm(Clay ~ LongitudinalCurvature, de3s)) plot(Clay ~ ValleyDepth, de3s) abline(lm(Clay ~ ValleyDepth, de3s))

Only valley depth is significant summary(lm(Clay ~ ValleyDepth+ConvergenceIndex+CrossSectionalCurvature+LongitudinalCurvature, de3s)) summary(lm(Clay ~ ValleyDepth+ConvergenceIndex+CrossSectionalCurvature, de3s)) summary(lm(Clay ~ ValleyDepth+ConvergenceIndex, de3s))

Check for Anisotropy. 135 seems best as it has the most consistent variance plot(variogram(Clay ~ ValleyDepth, de3s, alpha = c(105, 120, 135, 155, 180)))

h-scatterplots. Not much correlation beyond ~ 88 m.hscat(Clay ~ ValleyDepth, data = de3s, c(3, 9, 29, 88, 266, 800), variogram.alpha=135)

Empirical (experimental or sample) variogram. cvg3 <- variogram(Clay ~ ValleyDepth, de3s, alpha=135) plot(cvg3, plot.nu = FALSE) cvg3

Variogram modeling cvgm3.s <- fit.variogram(object=cvg3, model = vgm(nugget = 1, psill = 4, range= 350, model = 'Sph')) cvgm3.c <- fit.variogram(object=cvg3, model = vgm(nugget = 1, psill = 4, range= 350, model = 'Cir'))</pre> cvgm3.e <- fit.variogram(object=cvg3, model = vgm(nugget = 1, psill = 4, range= 350, model = 'Exp'))

plot(cvg3, cvgm3.s, pch = 19)
plot(cvg3, cvgm3.c, pch = 19)
plot(cvg3, cvgm3.e, pch = 19)

cvgm3.s

cvgm3.c

cvgm3.e

Leave-one-out cross validation ccv3.s = krige.cv(Clay ~ ValleyDepth, de3s, model = cvgm3.s) ccv3.c = krige.cv(Clay ~ ValleyDepth, de3s, model = cvgm3.c) ccv3.e = krige.cv(Clay ~ ValleyDepth, de3s, model = cvgm3.e)

MPE. Mean prediction error (predicted-observed) = bias. Positive = under prediction, negative = over prediction

mean(ccv3.s\$residual) # 0.036
mean(ccv3.c\$residual) # 0.039
mean(ccv3.e\$residual) # 0.033

MSE. Mean squared error mean(ccv3.s\$residual^2) # 2.22 mean(ccv3.c\$residual^2) # 2.10

mean(ccv3.e\$residual^2) # 2.25

RMSE (take the square root to get units in original units)

sqrt(mean(ccv3.s\$residual^2)) # 1.50

sqrt(mean(ccv3.c\$residual^2)) # 1.45

sqrt(mean(ccv3.e\$residual^2)) # 1.50

What is the spatial distribution of the residuals? bubble(ccv3.s, "residual", main = "Clay 15-30 cm Spherical") bubble(ccv3.c, "residual", main = "Clay 15-30 cm Circular") bubble(ccv3.e, "residual", main = "Clay 15-30 cm Exponential")

Kriging + uncertainty. Because I use elevation as a covariate then this is Kriging with an External Drift, rather than universal kriging (which is only if I use the coordinates as variables).
ck3.s <- krige(Clay ~ ValleyDepth, de3s, model = cvgm3.s, newdata = sgdf)</p>

ck3.c <- krige(Clay ~ ValleyDepth, de3s, model = cvgm3.c, newdata = sgdf)

ck3.e <- krige(Clay ~ ValleyDepth, de3s, model = cvgm3.e, newdata = sgdf)

Plotting. sqrt(var1.var) returns the standard deviation rather than the variance.

ck3.s %>% as.data.frame %>%

ggplot(aes(x=s1, y=s2)) + geom tile(aes(fill=sqrt(var1.var))) + coord equal() +

 $scale_fill_gradient(low = "yellow", high="red", limits = c(1,3)) + ggtitle('Spherical') + theme_bw()$

ck3.c %>% as.data.frame %>%

ggplot(aes(x=s1, y=s2)) + geom_tile(aes(fill=sqrt(var1.var))) + coord_equal() +

 $scale_fill_gradient(low = "yellow", high="red", limits = c(1,3)) + ggtitle('Circular') + theme_bw()$

ck3.e %>% as.data.frame %>%

ggplot(aes(x=s1, y=s2)) + geom_tile(aes(fill=sqrt(var1.var))) + coord_equal() +
scale fill gradient(low = "yellow", high="red", limits = c(1,3)) + ggtitle('Exponential') + theme bw()

I'm going with circular as it has the lowest RMES, a reasonable and low partial sill, and a reasonable range.

3.4 30-60 cm

Try 13-19. Wow, removing these totally changes which variables are significantly. It also makes variograms 'fit' the data better so that I got the models to converge.... it is suspicious to me that removing

this contigious 'batch' of pedon ids make the models fit. Also remove Pedon.ID 13. Including 13 (identified as an outlier) makes the models not converge and increases RMSE by 0.3%.

d4s <- subset(d4, Pedon.ID <13 | Pedon.ID > 19) de4s <- subset(de4, Pedon.ID <13 | Pedon.ID > 19)

Summary stats.
summary(d4s\$Clay)

skewness(d4s\$Clay) # -0.33

Histograms
hist(d4s\$Clay, col = "lightblue", border = "red")
rug(d4s\$Clay)

Plots to check for obvious spatial patterns
spplot(d4s, zcol = 'Clay', col.regions=brewer.pal(5, "Set1"))

```
# Look for spatial outliers. 16 is probably an outlier.
# c4.sel = plot(variogram(Clay ~ 1, d4s, cloud = TRUE), col = 'blue', pch = 19, digitize = TRUE)
# plot(c4.sel, d4s)
```

Fit Linear models

- summary($lm(Clay \sim Aspect$, de4s)) # Adj. R2 0.09
- summary(lm(Clay ~ ConvergenceIndex , de4s)) # Adj. R2 0.11

summary(lm(Clay ~ CrossSectionalCurvature, de4s)) # Adj. R2 0.16

 $summary(lm(Clay \sim DEM_5_utm \ , de4s))$

summary(lm(Clay ~ FlowAccumulation , de4s))

summary(lm(Clay ~ LongitudinalCurvature , de4s))

 $summary(lm(Clay \sim LSfactor , de4s))$

summary(lm(Clay ~ Slope , de4s))

summary(lm(Clay ~ TopographicWetnessIndex, de4s))

 $summary(lm(Clay \sim ValleyDepth , de4s))$

plot(Clay ~ CrossSectionalCurvature, de4s)

abline(lm(Clay ~ CrossSectionalCurvature, de4s))

plot(Clay ~ Aspect, de4s)

 $abline(lm(Clay \sim Aspect, de4s)) \#$ land only faces west and north. I'm not sure that I can explain this so I'm not going to include it.

plot(Clay ~ ConvergenceIndex, de4s)

abline(lm(Clay ~ ConvergenceIndex, de4s))

Together neither are significant. I'm going to use CrossSectionalCurvature as it has highest R2 value. summary(lm(Clay ~ CrossSectionalCurvature+ConvergenceIndex, de4s))

Check for Anisotropy. 120 seems best

 $plot(variogram(Clay \sim CrossSectionalCurvature, de4s, alpha = c(105, 120, 135, 155, 180)))$

h-scatterplots. Strongly correlated to ~ 90 m.

hscat(Clay ~ CrossSectionalCurvature, data = de4s, c(3, 9, 29, 88, 266, 800), variogram.alpha=120)

Empirical (experimental or sample) variogram. Leaving out longitudinalCurvature increases RMSE by \sim 0.4 so I left it in.

cvg4 <- variogram(Clay ~ CrossSectionalCurvature, de4s, alpha=135)

plot(cvg4, plot.nu = FALSE)

cvg4

Variogram modeling. The exponential model doesn't converge, but the values are realistic and stable (even with different values) so I will include the model.

cvgm4.s <- fit.variogram(object=cvg4, model = vgm(nugget = 0.5, psill = 1, range= 100, model = 'Sph'))
cvgm4.c <- fit.variogram(object=cvg4, model = vgm(nugget = 0.5, psill = 1, range= 100, model = 'Cir'))
cvgm4.e <- fit.variogram(object=cvg4, model = vgm(nugget = 0.5, psill = 1, range= 100, model = 'Exp'))</pre>

plot(cvg4, cvgm4.s, pch = 19) plot(cvg4, cvgm4.c, pch = 19) plot(cvg4, cvgm4.e, pch = 19)

cvgm4.s

cvgm4.c

cvgm4.e

Leave-one-out cross validation

ccv4.s = krige.cv(Clay ~ CrossSectionalCurvature, de4s, model = cvgm4.s) ccv4.c = krige.cv(Clay ~ CrossSectionalCurvature, de4s, model = cvgm4.c) ccv4.e = krige.cv(Clay ~ CrossSectionalCurvature, de4s, model = cvgm4.e)

MPE. Mean prediction error (predicted-observed) = bias. Positive = under prediction, negative = over prediction

mean(ccv4.s\$residual) # 0.008

mean(ccv4.c\$residual) # 0.009

mean(ccv4.e\$residual) # -0.004

MSE. Mean squared error mean(ccv4.s\$residual^2) # 2.36 mean(ccv4.c\$residual^2) # 2.33 mean(ccv4.e\$residual^2) # 2.37

RMSE (take the square root to get units in original units)

sqrt(mean(ccv4.s\$residual^2)) # 1.54

sqrt(mean(ccv4.c\$residual^2)) # 1.53

sqrt(mean(ccv4.e\$residual^2)) # 1.54

What is the spatial distribution of the residuals? bubble(ccv4.s, "residual", main = "Clay 30-60 cm Spherical") bubble(ccv4.c, "residual", main = "Clay 30-60 cm Circular") bubble(ccv4.e, "residual", main = "Clay 30-60 cm Exponential") # Kriging + uncertainty. Because I use elevation as a covariate then this is Kriging with an External Drift, rather than universal kriging (which is only if I use the coordinates as variables).

ck4.s <- krige(Clay ~ CrossSectionalCurvature, de4s, model = cvgm4.s, newdata = sgdf) ck4.c <- krige(Clay ~ CrossSectionalCurvature, de4s, model = cvgm4.c, newdata = sgdf) ck4.e <- krige(Clay ~ CrossSectionalCurvature, de4s, model = cvgm4.e, newdata = sgdf)

Plotting. sqrt(var1.var) returns the standard deviation rather than the variance.

ck4.s %>% as.data.frame %>%

ggplot(aes(x=s1, y=s2)) + geom_tile(aes(fill=sqrt(var1.var))) + coord_equal() +

 $scale_fill_gradient(low = "yellow", high="red", limits = c(0,3)) + ggtitle('Spherical') + theme_bw()$

```
ck4.c %>% as.data.frame %>%
```

```
ggplot(aes(x=s1, y=s2)) + geom_tile(aes(fill=sqrt(var1.var))) + coord_equal() +
```

 $scale_fill_gradient(low = "yellow", high="red", limits = c(0,3)) + ggtitle('Circular') + theme_bw()$

ck4.e %>% as.data.frame %>%

ggplot(aes(x=s1, y=s2)) + geom_tile(aes(fill=sqrt(var1.var))) + coord_equal() +

 $scale_fill_gradient(low = "yellow", high="red", limits = c(0,3)) + ggtitle('Exponential') + theme_bw()$

I'm choosing circular as this has the lowest RMSE and largest range.

#-----

Notes:

On singular model fits: If your variogram turns out to be a flat, horizontal or sloping line, then fitting a three-parameter model such as the exponential or spherical with nugget is a bit heavy: there's an infinite number of possible combinations of sill and range (both very large) to fit to a sloping line. In this case, the returned, singular model may still be useful: just try and plot it. Gstat converges when the parameter values stabilize, and this may not be the case. Another case of singular model fit happens when a model that reaches the sill (such as the spherical) is fit with a nugget, and the range parameter starts, or converges to a value smaller than the distance of the second sample variogram estimate. In this case, again, an infinite number of possibilities occur essentially for fitting a line through a single (first sample variogram) point.

In both cases, fixing one or more of the variogram model parameters may help you out (from fit.variogram notes: https://cran.r-project.org/web/packages/gstat/gstat.pdf)

5 Plotting kriging maps.

#Code modified from https://rpubs.com/nabilabd/118172 #Load libraries here so they don't mess with other packages library(ggplot2) library(dplyr)

#Sand

Convert variance into standard deviation
sk1.c\$SD <- sqrt(sk1.c\$var1.var)
sk2.c\$SD <- sqrt(sk2.c\$var1.var)
sk3.c\$SD <- sqrt(sk3.c\$var1.var)
sk4.s\$SD <- sqrt(sk4.s\$var1.var)</pre>

Give better names names(sk1.c)[1] <- 'Sand' names(sk2.c)[1] <- 'Sand' names(sk3.c)[1] <- 'Sand' names(sk4.s)[1] <- 'Sand'

Reproject and rename kriging SpatialGridDataFrame for better plotting

library(plotKML) CRS('+proj=longlat +ellps=WGS84 sk1 ll <- reproject(sk1.c, +datum=WGS84 +no defs +towgs84=0,0,0')) sk2 11 <reproject(sk2.c, CRS('+proj=longlat +ellps=WGS84 +datum=WGS84 +no defs +towgs84=0,0,0')) sk3 11 <- reproject(sk3.c, CRS('+proj=longlat +ellps=WGS84 +datum=WGS84 +no defs +towgs84=0,0,0')) sk4 11 <reproject(sk4.s, CRS('+proj=longlat +ellps=WGS84 +datum=WGS84 +no defs +towgs84=0,0,0'))

Create dataframe to plot points on figures

How do I put popints on plot

d1_ll <- spTransform(d1, CRS('+proj=longlat +ellps=WGS84 +datum=WGS84 +no_defs +towgs84=0,0,0'))

d1_ll_df <- as.data.frame(d1_ll)

d1s_ll<- spTransform(d1s, CRS('+proj=longlat +ellps=WGS84 +datum=WGS84 +no_defs +towgs84=0,0,0')) d1s ll df <- as.data.frame(d1s ll)

d2s_ll<- spTransform(d2s, CRS('+proj=longlat +ellps=WGS84 +datum=WGS84 +no_defs +towgs84=0,0,0'))

d2s ll df <- as.data.frame(d2s ll)

d3s_ll<- spTransform(d3s, CRS('+proj=longlat +ellps=WGS84 +datum=WGS84 +no_defs +towgs84=0,0,0'))

d3s_ll_df <- as.data.frame(d3s_ll)

d4s_ll<- spTransform(d4s, CRS('+proj=longlat +ellps=WGS84 +datum=WGS84 +no_defs +towgs84=0,0,0'))

d4s_ll_df <- as.data.frame(d4s_ll)

Mean prediction

sk1 ll %>% as.data.frame %>%

ggplot(aes(x=s1, y=s2)) + geom_tile(aes(fill=Sand)) + coord_equal() +

scale fill gradient(low = "yellow", high="red", limits = c(35,85)) +

ylab("Latitude") + xlab("Longitude") +

scale_x_continuous() + scale_y_continuous() +

annotate("text", x = -106.611, y = 32.589, label = "A") +

ggtitle('0-5 cm') +

theme_bw()

ggsave("./GeostatisticalModeling/Figures/Sand_0_5_mean.png", width=6, height=3, unit='in')

sk2_ll %>% as.data.frame %>%

 $ggplot(aes(x=s1, y=s2)) + geom_tile(aes(fill=Sand)) + coord_equal() +$

scale_fill_gradient(low = "yellow", high="red", limits = c(35,85)) +
ylab("Latitude") + xlab("Longitude") +
scale_x_continuous() + scale_y_continuous() +
annotate("text", x = -106.611, y = 32.589, label = "C") +
ggtitle('5-15 cm') +
theme_bw()
ggsave("./GeostatisticalModeling/Figures/Sand_5_15_mean.png", width=6, height=3, unit='in')

```
sk3_ll %>% as.data.frame %>%
ggplot(aes(x=s1, y=s2)) + geom_tile(aes(fill=Sand)) + coord_equal() +
scale_fill_gradient(low = "yellow", high="red", limits = c(35,85)) +
ylab("Latitude") + xlab("Longitude") +
scale_x_continuous() + scale_y_continuous() +
annotate("text", x = -106.611, y = 32.589, label = "E") +
ggtitle('15-30 cm') +
theme_bw()
ggsave("./GeostatisticalModeling/Figures/Sand_15_30_mean.png", width=6, height=3, unit='in')
```

```
sk4_ll %>% as.data.frame %>%
ggplot(aes(x=s1, y=s2)) + geom_tile(aes(fill=Sand)) + coord_equal() +
scale_fill_gradient(low = "yellow", high="red", limits = c(35,85)) +
ylab("Latitude") + xlab("Longitude") +
scale_x_continuous() + scale_y_continuous() +
annotate("text", x = -106.611, y = 32.589, label = "G") +
ggtitle('30-60 cm') +
theme_bw()
```

ggsave("./GeostatisticalModeling/Figures/Sand_30_60_mean.png", width=6, height=3, unit='in')

```
# Standard deviation
sk1_ll %>% as.data.frame %>%
ggplot(aes(x=s1, y=s2)) + geom_tile(aes(fill=SD)) + coord_equal() +
```

scale_fill_gradient(low = "yellow", high="red", limits = c(2,10)) +
ylab("Latitude") + xlab("Longitude") +
scale_x_continuous() + scale_y_continuous() +
annotate("text", x = -106.611, y = 32.589, label = "B") +
geom_point(data = d1_ll_df, aes(x=Easting, y = Northing)) +
ggtitle('0-5 cm') +
theme_bw()
ggsave("./GeostatisticalModeling/Figures/Sand_0_5_sd.png", width=6, height=3, unit='in')

```
sk2_ll %>% as.data.frame %>%
```

ggplot(aes(x=s1, y=s2)) + geom_tile(aes(fill=SD)) + coord_equal() +

scale_fill_gradient(low = "yellow", high="red", limits = c(2,10)) +

ylab("Latitude") + xlab("Longitude") +

scale_x_continuous() + scale_y_continuous() +

annotate("text", x = -106.611, y = 32.589, label = "D") +

geom_point(data = d1_ll_df, aes(x=Easting, y = Northing)) +

ggtitle('5-15 cm') +

theme_bw()

ggsave("./GeostatisticalModeling/Figures/Sand_5_15_sd.png", width=6, height=3, unit='in')

sk3_ll %>% as.data.frame %>%

 $ggplot(aes(x=s1, y=s2)) + geom_tile(aes(fill=SD)) + coord_equal() +$

scale fill gradient(low = "yellow", high="red", limits = c(2,10)) +

ylab("Latitude") + xlab("Longitude") +

scale_x_continuous() + scale_y_continuous() +

annotate("text", x = -106.611, y = 32.589, label = "F") +

geom_point(data = d1_ll_df, aes(x=Easting, y = Northing)) +

ggtitle('15-30 cm') +

theme_bw()

ggsave("./GeostatisticalModeling/Figures/Sand_15_30_sd.png", width=6, height=3, unit='in')

```
sk4_ll %>% as.data.frame %>%
ggplot(aes(x=s1, y=s2)) + geom_tile(aes(fill=SD)) + coord_equal() +
scale_fill_gradient(low = "yellow", high="red", limits = c(2,10)) +
ylab("Latitude") + xlab("Longitude") +
scale_x_continuous() + scale_y_continuous() +
annotate("text", x = -106.611, y = 32.589, label = "H") +
geom_point(data = d4s_ll_df, aes(x=Easting, y = Northing)) +
ggtitle('30-60 cm') +
theme_bw()
ggsave("./GeostatisticalModeling/Figures/Sand_30_60_sd.png", width=6, height=3, unit='in')
```

```
# Clay
ck1.c$SD <- sqrt(ck1.c$var1.var)
ck2.s$SD <- sqrt(ck2.s$var1.var)
ck3.c$SD <- sqrt(ck3.c$var1.var)
ck4.c$SD <- sqrt(ck4.c$var1.var)</pre>
```

```
# Give better names
names(ck1.c)[1] <- 'Clay'
names(ck2.s)[1] <- 'Clay'
names(ck3.c)[1] <- 'Clay'
names(ck4.c)[1] <- 'Clay'
```

Reproject and rename kriging SpatialGridDataFrame for better plotting

ck1_ll <- reproject(ck1.c, +towgs84=0,0,0'))	CRS('+proj=longlat	+ellps=WGS84	+datum=WGS84	+no_defs
ck2_ll <- reproject(ck2.s, +towgs84=0,0,0'))	CRS('+proj=longlat	+ellps=WGS84	+datum=WGS84	+no_defs
ck3_ll <- reproject(ck3.c, +towgs84=0,0,0'))	CRS('+proj=longlat	+ellps=WGS84	+datum=WGS84	+no_defs
ck4_ll <- reproject(ck4.c, +towgs84=0,0,0'))	CRS('+proj=longlat	+ellps=WGS84	+datum=WGS84	+no_defs

Mean prediction

ck1 ll %>% as.data.frame %>%

ggplot(aes(x=s1, y=s2)) + geom_tile(aes(fill=Clay)) + coord_equal() +

scale_fill_gradient(low = "yellow", high="red", limits = c(2,16)) +

ylab("Latitude") + xlab("Longitude") +

scale x continuous() + scale y continuous() +

annotate("text", x = -106.611, y = 32.589, label = "A") +

ggtitle('0-5 cm') +

theme_bw()

ggsave("./GeostatisticalModeling/Figures/Clay_0_5_mean.png", width=6, height=3, unit='in')

```
ck2_ll %>% as.data.frame %>%

ggplot(aes(x=s1, y=s2)) + geom_tile(aes(fill=Clay)) + coord_equal() +

scale_fill_gradient(low = "yellow", high="red", limits = c(2,16)) +

ylab("Latitude") + xlab("Longitude") +

scale_x_continuous() + scale_y_continuous() +

annotate("text", x = -106.611, y = 32.589, label = "C") +

ggtitle('5-15 cm') +

theme_bw()

ggsave("./GeostatisticalModeling/Figures/Clay 5 15 mean.png", width=6, height=3, unit='in')
```

```
ck3 11 %>% as.data.frame %>%
```

```
ggplot(aes(x=s1, y=s2)) + geom_tile(aes(fill=Clay)) + coord_equal() +
```

```
scale_fill_gradient(low = "yellow", high="red", limits = c(2,16)) +
```

ylab("Latitude") + xlab("Longitude") +

scale_x_continuous() + scale_y_continuous() +

annotate("text", x = -106.611, y = 32.589, label = "E") +

ggtitle('15-30 cm') +

theme_bw()

ggsave("./GeostatisticalModeling/Figures/Clay_15_30_mean.png", width=6, height=3, unit='in')

ck4 11 %>% as.data.frame %>%

ggplot(aes(x=s1, y=s2)) + geom_tile(aes(fill=Clay)) + coord_equal() +

scale_fill_gradient(low = "yellow", high="red", limits = c(2,16)) +

ylab("Latitude") + xlab("Longitude") +

scale x continuous() + scale y continuous() +

annotate("text", x = -106.611, y = 32.589, label = "G") +

ggtitle('30-60 cm') +

theme_bw()

ggsave("./GeostatisticalModeling/Figures/Clay 30 60 mean.png", width=6, height=3, unit='in')

Standard deviation

```
ck1 11 %>% as.data.frame %>%
```

ggplot(aes(x=s1, y=s2)) + geom_tile(aes(fill=SD)) + coord_equal() +

scale fill gradient(low = "yellow", high="red", limits = c(0,5)) +

ylab("Latitude") + xlab("Longitude") +

scale x continuous() + scale y continuous() +

annotate("text", x = -106.611, y = 32.589, label = "B") +

geom_point(data = d1s_ll_df, aes(x=Easting, y = Northing)) +

ggtitle('0-5 cm') +

theme_bw()

ggsave("./GeostatisticalModeling/Figures/Clay_0_5_sd.png", width=6, height=3, unit='in')

ck2 ll %>% as.data.frame %>%

ggplot(aes(x=s1, y=s2)) + geom_tile(aes(fill=SD)) + coord_equal() +

scale_fill_gradient(low = "yellow", high="red", limits = c(0,5)) +

ylab("Latitude") + xlab("Longitude") +

scale_x_continuous() + scale_y_continuous() +

annotate("text", x = -106.611, y = 32.589, label = "D") +

geom_point(data = d2s_ll_df, aes(x=Easting, y = Northing)) +

ggtitle('5-15 cm') +

theme bw()

ggsave("./GeostatisticalModeling/Figures/Clay_5_15_sd.png", width=6, height=3, unit='in')

```
ck3_ll %>% as.data.frame %>%
ggplot(aes(x=s1, y=s2)) + geom_tile(aes(fill=SD)) + coord_equal() +
scale_fill_gradient(low = "yellow", high="red", limits = c(0,5)) +
ylab("Latitude") + xlab("Longitude") +
scale_x_continuous() + scale_y_continuous() +
annotate("text", x = -106.611, y = 32.589, label = "F") +
geom_point(data = d3s_ll_df, aes(x=Easting, y = Northing)) +
ggtitle('15-30 cm') +
theme_bw()
ggsave("./GeostatisticalModeling/Figures/Clay_15_30_sd.png", width=6, height=3, unit='in')
```

```
ck4_ll %>% as.data.frame %>%
ggplot(aes(x=s1, y=s2)) + geom_tile(aes(fill=SD)) + coord_equal() +
scale_fill_gradient(low = "yellow", high="red", limits = c(0,5)) +
ylab("Latitude") + xlab("Longitude") +
scale_x_continuous() + scale_y_continuous() +
annotate("text", x = -106.611, y = 32.589, label = "H") +
geom_point(data = d4s_ll_df, aes(x=Easting, y = Northing)) +
ggtitle('30-60 cm') +
theme_bw()
ggsave("./GeostatisticalModeling/Figures/Clay_30_60_sd.png", width=6, height=3, unit='in')
```

#6 Tables

#Soil Survey Data (obtained from the White Sands Soil Survey by downloading the survey from WebSoilSurvey, opening the .mdb file and adding the tabular data, opening the component table and finding the chutum/dona ana complex component keys, then opening the horizon table and finding the component key. I then copied and pasted this data into excel (I had to do a bit of re-aranging to get the horizons right by depth).

 $ssd \le readWorkbook("./SoilData/physicalprop chorion.xlsx", rows=c(1:10), cols = c(2,4:16))$

#Convert to SPC and convert to standard depth intervals.

depths(ssd) <- Component.Key ~ top + bottom

Global soil map standard depth intervals: 0-5 cm, 5-15 cm, 15-30 cm, 30-60 cm, 60-100, & 100-200 cm. The following code modified from: https://ncss-tech.github.io/AQP/aqp/aqp-intro.html. However, many of these soils are < 100 cm deep. Because I have so few samples, I am only going to map soil texture to 60 cm.

Use the slice and slab functions in AQP to average over these depths

ssd.pc <- aqp::slice(ssd, fm=0:100 ~total.sand.low +

total.sand.rv + total.sand.high + total.silt.low + total.silt.rv + total.silt.high + total.clay.low + total.clay.rv + total.clay.rv +

Subset to GSM depths and calculate weighted mean values (I'm pretty sure that this does a weighted mean).

 $gsm.depths \le c(0, 5, 15, 30, 60, 100)$

ssd.gsm <- slab(ssd.pc, fm=Component.Key ~total.sand.low +

total.sand.rv + total.sand.high + total.silt.low + total.silt.rv + total.silt.high +

total.clay.low +

total.clay.rv +

total.clay.high,slab.structure = gsm.depths, slab.fun = median, na.rm=TRUE)

Reshape to wide format, convert to SPC, and make new hz names

ssd.d2 <- dcast(ssd.gsm, Component.Key + top + bottom ~ variable, value.var = 'value')

 $depths(ssd.d2) \leq Component.Key \sim top + bottom$

```
ssd.d2$hzname <- profileApply(ssd.d2, function(i) {paste0('GSM-', 1:nrow(i))})</pre>
```

Copy and paste the following into an excel spreadsheet, calculate weighted average from the proportions of components in the map unit, and reformat to make publication quality.

ssd.d2@horizons

Table 2

tab2a <- data.frame(cbind(rep('Sand', 4),

rbind('0-5',

'5-15',

'15-30',

'30-60'),

rbind(length(d1),

length(d2),

length(d3),

length(d4)),

rbind(summary(d1\$Sand),

```
summary(d2$Sand),
```

summary(d3\$Sand),

```
summary(d4$Sand)),
```

rbind(sd(d1\$Sand),

sd(d2\$Sand),

sd(d3\$Sand),

sd(d4\$Sand))))

```
tab2b <- data.frame(cbind(rep('Clay', 4),
               rbind('0-5',
                   '5-15',
                   '15-30',
                   '30-60'),
               rbind(length(d1),
                   length(d2),
                   length(d3),
                   length(d4)),
               rbind(summary(d1$Clay),
                   summary(d2$Clay),
                   summary(d3$Clay),
                   summary(d4$Clay)),
               rbind(sd(d1$Clay),
                   sd(d2$Clay),
                   sd(d3$Clay),
                   sd(d4$Clay))))
```

names(tab2b)[10] <- 'SD'

Table 3

```
tab3a <- data.frame(cbind(
```

```
rbind((as.character(svgm1.c$model)[2]),
```

```
(as.character(svgm2.c$model)[2]),
```

```
(as.character(svgm3.c$model)[2]),
```

```
(as.character(svgm4.s$model)[2])),
```

```
rbind(sqrt(mean(scv1.c$residual^2)),
```

```
sqrt(mean(scv2.c$residual^2)),
sqrt(mean(scv3.c$residual^2)),
sqrt(mean(scv4.s$residual^2))),
rbind(svgm1.c$range[2],
svgm2.c$range[2],
svgm3.c$range[2],
rbind(svgm1.c$psill,
svgm2.c$psill,
svgm3.c$psill,
svgm4.s$psill)))
```

names(tab3a) <- c('model', 'rmse', 'range', 'nugget', 'sill')

tab3b <- data.frame(cbind(

```
rbind((as.character(cvgm1.c$model)[2]),
```

```
(as.character(cvgm2.s$model)[2]),
```

(as.character(cvgm3.c\$model)[2]),

```
(as.character(cvgm4.c$model)[2])),
```

```
rbind(sqrt(mean(ccv1.c$residual^2)),
```

```
sqrt(mean(ccv2.s$residual^2)),
```

```
sqrt(mean(ccv3.c$residual^2)),
```

```
sqrt(mean(ccv4.c$residual^2))),
```

rbind(cvgm1.c\$range[2],

```
cvgm2.s$range[2],
```

```
cvgm3.c$range[2],
```

```
cvgm4.c$range[2]),
```

rbind(cvgm1.c\$psill,

```
cvgm2.s$psill,
```

```
cvgm3.c$psill,
```

```
cvgm4.c$psill)))
```

7. Variogram plotting
Make nice variogram lines for plotting
sand
s1line = variogramLine(svgm1.c, maxdist = max(svg1\$dist))
s2line = variogramLine(svgm2.c, maxdist = max(svg2\$dist))
s3line = variogramLine(svgm3.c, maxdist = max(svg3\$dist))
s4line = variogramLine(svgm4.s, maxdist = max(svg4\$dist))

clay
c1line = variogramLine(cvgm1.c, maxdist = max(cvg1\$dist))
c2line = variogramLine(cvgm2.s, maxdist = max(cvg2\$dist))
c3line = variogramLine(cvgm3.c, maxdist = max(cvg3\$dist))
c4line = variogramLine(cvgm4.c, maxdist = max(cvg4\$dist))

splot2 <-

```
splot3 <-
```

```
cplot2 <-
```

```
ggplot(cvg2, aes(x = dist, y = gamma)) +
geom_point() +
geom_line(data = c2line) +
ylim(c(0,10)) +
annotate("text", x = 75, y = 9.2, label = "Clay 5-15 cm") +
theme_bw() +
theme(axis.title.x=element_blank(),
    axis.title.y=element_blank(),
    axis.text=element_text(size=11))
```

```
cplot3 <-
ggplot(cvg3, aes(x = dist, y = gamma)) +
geom_point() +
geom_line(data = c3line) +</pre>
```

```
ylim(c(0,10)) +
annotate("text", x = 75, y = 9.2, label = "Clay 15-30 cm") +
theme_bw() +
theme(axis.title.x=element_blank(),
    axis.title.y=element_blank(),
    axis.text=element_text(size=11))
```

Arrange into one plot

sand

sfig <- ggarrange(splot1, splot2, splot3, splot4, ncol = 2, nrow = 2)

sfig <- annotate_figure(sfig,</pre>

```
bottom = text_grob("Distance (m)"),
```

```
left = text_grob("Semivariance", rot = 90))
```

```
ggsave(sfig, filename="Fig3.png")
```

clay

```
cfig <- ggarrange(cplot1, cplot2, cplot3, cplot4, ncol = 2, nrow = 2)
```

cfig <- annotate_figure(cfig,

```
bottom = text_grob("Distance (m)"),
left = text_grob("Semivariance", rot = 90))
```

ggsave(cfig, filename="Fig4.png")

X. Stochastic Simulations, i.e., equiprobable realizations of the variable that replicate the spatial characteristics found in the sample data. When all the simulated surfaces are assembled, they provide a distribution of values for each location in the study area. Models that well fit the data will have little variability between realizations. The nmax parameter results in local kriging, but without it, the command seems to go into an infinite loop.

#

##Kriging is a deterministic method whose function has a unique solution and does not attempt to represent the actual variability of the studied attribute. The smoothing property of any interpolation algorithm replaces local detail with a good average value; however, the geologist and reservoir engineer are more interested in finer-scaled details of reservoir heterogeneity than in a map of local estimates of the mean value. Like the traditional deterministic approach, stochastic methods preserve hard data where known and soft data where informative. Unlike the deterministic approach, though, it provides geoscientists and reservoir engineers with many realizations. The kriged solution is the average of numerous realizations, and the variability in the different outcomes is a measure of uncertainty at any location. Thus, the standard deviation of all values simulated at each grid node is the quantification of uncertainty.[2] [3] http://petrowiki.org/Geostatistical_conditional_simulation

I decided against stochastic simulation as I was more interested in getting a good prediction than in assessing local variability because kriging is twice as good at estimation as is stochastic simulation (Webster and Oliver, 2007, Geostats for Env. Sci, pg. 271) and because the standard deviation of the simulation was often > 100.

#0-5 cm

set.seed(4801)

sSS1 <- krige(Sand ~ DEM 5 utm, de1, model = svgm1.c, newdata = sgdf, nsim=100, nmax = 67)

#5-15 cm

set.seed(4801)

sSS2 <- krige(Sand ~ DEM_5_utm, de2, model = svgm2.c, newdata = sgdf, nsim=100, nmax = 67)

#15-30 cm

set.seed(4801)

sSS3 <- krige(Sand ~ TopographicWetnessIndex, de3, model = svgm3.e, newdata = sgdf, nsim=100, nmax = 67)

#30-60 cm

set.seed(4801)

sSS4 <- krige(Sand ~ DEM_5_utm+LongitudinalCurvature, de4, model = svgm4.s, newdata = sgdf, nsim=100, nmax = 67)

Convert simulations to raster brick

sSS1 <- brick(sSS1) sSS2 <- brick(sSS2) sSS3 <- brick(sSS3) sSS4 <- brick(sSS4)

Calculate mean and standard deviation of soil depth

s1.m <- calc(sSS1, mean) s2.m <- calc(sSS2, mean) s3.m <- calc(sSS3, mean) s4.m <- calc(sSS4, mean)

s1.sd <- calc(sSS1, sd) s2.sd <- calc(sSS2, sd) s3.sd <- calc(sSS3, sd) s4.sd <- calc(sSS4, sd)

```
par(mfrow = c(2,2))
plot(s1.m)
plot(s2.m)
plot(s3.m)
plot(s4.m)
```

plot(s1.sd)

plot(s2.sd)

plot(s3.sd)

plot(s4.sd)

Clay

```
set.seed(4801)
```

```
cSS1.c <- krige(Clay ~ ValleyDepth, de1s, model = cvgm1.s, newdata = sgdf, nsim=100, nmax=60)
```

cSS1.s <- krige(Clay ~ x, de1s, model = x, newdata = sgdf, nsim=100, nmax=60)

cSS1.c <- krige(Clay ~ x, de1s, model = x, newdata = sgdf, nsim=100, nmax=60)

cSS1.c <- krige(Clay ~ x, de1s, model = x, newdata = sgdf, nsim=100, nmax=60)

Convert simulations to raster brick

cSS1.r.s <- brick(cSS1.s)

Calculate mean and standard deviation of soil depth

```
c1.s.m <- calc(cSS1.r.s, mean)
```

c1.s.sd <- calc(cSS1.r.s, sd)

par(mfrow = c(1,2))
plot(c1.s.m)
plot(c1.s.sd)

APPENDIX E CODE USED FOR GEOSTATISTICAL MODELING OF SOIL DEPTH

R code used for geostatistical modeling of soil depth

Geostatistical modeling of soil depth in the the Tromble Weir Watershed

Colby Brungard, PhD

Load libraries

library(aqp)

library(sp)

library(rgdal)

library(raster)

library(gstat)

library(dplyr)

library(ggplot2)

```
# Set working directory
```

setwd("D:/Tromble Weir")

#1. Data preprocessing

read in and check data

dat <- read.csv("./Mikayla Data/R_Pit_Data_cwb.csv")

sdat <- read.csv("./Mikayla Data/R_Pit_Site_Data.csv")</pre>

head(dat)

Convert to SPC
depths(dat) <- Pedon.ID ~ HZ.Top + HZ.Bottom
site(dat) <- sdat</pre>

Create depth variable
dat\$depth <- profileApply(dat, FUN = max)</pre>

Convert site data to spatialpointsdataframe for further analysis

dsp1 <- dat@site coordinates(dsp1) <- ~ Longitude + Latitude proj4string(dsp1) <- '+proj=longlat +ellps=WGS84 +datum=WGS84 +no_defs'

Reproject
dsp <- spTransform(dsp1, CRS('+proj=utm +zone=13 +ellps=GRS80 +datum=NAD83 +units=m
+no_defs'))</pre>

Write to file for visulization in gis
writeOGR(dsp, "./Mikayla Data", "SoilDepthObservations", driver = "ESRI Shapefile")

Points 3 and 37 were located outside of the study area. Remove them dsp <- dsp[dsp\$Pedon.ID != 3 & dsp\$Pedon.ID != 38,]</pre>

Remove dsp1 so I'm not confused
rm(dsp1)

Read in the study boundary and plot points over it sarea2 <- readOGR(dsn = "./SoilData/spatial", layer = "SoilMU26") sarea <- spTransform(sarea2, projection(dsp)) plot(sarea) points(dsp, pch = 19, col = 'blue')

#2 Exploratory data analysis
summary(dsp\$depth)
sd(dsp\$depth) # 1919

Histogram

hist(dsp\$depth, col = "lightblue", border = "red", main = "Depth") rug(dsp\$depth)

This appears to be bi-modal distribution with soils <120 and >150 cm.

I could separate these by depths, but it doesn't make a lot of sense to separate by depth

Does a log transform help? Somewhat, I think, so I'll try it, but bimodal distribution is largest problem. dsp\$ldepth <- log(dsp\$depth) hist(dsp\$ldepth, col = "grey", border = "red", main = 'Log (depth)') rug(dsp\$ldepth)

No spatial patterns readily apparent bubble(obj = dsp, z = "depth", pch=1) bubble(obj = dsp, z = "ldepth", pch=1)

Look for outliers

sel = plot(variogram(depth ~ 1, dsp, cloud = TRUE), col = 'blue', pch = 19, digitize = TRUE)
#plot(sel, dsp) # No outliers readily apparent

#2.1 Exploratory relationships with terrain variables# Load all rasters. Rasters created from 5m ifsar DEM using geoprocess_by_area.bat. See readme file in tw folder.

brk <- do.call(brick, lapply(list.files(path = "./Terrain_derivatives/TD_5m", pattern = ".*tif", full.names = TRUE), raster))

Reproject rasters to points (if needed)
brk2<-projectRaster(brk, crs="+proj=utm+zone=13+ellps=GRS80+datum=NAD83+units=m+no_defs
+towgs84=0,0,0")</pre>

Mask to study area, then crop extent (significantly reduces processing time).
studyarea <- readOGR("./NestedSampllingExample", "SoilMU26")
brk3 <- mask(brk2, mask = studyarea)
brk4 <- crop(brk3, studyarea)</pre>

Extract covariate values

ec <- raster::extract(brk4, y = dsp)</pre>

Kriging and gaussian simulation requires a very fine underlying grid on which to predict.

Use rasters to create prediction grid

sgdf <- as(brk4, 'SpatialGridDataFrame')</pre>

Join covariate values to soil depth data
dsp2 <- cbind(dsp, ec)</pre>

Plotting

This plot shows a somewhat linear relationship between depth and all variables except upslope curvature and topographic position index. It also shows a lot of co-linearity between covariates.

scatterplotMatrix(as.data.frame(dsp2[,-1]))

Fit linear models between Sand and covariates

Significance only shows that the relationship is not-zero.

#Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

summary($lm(depth \sim Aspect$, dsp2))

 $summary(lm(depth \sim ConvergenceIndex , dsp2))$

summary(lm(depth ~ CrossSectionalCurvature, dsp2))

summary(lm(depth ~ DEM 5 utm , dsp2)) #** 0.1454

summary(lm(depth ~ FlowAccumulation , dsp2))

summary(lm(depth ~ LongitudinalCurvature , dsp2))

 $summary(lm(depth \sim LSfactor , dsp2))$

 $summary(lm(depth \sim Slope , dsp2))$

summary(lm(depth ~ TopographicWetnessIndex, dsp2))

 $summary(lm(depth \sim ValleyDepth , dsp2))$

Only elevation is significant. Not a very strong relationship, but I do need to account for this relationship.

Check for Anisotropy

plot(variogram(depth ~ 1, dsp, alpha = c(0, 15, 30, 45, 60, 75, 90, 105, 120, 135, 140, 155, 180)))# Looks like a variogram at 120 degrees would be best so I'm going with this.

h-scatterplots hscat(depth ~ 1, data = dsp2, c(3, 9, 29, 88, 266, 800), variogram.alpha=120) # Most correlated at < 30m, maybe 88m.

Look for spatial outliers. One possible outlier, but I do not interpret this as a 'real' outlier as this is likely in the area next to the small drainage.

```
# s1.sel = plot(variogram(depth ~ 1, dsp2, cloud = TRUE), col = 'blue', pch = 19, digitize = TRUE)
# plot(s1.sel, dsp2)
```

Empirical (experimental or sample) variogram.

 $dvg \leq variogram(depth \sim DEM_5_utm, dsp2, alpha=120)$

plot(dvg)

dvg

#Variogram modeling

#The experimental variogram is basically just two columns of numbers: distance and semivariance. To use this for predictions, we need to fit a model (like a regression line) to the variogram. Because the variogram modeling is a numerical optimization we need to provide starting values. psill is the partial sill, which is the sill-nugget.

```
dvgm1.s <- fit.variogram(object=dvg, model = vgm(nugget = 400, psill = 1600, range= 300, model = 'Sph'))
dvgm1.c <- fit.variogram(object=dvg, model = vgm(nugget = 400, psill = 1600, range= 300, model = 'Cir'))
dvgm1.e <- fit.variogram(object=dvg, model = vgm(nugget = 400, psill = 1600, range= 300, model = 'Exp'))
```

dvgm1.s

dvgm1.c

dvgm1.e

plot(dvg, dvgm1.s, pch = 19)
plot(dvg, dvgm1.c, pch = 19)
plot(dvg, dvgm1.e, pch = 19)

Leave-one-out cross validation

dcv1.s = krige.cv(depth ~ DEM_5_utm, dsp2, model = dvgm1.s) dcv1.c = krige.cv(depth ~ DEM_5_utm, dsp2, model = dvgm1.c) dcv1.e = krige.cv(depth ~ DEM_5_utm, dsp2, model = dvgm1.e)

MPE. Mean prediction error (predicted-observed) = bias. Positive = under prediction, negative = over prediction

mean(dcv1.s\$residual) # -0.351
mean(dcv1.c\$residual) # -0.165
mean(dcv1.e\$residual) # 0.205

MSE. Mean squared error measures on average how different predictions are from observations.

The MSE will be small if the predicted responses are very close to the true responses, and will be large if for some of the observations, the predicted and true responses differ substantially (ISL sixth printing).

mean(dcv1.s\$residual^2) # 1418

mean(dcv1.c\$residual^2) # 1452

mean(dcv1.e\$residual^2) # 1753

RMSE (take the square root to get units in original units)

sqrt(mean(dcv1.s\$residual^2)) # 37.7 cm

sqrt(mean(dcv1.c\$residual^2)) # 38.1

sqrt(mean(dcv1.e\$residual^2)) # 41.9

The spherical model has the lowest RMSE, largest range, and lowest nugget so I choose spherical. Still it his hard to model soil depth.

What is the spatial distribution of the residuals?

bubble(dcv1.s, "residual", main = "Sand 0-5 cm Spherical")

Kriging + uncertainty. Because I use elevation as a covariate then this is Kriging with an External Drift, rather than universal kriging (which is only if I use the coordinates as variables).

dk <- krige(depth ~ DEM_5_utm, dsp2, model = dvgm1.s, newdata = sgdf)

Plotting. sqrt(var1.var) returns the standard deviation rather than the variance.

dk %>% as.data.frame %>%

ggplot(aes(x=s1, y=s2)) + geom tile(aes(fill=sqrt(var1.var))) + coord equal() +

 $scale_fill_gradient(low = "yellow", high="red", limits = c(2,8)) + ggtitle('Spherical') + theme_bw()$

5 Plotting kriging maps for publication.

Convert variance into standard deviation

dk\$SD <- sqrt(dk\$var1.var)

Give better names
names(dk)[1] <- 'Depth'</pre>

Reproject and rename kriging SpatialGridDataFrame for better plotting
library(plotKML)
dk_ll <- reproject(dk, CRS('+proj=longlat +ellps=WGS84 +datum=WGS84 +no_defs +towgs84=0,0,0'))</pre>

Create dataframe to plot points on figures # How do I put points on plot? dsp2_ll <- spTransform(dsp2, CRS('+proj=longlat +ellps=WGS84 +datum=WGS84 +no_defs +towgs84=0,0,0')) dsp2_ll_df <- as.data.frame(dsp2_ll)</pre> # Mean prediction

dk 11 %>% as.data.frame %>%

ggplot(aes(x=s1, y=s2)) + geom_tile(aes(fill=Depth)) + coord_equal() +

scale fill gradient(low = "yellow", high="red", limits = c(30,150)) +

ylab("Latitude") + xlab("Longitude") +

scale x continuous() + scale y continuous() +

annotate("text",
$$x = -106.611$$
, $y = 32.589$, label = "A") +

theme_bw()

ggsave("./GeostatisticalModeling/Figures/Depth mean.png", width=6, height=3, unit='in')

Standard deviation

dk 11 %>% as.data.frame %>%

ggplot(aes(x=s1, y=s2)) + geom_tile(aes(fill=SD)) + coord_equal() +

scale fill gradient(low = "yellow", high="red", limits = c(30,45)) +

ylab("Latitude") + xlab("Longitude") +

scale x continuous() + scale y continuous() +

annotate("text", x = -106.611, y = 32.589, label = "B") +

geom_point(data = dsp2_ll_df, aes(x=Longitude, y = Latitude)) +

theme_bw()

ggsave("./GeostatisticalModeling/Figures/Depth sd.png", width=6, height=3, unit='in')

Variogram model plotting
Make nice variogram lines for plotting
dline = variogramLine(dvgm1.s, maxdist = max(dvg\$dist))

```
dplot <-
ggplot(dvg, aes(x = dist, y = gamma)) +
geom point() +</pre>
```

```
geom_line(data = dline) +
ylim(c(0,2500)) +
ylab('Semivariance') +
xlab('Distance (m)') +
annotate("text", x = 75, y = 2400, label = "Depth") +
theme_bw() +
theme(axis.text=element_text(size=13))
```

ggsave(dplot, filename="Fig5.png")

CONVERT spatialgriddataframe to raster and write to file. These are the predictions that could be used for ecohydrological modeling.

dPred <- raster(dk) writeGDAL(dk, "test2.tif", band=1) writeRaster(d.sd, "./Predictions/SoilDepth sd.tif")

4. Build a sampling grid for stage II sampling.

The key result from this geostatistical analysis is the range of the ordinary variogram.

d.vgm #range = 46m. So I need to sample at distances closer than this for better modeling.

TWW <- readOGR(dsn = "./Enriques Data", layer = "Watershed2 Dissolve")

#Buffer out a few meters to be able to sample surrounding areas. I chose the buffer distance iteratively so that I felt that I had enough points outside of the actual study area to make good predictions.

TWWb <- buffer(TWW, width = 30)

Make a sampling grid and select only the points inside the study area

grid <- makegrid(TWWb, cellsize = 45) #Cell size is 45m, < range of variogram.

grid <- SpatialPointsDataFrame(coords=grid[,c(1,2)], data=grid, proj4string = CRS(proj4string(TWWb))) sampGrid <- grid[TWWb,]

Plot plot(TWWb) points(sampGrid, pch = 19) # Write to file

writeOGR(sampGrid, ".", "SoilDepthSamplePoints", driver = "ESRI Shapefile")