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

# NM WRRI Technical Completion Report No. 382

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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#### **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 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.

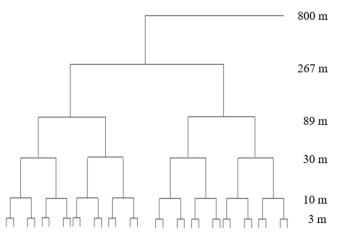


Figure 2. A schematic of the modified balanced nested sampling design used to identify sampling locations. Numbers indicate the physical distance between hierarchical stages. Adapted from Webster et al. (2006).

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  $\sim 30$  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.

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

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

<sup>\*</sup> 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 samplling 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.

		N	Measured values from field sampling						timated	values from se	oil 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
Clay	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 (R² <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 <sup>2</sup>
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

<sup>\*</sup> R<sup>2</sup> 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).

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

	Depth	Model	<b>RMSE</b>	Range	Nugget	Partial Sill	Sill	Nugget-to-Sill ratio
	cm		%	m	$C_0$	C	$C_0 + C$	$C_0 / (C_0 + C)$
	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
Clare	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

<sup>\*</sup>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 ~ 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 dependency while a ratio of one would indicate no spatial correlation. Following the 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  $\sim 50$  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.

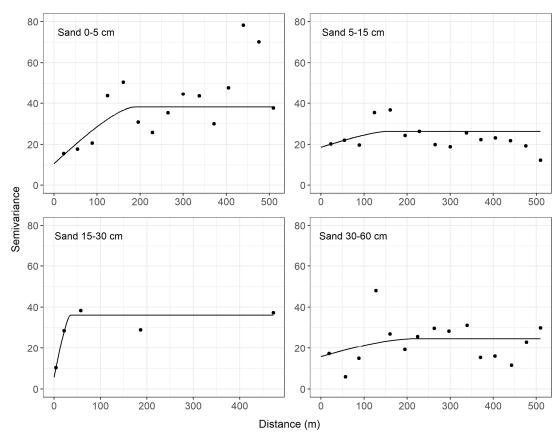


Figure 3. Variogram models of sand concentration. The variogram model for 15-30 cm is visually different than the other variogram models because stable model fit required established 'bin' sizes over which average semivariance values were calculated. Bin sizes were set to equal distances between the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

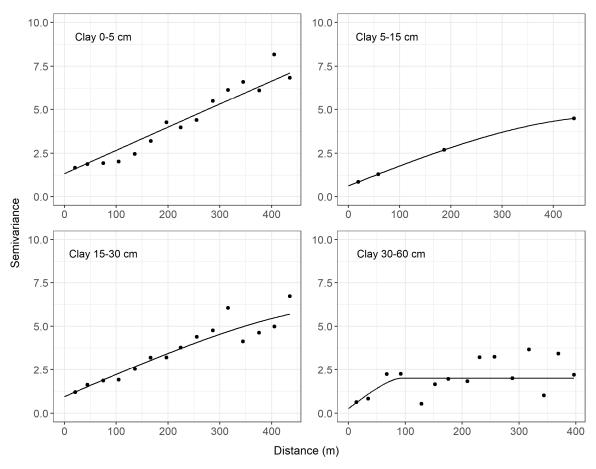


Figure 4. Variogram models of clay concentration. The variogram model for 5-15 cm is visually different than the other variogram models because stable model fit required established 'bin' sizes over which average semivariance values were calculated. Bin sizes were set to equal distances between the sampling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

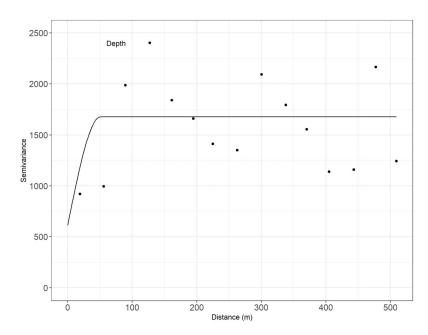


Figure 5. Variogram model of soil depth.

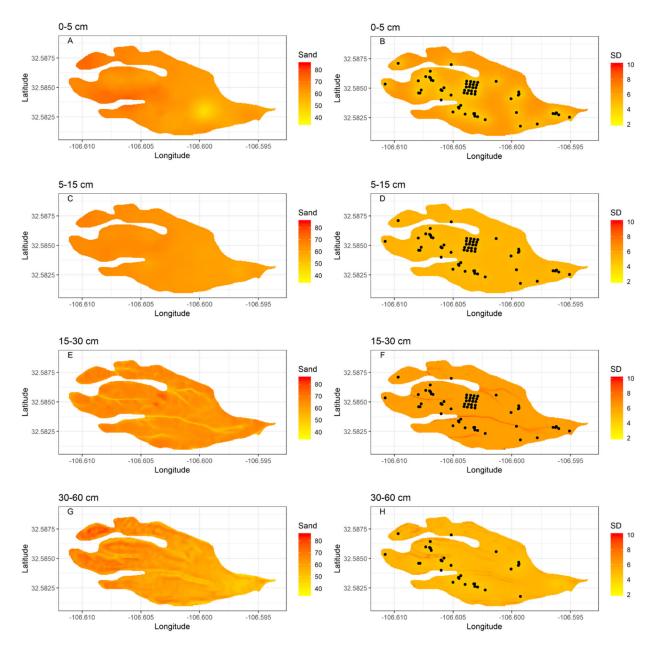


Figure 6. Sand concentration (%) predictions and prediction uncertainty. Left hand figures are the predictions of sand concentration at 0-5 cm (A), 5-15 cm (C), 15-30 cm (E), and 30-60 cm (G). Right hand figures are prediction uncertainty ( $SD = standard\ deviation\ of\ kriging\ variance$ ) at 0-5 cm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

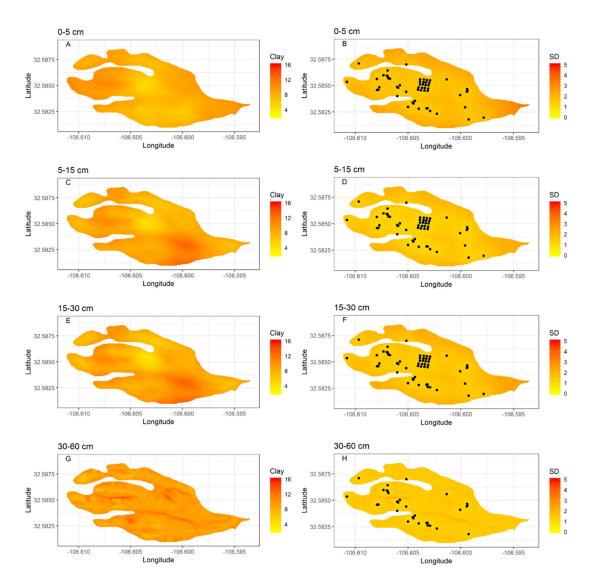
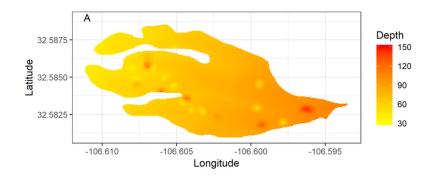


Figure 7. Clay concentration (%) predictions and prediction uncertainty. Left hand figures are the predictions of sand concentration at 0-5 cm (A), 5-15 cm (C), 15-30 cm (E), and 30-60 cm (G). Right hand figures are prediction uncertainty ( $SD = standard\ deviation\ of\ kriging\ variance$ ) at 0-5 cm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



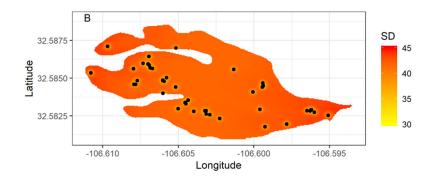


Figure 8. Soil depth predictions and prediction uncertainty. Top figure (A) is prediction. Bottom figure (B) is prediction uncertainty  $(SD = standard\ deviation\ of\ the\ kriging\ variance)$ . Filled circles on bottom figure are the sampling locations.

#### **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.

```
# Code written by:
```

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#### #Citation

#' @article {WEBSTER20061320,

```
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(".")
```

#' title = "Estimating the spatial scales of regionalized variables by nested sampling, hierarchical analysis

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

```
poly <- readOGR(dsn = ".", layer = "SoilMU26")
```

# 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 non-exponential decrease was desired.

# I chose 800 m because it seemed like a good idea and because it was approximately 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) {
# poly = polygon to sample in
# n = number of samples at each level</pre>
```

# 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)
# Centroids in dataframe format
samp <- as(spsample(strat), "data.frame")</pre>
names(samp) \leq- c('X1', 'X2')
# Identify sampling locations for all hierarchical levels past the first level.
hsamps <- list(samp)
# -1 since the first hierarchical level is already done
for(k in 1:(hlevels-1)){
# Generate samples with in each hierarchical level
newSampX <- vector()</pre>
newSampY <- vector()</pre>
samps2 <- data.frame(matrix(ncol = 2, nrow = nrow(samp)))
for (i in 1:nrow(samp)){
# Generation of random direction
dir < -runif(1, min = 0, max = 360)
# Generation of new point
dx \le -dists[k] * sin(dir)
dy < -dists[k] * cos(dir)
newSampX < -hsamps[[k]][i,1] + (dists[k] * sin(dir))
```

```
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))</pre>
coordinates(newSamp) < - \sim 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]
while(inPoly != TRUE) {
  # Generation of random direction
  dir < runif(1, min = 0, max = 360)
  # Generation of new point
  dx \le -dists[k] * sin(dir)
  dy \le -dists[k] * cos(dir)
  newSampX \le hsamps[[k]][i,1] + (dists[k] * sin(dir))
  newSampY \leftarrow 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))</pre>
  coordinates(newSamp) < - \sim newSampX + newSampY
  proj4string(newSamp) = proj4string(poly)
  # Is the new point in the boundaries of the polygon?
  inPoly <- !is.na(over(newSamp, poly))[1,1]
 } # end while
```

```
samps2[i,] <- data.frame(newSamp)</pre>
}# end inner for loop
# Join all samples into a list
hsamps[[k+1]] \le -samps2
} # end outer for loop
return(hsamps)
}
# 4. Run nested sampling
try1 < -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]]$level <- rep('Level1', nrow(try1[[1]]))</pre>
try1[[2]]$level <- rep('Level2', nrow(try1[[2]]))</pre>
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)
dat$id <- paste0(0,seq(01,nrow(dat)))
write.csv(dat, "./SamplingPoints.csv", row.names = FALSE)</pre>
```

# 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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UTM: Zone: mE: mN: Topo	Quad: Site ID:	Yr: State: County:		ey Area: MLRA / LRU	Sec. T. R.
Landscape: Landform: Microfeature:	Anthro: Elevation:	T			Stop #: Interval;
	Lievation:	Aspect: Slope (%):	Slope Complexity:	Slope Shape: (Up &	Dn / Across )
Hillslope Profile Position: Geom. Component:	Microrellef: Physio. Division:	Physio. Province:	Physio. Section:	L	<b>V</b>
Drainage: Flooding:			, injuries decitors,	State Physio. Area:	Local Physio, Area;
, Ploouing:	Ponding: Soil Moisture State	us: Permea	bility:	Land Co	over/Use:
Parent Material: Bedrock:	Kind: Fract.: Hard.: C	K <sub>sat</sub> :			
	778011 77810	Depth: Lithostr.	at. Units: Gr	oup: Formation	n: Member:
Erosion: Kind: Degree: Runoff:	Surface Frag %:	GR: 90CB: ST: BD:	: CN: FL: Die	agnostis II I n	
P. S. Control Section : Ave. Clav %: Ave. B	Kind:		74.	ignostic Horz. / Prop.:	Kind: Depth:
Depth Range:  Ave. Clay %: Ave. R	ock Frag %:				1
VEGETATION:	A CONTRACTOR OF THE PARTY OF TH	Control of the Contro			
SYMBOL: COMMON NAME	V CD COVER	MISCELLA	NEOUS FIELD N	OTES / SKETC	H:
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Chrosote	105 0	N CONTRACTOR	all along	A	
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USDA-NRCS 2-75	September 2002				93
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				CU	lime

Obser.	Depth Co	Horizon	Bnd	Mat	anti-Archusence	5 10 1 122 W 3 W 1 W 1 W 1 W 1 W 1 W 1 W 1 W 1 W 1	of the company works			Symbol:					Date:		
Method	(in) (cm)		Bna		Moist	Texture	Rock Fi		Grad	Structure e Sz Type	Drv	Consist Mst		Pie	Mottles % Sz G		
	0-6	A.	W			VFSL	3% MXR 2% MX	565	1	1 SG	65711-817-12-12-12-12-12-12-12-12-12-12-12-12-12-		- CYIN:	30/61936		L. COI	vist. Sp. Lt
	6-53	BK				VESL	2% MXR	FG.	2	FSBX							
	53-8Z	BKZ				L	3 % WX	REG.	-	FSBR		-					
	82-105	PKK	I			1-	1% MX	REFIT		SG			$\neg$				-
	105+	BILKM	J-						+	30		+		-			
	R4 f	Fallin							$\dagger$		_	1	-				
						191 - 201			+	-	+	$\dashv$					
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% Sz C	oxlinorphic Features in Hd Sp Kd Loc E				c Bd Col 9	Ped / V. Surfa 6 Dat Cont F	ce Features (d Loc Col CAF	Roots Gty Sz		Pores Oty Sz Shp	pH (meth)	Effer (agent)	Clay %	CCE	12.50.000	Notes	State and Land
% Sz C	oximorphic Features		z Cn H		c Ba Col %	6. Dst Gont H	CAF				pH (meth)	(agent)	.%	CCE	West Commencer		State and Land
% Sz C	oximorphic Features of Hd Sp Kd Log E	2 Col 4 S	z Cn H	d Sp Kd Lo	c Ba Col %	FF PF	CAF				pH (meth)	(agent)	8 6	CCE	West Commencer		上上
% Sz C	oximorphic Features	2 Col 4 S	z Cn H	d Sp Kd Lo	c Ba Col %	FF PF	CAF				pH (meth)	(agent)	8 6	CCE	West Commencer		上上
% Sz C	oximorphic Features in Jid. Sp. Kd., Loc. E	2 Col 4 S	z Cn H	d Sp Kd Lo	c Ba Col %	FF PF	CAF				pH (meth)	(agent)	8 6	CCE	West Commencer		上上
% Sz C 1 1 2 2 3 3 4 4 5 5 6 6 7 7	oximorphic Features in Hd. Sp. Kd., Loc. E	2 Col 4 S	z Cn H	d Sp Kd Lo	c Ba Col %	FF PF	CAF				pH (meth)	(agent)	8 6	CCE	West Commencer		上上
% Sz C 1 1 2 2 3 3 4 4 5 5 6 6 7 7 8 8	oximorphic Features	2 Col 4 S	z Cn H	d Sp Kd Lo	c Ba Col %	FF PF	CAF				pH (meth)	(agent)	8 6	CCE	West Commencer		上上

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Series or Component Name:	<b>CARLES</b>		PEDON	DESC	RIPT	ON	L. Carlo	PEDON II	D #:	3	DRAFT 3/200	water .
		Map Unit Syn	nbol: Photo#:	Classificatio	in:		and and the	· ·		and the parties of	st. Regime (Tax.):	
Describer(s): Dat	te:	Weather:	Trans. M.			F.				l con mor	st. negine (lax.):	
MIA	619117	Weather.	Temp.: Air:		Latitude:		1	"N [	Datum:	Location:		-
UTM: Zone: mE:		po Quad:		Depth:	Longitude			* w				
	101	po quad:	Site ID:	Yr: State:	County:	Pedon #:	Soll Surv	rey Area: M	LRA/LRU:	Sec. T.	R.	-
Landscape: Landform:	Microfeature	: Anthro:	The state of the s	T						Stop #:	Interval:	
		"   Alluno.	Elevation:	Aspect:		Slope Con	plexity:	Slope Sha	pe: (Up & I	On / Across )	interval;	=
Hillstope Profile Position: Geor	m. Component:	Microrellef:	Dhurt Blit	350°	6		`_		1_	V.		
. +5			Physio. Division:	Physio. Prov	vince:	Physlo. Sec	ction:	State Phys	io. Area:	Local Phy	slo. Area:	-1
rainage: Floo	oding:	Ponding:	10.1111									
		. rollang.	Soll Moisture Statu	IS:	Permea	bility:			Land Co	ver / Use:		4
arent Material:	Bedrock:	Kind: Fra			K <sub>sat</sub> :							
	- unoun	Kind: Fra	ct.: Hard.: De	epth:	Lithost	rat. Units:	G	oup:	Formation	: Membe		4
rosion: Kind: Degree:	Runoff:	-	Confer W at							WEINDE		1
				GR: CB:	ST: BD	: CN:	FL: DI	agnostic Hor	z. / Prop.:	Kind:	D#	-
. S. Control Section : Ave. C	N	Rock Frag %:	Kind:							runu.	Depth:	
						_						1
SYMBOL COMMON	INAME	S GD COVER	1000000	MI MI	SCELLA	NEOUS I	FIELD I	OTES /	SKETC	He		
SYMBOL COMMON	INAME	GD COVER	100000						OD	i: OYP	52050	0
SYMBOL COMMON	INAME	% GD COVER	. Man	4 001	NOW	o'an	ch c	NOTES /	OD	<b> -</b>  이건 ==	32.550	, o c
SYMBOL: COMMON	INAME	GD COVER	1	4 001	NOW		ch c		OD	1 <b>:</b> 075	-2.5-0	
SYMBOL: COMMON	INAME	GD COVER	. Man	4 001	NOW	o'an	ch c		OD	1. 0.75	5930500	900
SYMBOL COMMON	TNAME	GD COVER	. Man	4 001	NOW	o'an	ch c		OD	10 00 00 00 00 00		
SYMBOL COMMON	UNAME	GD COVER	. Man	4 001	NOW	o'an	ch c		OD	1 <u>:</u> 97 = 1		
SYMBOLIT COMMON	MAME TO THE STATE OF THE STATE	% GD.COVER	. Man	4 001	NOW	o'an	ch c		OD			
SYNEOLY COMMON	TRAME	* GD.COVER	. Man	4 001	NOW	o'an	ch c		OD			
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SYMBOLIT COMMON	TNAME	A COCOUNT	- Morn	M CO	W GO	o'an	ch c		OD			
SYMBOLT? COMMON	TNAME	A COCOUNT	- Morn	M CO	W GO	o'an	ch c	ofival	OD			
S/NBOL72 COMMON	TNAME	COCOURT .	- Morn	M CO	W GO	o'an	ch c	ofival	OD			
S/MBOL7/	TNAME	SCD COVER	- Morn	M CO	W GO	o'an	ch c	ofival	OD			
COMMON	NAME	A CO COVER	- Asam gyan	M CO	W GO	o'an	ch c	ofival	OD			200
VEGET/ SYMBOLY	TNAME	A CO COVER	- Morn	M CO	W GO	o'an	ch c	ofival	OD			200
Symooty	NAME	A CO COVER	- Asam gyan	M CO	W GG	o'an	ch c	ofival	OD			200
Symooty	NAME	A CO COVER	- Asam gyan	M CO	W GG	o'an	ch c	ofival	OD			200
COMMON	NAME	A CO COVER	- Asam gyan	M CO	W GG	o'an	ch c	ofival	OD			200

Method	Depth	mponent N		Ma	riv Calar	Texture	Rock Frá		nit Symbol:	I was drawn to the		-		_Date:
52.5000000	(in): (cm)				Moist	iexture	Knd % Bnd	Sz G	Structure	Dry	onsiste Mst	ence Stk F	Pis	Mottles % Sz. Gn. Col. Mst. Sp. Loc
	6-7	18	5			VESV	MXRIA	191	SG				410-42/6/44	
	7-22	BU	5			VED	MXR 3F	5	VESBY				1	
	22-47	BKK	T			FSL	CAC/IAN	51	VF JBK	-	$\dashv$		+	
	47+	BULL	W				CHOTIKIS		1. 50-		$\dashv$	_	+	
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USDA-NRCS	DED	ON DESCR	IDTION	And Advanced to the Park of th			
Series or Component Name:	Map Unit Symbol: Photo	#: Classification:	IPTION	PEDON	ID#:	DRAFT 3/2002	
Described to		". Classification:				Soll Molst. Regime (Tax.):	
Describer(s): Date: 0/9/17	Weather: Temp.: A	ir: La	titude: •	" "N	Determina		
UPIA. Tour	Sc		ongitude: °	' 'W	Datum: .	Location:	
OTM: Zone: mE: mN: To	oo Quad: Sit			Soil Survey Area:	MLRA / I RU	Sec. T. R. Transect: ID:	
Landscape: Landform: Microfeature	: Anthro: Elev				,	Stop #: Interval:	
	Elei	vation: Aspect: s	ope (%): Slope Comp	lexity: Slope S	hape: (Up &		
Hillslope Profile Position: Geom. Component:	Microrellef: Physio. Di		5 C		1	V/.	
Deales		r nysio, Provin	ce: Physio. Secti	on: State Ph	ysio. Area:	Local Physio. Area:	
Drainage: Flooding:	Ponding: Soil Moist	ure Status:	Permeability:		II and O		
Parent Material: Bedrooks			K <sub>sat</sub> :		Land Co	ver / Use:	
Bedrock:	Kind: Fract.: Hard.	: Depth:	Lithostrat. Units:	Group:	Formation	* 14-1	
Eroslon: Kind: Degree: Runoff:	Confere Pro					Member:	
*	Kind:	g %: # GR: 7 SB: S	T: BD: CN: FL	: Diagnostic H	lorz. / Prop.:	Kind: Depth:	
P. S. Control Section: Ave. Clay %: Ave.	Rock Frag %:						
Depth Range:							
VEGETATION:	(Marie Marie	and the second second					
SYMBOL: COMMON NAME		WISC	CELLANEOUS FI	ELD NOTES	/ SKETC	H:	
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Obser. Method	Depth	omponent N Horizon	Bnd	Mat		Texture	Rock Frags		t Symbol:	Cons	stence:	Date Motile	
instant.	(Cm)		19,14	Dry	Moist	100 -100 -100 -100 -100 -100 -100	Knd % Bnd s	z Gra	ide Sz Type		Sik		Cn Col Mat Sp Loc
	6-4	AB.	5			SIL.	3 FCT .	)	36				
	6-22	BK	5			SIL	3 FG	١	SBK				
-	25.38	BUL	W			SCL	3 MG	1	24				
	38+	BICKM	W				1						
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		USDA-NRCS			PEDON	DECC			· Tradenania	-	_	100-0	03777	
		Series or Component Name:		Map Unit Symbo	ol: Photo #:	Classification	Lille	ON		PEDON II	D #:	5	DRAFT 3/2002	
	(	Describer(s);	1			Olassincatio	MI:					Soll Moist.	Regime (Tax.):	54
	1	MIA	Date:	Weather:	Temp.: Air:		Latitude:	•	,	*N D	atum:			1
		UTM: Zone: mE:	mN: Topo C			Depth:	Longitude:		10.	* w	atuiii:	Location:		
			Topa C	auad:	Site ID:	Yr: State:	County:	Pedon #:	Soil Sun	ey Area: MI	RA/LRU:	Sec. T. Transect: ID:	R.	4
	( )	Landscape: Landfo	orm: Microfeature:	Anthro:	Elevation:	Aspect:	Clare (N/)	01 -				Stop #:	nterval:	
		Hillstope Profile Position:				3550	Slope (%);	Slope Com	plexity:	Slope Sha	pe: (Up & I	On / Across )		٦
		rimsiope Piolite Position:	Geom, Component:	Microrellef:	Physio, Division:	Physio. Pro	vince:	Physio, Sec	tion:	State Physi	2 Array	V ·		J
	(	Drainage:	Flooding:	Pohding:	0.1111.1.1					Otate Filysi	o. Area;	Local Physio.	Area:	
				oluling:	Soil Moisture Status	S:	Permea	bility:			Land Co	ver / Use:		4
		Parent Material:	Bedrock: K	Gind: Fract.:	Hard.: De	pth:	K <sub>sat</sub> :							
		Erosion: Kind: Den			-	pur.	Lithostra	at. Units:	G	roup:	Formation	: Member:		
		Erosion: Kind: Deg	ree: Runoff:	. S	urface Frag %: 700	BR: GCB: (C	ST: BD:	CN: F	FL: Di	agnostic Hor	10-1			
53		P. S. Control Section :	Ave. Clay %: Ave. Roc	k Frag %:	(ind:	**0				agnostic non	/ Prop.:	Kind:	Depth:	
		Depth Range:	Tro. Flop	A ray %:										4
		VEC	GETATION:	CONTRACT B	A Section Control of the Control	-Over						P. P. C. S. A. S.		
		SYMBOL: CO	MMON NAME	GD COVER		MI	SCELLA	NEOUS F	IELD N	OTES /	SKETC	16.		3
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Obser.	Depth	Horizon	Vaine:	Ma	trix Color	Texture			it Symbol: Structure	therefore 6	OBSTRUCTURE.	Correction to	Date: Mottles		a non-in-
Method	(in) (cm)			Dry	Moist		Knd % Bn	d Sz G	ade Sz Type				Mottles % Sz Cn		Sp. Loc
	6-7	AB.	i			VFSI	3% MX	266	SG				, and the same of	ere of the second	ester Carre
	7-27	BK				VESL	35% MX12	to 1	1						
	27-36	BLYM	1			FSL	2% MXR	C. (-	VF Sty	-					
	36+	RXXM	2				1 3 1 0 00		1			1			
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Red % Sz	doximorphic Feature Cn Hd Sp Kd Loc	Bd Col % s	Cor	ncentrations	ic Bd Col	Ped / V. Surfi % Dst Cont	ace Features	Roots		pH i	ffer Clay	CCE		Notes	5167
Rei % Sz	doximorphic Feature Cn. Hd :Sp. Kd. 'Loc	Bd Col % s	) Cor Sz Cn I	ld Sp Kd Lo	oc.Bd.CoK	% Dat Cont	Kd Loc Col	Oty Sz. L	Pores oc. Qty Sz Shr	pH (meth) (	effer Clay	CCE		Notes:	
Rec % Sz	doximorphic Feature On Hd Sp Kd Loc	Bd Col % (	) Cor Sz Gn I	ld Sp Kd Lo	ic Bd. Coll	% Dat Cont	AFILF AFILF AF RE/C	Oty Sz. L		pH (meth) (i	igent) %	C.VIII		エ	
Red % Sz	doximorphic Feature On Hd. Sp. Kd. Loc	is iBd Col % (	l Cor Sz Gn I	ld Sp Kd Lo	oc.Bd.CoK	SO DST CONT	AFILF AFILF AF RE/C	Oty Sz. L		pH i	igent), %	C.VIII		エサ	
Rev % Sz	doximorphic Feature On Hd Sp Kd Loc	s Bd Col∵% s	) Cor Sz Cn I	ld Sp Kd Lo	oc.Bd.CoK	SO DST CONT	AFILF AFILF AF RE/C	Oty Sz. L		pH (meth)(i	igent), %	C.VIII		エサ	
Rei	doximorphic Feature Ch' Hd. Sp. Kd. Ecc.	S Bd. Col. 56 s	) Cor Sz Gn I	Hd Sp Kd Lo	oc.Bd.CoK	SO DST CONT	AFILF AFILF AF RE/C	Oty Sz. L		pH i (meth) (i	igent), %	C.VIII		エサ	
Rei	doximorphic Feature On Hd. Sp. Kd. Loc	Bd Col. %	ł Cor Sz Gn. I	Hd Sp Kd Lo	oc.Bd.CoK	SO DST CONT	AFILF AFILF AF RE/C	Oty Sz. L		pH: (meth) (i	igent), %	C.VIII		エサ	
Rev	doximorphic Feature On Hd Sp. Kd. Loc	Bd Col. % s	) Cor	Hd Sp Kd Lo	oc.Bd.CoK	SO DST CONT	AFILF AFILF AF RE/C	Oty Sz. L		pH (meth) (i	igent), %	C.VIII		エサ	
Rev	doximorphic Feature On Hd. Sp. Kd. Loc	is Bid Col. %, s	Con I	Hd Sp Kd Lo	oc.Bd.CoK	SO DST CONT	AFILF AFILF AF RE/C	Oty Sz. L		pH (meth) (i	igent), %	C.VIII		エサ	
Rev	doximorphic Feature Cn. Hd. Sp. Kd. Loc	is is is sold so	) Con Sz Cn I	Hd Sp Kd Lo	oc.Bd.CoK	SO DST CONT	AFILF AFILF AF RE/C	Oty Sz. L		pH (meth)(i	igent), %	C.VIII		エサ	
Rei	Ori Hd Sp. Kd Loo	Be Col: %, s	l Cor	Hd Sp Kd Lo	oc.Bd.CoK	SO DST CONT	AFILF AFILF AF RE/C	Qty Sz. i		pH (meth)(i	(gent); %.	C.VIII		エサ	
Reid	Ori Hd Sp. Kd Loo	Be Col: %; s	l Cor	Hd Sp Kd Lo	oc.Bd.CoK	SO DST CONT	AFILF AFILF AF RE/C	Qty Sz. i	oc. Oty Sz. Shi	pH (in this) (meth) (i	(gent); %.	C		エササ	
Rein	Ori Hd Sp. Kd Loo	Be Cot: %; s	Cor	Hd Sp Kd Lo	oc.Bd.CoK	SO DST CONT	AFILF AFILF AF RE/C	Qty Sz. i	oc. Oty Sz. Shi	pH (	(gent); %.	C		エササ	

USDA-NRCS Series or Component Name:	PED  Map Unit Symbol: Photo s	ON DESCR	IPTION	141' 32.58 long! -1600 PEDONID#: 6	· 60 603 to	
Landesave	Weather: Temp.: Ail Soil Quad: Site	t: Depth: Loi	itude: orgitude: ounty: Pedon #: Soll Su	"N Datum: "W rvey Area: MLRA/LRU:	Location: Sec. T. R. Transect: ID:	
Hillslope Profile Position: Geom. Component:	Anithro: Elevi Microrellef: Physio. Div Ponding: Soli Moistu	Islon: Physio, Province		Slope Shape: (Up & I	Stop #: Interval: On / Across )  Local Physio, Area:	
F	Kind: Fract.: Hard.:		Permeability:  K <sub>sat</sub> :  Lithostrat. Units:	Land Co Group: Formation	ver / Use: : Member:	
Dogram Segram number:	Surface Frag Kind:	%: GR: CB: ST.	BD: CN: FL: C	Diagnostle Horz. / Prop.:	Kind: Depth:	
VEGETATION:	GD COVER	MISC	ELLANEOUS FIELD	NOTES / SKETC	1:	] o cm
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USDA-NRCS 2-75	September	2002		la		70 c

	Depth	Horizon E	rie:	Matrix Colo	PROBATE 1	Texture	Rock Fra			Symbol:	Trezentar	Consis	. 1952 April	7.2.27.11W	Date: Mottles	ORPOREZETE	**************************************
Method	(in) (cm)		Dry	Mo	st		Knd % Rnd	Sz							% Sz Cn		st Sp. Loc
	0-5	AB.				FSL	27 MYR	6	6	SA							
	5-29	BKF				FSL	3% MXK	F(7)	IV	IF SIBK							
	19-105	BEENI				SL	3% CA C	5	2	SG							
	ust	BYRNI					17.17.0		1								
							-		$\dagger$		1						
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Redoxinorphic Features    Concentrations   Ped/V. Surface Features   Roots   Pores, pH Effer Clay OCE   Notes	Redoximorphic Features   Concentrations   Fed/V. Surface Features   Roots   Pores   pH Effer Clay CCE   Note: % Sx Cn Hd Sp Kd Loc Bd Cdl % Sx On Hd Sp Kd Loc Bd Cdl % Dst Con Kg Loc Cdl Qv Sx Sho (meth) (agent); %   VF D D (AF VF   C	
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Redoximorphic Features   Concentrations   Ped IV. Surface Features   Roots   Pores   pH   Effer Clay CCE   Notes   % SZ Cn   Hd   Sp   Kd   Loc   Bd   Col   % SZ   Cn   Hd   Sp   Kd   Loc   Bd   Col   % SZ   Cn   Hd   Sp   Kd   Loc   Bd   Col   % SZ   Shp   (meth)(agent)	S. SZ CPI Hd Sp. Kd. Loc Bd Col. S. SZ CPI Hd Sp. Kd. Loc Bd Col. S. DSI CONT Kd. Loc Col. Col. Sz. Sp. (meth) (agent). S. Loc Col. Sz. Sp. (meth) (agent). Sp	
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Redoximorphic Features   Roots   Peres   pH   Effer Clay CCE   Notes	Redoximorphic Features   Concentrations   Ped /V. Surface Features   Roots   Poves, BH Effer, Clay CCE   Note:  Sec Cri. Hd. Sp. Kd. Loc. Bd. Col. %, Se Cri. Hd. Sp. Kd. Loc. Bd. Col. %, DSI Corn. Kd. Loc. Col. Clay Set. Loc. Clay	
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andscape: Landf			Anthro:	El	levation:	Aspect:	Slope (%):	Slope Cor	nplexity:	Slope Sh	ape: ( Up &	Stop #: Dn / Across )		erval:
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osion: Kina: De	gree: Runoff	:		Surface Fi	rag %:	GR: CB:	ST: BD.	CN:	FL: DI	agnostic Ho	rz. / Prop.:	K	ind:	Depth:
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Obser.	Depth	Horizon	lames.	Ma	an Salar	est uniquenta	GADA I AND THE REAL PROPERTY OF THE CASE	Wap Uni	i Symbol:				Date:	6/16	7/14
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% Sz: 0	oximorphic Features Cn. Hd. Sp. Kd. Loo B	d Cal % s	l Coni	t Sp Kd Lo	e Bd Col	% Dst Cont	CAF HE			pH p (meth) (	agent) %	) } 	Sec. 25 - 1 - 1 - 1		
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		USDA-NRCS Series or Component Name:	Map Unit Sy	PEDON Photo #:	DESCRI Classification:	IPTION	P	EDON ID #:	DRAFT S/A	2002
	( )	Date:  UTM: Zone: mE: mN: Top:	Weather:	Temp.: Air: Soil: Site ID:	Depth: Lor	titude: •		"N Datum:	Location:	
	( )	Landscape: Landform: Microfeature:		Elevation:		oppe (%): Slope Co	1	y Area: MLRA / LRU: Slope Shape: (Up & 1	Transect: ID: Stop #: Interval:	
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		Parent Material: Bedrock:				Permeability: K <sub>sat</sub> : Lithostrat. Units:	Grou		ver / Use:  : Member:	
		Eroslon: Kind: Degree: Runoff:  P. S. Control Section: Ave. Clay %: Ave. F	lock Frag %:	Surface Frag %: (6) Kind:	GR: SOCB: 10 ST	BD: CN:	FL: Diag	nostic Horz. / Prop.:	Kind: Depth:	
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Obser.	Depth	Horizon	Bnd	Ma	trix Color	Texture	Rock Fr			Sýmbol: tructure	(CONST	Consis	tence	Taresid	Date:	NUMBER OF STREET
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	6-44	BTK	5			Sil	3% CAR	19	11	IF SBIL						-
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Elevation: Aspect: Slope (%): Slope Complexity: Slope Shape: (Up & Dn / Across)  Illistope Profile Position: Geom. Component: Microrellef: Physio. Division: Physio. Province: Physio. Section: State Physio. Area:  Illistope Profile Position: Geom. Component: Microrellef: Physio. Division: Physio. Province: Physio. Section: State Physio. Area:  Illistope Profile Position: Geom. Component: Microrellef: Physio. Division: Physio. Province: Physio. Section: State Physio. Area: Local Physio. Area:  Island Cover / Use:  Ksat: Permeability: Land Cover / Use:  Ksat: Lithostrat. Units: Group: Formation: Member:  Island Cover / Use:  Ksat: Physio. Area: Local Physio. Area:  Island Cover / Use:  Ksat: Diagnostic Horz. / Prop.: Kind: Depth:  Kind: Depth: Mind: Depth:  Wind: Diagnostic Horz. / Prop.: Kind: Depth:  Wind: Depth: Area: Diagnostic Horz. / Prop.: Kind: Depth:  Wind: Depth: Area: Diagnostic Horz. / Prop.: Kind: Depth:  Wind: Depth: Area: Diagnostic Horz. / Prop.: Kind: Depth: Diagnostic Horz. / Prop.: Kind: Depth:  Wind: Depth: Area: Diagnostic Horz. / Prop.: Kind: Depth: Diagnostic Horz. / Prop.: Diagnostic Horz. / Prop.: Diagnostic Horz. / Prop.: Diagnostic Horz. / Prop.:	ž.	Í				136.796
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almage: Flooding: Pointing: Soil Moisture Status: Permeability: Land Cover / Use: Vent Material: Bedrock: Kink: Fract.: Hand: Depth: Lithostrat. Units: Group: Formation: Member: Cosion: Kind: Degree: Runoff: Surface Frag %: GR: CB: ST: BD: CN: FL: Diagnostic Horz. / Prop.: Kind: Depth: Mind: Depth: VEGETATION:  Sylpad: Cosmoon Navie: Status: Permeability: Permeability: Rand: Depth: Mind: Dept	illislope Profile Position: Geom. Componer	t: Microrellef: Physio. Division:		Dhuele Cartley	L 1 L .	
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ries or Component	Name:		Map Unit Sym	bol: Ph	EDON:	Classificatio		ON .		PEDON	ID#:	12:	A 4-35	DRAFT 3/2
escriber(s):	Date:				T/	- Industria							Soil Moist.	Regime (Tax
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andscape:	Landform:	Microfeature:	Arithro:		Elevation:	To						Stop		Interval:
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lislope Profile Pos	itlon: Geom.	Component:	Microrellef:	Physic	o. Division:	Physio. Pro		Physio. S	ection:	State Ph	nysio, Area:		Local Physi	o. Area:
ilnage:	Floodi	ng:	Ponding:	Soll N	Moisture Statu	s:	Permea	hilibu						
							K <sub>sat</sub> :	omty.			Land	Cover/L	Jse:	
rent Material:		Bedrock:	Kind: Fra	ct.:	Hard.: De	epth:		at. Units:	Gi	гоир:	Format	ion:	Member:	
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S. Control Section pth Range:	: Ave. Cla	Y%: Ave. FI	GD COVER	Kind:		M	ISCELLA			NOTES	•			Depth

Obser. Method	Depth			M	trix Color	Texture	Rock F		nit Symbol:	destruction of			Date:	
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USDA-NRCS			DESCRIPT	ION	PEDON ID #:	24 DRAFT 3/2002	1
ries or Component Name:	Map Unit S	ymbol: Photo #:	Classification:	and the second property and the second position of the second positi	Manual Control of the	Soll Moist, Regime (Tax.):	
Date:	/ (7 Weather:	Temp.: Air:	Latitude:	•	"N Datum:	Location:	
TM: Zone: mE: mN:	Topo Quad:	Soll:	Depth: Longitude Yr: State: County:		* W .	Sec. T. R.	
Landscape: Landform: Micro				Soll Sur	vey Area: MLRA / LRU:		
Landscape: Landform: Micro	ofeature: Anthro:	Elevation:	Aspect: Slope (%	: Slope Complexity:	Slope Shape: (Up &		1
Hillslope Profile Position: Geom. Compo	nent: Microrellef:	Physio. Division:	S 80   Physio. Province:	5		L.	
		, system and since	Physio. Province:	Physio. Section:	State Physio. Area:	Local Physio. Area:	1
rainage: Flooding:	Ponding:	Soil Moisture Statu	us: Perme	ability:	Land Co	ever / Use:	
arent Material: Red	rock: Kind: F		K <sub>sat</sub> :				
Bed	iouk. Kina: F	ract.: Hard.: D	Pepth: Lithos	trat. Units:	Group: Formation	n: Member:	1
rosion: Kind: Degree: Run	off:	Surface Frag %	GR:   CB: CST: B	D: CN: FL: D	lagnostic Horz. / Prop.:		
		Kind:	05 5		nagnostic norz. / Prop.:	Kind: Depth:	
S. Control Section : Ave. Clay %: epth Range:	Ave. Rock Frag %:		18				-
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Obser.	Depth	Horizon		Ma	HIV COLOR	CORD   12.63	Texture	erless spraces			t Sýmbol:					Date:		<u> </u>
Method	(in): (cm)			Dry			exture	Knd %	And S	Gra	Structure ide Sz Type	Dry				Mottles % Sz Cn		
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es or Component Name:		PEDON	DESCI	RIPTIO	NC.	PI	EDON ID	#:	/5	DRAFT 3/2002
	Map Unit Symbo	ol: Photo #:	Classification	:	- State of the State of the sta	Productive of the	to a lentile to		Soil Mol	st. Regime (Tax.):
criber(s): Date:	Weather:	Temp.: Air:		atitude:	• (		"N Da	tum:	Location:	J ()
: Zone: mE: mN:	Topo Quad:		Depth:     Yr: State:	ongitude:	edon#: So		W Area: MLI		Sec. T	R.
dscape: Landform: Microfe	ture: Anthro:	Elevation:	Aspect:	Slope (%):	Slope Complex				Stop #:	Interval:
slope Profile Position: Geom. Compone	t: Microrellef: I	Physio, Division:	Physio. Provi	nce:	9 Physio. Section		State Physic	/	Local Phys	
nage: Flooding:	Ponding:	Soll Moisture Statu	s;	Permeabi			- Into Triyolo		ver / Use:	sio. Area:
nt Material: Bedroo	: Kind: Fract.:	Hard.: De	opth:	K <sub>sat</sub> :	Unite					
Ion: Kind: Degree: Runoff:		urface Frag %:10				Grou		Formation	: Membe	7:
Control Section : Ave. Clay %;	kve. Rock Frag %:	(ind:	(5 ob. 5	ST: BD:	CN: FL:	Diag	nostic Horz.	/ Prop.:	Kind:	Depth:
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Obs		omponent N Horizon		V SANGET	rix Color	Texture	of property and the			Symbol:	look and the	***************************************			Date:
Meti	od (in) (cm)	M. D. S.	Bnd		Moist	lexture	Knd % B	nd Sz		Structure le Sz Type	Dry	Consist Mst	tence.	Pls	Mottles % Sz Cn Col Mst Sp Lo
	0-7	AB	. 5			VESL	2% MX	126	N	SET			AT STATE	Lactor M	- Contracting the contraction of
	7-37	BLK				VESL	3 CACAN	FG	1	VF SKY					
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VOY 75600556. 1000 - 100.604SS USDA-NRCS PEDON DESCRIPTION Date: 6 | 21/17 Site ID: Stop #: Hillslope Profile Position: Local Physio. Area: Physio. Division: Physio. Province: tate Physio. Area: Soil Moisture Status Land Cover / Use: K<sub>sat</sub>: Hard.: Lithostrat. Units: Member: Degree: Runoff: Surface Frag %: GR: CB: ST: Diagnostic Horz. / Prop.: Kind: Depth: P. S. Control Section : Depth Range: Ave. Clay %: Ave. Rock Frag %: VEGETATION: MISCELLANEOUS FIELD NOTES / SKETCH: - MAR COPPER IN PRIVITAGEIC 7 cm 28 cm USDA-NRCS 80 cm 2-75 September 2002

Metho	r, Depth	Horizon	Bnd N	atrix Color	Texture	Rock F		nit Sýmbol: Structure	December 2	sistence	Topics of	Date:	Activities and the control of the co
CONSCRETE STATE OF STREET	(in): (cm)	Market St.	Dry	Moist		Knd % A	d Sz G	rade Sz Type	Dry M	st Stk		SAME SAME SAME SAME SAME SAME SAME SAME	Mst Sp. Loc
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10800.000-6 pm) PEDON DESCRIPTION PEDON ID #: DRAFT 3/2002 Describer(s):

UTM: Zone: Site ID: Landform: Physio. Division: State Physio, Area Flooding: Soil Moisture Status Land Cover / Hear Parent Material: K<sub>sat</sub>: Lithostrat, Units: Hard.: Member: Erosion: Kind: Runoff: Surface Frag %: GR: CB: ST: BD: CN: FL: Diagnostic Horz. / Prop.: Kind: P. S. Control Section : Ave. Clay %: VEGETATION: MISCELLANEOUS FIELD NOTES / SKETCH: LESS OVANTIC Charaes tumique publi 0 how your scottered 30 USDA-NRCS 2-75 September 2002

Obser.	Depth	imponent N		erfatographie	rix Color	or busy move someon	elia, erasas unti			Symbol:					, Date:	
Method	(in) (cm)	Horlżon			Moist	Texture	Knd % Br	nd Sz	Grade	Structure e Sz Type	Dry	Consis Mst	tence Stk	Pls	Mottles % Sz Cn	Col Mit Sp. Loc
	0-6	AB.				VEST	AN MXX	2.FF	11	562				A E LIVE	100000000000000000000000000000000000000	distance of the congress
	6-50	BK				1881	APRICAR STURAR	FG	1	VF SBK				700		
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USDA-NRCS Series or Component Name:	PEDON DESCR	IPTION PEDONID#:	G-GSTTL
Describer(s): Date:	Map Unit Symbol: Photo #: Classification:		Soll Moist. Regime (Tax.):
UTM: Zone: mE: mN: Topo	Soil: Depth: Lo	etitude: ° ' "N Datum: ongitude: ° ' W	Location:
Landscance	Arthres	County: Pedon #: Soll Survey Area: MLRA / LRI	Sec. T. R. I: Transect: ID: Slop #: Interval:
Hillslope Profile Position: Geom. Component:	Microrellef: Physio. Division: Physio. Provin	lope (%): Slope Complexity: Slope Shape: (Up &	
Drainage: Flooding:	Ponding: Soil Moisture Status:	State Physio. Area:	Local Physio. Area:
Parent Material: Bedrock:	Kind: Fract.: Hard.: Depth:	K <sub>sat</sub> :	over / Use:
Erosion: Kind: Degree: Runoff:	Surface Frag %: GR: CB: S	aroop. Poimaid	monage,
P. S. Control Section : Ave. Clay %: Ave. Ros Depth Range:	Kind:	- mgmodio Horz./ Flap.	Kind: Depth:
VEGETATION:	Misc	CELLANEOUS FIELD NOTES / SKET	
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Method	(in) (cm)	Horizon	Bnd		Moist		Knd% :Rn	d Sz G	Structure irade Sz T	pe Dry	Consis Mst	tence	Pis	Mottles % Szi-Cn. Col Mst Sp. Lor
	0-9	NB	L			NESL	3% WX	CE C	) 20			4,4,2,1,1,1	- Contract	en en en en en en en en en en en en en e
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USDA Series or (	-NRCS Component Name:	Maria de	ote (	Map Unit S	F	EDON	DESC	RIPT	ON	SORUM TO SERVICE	PEDON	06.59 D#:	29	DRAFT 3/2	003
		12		wap ont S	ymbol:	Photo #:	Classification	on:					Soll Mois	st. Regime (Tax	
Describer	r(s):	Date:	7	Weather:	Tem	p.: Air:		Latitude:			***				"
. 0	Zone: mE:					Soil:	Depth:	Longitude:			* N	Datum: .	Location:		
	me.	mN:	Торо	Quad:		Site ID:	Yr: State:		Pedon #:	Soll Sun	* W vey Area: 1	MLRA/LRU:	Sec. T.	R.	
Landscap	pe: Landfo	orm: Microf	eature:	Anthro:		Elevation:	Aspect:	Slone (9/)	Diama 0			- 1	Stop #:	Interval:	
Hillsiona	Profile Position:						280	Olobe (%):	Slope Co	mplexity:	Slope St	nape: (Up & l	Dn / Across )		
· illiaiope	Profile Position:	Geom. Compon	ent:	Microrellef:	Phys	sio, Division:	Physio. Pro	vince:	Physio. Si	ection:	State Phy	rsio. Area:	l Daniel Die		
ralnage:		Flooding:		Ponding:	10.11		1.		35.070000		o.u.c ( ny	SIO. AIEE:	Local Phys	sio. Area:	
				rolling;	Soll	Moisture State	us:	Permea	bility:			Land Co	ver / Use:		_
arent Mat	terial:	Bedro	ck:	Kind: F	ract.:	Hard.: D	Depth:	K <sub>sat</sub> :							1
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rosion:	Kind: Deg	ree: Runof	f:		Surfa	ce Frag %:	GR: CB:	ST: BD.	CN:	FL; Di					
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Method   (in)   (cm)     Dry   Molat     Red   Sz   Grade   Sz   Type   Sty   Mis   St.   Pie   Mis   Sp. Lo		Depth	Morizon		econ charge	Time Action	Texture				Sýmbol:	Assert Car	-Tayerman			Date:	
Pedoximorphic Features    Concentrations   Ped/V. Surface Features   Roots   Peres   Ph   Effer Clay OCE   Notes	Method	(in) (cm)	Horizon									Dry	Consis Mst				i Col Mst Sp. Lo
Redoximorphic Features    Redoximorphic Features   Concentrations   Fed / V. Surface Features   Roots   Peres   pN   Effer Clay OCE   Notes		0-7	AB	S			VFSL	124 OAK	10	0					2 11.11.11	to the state of	
Redox/morphic Features  SEC STONE (F. C. S.9)  Redox/morphic Features  SEC ON Hall Sp. Kd. Loc Bd. Col. 96. Sp. Cn. Hall Sp. Kd. Loc Bd. Col. 196. Dat. Cont. Kd. Loc 1001. Day Sp. Loc. Tday Sp. Sp. (methylespen). 38.  C. D. C. M. F. Fill.  D. D. C. M. F. Fill.  D. C. M. Fill.  D. C. M. Fill.  D. C. M. Fill.  D. C. M. Fill.  D. C. M. F	2	7-28	BW	5			1	A (4000)	11-	١	VE SBIC						
Redoximorphic Features    Roots   Pore	3	28-46	BULL	W				STOAR	EG	0	2000						
Pedextimorphic Features  Concentrations  Ped / V. Surface Features  Floots  Peres, pH; Effer Clay CCE  Notes  Sec on Hd Sp; Kd; Lcc; Bd Col; %, Sz on Hd Sp; Kd; Lcc; Bd Col; Sv; Sz; Cort Kd; Lcc; Cdr; Sz; Shp; (meth) (spon)); %,  CDC OFF FIRE  MDC CAF CC  III  8  9  10			BULLIN	( )			0.0	5 0 1			3(1		-		-		
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ries or Component Name:		Map Unit Syn	PEDON nbol: Photo #:	Classification	on:		- escape a	EDON ID	***	3		AFT 3/200 gime (Tax.):
scriber(s): Date		Weather:	Temp.: Air:		Latitude:						moist. Rej	gime (lax.);
MA	6(2511)		Soil:	Depth:				"N Da	atum: .	Location:		
M: Zone: mE:	mN: Topo	Quad:	Site ID:	Yr: State:	Longitude: County:	Padon #: S		w .		Sec.	T.	R.
indscape: Landform:	Microfeature:	TA:					on surve	Area: ML	RA/LRU:			
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listope Profile Position: Geom	. Component:	Microrellef:	Physio. Division:	-	1	S		/		\ /		
			. Hysia, Division:	Physio. Pro	vince:	Physio. Section	on:	State Physic	Area:	Local	Physio. Ar	'ea:
Inage: Flood	ing:	Ponding:	Soil Moisture State	us:	Permeat	allia						
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ent material:	Bedrock:	Kind: Fra	ct.: Hard.: D	Pepth:	K <sub>sat</sub> :	t. Units:						
sion: Kind: Degree:	Runoff:	-				IIII.	Grou	ip:	Formation:	Me	mber:	
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Redoximorphic Features  Redoxi	Method   (th)   Ch   Ch   Ch   Ch   Ch   Ch   Ch	77
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S - W BY   S   W S   A TAMPETA   F SBY     W S	Redoximorphia Festures    Redoximorphia Festures   Concentrations   Ped /V Surface Features   Roots   Forea   pit   Effer Clay CCE   Notes	11 12 14 14 14 14 14 14 14 14 14 14 14 14 14
N-A3 PXV W SIL PACKET OSC SC SC SC SC SC SC SC SC SC SC SC SC S	N-A3 FX W W SIL 37 CM2 FG   NF SBX    Redoximorphic Features   Concentrations   Pad / V. Surface Features   Roots   Fores   pit   Effer Clay CCE   Notes    Sz Cn Hd. Sp Kd Loc Bd. Cot	
Redoximorphic Features    Rodoximorphic Features   Concentrations   Ped / V. Surface Features   Rodox   Pores, pH   Effer Clay OCB   Notes	A3-71 BYNLY W  SI TYCKN CG NF SBY  Redoximporphile Features  Sec on Ho Sp (d Loo Bd Ool % SZ On Ho Sp (d Loo Bd Ool % Det Cont Kd Loo Cot Cot Sp (SZ Shp) (methylagen) 55  CD CAF LLL  AD C (AF (L)  M	
Redox/morphic Features  Set Cn Hd Sp Kd Loc Bd Col % Sz Cn Hd Sp Kd Loc Bd Col Set Loc Col Col Col Col Col Col Col Col Col Col	Redoximorphic Features  See On Hd Sp Kd Loc Bd, Col 1/4, Sz On Hd Sp Kd Loc Bd Col 1/4, Dat Cont Kd Loc Col 1/2, Sz Shp (moth) (agent); 1/4  C D C AF (L	
Red x   Red	Ped / V. Surface Features    Roots   Pores   pH   Effer Clay COB   Notes     Szr Cn Hd Sp Kd Loo Bd Col   % Sz On Hd Sp Kd Loc Bd Col   % Dat Cont Kd Loc   Col   Chy Sz Shp   (moth) (spen))   %     2	
Redeximorphic Features  Secondary Se	Redoximorphic Features % Sz Cn Hd Sp Kd Loc Bd Col % Sz On Hd Sp Kd Loc Bd Col W Day Sz Loc Cly Sz Shp (meth) (agent) %   C D C AF L(()	
Redeximorphic Features   Concentrations   Ped /V. Surface Features   Roots   Pares   pR   Effer Clay CCE   Notes   % Siz On Hoi Sp Kd Loo Bd Col % Siz On Hoi Sp Kd Loo Bd Col   % De Cont Kd Loo Col   Qy Siz Shp   (moth) (agent)   %    C D C (AF (C)   Q   T    MD C (AF (C)   Bd   Col   MD   Col   MD   Col   MD   Col	Redoximorphic Features  S. Sz. Ch. Hd. Sp. Kd. Loc. Bd. Col.  Ch. Ch. Ch. Ch. Col.  Ch. Ch. Ch. Ch. Ch. Ch. Ch. Ch. Ch. Ch.	
Redoximorphic Features  Sec on Hall Sp. Kd. Loc Bd. Col.  Sec on Hall Sp. Kd. Loc Bd. Col.  Redoximorphic Features  Sec on Hall Sp. Kd. Loc Bd. Col.  Sec on Hall Sp. Kd. Loc Bd	Redcx  morphile Features	
Redoximorphic Features Concentrations Ped /V. Surface Features Roots Pores Ph. Effer Clay CCE Notes Notes So Con Hd Sp Kd Loc Bd Col % Sz Con Hd Sp Kd Loc Bd Col Se Det Con Kd Loc Col Coy Sz Cop (misth/lagon). %  CDC CAF LLC  CDC CAF CC  MDC CAF CC  MDC CAF CC  Pores Ph. Effer Clay CCE Notes Notes  Notes  Notes	% SZ Cn Hd SP Kd Loc Bd Col % SZ Cn Hd SP Kd Loc Bd Col % DE Con Kd Loc Col Chy SZ Loc Chy SZ Shp (meth) (agent) . %	
# \$2 Ch Hd Sp Kd Loc Bd Col	S SZ CN Hd SP Kd Loc Bd COI % SZ CN Hd SP Kd Loc Bd COI % DE CON Kd Loc Col CNy SZ Loc CNy SZ SPp (meth) (agent) . 5	
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		USDA-NRCS Series or Component Name: Man Unit S	PEDON DESCRIPTION PEDON ID #: 37 DRAFT 2/2020	
	( )	Describer(s): Date:	Temps: Air: Latitude: "N Datum: Location:	
	 (	UTM: Zone: mE: mN: Topo Quad:  Landscape: Landform: Microfeature: Anthro:	Site ID: Yr: State: County: Pedon #: Soil Survey Area: NLRA / LRU: Transect: ID:	
		Hillslope Profile Position: Geom. Component: Microrelled	Slope Shape: (Up & Dn/Across)	
	( )	Drainage: Flooding: Ponding:  Parent Material: Bedrock: King.	Soil Moisture Status: Permeability: Land Cover / Use:	
		Erosion: Klind: Degree: Runoff:	Tract: Hard: Depth: Lithostrat Units: Group: Formation: Member:  Surface Frag %: NGR: A   OB: (  S7: BD: CN: FL: Diagnostic Horz. / Prop.: Kind: Depth:	
		P. S. Control Section : Ave. Clay %: Ave. Rock Frag %: Depth Range:	Kind: Depth:	
		VEGETATION:	Nik accaled	
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Obser. Method	(in) (cm)	norizon	Bna.	Dry	Moist		. Rock Frags . Knd % Rnd S	z (Gr		Dry		tence .		Mottles % Sz Cn	Col Ms	Sn Loc
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eries or Component Name	:		Map Unit Syr	mbol: Phot	o #:	Classification	RIPTI	Ar wall that I would	THE PERSON NAMED IN	100000000000000000000000000000000000000	VID#: 3	3	DRAFT 3/2
escriber(s):						o i a sanica u	O11.				. ,	Soll Mol	st. Regime (Tax.
MJA	Date:		Weather:	Temp.:	Àir:		Latitude:						
	6/2	7/17			Soil:	Depth:				* N	Datum: .	Location:	
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andscape: Landf							outiny.	redon #:	Soll Su	rvey Area:	MLRA/LRU	Transect: ID	
andscape: Landf	orm:	Microfeature:	Anthro:	E	evation:	Aspect:	Slope (%):	Slope Co	mulauti			Stop #:	Interval:
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ainage:	1							i ilyaid. a	ection:	State P	hysio. Area:	Local Phy	sio. Area:
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rent Material:							K <sub>sat</sub> :				Land C	over / Use:	400000000000000000000000000000000000000
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osion: Kind: De								ui. Omis.		Group:	Formatio	n: Membe	:
osion: Kind: De	gree:	Runoff:		Surface F	rag %:75 (	GR:7) CB:	ST: BD:	: CN:	FL: [			1	
S. Control Section :				Kind:		.0 .	, 55.	. Oiv.	PL:	Diagnostic	Horz. / Prop.:	Kind:	Depth:
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yeb flange:	GETATIO	ON:	SNG D COVER			i M		NEOUS	FIELD	NOTES	/ SKETC	3H :	
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pth Range:	GETATIO	ON:	SNG D COVER			M		NEOUS	FIELD	NOTES	SKEIC	H -	
year year of	GETATIO	ON:	SNG D COVER			M		NEOUS	FED	NOTES	SKETC	341 :	

Obser.	The same of the sa			35.05.054.655	trix Color	continue as weathers			it Sýmbol:					_Date:	
Method	(in) (cm)	Horizon	Bnd	Dry	Moist		Knd % Rnd	Sz G	Structure	Drv	Consis Msi	tence	Pie	Mottles % Sz Cn	Col Mst Sp. Loc
	0-10	A.				FSL	1 × MYR	671.	56		20777		SOMERAN		otto and a state of the state o
	10-27	BK				VEXI	2% CAR 6 2% CAR A	51	VF JBC				-		
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									1	1 1					
Red % Sz 0	oximorphic Features on Hd Sp Kd Loc i	Bd Gol % 5	Con Sz Cn F	centrations	oc Bd Coll	UFDC	Kd Loc Col .	Roots 2ty/Sz:L	Pores oc 'Qiy Sz' Shi	pH (meth	Effer ) (agent	7	CCE	L	lotes
Red % Sz.C	On Hd Sp Kd Loc E	3d. Col. %, s	Con F	ld Sp:Kd L	ne Bo Coli	% DSI CONT	Kd Loc Col	Roots	Pores.	pH: (meth	Effer	Clay 5, % 7 9	CCE	istalia ist	lotes
Red % Sz: C	On Hd Sp Kd Loc E	3d Col: % s	l Cor Sz Cn F	ld Sp:Kd L	oc Bd Col	% DSI CONT	CAF RF	Roots Sty Sz L	Pores, co 'Oty Sz' Shi	pH (meth	Effer) (agent	7	CCE	istalia ist	lotes
% Sz: 0 1 2 3	On Hd Sp Kd Loc E	3d Ool: %, s	Con F	ld Sp:Kd L	oc Bd Col	% DSI CONT	CAF RF	Roots Sty S2 L	Pores oc (Gly Sz Shi	pA: meth	Effer (agent	7	CCE	istalia ist	lotes,
'Red % Sz: C	On Hd Sp Kd Loc E	3d (col. %, s.	Corn F	ld Sp:Kd L	oc Bd Col	% DSI CONT	CAF RF	Roots 2by Sz L	Pores, co 'City Sz Shi	pH (meth	Effer ) (agent	7	CCE	istalia ist	lotes,
Red: % Sz: C	On Hd Sp Kd Loc E	8d, Col. %, s	Sz on F	ld Sp:Kd L	oc Bd Col	% DSI CONT	CAF RF	Roots 2by Sz L	Pores Chy Sz Sh	pH ; (meth	Effer (agent	7	CCE	istalia ist	lotes.
Red: % Sz C	On Hd Sp Kd Loc E	3d, ool: %, c	Sz Cn F	ld Sp:Kd L	oc Bd Col	% DSI CONT	CAF RF	Roots 2ty Sz. L	B Peres.	pH: (meth	Effer )(agent	7	CCE	istalia ist	lotes
	On Hd Sp Kd Loc E	ad Cols %, s	l Con	ld Sp:Kd L	oc Bd Col	% DSI CONT	CAF RF	Roots 22ly Sz. L	B Pores.	pH in the state of	Effer (agent	7	CCE	istalia ist	lotes.

19 7 32 SBS10A long 7-106.40671 USDA-NRCS PEDON DESCRIPTION PEDON ID #: SA DRAFT 3/2002 Describer(s); 612717 Datum: Site ID: MLRA/LRU: Transect: ID: Stop #: Slope Shape: (Up & Dn / Across) KO. Physio. Province: State Physio. Area: Local Physio. Area Flooding: Soil Moisture Status: Land Cover / Use K<sub>sat</sub>: Lithostrat. Units: Fract.: Hard.: Formation Erosion: Runoff: Surface Frag %: \ GR: \ GB: \ ST: BD: CN: FL: Diagnostic Horz. / Prop.: Kind: P. S. Control Section : Depth Range: Ave. Clay %: Ave. Rock Frag %: VEGETATION: MISCELLANEOUS FIELD NOTES / SKETCH: after zna nenten 8 30

USDA-NRCS

2-75

September 2002

Obser.	Depth Co	Horizon		M	atrix Color	Texture		Wap U		ymbol: ructure	tic early	Consis	eody.ev	0.000	Date:	to an exchange of the larger of the first
Method	(in) (cm)			Dry			Knd % Br	d Sz G		Sz Type				Pis	Mottles % Sz Cn	Col Mst Sp. Loc
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	USDA-NRCS	PEDON DESCRIPTION PEDON IS	10x756.30517
( )	Describer(s): Date: W	p Unit Symbot   Photo #: Olessification:  eather: Temp. Air:	#: 3 DRAFT 3/2002  Soll Molst. Regime (Tax.):  Location:  Sec. T. F.
$C_{j}$	Landscape: Landform: Microfeature: Ar	thro: Elevation: Aspect: Slope (%): Slope Complexity: Slope Sha	RA/LRU: Transect: ID: Stop #: Interval: De: {Up & Dn/Across}
( ',	Power A Mark A M	nding: Soil Moisture Status: Permeability:	b. Area: Local Physio. Area:
	Erosion: Kind: Degree: Runoff:	th: Fract.: Hard.: Depth: Lithostrat. Units: Group:  Lithostrat. Units: Group:  Lithostrat. Units: Group:  Lithostrat. Units: Diagnostic Hor.  Klind:	Formation: Member:  c. / Prop.: Kind: Depth:
•	P. S. Control Section : Ave. Clay %: Ave. Rock. Depth Range:  VEGETATION:  SYMBOL: COMMON NAME  Ave. Rock.	MICOFILINICIO	SKETCH:
. ' )		- Hir a singer word petro after the 7nd Montanon too many carbs, verive	
t ·		- Hem voors turalgrout	
	USDA-NRCS 2-75	September 2002	
			* ×

'Method	Depth		Bnd	Ma	trix Color	Texture	or of branch	, Map Fracs	Uni	t Sýmbol:	/ Isansanya	Contract Contract			Date:	
1 Section 18	(Cin)	Design Control of the last			Mois		Knd %	Bnd Sz	Gra	de Sz Type	Drv	Consis Mst	tence:	Ple	Mottles % Sz Cn. Col	
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3	28-47	BYKM				UCSA	8 1 CA	1200	1)							
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3 4 5 5 6 7 7							CAF PFICE	N (1)		A-NIFICS		- //		76		ptember 2002
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54.58562 -106.60796 USDA-NRCS PEDON DESCRIPTION PEDON ID #: 340 DRAFT 9/2002 Date: 6/27/17 MJA Location UTM: Zone: mN: Site ID: Sec.
MLRA/LRU: Transect: Stop #: Slope Shape: (Up & Dn / Across) Hillslope Profile Position: Geom. Component: Physio. Division: Physio. Province: Drainage: Soil Moisture Status: Permeability: Land Cover / Use: Parent Material: K<sub>sat</sub>: Lithostrat. Units: Bedrock: Hard.: Depth: Group: Formation Member: Erosion: Kind: Runoff: Surface Frag %: % GR: \CB: \ST: BD: CN: FL: Diagnostic Horz. / Prop.: Kind: Depth: P. S. Control Section : Ave. Clay %: VEGETATION: MISCELLANEOUS FIELD NOTES / SKETCH: COMMON NAME: % GD, COVER Hit a Shallow Retro. 9 and work the Son deports over 22

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USDA-NRCS

2-75

September 2002

Obser.		omponent l		second education	and South to detail	or the company		Map				Lavara				Date:	
Method	Depth (cm)	Horizon	Bnd	Mat Dry	rlx Color Moist	Texture	: Rock F Knd % : Ri				cture Sz Type		Consis		Pls	Mottles % Sz Cn	Col Mst Sp Lo
	0-9	NB					7 % MXY	FFI	1 1		SBK	10,1161	T .	L. T. St. V.	CHATHALA	ent signapayona	and the second second
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	0-6	MB.			*		1% MX B	-86	1	SA	Lory	MSU	Stk	Pis	% Sz Ci	: Col Ms	t Sp. Loc
	6-49	B+1	+			1.	7% MXV	567	IN	-				-			
	44-115	B+ 2				Sil	12 MX		_		7.0						
	115-180	BXX				SI	5% CAN	of		SIBIC						_	
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	180							1	t		-	-	-	-			
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Red % Sz 0	loximorphic Features On Hd Sp Kd Loc E	3d Col & s	Con	centrations		Ped / V. Surf	ace Features	Roots		Pores	рĤ	Effer	Clay	CCE		Notes	With the second
Red % Sz (	loximorphic Features On Hd Sp Kd Loc E	3d Cal. % s	Con	icentrations ld Sp Kd Le	oc Bd. Cor.	"Ped/V. Surf. "% Dst Cont" VF DD	ace Features  Kd Loc Col  CAF RS			Pores Gly Szi Shp	pH (meth)	Effer (agent)	Clay % 12	CCE		Notes	
% Sz (	loximorphilo Features On Hd Sp Kd Loc E	ed Col: % E	Con ≥ Cn F	centrátions ld. Sp.:Kd. Le	oc Bd Col	WFDD VFDD VFDD	Kd Loc Col				pH (meth)	(agent)	12	CCE			
% Sz (	loximorphic Features On Hd Sp Kd Loc E	3d Col. % s	Con	ocentrátions Id. Sp. Kd. Ld	oc Bd Col	WFDD VFDD VFDD	CAF RS				pH (meth)	(agent)	12	CCE			
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% S2 C	doximorphie Features Cn. Ha. Sp. Kd. Loc. E	% s	Correction	icentrallons	oc Bd Col	WFDD VFDD VFDD	CAF RS CAF RS				pH (meth	(agent)	12 15	CCE			7.505
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USDA-NRCS Series or Compone		West and		Map Unit Sy	PEDON mbol: Photo #:	Classificati	RIPT	ION	P	EDON	(0/19- 10#: 3	7	Soll Mois	DRAF	T 3/2002
Describer(s): か ナ ム		Date: (c/2 7	117	Weather:	Temp.: Air:		Latitude:			* N	Datum:	Locati			
UTM: Zona:	mE:	mN:	Торо	Quad:	Soil:	Depth: Yr: State:	Longitude County:			" W y Area:	MLRA/LRU:	Sec.	T.	R.	
Landscape:	Landform	n: Micro	feature:	Anthro:	Elevation:	Aspect:	Slope (%):	Slope Complex	xity:	Slope Sl	nape: ( Up & I	Stop i		Interval:	
Hilislope Profile Po	sition: G	eom. Compo	nent:	Microrellef:	Physic. Division:	3(O Physio, Pro	vince:	Physio. Section			sio. Area:		ocal Physi	lo Aran	
Orainage:	F	looding:		Ponding:	Soll Moisture Sta	itus;	Permea	ability:			Land Co				
Parent Material:		Bedi	ock:	Kind: Fr	act.; Hard.:	Depth:	K <sub>sat</sub> ;	rat. Units:	Grou	up:	Formation		Member:		
Erosion: Kind:	Degree	Runc	ff:	+-	Surface Frag %:								memoer.		- 1
				1.	Kind:	GR: CB:	ST: BD.	: CN: FL:	Diag	nostic Ho	orz. / Prop.:		Kind:	De	epth:
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P. S. Control Section Daphin Flange:	VEGE	Clay %:			- ven	y few ravo	SCELLA 2 VC	NEOUS FIEI	D NO	DTES!	SKETC	1:	Kind:	De	apth:
Depth Range:	VEGE	Clay %:			- ven	y few ravo	SCELLA 2 VC	NEOUS FIEI	D NO	ones# octoo	SKETC	16	Kind:	De	epth:
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(at -) 3L 58045

(	Describer(	s):	Date:		Weather	mbol: Photo #: Temp.: Air:	Classificati		10					Soll Moist, Re
	UTM:	Zone: mE:		12811	+	Soil:	Depth:	Latitude: Longitude			" N	Datum: ,	Loca	ition:
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1 /		Land	22000	Microfeatu	re: Anthro:	Elevation:	Aspect:	Stope (%)	Slope Comp	lexity:	Slope S	Shape: (Up &	Stop S Dn / Ac	
	Hillstope P	rofile Position:	Geom.	Component:	Microrellef:	Physio. Division:	Physio. Pro	ovince:	Physio, Secti	on:		ysio. Area:	iL	Local Physio. A
( )	Drainage:	,	Floodin	ng:	Ponding:	Soil Moisture State	us;	Permea	ability:				1	
	Parent Mate	erial:		Bedrock:	Kind: Fra	ct.: Hard.: D	Pepth:	K <sub>sat</sub> :				Land C	Cover / L	Jse:
	Erosion:	Kind: Deg	gree:	Runoff:					rat. Units:	Gr	oup:	Formatio	on:	Member:
	P. S. Contro	Section:	Ave. Clay	n		Kind:	GR: CB:	ST: BD	: CN: FL	Dia	gnostic H	lorz. / Prop.:		Kind:
	Depth Range		Ave. Olay	76: AVE	. Rock Frag %:		1 2						-	
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	SYMBOL	VE	GETATI			# 2 - 3 a	∦ Mi	ISCELLA	NEOUS FI	=1 D N	OTEO	1 Oktober	Operation	
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		Sandr	AVNOC	ne cod?		- at the		of M	esque	2/1	inn or		:H3	

		c/							t Sýmbol:				Date:	
	Obser. Method	Depth (in) (cm)		Bnd Dry		Texture	Rock Frags Knd % Rnd S		Structure		nsistence		Mottles	Col Mst Sp Loc
	1	1-17	AB	discourse and the second	- Company Miloso	SiL			FSBK	, Lay	vist: Your	TOTAL STATE OF THE PARTY OF THE	and and the last	Cor iwst. Sp. Loc
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	Redoxin	norphic Feature	es	Concentration	ons	Ped / V. Surf	ice Features (/ )	Roots	Pores	l pH i	ffer Clay	CCE	M. 2004 S	Notes
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ries or Component Name:	n nan natanasan sa sa sa sa sa sa sa sa sa sa sa sa sa	Map Unit Syn	PEDON	Classification	MOLLAIN		PEDON ID	#:	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	RAFT 3/2002
and the same of the	74			old Sall Culton,			•		Soll Moist. F	Regime (Tax.):
escriber(s):	Date:	Weather:	Temp.: Air:	L	atitude: •	-	*N Da			
1 12/1	6/28		Soil:	ereason of	ongitude: °				Location:	
TM: Zone: mE:	mN: Tops	Quad:	Site ID:		County: Pedon		* W vey Area: MLI		Sec. T. Transect: ID:	R.
andscape: Landfo	rm: Microfeature:	Anthro:	Elevation:			Complexity:	Slope Shap	e: ( Up & D		nterval:
ilislope Profile Position:	Geom. Component:	Microrellef:	Physio, Division:	246 Physio. Provin	nce: Physic	o. Section:	State Physic	L	$\vee$ .	
					i injuit	. dedilon.	State Physic	. Area:	Local Physio.	Area:
alnage:	Flooding:	Ponding:	Soil Moisture Statu	is:	Permeability:			Land Cov	er / Use:	
arent Material:	Bedrock:	Kind: Fra			K <sub>sat</sub> :					1
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rosion: Kind: Deg	ree: Runoff:	2.5	Surface Frag %:	GR: A)CB: ()	ST: BD: CN	: FL: D	lagnostic Horz	. / Prop.:	Kind:	Depth;
S. Control Section :	Ive. Clay %: Ave. I	Rock Frag %:	Kind:							Depin.
VEC	MONNAME		The second	MIS.	CELLANEOU	IS FIELD	NOTES / S	SKETC	ii.	ATT L
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	2-75		September 2002				4.			

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Obser.	Dante	omponent i Harizon		M	atrix Color	Textur	on book	Wap Frags		t Sýmbol:	Danier via	Set side suit			Date:		
Method	(in) (cm)	100 mg			Moi		Knd %	and Sz	Gra	Structure ide Sz Type	Drv	Consis Msi	tence Stk	Die	Mottles % Sz Cn	Col Mari	n e
	0-8	AB.	5			WEST	39 CH	Ulfo	-	SG7	12.112.11	1000000	Cinc	7. 1. 1.	ANT PROPERTY.	COLIMBI	Sp. Loc
	8-37	BYK	5			. 188	001	8.86	7	FSBK			-	_			
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104737.58288 long > - 106-60291 USDA-NRCS PEDON DESCRIPTION PEDON ID #: DRAFT 3/2002 Describer(s): "The Mikayla Gropher" () Latitude: 32 \* 50258 \*N
Longitude: 100 WOZ9 1 \*W
County: Pedan #: Soll Survey Arc Site ID: () Stop #: Hillslope Profile Position: Physio. Province: Local Physio. Area: Soil Moisture Status K<sub>sat</sub>: Lithostrat. Units: Hard.: Member: Runoff: Surface Frag %: g%: GR: CB: ST: BD: CN: FL: 76-0GR 10:CB Diagnostic Horz. / Prop.: Depth: P. S. Control Section : Ave. Clay %: Ave. Rock Frag %: Depth Range: VEGETATION: MISCELLANEOUS FIELD NOTES / SKETCH:
SHOUGH ACCA SYMBOL % GD COVER CREOSOFE Megguile - mever boundaries caros. Turo vennar 34 87

USDA-NRCS

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September 2002

Obser. Method	Depth 🙉	Horizon	Bnd	Matri	x Color	Texture	No. Parke		it Symbol:	disagraphics.	1 steronomonomon		Date:	
Method	(in) (cm)				Molst		Knd % B	nd Sz G	structure rade Sz Type		onsistence Mst Srk		Mottles % Sz Cn. Col	Met So Loc
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(at ) 32.58262 icng > -106,60315 PEDON DESCRIPTION Date: 6(26 NIA Landscape: Stop #: Aspect: Slope (%): Slope Complexity: Physio. Division: State Physio. Area: Land Cover / Use: Parent Material: K<sub>sat</sub>: Lithostrat. Units: Hard.: Erosion: Kind: Surface Frag %: SGR: CB: ST: BD: Kind: P. S. Control Section : Ave. Clay %: VEGETATION: MISCELLANEOUS FIELD NOTES / SKETCH: Diagable intil vie hit petyls - Roots turnighant 20 39 USDA-NRCS 2-75 September 2002

Obser.	Depth Co			no en en en en en en en en en	Description and and	of Unitary			t Symbol:	4				Date:	
Method	(in): (cm)	Horizon	Bnd	Ma Dry		Texture	Rock Frags Knd % Rnd S							Mottles % Sz Cn. C	Col Mst Sp. Loc
	0-7	HB				NESL	35% CAR CE	0	56					-0.1.334,00.34,01	Marini and Andrews
2	2-20	BX	W			IESL	3% CAR FG	1	VESBK						
	70-39	Blue				VFSL	ST CAR FIN	0	567				-		
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% Sz: 1 2 3 4 5 6 7 8	Ch Hd Sp Kd Loo s		z Gn i	Ha Sp Ka L	oc Bd Col	% Dat Cont  F b b (  C D C (	RE RE AL BENC	Sz. L	Go Go Sz Ship			8 10	1800		ゴ
% Sz: 1 2 3 4 5 6 7 8	Ch Hd Sp Kd Loo s		z Gn i	Ha Sp Ka L	oc Bd Col	% Dat Cont  F b b (  C D C (	RE RE AL BENC	Sz. L	Go Go Sz Ship			8 10	1800		ゴ

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	USDA-NRCS			PEDON	DESCRI	PTIO	Ü.	PEDON	ID#4	DBAFT 3/2
	Series or Component Name	9:	Map Unit Syr	nbol: Photo #:	Classification:			1		DRAFT 3/2 Soll Molst, Regime (Tax.
( )	Describer(s):	Date: 6/29/1	7 Weather:	Temp.: Air:		tude:	• 1	* N	Datum:	Location:
	UTM: Zone: mE:	mN: To	po Quad:	Soil:		gitude: ounty: Pede	on #: Soll Si	" W urvey Area:	MLRA/LRU:	Sec. T. R. Transect: ID:
( )	Landscape: Lands	form: Microfeatur	e: Anthro:	Elevation:	Aspect: Sid	pe (%):   Slo	pe Complexity:		Shape: (Up & I	Stop #: Interval:
	Hillslope Profile Position:	Geom. Component:	Microrellef:	Physio. Division:	Physio. Provinc	e: Phy	Syslo. Section:		lysio, Area;	Local Physio, Area:
( )	Drainage:	Flooding:	Ponding:	Soll Moisture Stat	us:	Permeability	:			ver/Use:
	Parent Material:	Bedrock:	Kind: Fra	ot.: Hard.: [		K <sub>sat</sub> : Lithostrat, U				
	Eroslon: Kind: De	egree: Runoff:		Surface Frag %:				Group:	Formation	: Member:
	P. S. Control Section :	Ave. Clay %: Ave	. Rock Frag %:	Kind:	GH: 1()CB: 5 ST	BD;	CN: FL:	Diagnostic I	Horz. / Prop.:	Kind: Depth:
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Obser.	Depth C	Horizon	Bnd		irix Color	15 301,40	xture	de la companya de la companya de la companya de la companya de la companya de la companya de la companya de la	Wap	Unit	Sýmbol:	and the second	*-//			Date:		
Method	(in). (cm)			Dry	Moist		ALUTE	Knd % B	nd Sz	Gra	Structure	voe Dr	Cons	stence	Die	Mottles	Col Mst	
	0-6	AB			15	WE	SI	396 WX	185	0	SE			T GIR	37.189	MATERIAL STATES	Gur Mst	op. Loc
	6-17	BK				14,	- 1/	4 % CHY	2 FG	1	VF SB	_	-					
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1057 37.88178 1009-7106.599726 USDA-NRCS PEDON DESCRIPTION Map Unit Symbol: Photo #: UTM: Zone 6/29/17 Datum: Longitude: County: Soll Survey Ar MLRA/LRU: Transect: /D: Stop #: Slope Shape: (Up & Dn / Across) Aspect: Slope (%): Slope Complexity: State Physio, Area: Local Physio. Are Soll Moisture Status: Land Cover / Use: K<sub>sat</sub>: Lithostrat. Units: Parent Material: Bedrock: Hard.: Depth: Member: Erosion: Kind: Degree: Runoff: Surface Frag % S GR: 9 CB: 5 ST: BD: CN: FL: Diagnostic Horz. / Prop.: Kind: P. S. Control Section : Ave. Clay %: Ave. Rock Frag %: VEGETATION: MISCELLANEOUS FIELD NOTES / SKETCH: % GD COVER - and too much covo. develop. lests in 2nd nontor 27 USDA-NRCS 2-75 September 2002

Obser.	Depth.	Horizon		itrix Color	on Tank Appendicus			it Symbol:	destruction			Date:
Method	(in) (cm)	Horizon A. A	Dry		Texture	Rock Fr Knd % - Bn		Structure ade Sz Type		onsistence Mst Stk		Mottles % Sz. Cn. Col Mst. Sp. Loc
	0.5	126	1		WESL	6% MY10		1 59			- Carrie	
	5-27	BK	ř.		V88L	ATE CAR	61	FSBK				
	27-75	BKK			SiL	7 TOTAL	-G 2	VF SIBK				
	75-180	BX			SIL	ZXMXX		VESKIC			+	
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ries or Component Name:	Map Unit Symbol:	EDON: DESCR Photo #: Classification:	IPTION	PEDON ID #:	DRAFT 3/2002 Soll Moist, Regime (Tax.):
escriber(s):  Date:  (I)  TM: Zone: mE: mN:	29/17 Weather: Temp	Soil: Depth: Lo	ngitude: ° ' Soll Sun	"N Datum:	Location:
	crofeature: Anthro:		ope (%): Slope Complexity:	Slope Shape: (Up & I	Stop #: Interval:
illslope Profile Position: Geom. Com alnage: Flooding:		lo. Division: Physio. Province		State Physio, Area:	Local Physio. Area:
		Moisture Status:  Hard.: Depth:	Permeability: K <sub>sat</sub> :	Land Co	ver / Use:
rosion: Kind: Degree: Ru	inoff: Surfac	e Frag %: 90 GR: 950B: 5 ST		roup: Formation	monuel.
S. Control Section : Ave. Clay %:	Ave. Rock Frag %:			agilostic Horz. / Prop.:	Kind: Depth;
VEGETATION COMMON NAME	STGD.COVER		ELLANEOUS FIELD I	NOTES / SKETC	H3.
		next to an	200000 ST		7
	1.	lit a petro	row Circa	eus C	29/12
	. 4	MOSTIN All	mal dipon	rtien O	165J
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ISDA-NRCS	2-75 Septem	nber 2002			
	Septen	TIDET 2002		.,	

	Obser.	Depth	mponent N Horizon		Mat	rix Color	Texture	Rock			Sýribol:	CENTRAL	Concle	tanca	25. VShil	Date:	PARTE BOSES
Redoximorphic Features    Concentrations   Fed / V. Surface Features   Floots   Pores   Ph. Effer . Clay CCE   Notes	Method	(in) (cm)	N o		Dry	Moist		Knd % B	nd Sz	Gra	de Sz Type	Dry					
Redoxtmorphic Features   Concentrations   Ped/V. Surface Features   Roots   Peres   pH   Effer Clay CCE   Notes, So 20 H   Sp Kd   Loo Bd Col   % Sr On Hd   Sp Kd   Loo Bd Col   % Clat   Con't Kd   Loo Col   On Sr   St   Do (meth) (seen)   %	2	0-+	W				UFSL	3% M	1 11/XX	0	SA		100				
Redoximorphic Features   Concentrations   FPed / V. Surface Features   Roots   Pares   ph   Effer City CCE   Notes, % 5z On Hd Sp Kd Loc Bd Col		4-4	BWF	100			SIL	STOAR AT/COAX	me	1	VF SBK						
Redoximorphic Features   Concentrations   Ped / V. Surface Features   Roots   Panes   pH   Effer City CCE   Notes, % Sx on Hd Sp Kd Loc Bd Col   % Sx on Hd Sp Kd Loc Bd Col   % Dx Con Kd Loc Col   Dx Sx Loc City Sx sp (meth) (asont)   %																	
Redoximorphic Features   Concentrations   SPed / V. Surface Features   Roots   Pores   p.H.   Effer Clay CCE   Notes   % Sz. Cri. Hd. Sp. Kd. Loc Bd. Col.										П							-
RedoxImorphic Features   Concentrations   Fed/V. Surface Features   Roots   Pores   p.H. Effer Clay CCE   Notes   % Sz. Cn. Hd. Sp. Kd. Loc Bd. Col. % Sz. Cn. Hd. Sp. Kd. Loc Bd. Col. 58. Dat. Cont. Kd. Loc Col. Ony Sz. Loc. Chy. Sz. Shb. (meth) (assent), 56.									- 1	1						-	
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# \$2 Ch Hd Sp Kd Loc Bd Col										H				-	_		
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# \$2 Ch Hd Sp Kd Loc Bd Col	SO SO	SOME SECTION AND ADDRESS.	and Sale Teacher	3 2000	7 - Dog - 70	Complete Constitution of the Constitution of t	a probable to the second		i								
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eries or Component Name:		PEDON	Classification		a were said	v. 1.38	Propiet Section			Soll Moist.	DRAFT 3/2002 Regime (Tax.):	
MJA 61291	7   Weather:	Temp.: Alr: Soll:	Depth:	Latitude: Longitude:			" N	Datum:	. Lo	cation:		
andscape: Landform: Microfea	Topo Quad:		Yr: State:	County:			vey Area:	MLRA/L	RU: Tra	insect: ID:	R.	1
illslope Profile Position:   Geom. Componen		Elevation:	Aspect:	1	Slope Cor	mplexity:	Slope S	Shape: (U)			пистуан.	1
		Physio. Division:	Physio. Pro	vince:	Physio. Se	ction:	State Ph	ysio. Area	:	Local Physic	o. Area;	
	Ponding:	Soil Moisture Statu	is:	Permea K <sub>sat</sub> :	bility:	_		Land	Cover.	/ Use:		
Bedrock	: Kind: Fra	ct.: Hard.; D	epth:		at. Units:	G	roup:	Forma	ation:	Member:		-
Bullon:		Surface Frag %: 90	GR: SCB: S	ST: BD:	: CN:	FL: Di	agnostic i	Horz. / Pro	p.:	Kind:	Depth:	-
S. Control Section: Ave. Clay %: Appth Range:	ve. Rock Frag %:											1
pgor									-			7
VEGETATION:	ZWI Free Distriction	KIT MA		SCELLA	NEOUS.	FIELD.	NOTES	/ SKE	(ASIE	en ang anakawa	Contract Park	9
VEGETATION:	Signicoven	- didu+	hall	SCELLA	NEOUS		NOTES	/ SKE	ICH	Ø 97	)\$\f\\	
VEGETATION:	JGD COVER	- didut	Hall	SCELLA LL, V	Ker Ker	20 10	0VD	/ SKE	ICH:	) ST		2
VEGETATION:	3 GD.COVER	- didut	Hall	SCELLA 2U, V 2U, V	Ker Ker		0VD	/ SKE				2
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VEGETATION:	₩GO.COVER	- didut	Hali	SCELLA LLY V	Ker Ker	20 10	0VD	SKE	ic:			
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Obser.	Depth C	Horizon	Bnd	Ma	trix Color	Texture	Rock			t Symbol:	dwe.com	National Service	n- may an		_Date:	-
Method	(in) (cm)	March.		Dry			Knd % F	nd Sz	Gra	Structure ide Sz Type	Dry		stence Stk		Mottles % Sz. Cn. Col Mi	t Sp. Lor
	0-6	NB.				V88V	5 % MX	266	0	SG			4.745.	N. C. C. C. C. C. C. C. C. C. C. C. C. C.	ent compression and compression	
	8-61	BUK				Sil	89. UA)	450		VESOK						
	(02-90	BRUM				SiL	85 CHY	102	0	58						
	402						Till vet at	117		301		-				
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TO SECURE	CACA CESCO A DENIA							i :				v				
% Sz Cr	ximorphic Features n Hd Sp Kd Loc E	3d Col % s	Con Z Cn H	centrations		Ped / V. Surf % Dst Cont	ace Features		ots	Pores c Oty Sz Shp			Clay	CCE	Notes	dan.
		1.				F h D /	AFRE	igity 5	Z LO	c Quy Sz Shp	(meun	(agent	7	MC(7)	1200010 25 15 15 15	Parks Riv
2				ř	-	NDCO	AFCC	1	1	+		•	a	-	J ++-	
						MDCCA	f 28/1		t				10		11	
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Islope	Profile Pos	ition:	Geom. (	omponent		Microre	llofe	lnt	o. Division:	380	2	0	·	Stope .	onape: (	Up & Un	n / Acro	oss)			
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sion:	Kind:	Degi	ree:	Runoff:	_	-	1	Surfac	e Fran % - x16	on V on V								wember			
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ries or Component	Name:		Map Unit Sy	PEDON	Classificat	ion:			PEDON II	#	A7	DRAFT 3/200
escriber(s):	Date		Weather:							. •	Soll Moi	lst. Regime (Tax.):
NOA	6	130/17	weather;	Temp.: Air:		Latitude:	•		"N D	atum:	Location:	-
TM: Zone:	mE:	mN: Top	Quad:	Soil: Site ID:	Depth: Yr: State:	Longitude:			" W		Sec. T	R.
Landscape:				one ib.	ii. State:	County:	Pedon #:	Soll Sur	vey Area: ML	RA/LRU:	Transect: ID	
-andscape:	Landform:	Microfeature:	Anthro:	Elevation	Aspect:	Slope (%):	Slope Com	nlovitu	Tax		Stop #:	Interval:
Hillstope Profile Post	tion: Geom	Component:	-		240	1	S	ipiexity:	Slope Shap	pe: ( <i>Up &amp; L</i>	On / Across )	
		component:	Microrellef:	Physio. Division:	Physio. Pr	ovince:	Physio. Sec	ction:	State Physi	o. Area:	Local Phy	sio. Area:
rainage:	Flood	ing:	Ponding:	Soil Moisture Str	· ·							JIO. Alea:
				moistale 3t	itus;	Permea	bility:			Land Co	ver/Use:	
arent Material:		Bedrock:	Kind: Fr	act.: Hard.:	Depth:	K <sub>sat</sub> :	at. Units:					
rosion: Kind:	Degree:					Linioani	al. Units:	G	roup:	Formation:	: Membe	ir:
	Degree:	Runoff:		Surface Frag %:()	()GR: 9()CB:	ST: BD:	CN: I	FL: DI	agnostic Hora	/D		
S. Control Section :	Ave. Clay	19/1 Aug 5	David St. 1	Kind;					agnostic (10)	a / Prop.:	Kind:	Depth:
pth Range:	Ave. Glaj	7%: AVB. F	Rock Frag %:		3					!		
										1		
the same of the same	in the control											
Wilson Co.	VEGETAT		6		· M M	ISCELL'A	NEOUS E		VOTEO		EPSONEHADAL	
SYMBOL	VEGETAT COMMON N		% GD COVER		≥ š  M	ISCELLA	NEOUS F	ELD I	NOTES /			
STABOL TO STATE OF THE STATE OF	VEGETAT COMMON N		% GD COVER	- Pit is	MANA					SKETC		
SYMBOL	VEGETAT COMMON N		% GD COVER					Mich	die			
sylledis.	VEGETAT COMMON N		GD, COVER	- Pit is	PIGNA	rint	out	Mich				
Villade Village	VEGETAT		%GD,COVER	- Pit is OV ON	PIGNA	int	ve p	Mich	du			\$ 5083 \$ 5083
YMBO T	VEGETAT		GD COVER	- Pit is	PIGNA	rint	ve p	Mick	du			
SYMBO OF	VEGETAT COMMONN		GD COVER	- Pit is Of a	masi melep	MAIN	ve p out t, n	Mi cho TM MOST	du			
	COMMON N	AME	GD COVER	- Pit is OV ON	MOLEN WELCH	rint	ve p	Mi cho TM MOST	du			
77.26 57	COMMON N	AME	% GD COVER	- Pit is Of a	masi melep	MAIN	ve p out t, n	Mi cho TM MOST	du			
YVI OUT BENEFIT	COMMON N	AME	% GD COVER	- Pit is Of a	masi melep	MAIN	ve p out t, n	Mi cho TM MOST	du			
YULOU BERTHAN	COMMON N	AME	GDICOVER	- Pit is Of a	masi melep	MAIN	ve p out t, n	Mi cho TM MOST	du			\$16083 (10) c (3) 7/4
Wilder	COMMON N	AME	(A.G.) COVER	- Pit is Of a	masi melep	med mal lpchi ind	ve p out t, n	Mi cho TM MOST	olle Ollan			
YMEGE:	COMMON N	AME	Sco coven	- Pit is Of a	masi melep	med mal lpchi ind	ve p out t, n	Mi cho TM MOST	olle Ollan			
sylladi.	COMMON N	AME	Red Cover	- Pit is Of a	masi melep	med mal lpchi ind	ve p out t, n	Mi cho TM MOST	dle Dutan			\$ 6060 C
SVIII oct	COMMON N	AME	3.cD.coven	- Pit is Of a	masi melep	med mal lpchi ind	ve p out t, n	Mi cho TM MOST	dle Dutan			
SYMBOL	COMMON N	AME		- Pot is	pight mass merce al al	med mal lpchi ind	ve p out t, n	Mi cho TM MOSTI	dle Dutan			
SYMBOL	COMMON N	AAG		- Pit is Of a	pight mass merce al al	mt nud Man (pom ind)	ve p out t, n	Mi cho TM MOSTI	dle Dutan			
SYMBOL	COMMON N	AAG		- Pot is	pight mass merce al al	mt nud Man (pom ind)	ve p out t, n	Mi cho TM MOSTI	dle Dutan			
SYMBOL	COMMON N	AAG		- Pot is	pight mass merce al al	mt nud Man (pom ind)	ve p out t, n	Mi cho TM MOSTI	dle Dutan			

Obser.	Depth Co	- Horizon	Names, Bnd	Mati	no entre	Texture		Wap U		ýmbol: Iructure	No. of the	71 W77 W	e vafeir son	200-0-12	Date:		-1"
Method	(in) (cm)			Dry			Knd % Rn	d Sz C					tence Stk		Mottles % Sz Cn.	Col Mist Sp	. Loc
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	30	Ī	8°	1at -> 32.58284.
	USDA-NRCS Series or Component Name:	PEDO	N DESCRIPTION PEDO	1Mg - 100.60324
( )	Describer(s): Date:	Map Unit Symbol: Photo #:  Weather: Temp.: Air:	Classification:  Latitude: * * N	Soll Moist. Regime (Tax.):
,	UTM: Zone: mE: mN: To	po Quad: Site ID:	Depth: Longitude: " W	Datum: Location:  Sac. T. R.  MLRA / LRU: Transect: ID:
ارا	Landscape: Landform: Microfeature  Hillslope Profile Position: Geom. Component:	Elevation  Microrellef: Physio. Division	Slope Complexity: Slope	Stop #: Interval: e Shape: (Up & Dn / Across)
( )	DraInage: Flooding:	Ponding: Soil Moisture S	Physio. Section: State	Physio. Area: Local Physio. Area:
	Parent Material: Bedrock:  Erosion: Kind: Degree: Bunoff:	Kind: Fract.: Hard.:	K <sub>sat</sub> :  Depth: Lithostrat. Units: Group:	Formation: Member:
	P. S. Control Section : Ave. Clay %: Ave.	Surface Frag %: Kind: Rock Frag %:	GR: CB: ST: BD: CN: FL: Diagnosti	c Horz. / Prop.: Kind: Depth:
	Depth Range:  VEGETATION: SYMBOL: COMMON NAME		MISCELLANEOUS FIELD NOTE	S / SKETCH:
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	USDA-NRCS 2-75	September 200	2	
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Obser.	Depth	omponent N Horizon		Ma	Team Sometime	overflects consumicates			it Sýmbol:					Date:		
Method	(in) (cm)	norizon	Bnd		Moist				Structure rade Sz Type	Drv	Consist Mst	lence.	Pis	Mottles % Sz Co	Col. M	st Sn Loc
	0-7	AB.				VESL	4 % MX	Villala	59		Sell Title	27213	CARLEAU.	end to the second		
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	26-80	BKK				Sil	17% (AK 84 CAK		VF SBK							
							109 CME	- IVIE	1, 2010							
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1	On Hd Sp Kd Loc I	Bd Col % s	Sz Cn I	icentrations Id Sp Kd L	oc Bd Col	% Dst Cont	AFRF	Roots Oty Sz (	Pores GC (Qty Sz Shp				CCE		Notes	
1 2 3		Bd. Gol. % s	Sz Cn I	ld Sp Kd L	oc Bd Col	% Dat Cont	AFRF AFRF					%	CCE	ī	ALCOHOL: NO	
2		Bd. Col. % s	Sz Gn I	ld Sp Kd L	oc Bd Col	% Dst Cont	AFRF AFRF					%	CCE	I	ALCOHOL: NO	
2		Bd Col % s	sz 'Gn I	ld Sp Kd L	oc Bd Col	% Dat Cont	AFRF AFRF					%	CCE	I	ALCOHOL: NO	
3		Bd. Col. 1%, s	Sz Gn I	ld Sp Kd L	oc Bd Col	% Dat Cont	AFRF AFRF					%	CCE	I	ALCOHOL: NO	
1 2 3 4		Bd. Col. 1% s	šž Cn i	ld Sp Kd L	oc Bd Col	% Dat Cont	AFRF AFRF					%	CCE	I	ALCOHOL: NO	
1 2 3 4 5 6		Bd. Col. 1% s	Sz Cn I	ld Sp Kd L	oc Bd Col	% Dat Cont	AFRF AFRF					%	CCE		ALCOHOL: NO	
1 2 3 3 4 4 5 5 6 6 7 7		Bd, Col. 1%, 5	az 'Cn i	ld Sp Kd L	oc Bd Col	% Dat Cont	AFRF AFRF					%	CCE	I	ALCOHOL: NO	
1 2 3 3 4 4 5 5 6 6 7 7 8 8		Bd, Col. 1%, 5	Bz Cn I	ld Sp Kd L	oc Bd Col	% Dat Cont	AFRF AFRF		.cc (Gry Sz Shp			%	CCE	I	ALCOHOL: NO	
1 2 3 4 4 5 5 6 6 7 7 8 8 9 9		8d, Col. 1%, 5	sz Gni l	ld Sp Kd L	oc Bd Col	% Dat Cont	AFRF AFRF	ON/SZ I	.cc (Gry Sz Shp			679	76	I	十二十二十二十二十二十二十二十二十二十二十二十二十二十二十二十二十二十二十二	ember 200
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AWN		6	(30	117	Weath	er:	Temp.	Air: Soll:		Latitude:	•	1	" N	Datu	m: .	Loca	tion:	
JTM: Zone:	mE:	n	iN:	Торо	Quad:			Site ID:	Depth: Yr: State:	Longitude: County:	Pedon #:	Soll Sur	" W vey Area	MLRA	/LRU:	Sec.	T.	R,
Landscape:	Landfo	rm:	Microfea	ture:	Anthro	);		Elevation:	Aspect:	Slope (%):	Slope Cor			Shape:		Stop	#:	interval:
Hillslope Profile Pos	itlon:	Geom. (	componer	t:	Micror	ellef:	Physio	. Division:	Physio. Pro	vince:	Physio, Se	ection:		hysio.	6		L.	
rainage:		Floodin	g:		Pondin	g:	Soil M	oisture Statu	ls:	Permea	bility:							rsio. Area:
arent Material:			Bedrock											I.	and Co		SA:	
			Dening)	G .	Kind:	Fract	: H	ard.: D	epth:	K <sub>sat</sub> :	at Unite	-						
	Degr		Runoff:						epih: GR:\$\SCB:\G		at. Units:		roup: agnostic		rmation		Membe Kind:	r: De
S. Control Section	: A	ve. Clay	Runoff:	lve. Ro	ck Frag	%:	Surface		GR: \$ CB: 9	Lithostr ST: BD:	CN:	FL: DI	agnostic	Horz./	Prop.:		Membe	
S. Control Section apth Range:	: A	ive. Clay	Runoff:	lve. Ro	ck Frag	%:	Surface Kind:		GR: \$ CB: 9	Lithostr	CN:	FL: DI	agnostic	Horz./I	Prop.:		Membe	
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S. Control Section apth Range:	: A	ve. Clay	Runoff:	lve. Ro	ck Frag	%:	Surface Kind:  -Dx	Frag %: ()	Mid a	Lithostr ST: BD:	CN:	FL: DI	NOTES COL	Horz./I	Prop.:		Membe	
S, Control Section plh Range:	: A	ve. Clay	Runoff:	lve. Ro	ck Frag	%:	Surface Kind:  -Dx	duit	Mid a	ST. BD:	VEOUS	FL: DI	NOTES COL	/ SK	Prop.:		Membe	
s. Control Section epith Range:	: A	ve. Clay	Runoff:	lve. Ro	ck Frag	%:	Surface Kind:  -Dx	duit	Mid a	ST. BD:	VEOUS	FL: DI	NOTES COL	/ SK	Prop.:		Membe	
S, Control Section plh Range:	: A	ve. Clay	Runoff:	lve. Ro	ck Frag	%:	Surface Kind:  -Dx	duit	Mid a	ST. BD:	VEOUS	FL: DI	NOTES  CCU  ACU  D Vo	/ SK	Prop.:		Membe	

Obser.	Depth	Horizon		to an estate and	trix Color	Texture	eden armentak			Symbol:	No. care a	25002 CM	E STORAGE	Oran Maria	Date:	PHOTOGRAPH 1	Construction and
Method	(in). (cm)	Horizon	Bna	Dry			Rock F			Structure le Sz Type					Mottles % Sz Cr		t Sp. Loc
	0-5	AB				VESL	3% WX		0	Sín			10000000	S A S S S S S S S S S S S S S S S S S S	PATE DECEMBER 13	er eessess	A. Maller - Mary
	5-47	BKI				CIESL	41/ CAR		1	MSBK							
	47-84	BYZ				SiL	84-CAR	FFI	+	UF SBIC							
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% Sz C	oximorphic Features in Hd Sp Kd Loc E			centrations d∵Sp∷Kd Le		"Ped/V. Surfa % Dst Cont"			76	Pores			Clay			Notes	(3.54). <sup>2</sup> (3.54). <sup>2</sup> (3.54). <sup>2</sup>
% Sz C				d Sp Kd Le	oc Bd Col	% Dat Gont I	AFRF		76				/ %			Notes	
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% Sz C 1 1 2 2 3 3 4 4 5 5 6 6 7 7 8 8				d Sp Kd Le	oc Bd Col	% Dat Cont	AFRF		76				6			I I	

## 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	A	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
11	A	0	8	62	28	10
11	Bk1	8	30	69	23	8
11	Bk2	30	48	72	19	9
11	Btk	48	150	61	28	11
12	A	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	A	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	AB	0	6	63	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	A	0	6	64	25	11		
32	Btk	6	26	63	29	8		
32	Bkk	26	44	63				
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		

36	AB	0	9	61	29	10	
36	Bkk	9	22	62	28	10	
37	AB	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		
40	Bkk	34	87	64	29	9 7	
41	AB	0	7	62	26	12	
41	Bk	7	20	62	25	13	
41	Bkk	20	39	61	30	9	
42		0	6	57	33	10	
42	AB Bk	6	24		28	9	
42	AB	0	5	63 64	29	7	
43	Bk	5	27	60	28	12	
43	Bkk	27	75	62	29		
43	Bt	75		52	44	9	
44			150 7			4	
	AB	7		35	61		
44	Bwk		28	59	27	9	
45	AB	0	8	58	33		
45	Bkk	8	62 90	59	31	10	
45	Bkkm	62		60		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		
ID	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	32.5848680	-106.6060360
7	32.5847900	-106.6059400
8	32.5844060	-106.6051760
9	32.5848400	-106.6060240
10	32.5864240	-106.6069420
11	32.5856800	-106.6068600
12	32.5845080	-106.5993850
13	32.5844800	-106.5993800
14	32.5825330	-106.5950810
15	32.5827400	-106.5960000
16	32.5828400	-106.5964900
17	32.5829000	-106.5962230
18	32.5829000	-106.5961900
19	32.5828300	-106.5962900
20	32.5840000	-106.6060200
21	32.5859300	-106.6070100
22	32.5859200	-106.6069800
23	32.5858400	-106.6069200
24	32.5833000	-106.6044900
25	32.5833900	-106.6045200
26	32.5833800	-106.6045500
27	32.5829700	-106.6050100
28	32.5848400	-106.6077200
29	32.5846700	-106.5994100
30	32.5844100	-106.5994400
31	32.5855800	-106.6013400
32	32.5853400	-106.6107900
33	32.5869900	-106.6051600
34	32.5856400	-106.6067100
35	32.5859700	-106.6073300
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: <a href="https://repository.asu.edu/items/21017">https://repository.asu.edu/items/21017</a>. Additional details can be found in the thesis.

		%	% modium	% fine	% very	%	% modium	% fine	% very	% silt	
		gravel	gravel	gi avei 2-	sand	sand	sand	106-	sand	mm'cc-7	% clay
Profile	Depth [cm]	>19mm	4.75- 19mm	4.75mm	1-2mm	0.5- 1mm	250- 500 m	250μm	53- 106mm		muiz>
JER1	0-7	6.40	15.28	3.74	0.89		1.49	12.07	15.67	36.71	88.9
JER1	7-17	0.00	14.91	4.99	1.17		1.74	12.85	17.17	38.41	7.94
JER1	17-27	3.64	21.37	8.50	1.30		1.88	9.90	14.09	33.39	4.73
JER2	2-0	0.00	16.61	6.54	2.26		2.44	14.53	17.27	32.63	5.98
JER2	7-17	9.81	22.18	7.53	2.02		1.58	9.28	12.39	30.17	3.95
JER2	17-27	18.60	11.93	7.77	2.43		1.95	66.6	13.63	28.08	4.06
JER3	2-0	0.00	20.55	6.72	2.29		1.99	12.71	17.72	30.43	4.86
JER3	7-17	9.90	17.23	7.98	1.80		1.87	9.03	14.71	32.57	3.60
JER3	17-27	0.00	20.52	12.02	3.10		2.23	8.78	13.51	33.71	4.32
JER4	0-7	4.94	14.39	7.75	2.58		3.25	18.44	18.84	24.24	3.56
JER4	7-17	0.00	16.79	8.30	2.38		3.38	16.63	16.81	29.24	4.39
JER4	17-27	9.15	17.51	11.57	3.62		3.40	11.25	11.01	23.74	5.13
JER5	2-0	0.00	18.67	7.71	2.55		3.59	19.37	17.21	22.84	5.89
JER5	7-17	0.00	21.71	7.95	2.35		2.63	13.74	14.37	29.61	5.85
JER5	17-27	0.00	11.80	9.19	2.65		3.37	14.63	15.48	33.54	6.37
JER6	2-0	0.00	18.83	7.47	2.21		1.96	12.67	18.65	31.62	5.07
JER6	7-17	3.42	19.08	11.43	1.77		1.50	7.95	12.97	35.31	5.48
JER6	17-27	25.46	27.83	9.40	3.65		1.78	4.36	5.75	16.38	3.26
JER7	2-0	7.29	12.46	7.46	2.99		2.59	15.50	19.44	26.46	3.66
JER7	7-17	15.40	10.10	6.04	1.97		2.32	13.12	16.56	28.52	4.45
JER7	17-27	0.00	24.20	08.9	2.13		2.24	11.87	15.72	31.34	3.94
JER8	2-0	0.00	6.94	6.43	2.78		3.02	19.28	24.70	31.08	3.77
JER8	7-17	23.15	12.33	5.47	2.08		1.62	10.32	14.54	25.41	3.88
JER8	17-27	4.58	21.18	10.26	2.58		1.81	6.77	14.49	29.22	4.44
JER9	2-0	6.15	19.90	6.47	2.13		3.11	15.53	15.77	24.05	4.93
JER9	7-17	34.89	12.66	69.8	2.06		1.31	6.58	8.57	19.80	4.46

									l															I								
3.62	4.63	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	2.66	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	13.23	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	12.62	15.43	69.6	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	90.6	13.60	5.74	16.48	9.05	4.07	11.78	7.34	9.01	14.89	10.15	96.8	14.43	13.69	5.82
1.61	3.14	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	5.69	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	2.51	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	10.43	8.85	10.52	88.9	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	92.9	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	17.13	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	10.77	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	2-0	7-17	17-27	2-0	7-17	17-27	2-0	7-17	17-27	2-0	7-17	17-27	2-0	7-17	17-27	2-0	7-17	17-27	2-0	7-17	2-0	7-17	17-27	2-0	7-17	17-27	2-0	7-17	17-27	2-0	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: <a href="https://repository.asu.edu/items/21017">https://repository.asu.edu/items/21017</a>.

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	TB	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(raster) library(gstat) library(ggplot2) 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") # Reproject coordinates to UTM Zone 13N coordinates(mloc) <- ~ Longitude + Latitude

```
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)
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 slighly 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)
```

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.

```
adat$Sand <- apply(adat[,c(3:10)], 1, sum)
adat$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 \le 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)]
# 1.3 Join both datasets and format as needed
# Pedon data
dat <- rbind(mdat, adat2)</pre>
dat$HZ.Bottom <- as.numeric(dat$HZ.Bottom)
dat$HZ.Top <- as.numeric(dat$HZ.Top)</pre>
# 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 \leftarrow aqp::slice(dat, fm=0:100 \sim 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) \le Pedon.ID \sim top + bottom
gsmpedons$hzname <- profileApply(gsmpedons, function(i) {paste0('GSM-', 1:nrow(i))})
# Note: Use new gampedons 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 <- gsmpedons[, 1]
d2 <- gsmpedons[, 2]
d3 <- 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) <- ~ 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")
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 \le cbind(d4, ec4)
# 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>
# 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 ~ Aspect
                                     , de1))
summary(lm(Sand ~ ConvergenceIndex
                                           , de1))
summary(lm(Sand ~ CrossSectionalCurvature, de1))
summary(lm(Sand \sim DEM 5 utm)
                                         , de1)) #** Adj. R2: 0.099
                                           , de1))
summary(lm(Sand ~ FlowAccumulation
summary(lm(Sand ~ LongitudinalCurvature, de1))
summary(lm(Sand ~ LSfactor
                                      , de1))
summary(lm(Sand ~ 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 \sim 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 \sim 1, data = de1, c(3, 9, 29, 88, 266, 800), variogram.alpha=120) # Most correlated (has the lowest semivariance) below \sim 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</pre>
```

## # 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'))
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)</pre>
```

 $scv1.c = krige.cv(Sand \sim DEM 5 utm, de1, model = svgm1.c)$ 

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)
# 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 ~ Slope
                                    , de2))
summary(lm(Sand ~ TopographicWetnessIndex, de2)) #** Adj. R2 0.14
summary(lm(Sand ~ ValleyDepth
                                        , de2))
plot(Sand ~ TopographicWetnessIndex, de2)
plot(Sand ~ 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 \sim 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 \sim 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 uncertainty 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)
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'))
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 \sim DEM 5 utm, de2, model = svgm2.s)
scv2.c = krige.cv(Sand \sim DEM 5 utm, de2, model = svgm2.c)
scv2.e = krige.cv(Sand \sim 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)
# 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 ~ Aspect
                                    , de3)
summary(lm(Sand ~ ConvergenceIndex , de3)) #* Adj. R2 0.05
summary(lm(Sand ~ CrossSectionalCurvature, de3)) #** Adj. R2 0.09
summary(lm(Sand ~ 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 ~ Slope
summary(lm(Sand ~ TopographicWetnessIndex, de3)) #*** Adj. R2 0.16
summary(lm(Sand ~ 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 \sim 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 \sim 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, 1)]
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'))
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 topographic wetness index 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 ~ Aspect
                                    , de4))
summary(lm(Sand ~ ConvergenceIndex
                                         , de4)) \#* Adj. R2 = 0.12
summary(lm(Sand ~ CrossSectionalCurvature, de4)) #** Adj. R2 = 0.15
summary(lm(Sand ~ 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 ~ Slope
                                    , de4)) #*** Adj. R2 = 0.25
summary(lm(Sand ~ TopographicWetnessIndex, de4)) #* Adj. R2 = 0.13
summary(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 \sim 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 \sim 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 \sim 1, data = de4, c(3, 9, 29, 88, 266, 800), variogram.alpha=120)
hscat(Sand \sim 1, data = de4, c(3, 9, 29, 88, 266, 800), variogram.alpha=135)
# Empirical (experimental or sample) variogram. Leaving out longitudinalCurvature increases RMSE by ~
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'))
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)
sk4.c <- krige(Sand ~ DEM 5 utm+LongitudinalCurvature, de4, model = svgm4.c, newdata = sgdf)
sk4.e <- krige(Sand ~ DEM 5 utm+LongitudinalCurvature, de4, model = svgm4.e, newdata = sgdf)
# 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$Pedon.ID %in% c(14:19,41)),]
# 4.1 0-5 cm.
# Summary stats. Webster and Oliver suggest the transformation be applied if the skewness is > 0.5.
summary(d1s$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)
```

```
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 ~ Aspect
                                     , de1s))
summary(lm(Clay ~ ConvergenceIndex
                                           , de1s))
summary(lm(Clay ~ CrossSectionalCurvature, de1s))
summary(lm(Clay \sim DEM 5 utm)
                                         , de1s)) #* Adj. R2 0.07
summary(lm(Clay ~ FlowAccumulation
                                           , de1s))
summary(lm(Clay ~ LongitudinalCurvature, dels))
summary(lm(Clay ~ LSfactor
                                      , de1s))
summary(lm(Clay ~ Slope
                                     , de1s))
summary(lm(Clay ~ TopographicWetnessIndex, dels))
summary(lm(Clay ~ ValleyDepth
                                       , de1s)) #** Adj. R2 0.15
# Only Convergence index is significant
plot(Clay \sim ValleyDepth, data = dels)
abline(lm(Clay ~ ValleyDepth, dels))
# Check for Anisotropy. 120 seems best
plot(variogram(Clay \sim ValleyDepth, de1s, alpha = c(105, 120, 135, 155, 180)))
# h-scatterplots. Correlation out to \sim 270 m.
hscat(Clay \sim 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
# 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'))
cvgm1.c <- fit.variogram(object=cvg1, model = vgm(nugget = 1, psill = 5, range= 300, model = 'Cir'))
cvgm1.e <- fit.variogram(object=cvg1, model = vgm(nugget = 1, psill = 5, range= 300, model = 'Exp'))
plot(cvg1, cvgm1.s, pch = 19)
plot(cvg1, cvgm1.c, pch = 19)
plot(cvg1, cvgm1.e, pch = 19)
cvgm1.s
cvgm1.c
cvgm1.e
# Leave-one-out cross validation
ccv1.s = krige.cv(Clay \sim 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 uncertainty is only
concentrated around the sample locations and RMSE slightly increased, so I am not taking this approach.
ConvergenceIndex+ValleyDepth
cvg2 \le variogram(Clay \sim 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'))
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 \sim 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[!(d3Pedon.ID \%in\% c(14:19)),]
de3s < -de3[!(de3Pedon.ID \%in\% c(14:19)),]
# 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 \sim 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 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 ~ LSfactor
                                     , de3s))
summary(lm(Clay ~ Slope
                                    , de3s))
summary(lm(Clay ~ TopographicWetnessIndex, de3s))
```

```
, de3s)) #*** Adj. R2 0.26
summary(lm(Clay ~ ValleyDepth
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 \sim 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'))
```

```
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 \sim 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)
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 \le subset(d4, Pedon.ID \le 13 \mid Pedon.ID \ge 19)
de4s \le subset(de4, Pedon.ID \le 13 \mid Pedon.ID \ge 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
                                     , de4s)) # Adj. R2 0.09
summary(lm(Clay ~ Aspect
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 ~ LSfactor
                                     , de4s))
summary(lm(Clay ~ Slope
                                    , de4s))
summary(lm(Clay ~ TopographicWetnessIndex, de4s))
summary(lm(Clay ~ ValleyDepth
                                       , de4s))
```

```
plot(Clay ~ CrossSectionalCurvature, de4s)
abline(lm(Clay ~ CrossSectionalCurvature, de4s))
plot(Clay ~ Aspect, de4s)
abline(lm(Clay ~ 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 ~ 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 ~
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'))
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.sSD  $\leq sqrt(sk4.s$ var1.var)

### # 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)

```
# 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 11<-
                                                     +ellps=WGS84
           spTransform(d1s,
                               CRS('+proj=longlat
                                                                       +datum=WGS84
                                                                                          +no defs
+towgs84=0,0,0')
 d1s 1l df <- as.data.frame(d1s 1l)
                               CRS('+proj=longlat
d2s 11<-
           spTransform(d2s,
                                                     +ellps=WGS84
                                                                       +datum=WGS84
                                                                                          +no defs
+towgs84=0,0,0')
 d2s 11 df <- as.data.frame(d2s 11)
d3s 11<-
           spTransform(d3s,
                               CRS('+proj=longlat
                                                     +ellps=WGS84
                                                                       +datum=WGS84
                                                                                          +no defs
+towgs84=0,0,0')
 d3s 11 df <- as.data.frame(d3s 11)
                                                                       +datum=WGS84
d4s 11<-
           spTransform(d4s,
                               CRS('+proj=longlat
                                                     +ellps=WGS84
                                                                                          +no defs
+towgs84=0,0,0')
 d4s ll df <- as.data.frame(d4s ll)
# Mean prediction
sk1 11 %>% 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 11 %>% 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 11 %>% 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 11 %>% 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 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(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 11 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 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(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 11 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 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(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 11 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 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(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 11 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)
# 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
              reproject(ck1.c,
                               CRS('+proj=longlat
                                                     +ellps=WGS84
ck1 11
       <-
                                                                       +datum=WGS84
                                                                                          +no defs
+towgs84=0,0,0')
ck2 ll <- reproject(ck2.s,
                               CRS('+proj=longlat
                                                     +ellps=WGS84
                                                                       +datum=WGS84
                                                                                          +no defs
+towgs84=0,0,0')
ck3 11
             reproject(ck3.c,
                               CRS('+proj=longlat
                                                     +ellps=WGS84
                                                                       +datum=WGS84
                                                                                          +no defs
       <-
+towgs84=0,0,0')
                               CRS('+proj=longlat
                                                     +ellps=WGS84
ck4 11
       <- reproject(ck4.c,
                                                                       +datum=WGS84
                                                                                          +no defs
+towgs84=0,0,0')
```

```
# Mean prediction
ck1 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 = "A") +
 ggtitle('0-5 cm') +
 theme bw()
ggsave("./GeostatisticalModeling/Figures/Clay 0 5 mean.png", width=6, height=3, unit='in')
ck2 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 = "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 11 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 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 = "D") +
 geom point(data = d2s 11 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 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 = "F") +
 geom point(data = d3s 11 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 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 = "H") +
 geom point(data = d4s 11 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')
```

#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 \leftarrow 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 \sim 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.high + total.silt.low + total.silt.rv + total.silt.rv + total.silt.rv + total.silt.high +
```

total.clay.low + total.clay.rv + total.clay.high)

# 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)

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) \leftarrow Component.Key \sim top + bottom
ssd.d2\hzname <- profileApply(ssd.d2, function(i) \{paste0('GSM-', 1:nrow(i))\})
# 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))))
```

```
names(tab2a)[10] <- 'SD'
```

```
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],
       svgm4.s$range[2]),
    rbind(svgm1.c$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))
# Sand
splot1 <-
ggplot(svg1, aes(x = dist, y = gamma)) +
 geom point()+
 geom_line(data = s1line) +
 y\lim(c(0,80)) +
 annotate("text", x = 75, y = 75, label = "Sand 0-5 cm") +
 theme bw() +
 theme(axis.title.x=element blank(),
    axis.title.y=element_blank(),
     axis.text=element text(size=11))
splot2 <-
```

```
ggplot(svg2, aes(x = dist, y = gamma)) +
 geom point() +
 geom line(data = s2line) +
 y\lim(c(0,80)) +
 annotate("text", x = 75, y = 75, label = "Sand 5-15 cm") +
 theme bw() +
 theme(axis.title.x=element_blank(),
    axis.title.y=element blank(),
    axis.text=element text(size=11))
splot3 <-
ggplot(svg3, aes(x = dist, y = gamma)) +
 geom point() +
 geom line(data = s3line) +
 ylim(c(0,80)) +
 annotate("text", x = 75, y = 75, label = "Sand 15-30 cm") +
 theme bw() +
 theme(axis.title.x=element blank(),
    axis.title.y=element_blank(),
    axis.text=element text(size=11))
splot4 <-
ggplot(svg4, aes(x = dist, y = gamma)) +
 geom point() +
 geom line(data = s4line) +
 ylim(c(0,80)) +
 annotate("text", x = 75, y = 75, label = "Sand 30-60 cm") +
 theme bw() +
 theme(axis.title.x=element blank(),
    axis.title.y=element blank(),
    axis.text=element text(size=11))
```

```
# Clay
cplot1 <-
 ggplot(cvg1, aes(x = dist, y = gamma)) +
 geom point()+
 geom_line(data = c1line) +
 y\lim(c(0,10)) +
 annotate("text", x = 75, y = 9.2, label = "Clay 0-5 cm") +
 theme_bw() +
 theme(axis.title.x=element blank(),
     axis.title.y=element blank(),
     axis.text=element_text(size=11))
cplot2 <-
 ggplot(cvg2, aes(x = dist, y = gamma)) +
 geom_point() +
 geom_line(data = c2line) +
 y\lim(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) +
```

```
y\lim(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))
cplot4 <-
 ggplot(cvg4, aes(x = dist, y = gamma)) +
 geom point() +
 geom_line(data = c4line) +
 y\lim(c(0,10)) +
 annotate("text", x = 75, y = 9.2, label = "Clay 30-60 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,
          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)
```

# # 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 \le calc(sSS2, sd)
s3.sd \leftarrow 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")
head(dat)
# Convert to SPC
depths(dat) <- Pedon.ID ~ HZ.Top + HZ.Bottom
site(dat) <- sdat
# 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'))
# 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 \leftarrow dsp[dsp\Pedon.ID != 3 \& dsp\Pedon.ID != 38,]
# 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))</pre>
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")
# Mask to study area, then crop extent (significantly reduces processing time).
studyarea <- readOGR("./NestedSampllingExample", "SoilMU26")
brk3 <- mask(brk2, mask = studyarea)
brk4 <- crop(brk3, studyarea)
```

```
# Extract covariate values
ec <- raster::extract(brk4, y = dsp)
# 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)
# 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 ~ Aspect
                                       , dsp2)
summary(lm(depth ~ ConvergenceIndex
                                            , dsp2))
summary(lm(depth ~ CrossSectionalCurvature, dsp2))
                                           , dsp2)) #** 0.1454
summary(lm(depth \sim DEM 5 utm
summary(lm(depth ~ FlowAccumulation
                                             , dsp2))
summary(lm(depth ~ LongitudinalCurvature , dsp2))
summary(lm(depth \sim LSfactor)
                                       , dsp2))
summary(lm(depth ~ 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 \sim 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 \sim 1, data = dsp2, c(3, 9, 29, 88, 266, 800), variogram.alpha=120) \# Most correlated at < 30m,
maybe 88m.
# Look for spatial outliers. One posible 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 <- variogram(depth ~ 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
dev1.s = krige.ev(depth \sim DEM 5 utm, dsp2, model = dvgm1.s)
dcv1.c = krige.cv(depth \sim DEM 5 utm, dsp2, model = dvgm1.c)
dev1.e = krige.ev(depth \sim 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 \le krige(depth \sim 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'
# Reproject and rename kriging SpatialGridDataFrame for better plotting
library(plotKML)
dk 11 <- reproject(dk, CRS('+proj=longlat +ellps=WGS84 +datum=WGS84 +no defs +towgs84=0,0,0'))
# Create dataframe to plot points on figures
# How do I put points on plot?
dsp2 11 <- spTransform(dsp2, CRS('+proj=longlat +ellps=WGS84 +datum=WGS84 +no defs
+towgs84=0,0,0')
dsp2 ll df <- as.data.frame(dsp2 ll)
```

```
# 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 11 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()+
```

```
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, ]</pre>
# Plot
plot(TWWb)
points(sampGrid, pch = 19)
```

```
# Write to file
```

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