PREDICTING TOPSOIL BALANCE FROM DIFFERENT LEVELS OF SOIL SURVEY[1]

B.A. Buchanan[2] and B. D. Musslewhite

Abstract: Developing a topsoil material balance is a required part of most surface coal mine permits. Mapping scale can greatly affect the accuracy of predicting soil attributes. One example is the effect of scale on accurately estimating location and depth of soils suitable for salvage and subsequent use as topsoil. This study is a comparison of estimating topsoil volumes and locations using three levels of soil mapping within the same resource area. The study area is approximately 850 ha consisting of complexes and consociations of highly contrasting soils ranging in depth and suitability.

One level of mapping represents a general soils map presented at a scale of 1:63,360. The volume of topsoil estimated from the general soils map is approximately 5.7 million bank cubic meters (bcm). The second level is a reconnaissance survey presented at a scale of 1:12,000. The volume of topsoil estimated from the reconnaissance survey is approximately 3.1 million bcm. The third level is a detailed soil grid, established with sample points on 35 m centers and presented at a scale of 1:6,000. The estimated volume of topsoil from the grid sampling is approximately 3.7 million bcm.

The detailed soil grid (1:6,000 scale) is considered the best representation of topsoil volume, depth and location. The general soils map (1:63,360 scale) approximates are nearly double the volume estimated from the detailed map and also poorly represents the estimated depth and location of topsoil. The reconnaissance level (1:12,000 scale) predicts the topsoil volume to be within 20% of the volume predicted by the detailed soil survey. In this study, the materials balance was best estimated using the detailed soil grid rather than the other two soil surveys.

Additional Key Words: soil mapping, cover soil, topdressing, map scale

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[2] Bruce A. Buchanan, President, Buchanan Consultants, Ltd., Farmington, NM 87499, Brent D. Musslewhite, Manager, Environmental Services , BHP Billiton – New Mexico Coal, Fruitland, NM 87416

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Introduction

An integral part of any surface mine plan is an accurate projection of the soil materials that are available for salvage and subsequent use during reclamation. This projection is termed topsoil balance. At a time when soil was considered just "dirt" over the mining product, the salvage of topsoil was of little or no concern. With the passing of the Surface Mining Control and Reclamation Act (SMCRA), the salvage and management of topsoil has become important to successful mine reclamation (Darmody, et.al, 2009).

Topsoil, aka, topdressing, cover soil and surface soil can come from different parts of the soil profile depending on the region of the country (Darmody, et.al, 2009). In the mid-eastern Mollisol region, it is commonly restricted to the A horizon. Normally in agricultural areas, it will include only the Ap horizon. Typically, in semi-arid and arid areas of the west, both the A and B horizon (solum) are salvaged, and in some of these areas it may include the entire regolith. Topsoil is seldom segregated for reclamation in some areas of the eastern USA Appalachian coalfields due to thin, low quality native soil materials. Mines that have substantial areas of Badlands (i.e., exposed carbonaceous shale bedrock), saline/sodic soils or other unsuitable soils, often remove suitable topsoil substitute material well beyond 2 m to extract “topsoil”. Generally, mines anticipating potential topsoil deficits will stockpile all suitable regolith to meet their needs.

Prior to initiation of mining activities, a soil scientist is requested to conduct necessary soil surveys to provide an estimate of how much topsoil is available. In the end, a topsoil balance is provided that defines the location and amount of available topsoil or topsoil substitute.

There are several technologies, including ground penetrating radar (Davis and Annan, 1989) and electromagnetic induction (Anderson-Cook et. al, 2002), available to soil scientists for estimating the volume of topsoil material available from a resource area. The most common technology is soil survey, typically, supported by remote sensing techniques like aerial photographs and satellite data. Soil surveys have been conducted in the United States since the early 1900s.

A soil scientist commonly uses soil survey techniques to provide the topsoil balance. A balance can be developed from either a soil map or a sample grid. Maps and grids are produced at different map scales (levels of intensity) and therefore the prediction of topsoil volume, a soil attribute, inherently has different levels of accuracy (Turner et.al, 1989). The purpose of this study was to evaluate the topsoil balance produced from three different map scales, to determine if scale significantly affects the prediction of topsoil. Topsoil balance predictions in this study were created for an area known to have complex and contrasting soil types. Similar studies have been completed comparing map scale for other soil attributes. Some include rainfall-runoff (Mednick, 2010), permeability, percent clay, and hydrologic group (Juracek and Wolock, 2002), and landscape pattern (Turner, et.al., 1989). The hypothesis in this study was that topsoil balance predictions would be significantly different at different map scales. Additionally, location of topsoil would be better identified using large scale compared to small scale surveys.

Methods

Initially, a small area of approximately 150 ha, located at BHP Navajo Coal Company's Navajo Mine, San Juan County, New Mexico and composed of numerous contrasting soils, was selected for a pilot study. The area had been mapped at three map scales and provided an opportunity to evaluate the study hypothesis. The general soils map (USDA, 1980) presented at a scale of 1:63,360 consisted of two complexes (six soil components) and predicted a topsoil volume of nearly 540,000 bank cubic meters (bcm). The same area mapped at 1:12,000 scale, (Buchanan, 1990) consisted of four consociations and three complexes (10 soil components) and predicted approximately 230,000 bcm of topsoil. The third soil map (Buchanan, 2007), mapped at a 1:6,000 scale, consisted of fourteen consociations and two complexes (18 soil components) and predicted a topsoil volume of 489,000 bcm. Results from the pilot study did support, in part, the hypothesis that materials balance predictions were significantly affected by map scale. It was surprising that predictions from the general soil map were within 10% of the detailed (1:6,000) soil map. The similarity of values from the general and detailed soil maps is believed to be an isolated coincidence unique to the pilot study area rather than a typical representation of spatial differences associated with scale. Although the balance estimates were similar, there were vast differences between topsoil locations characterized by the two maps. The pilot study was limited due to size but established that a study of a larger area was merited. Therefore an expanded study was selected to more accurately test the hypothesis.

Study Area

The expanded study area, approximately 850 ha, was also located at Navajo Mine, San Juan County, New Mexico. Before mining, the area consisted of numerous soil types which varied in depth and topsoil suitability. The area was originally mapped in 1980 by the NRCS as part of a County Soil Survey at a scale of 1:63,360 (USDA, 1980). The same area was mapped by Buchanan Consultants, Ltd in 1987 – 1990 (Buchanan, 1990) as part of the permit application for mining. Soils information from this survey was presented at a scale of 1:12,000, or approximately one sample site per 10 ha. Grid sampling of the area was completed by Buchanan Consultants, Ltd. from 1995 through 2007 (Buchanan, 2007). The grid was developed with sample points on approximately 35 m centers, or approximately one sample site per 0.30 ha. At each sample site, depth of soil suitable as topsoil or topsoil substitute was determined. Soils were excavated to bedrock or to a depth of 1.5 m.

General Soil Survey

General soil survey information was used to calculate a weighted average topsoil depth for each soil mapping unit within the study area. A topsoil depth was determined from the soil profile description for each soil component. Percent of each soil component was used to determine a mean weighted depth of topsoil for each respective mapping unit. Soil complexes typically had 3 - 5 components and consociations had 2 - 3 components. Mean weighted depth of topsoil was multiplied by the area of each map unit to produce a topsoil volume. Topsoil volumes for map units in the study area were summed to produce a total volume of topsoil for the survey area.

Reconnaissance Soil Survey

Reconnaissance soil survey information was used to determine the volume of topsoil for each soil map unit at a scale of 1:12,000. As with the general soil survey, a topsoil depth was determined from the soil profile description for each soil component. Percent of each soil component was used to determine a mean weighted depth of topsoil for each respective mapping unit. Mean weighted depth of topsoil was multiplied by the area of each map unit to produce a topsoil volume. The sum of the topsoil volumes for map units in the study area produced a total volume of topsoil.

Detailed Soil Survey

Detailed soil survey information was used to determine the volume of topsoil from the grid sampling. At this level, a topsoil depth was determined for each site on the sample grid. The Thiessen polygon method (Oxford University Press, 2004) was used to determine an area for each sample site. Sample sites were located on approximately a 35 m grid pattern, therefore, each Thiessen polygon represented approximately 0.30 ha. Topsoil volume was calculated by multiplying each site's topsoil depth by its area. Total volume for the study area is equal to the sum of each site's volume.

Results

Study area boundaries, Fig. 1, were defined by a composite of six detailed soil surveys conducted over the period from 1995 to 2007. A portion of the area is un-mined but the majority has been mined. It consists of 854 ha and represents nearly all of the soil types that exist within the permitted area of Navajo Mine.

General Soil Survey

The general soil map, Fig 1, described the 854 ha area with 8 mapping units. One is an association, four are complexes and the remaining three are consociations. There are 12 soil types and two miscellaneous types (Badlands and Rock Outcrop) for a total of 14 soil types. Seven of the types are sources of topsoil and the remaining seven provide no topsoil. Of the seven soils providing topsoil, the depth of available topsoil was typically 1.5 m. Generally, A horizon material provided 15 cm of topsoil, the B horizon 60 cm and the remaining topsoil material was C horizon. The soil types that provide topsoil comprise 370 ha (43%) of the area and the soil types that are not sources of topsoil total 484 ha (57%) of the area. The volume of topsoil predicted from the general soil survey is approximately 5.7 million bcm, Table 1.

Table 1. Topsoil Volume Predicted Using Three Levels of Soil Map Intensity.

Soil Map	Map Scale	Hectares	bcm*
General	1:63,360	854	5,671,773
Reconnaissance	1:12,000	854	3,101,571
Detailed	1:6,000	854	3,732,519

*bcm - bank cubic meters

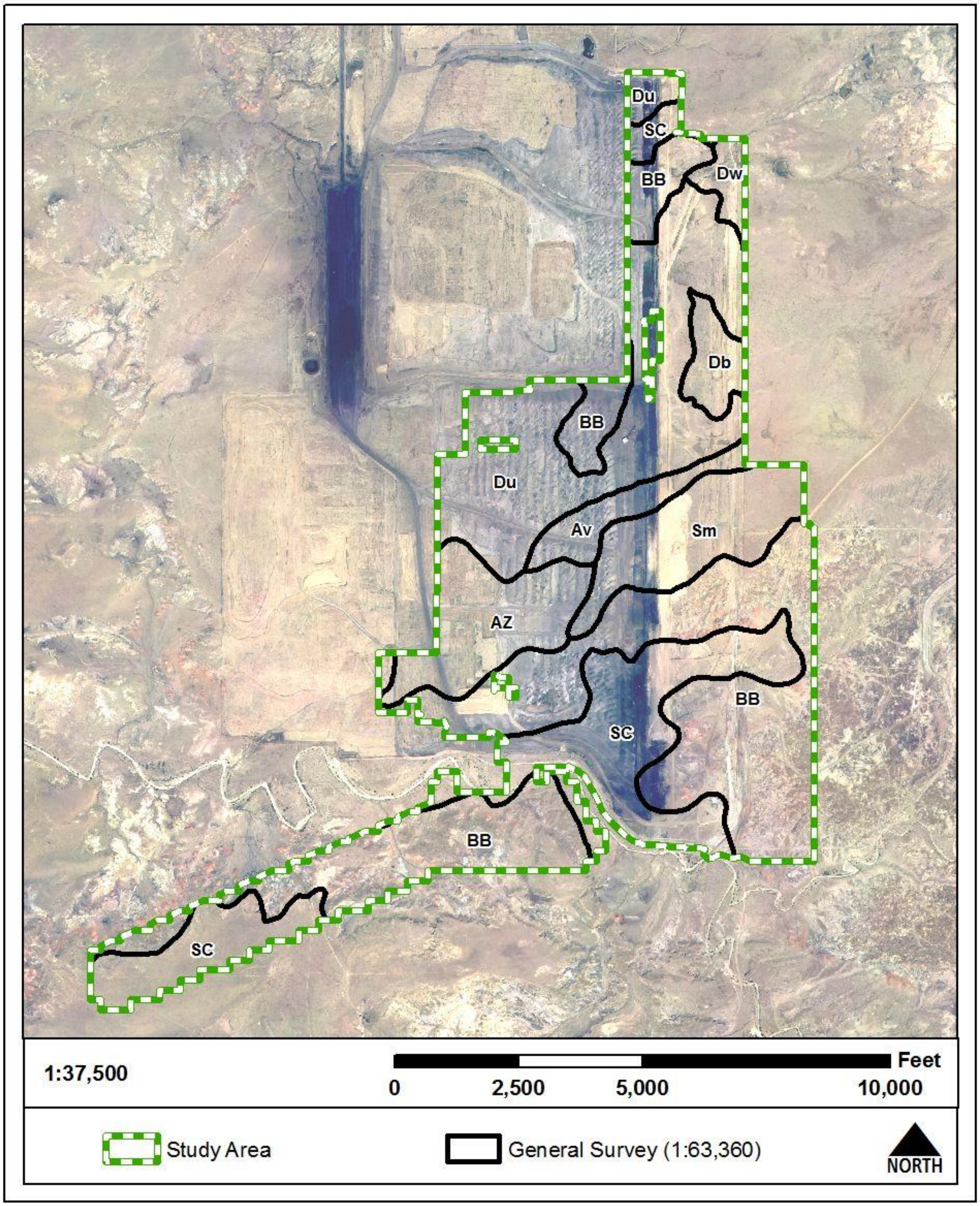

Figure 1. Topsoil Study Area: General Soil Survey for 854 ha, Navajo Mine, New Mexico.

Reconnaissance Soil Survey

The reconnaissance soil survey, Fig. 2, describes the 854 ha area with 19 mapping units. Five are complexes and the remaining 14 are consociations. There are 17 soil types and one miscellaneous type (Badland) for a total of 18 soil types. One of the soil types is called Natrargids. It is composed of three saline and sodic soils that vary in depth and represent three different soil series. None are suitable sources of topsoil. The soil types providing topsoil range in depth from 15 to 150 cm. Seven of the types have between 120 and 150 cm of topsoil and eight types have less than 60 cm of available topsoil. In most cases, suitable topsoil comes from a thin A horizon (<15 cm thick) and the majority from either a B or C horizon that can extend to depths of 150 cm. The soil types providing topsoil represent a total of 312 ha (36%) of the area and the non topsoil types (Badlands and Natrargids) represent a total of 542 ha (64%) of the area. The volume of topsoil predicted from the reconnaissance soil survey is approximately 3.1 million bcm, Table 1.

Detailed Soil Survey

The detailed soil survey, Fig 3, described the 854 ha area with 2,814 sample points where each point represents approximately 0.30 ha. Generally, the number of soil types and distribution of topsoil in the profile is similar to the reconnaissance mapping. Precision of location (extent) of topsoil and the depth of topsoil predicted are considered to be greatly improved over the previous soil surveys. The volume of topsoil predicted from the sample points is approximately 3.7 million bcm, Table 1.

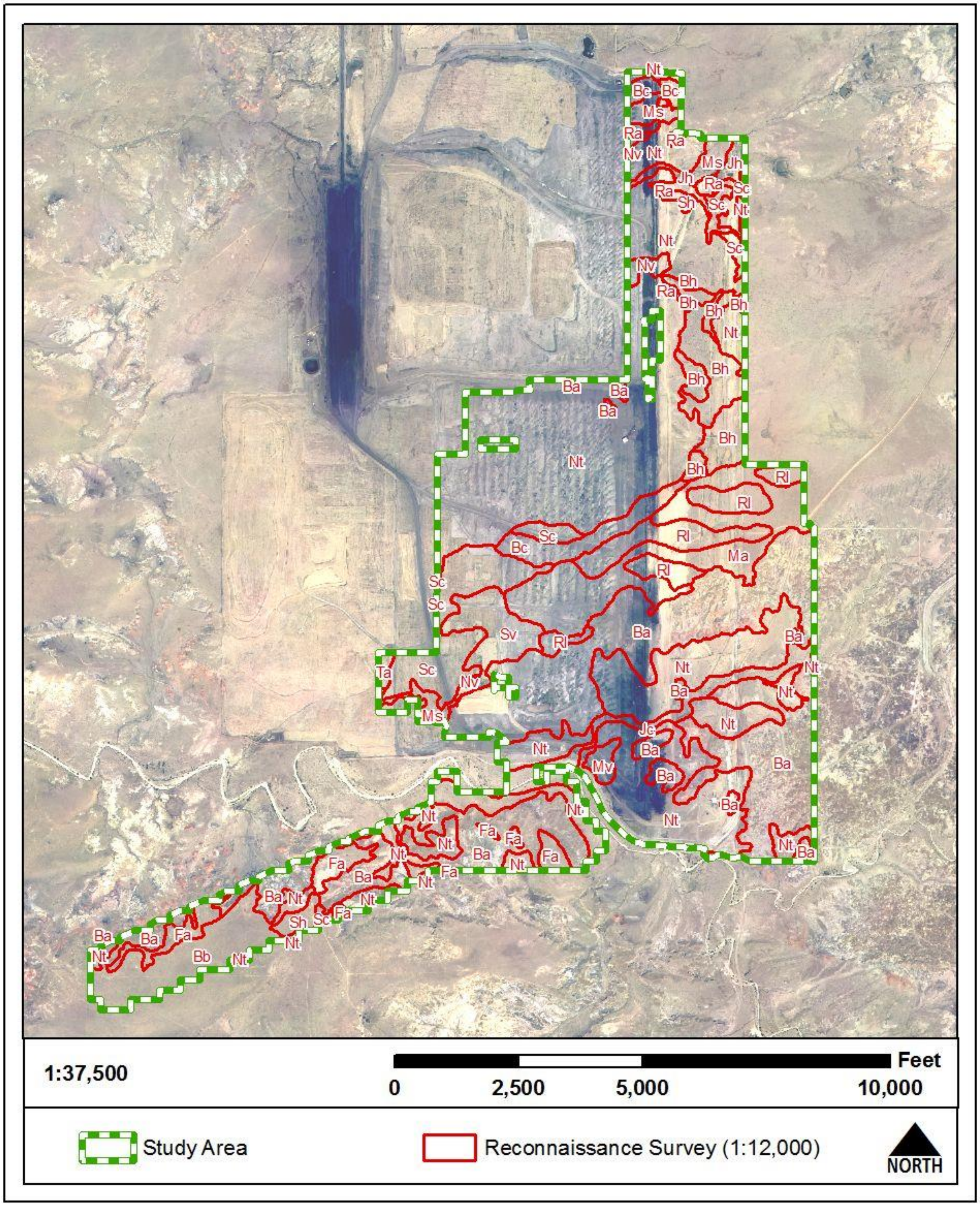

Figure 2. Topsoil Study Area: Reconnaissance Soil Survey for 854 ha, Navajo Mine, New Mexico.

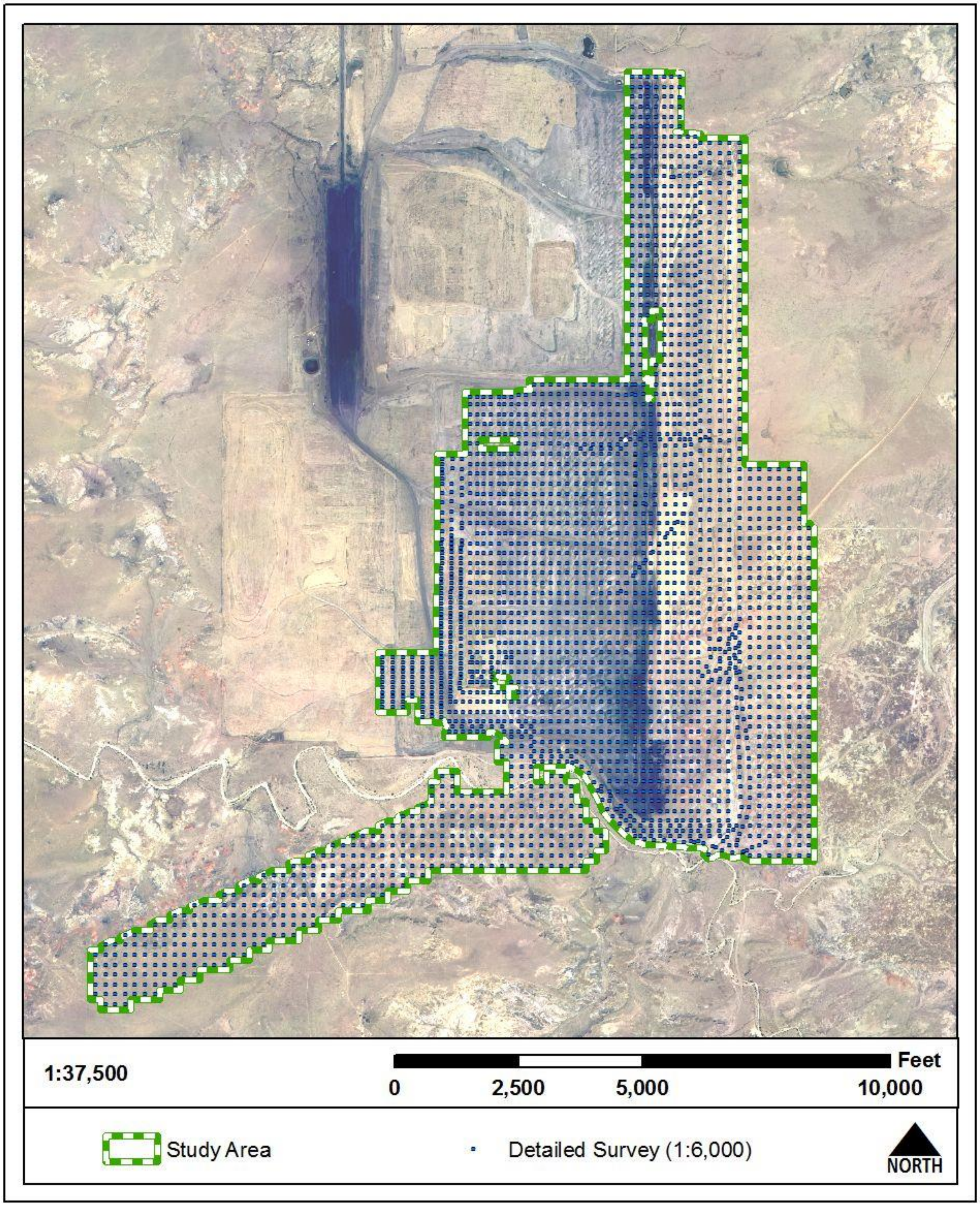

Figure 3. Topsoil Study Area: Detailed Soil Survey for 854 ha, Navajo Mine, New Mexico.

Discussion and Conclusion

Theoretically, any soil survey, regardless of scale, would be appropriate to predict a soil attribute if the study area was composed of one homogeneous soil type. As diversity of landscape pattern increases the effects of scale becomes important to predict spatial differences, (Turner, et. al, 1989). In this study, the general soil survey (small scale) projected a topsoil balance that was nearly twice the volume predicted by the large scale soil surveys. Additionally, the general soil survey, produced by the NRCS, did not reflect an accurate estimate of topsoil location for the conditions at Navajo Mine. The reason for the discrepancy in the topsoil volume and topsoil location is associated with the heterogeneity of mapping units and soil types. Juracek and Wolock (2002) found site-specific variability between correlated databases at scales of 1:250,000 and 1:24,000. They used permeability, percent clay and hydrologic group as soil attributes.

The reconnaissance level of mapping (1:12,000) produced a topsoil balance nearly 17% lower than the detailed soil survey (1:6,000). The volume estimate for the reconnaissance level may be adequate for general planning; however, it is not suitable for the identification of topsoil depth and location within heterogeneous areas of contrasting soils. The detailed survey was required, for this area, to accurately locate topsoil sources and to ensure such materials are salvaged from the proper depth.

Similar to the study conducted by Mednick 2010, the accuracy and precision of predicting a soil attribute is closely associated with mapping intensity. This study showed that large scale soil surveys provide a more accurate prediction of topsoil depth and location than small scale soil surveys, particularly in areas with complex soils. At Navajo Mine, a detailed soil survey requires greater resources. However, the benefit of accurately removing all available topsoil, where deficits are common, easily justifies the added expense of conducting a detailed soil survey.

Literature Cited

Anderson-Cook, C.M., M.M. Alley, J.K.F., Roygard, R. Khosla, R.G., Noble, and J.A. Doolittle. 2002. Differentiating soil types using electromagnetic conductivity and crop yield maps. Soil Science Society of America Journal. Sept/Oct 2002. v. 66 (5), p. 1562-1570. http://dx.doi.org/10.2136/sssaj2002.1562 0.

Buchanan, B.A. 1990. Soils of Navajo Mine. Internal report produced by Buchanan Consultants, Ltd. for Navajo Mine, 1987-1990.

Buchanan, B.A. 2007. Pre-Strip Topsoil Inventory. Internal report produced by Buchanan Consultants, Ltd. for Navajo Mine 1995-2007.

Darmody, R. G., W. L. Daniels, J.C. Marlin and D. L. Cremeens. 2009. Topsoil: What Is It and Who Cares? Proceedings America Society of Mining and Reclamation, 2009 pp 237-269. http://dx.doi.org/10.21000/JASMR09010237.

Davis, J. L. and Annan, A. P. 1989. Ground-Penetrating Radar for High-Resolution Mapping of Soil and Rock Stratigraphy. Geophysical Prospecting, 37: 531–551. http://dx.doi.org/10.1111/j.1365-2478.1989.tb02221.x.

Juracek, K.E. and D. M. Wolock. 2002. Spatial and statistical differences between 1:250,000 – and 1:24,000 – scale digital soil databases. Soil and Water Conservation Society. Journal of Soil and Water Conservation 57(2):89-94.

Mednick, A.C. 2010. Does soil data resolution matter? State Soil Geographic database versus Soil Survey Geographic database in rainfall-runoff modeling across Wisconsin. Soil and Water Conservation Society. Journal of Soil and Water Conservation 65(3):109-199. http://dx.doi.org/10.2489/jswc.65.3.190.

Oxford University Press. 2004 A Dictionary of Geography, Thiessen Polygons. Answers.com, May 31, 2011.

Turner, M.G., R.B. O'Neill, R.H. Gardner, and B.T. Milne. 1989. Effects of changing spatial scale on the analysis of landscape pattern. Landscape Ecology 3: 153-162. https://doi.org/10.1007/BF00131534

USDA. 1980. Soil Survey of San Juan County New Mexico, Eastern Part, C. Wesley Keetch, Soil Conservation Service, US Department of Agriculture, November 1980.