Studies of VEGETATION HABITAT ASSOCIATION for surface mine reclamation. (VHA)

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ABSTRACT/ SUMMARY & CONCLUSIONS.

To re-vegetate a post-mine landscape with native vegetation one must identify target communities and establish them in suitable micro-environments. Our project explores these (two) operations at regional (Chapter 1) and local (Chapter 2-6) scales. While developing/testing of approaches was our primary goal, the project yielded facts relevant to managers in the region. The chapters are free-standing, each with its own introduction, conclusions and figure/table numbering system. Appendices reside with their chapters.

At the regional scale (Chapter 1, Table 6), we identify nine/twelve physiognomically distinct vegetation types including grassland, sage grassland, and pine savanna. We correlated them simultaneously with precipitation (13-17"/year), aspect (N-S facing), and landscape position (ridge, slope, slope-toe, and bottom). Vegetation responses were consistent with the hypothesis that vegetation in this semi-arid region varies with water availability- - as driven by precipitation, evapotranspiration (aspect), and soil storage (topographic positions). Our review provides a basis for selection of vegetation for sites at both regional and microenvironment (aspect/position) levels. We expect to publish this chapter as an independent paper.

We undertook a more detailed pilot analysis of vegetation and its relation to its environment at the Absaloka mine (Chapters 2-6). Our analysis- - identification of target vegetation types and their environmental correlates/factors- - was based on its exceptionally large, varied, detailed, and internally consistent pre-mine data set (~800 sample sites). The analysis proceeded in five steps described below.

Qualitative (species list) and quantitative (cover) descriptions of vegetation based on point samples were ordinated and classified to identify eight vegetation types (15 varieties, Chapter 2, Task 1). The communities identified were consistent with our physiognomic types (Chapter 1), Westech subjective types, and our more regional types (Weaver and Aho 2006).

Environmental data for characterizing the sample points were sought (Chapter 3, Task 2, Table 1). The object was to contrast environments occupied by pre-mine vegetation types/ post-mine targets as a base for identifying/creating microenvironments on which each type might be

expected to establish. The first source was slope, aspect, and soil gathered at sites sampled during the vegetation inventory. We only contracted analysis for these. We gathered additional data from public data sets (e.g. NRIS & USGS) to determine whether their inclusion in descriptive models would improve our capacity to recognize habitat appropriate for particular vegetation types.

The incongruence of public data with ground truth largely disqualified its use, for our application (Chapter 4). Average slopes calculated from a 30 DEM were low (25% of ground truth), but while the average aspects were consistent the variances associated with both showed these data to be undependable. We attribute the deviance to averaging of environmental information when small sample units are combined into large sample units. Soil texture data drawn from the two data sources also correlated poorly. The deviance might be attributed either to error in sampling from coarse public data or to inexpert analysis by field technicians recording pre-mine environments. Analysis could be made more certain- - for both professional and technical analysts, if samplers incorporated simple/inexpensive quantitative methods. Our results should be published and the problem should be investigated further to develop/test the promise of public data.

Correlation between vegetation and environment suggests causal influence of environment on vegetation. We tested five methods. 1) Environments of the vegetation types were described, character-by- character, and contrasted. Several presumptive factors seemed influential (Chapter 4, Table 16), either due to direct causation likely transferable to the post-mine landscape (e.g. slope, aspect, and position) or to not extendable survey mechanics (e.g. soil type and range site).

2) Factor pairs may be profitably combined. Such combinations may be modeled physically or mathematically, as when one properly integrates radiation& heat delivery/evapotranspiration from slope and aspect (chapter 4 & 5).

3) Two-factor scatter diagrams, despite their lack of physical basis, usefully compared communities. While western wheatgrass occupies toe slopes without regard to aspect, P pine is shown to prefer steeper north-facing slopes. And because distinct old field communities occupying Agropyron and Stipa environments are energetically similar, we must attribute environmental differences to edaphic factors.

4) Multifactor logistic regressions were used community-by-community to determine the environments best suited for planting a community desirable for its productivity, appearance or

support of rare species. While single factors had highly significant effects, overall predictions were poor (D^2, similar to R^2 = 0.02-0.40). This may suggest that we haven't measured controlling factors, that we haven't measured them well, or that our combination/modeling of factors inadequately expresses causal mechanisms.

5) Because all vegetation types are considered concurrently, multifactor CART regressions should assign vegetation types optimally to a varied surface. The match between vegetation assignments made from pre-mine environmental data and pre-mine vegetation improves as 'confusing' multi-environment communities (old fields) were removed, as the number of vegetation types was reduced as the number of environmental correlates/ factors increased. While the last sentence seems logically obvious, the measure may be misleading, because some of the data added (range site and soil type) may not be independent of the predicted vegetation type. Despite trends, the 30-70% error rate in predicting pre-mine vegetation from pre-mine environment is disappointing.

Integrating across the entire project we draw six conclusions.

1) Precipitation level affects vegetation presence (Chapter 1).

2) Slope/aspect and derivative radiation, heat, and evaporative loads affect vegetation presence (Ch. 5&6).

3) It seems clear that soils are major determinants of habitat quality (Chapters 1, 5, and 6) and the omission of soils from many of our models may be responsible for their low predictive power. Soil effects are, however, especially hard to evaluate (Chapters 5& 6) both because of the unknown quality of both field and public data. And because we have no measures of below-ground conditions.

4) If pre-mine vegetation were seral, between stage heterogeneity might 'confuse' correlations as it did between old field types. We doubt that this contributes significantly in our lightly populated region- - and to the extent that it might be, it was stratified against by samplers who excluded disturbed sites.

5) Land to be reclaimed will have a given precipitation, a variety of slopes and aspects and soils with little known relationship to pre-mine soils. We have shown that macroenvironment (precipitation) and the slope/aspect aspect of microenvironment are insufficient for accurate prediction of pre-mine vegetation. While better understanding of soil effects should improve prediction of pre-mine vegetation, the introduction of newly created 'mine soils' will add, so far, unstudied soil effects.

6) The fruitful pursuit of the VHA concept may depend on more use of mechanistic (vs correlation) models and will certainly depend on more investigation of substrate effects.

7) The potential for investigation of soil effects is very exciting- - because it will provide reclamation engineers, not only a tool for understanding the distribution of vegetation, but a tool for constructing soils that will support the vegetation they desire.

TABLE OF CONTENTS

[1] Chapter and task numbers.

ACRONYMS

ASA	Absaloka Study Area
ASW	Average Sillouette Width
CAD	Computer Aided Design
CART	Classification And Regression Tree
DEM	Digital Elevation Model
DOQ	Digital Orthophoto Quad
GIS	Geographical Information System
GPS	Global Positioning System
ISA	Indicator Species Analysis
ISAMIC	Indicator Species Analysis … Minimizing Intermediate Constancies
NA	Not Available
NAIP	National Agricultural Imagery Program
NMDS	Non-Metric Multidimensional Scaling
NRCS	Natural Resources Conservation Service
NRIS	Natural Resources Information System
PCoA	Principal Coordinates Analysis
SCS	Soil Conservation Service
SSURGO	Soil Survey Geographic Database
STATSGO	State Soil Geographic Database
USGS	United States Geological Survey
VHA	Vegetation-Habitat Association

INTRODUCTION.

Twelve square miles [[or 7600 acres???) are under reclamation in Montana and almost none of the re-vegetation bonds have been released. Mines in similar environments of adjacent states are in similar condition. With exponentially increases in expansion of mined lands it is obviously important both to define native communities likely to succeed in these areas and to learn how to emplace them on sub-sites where they will be successful.

On the assumption that pre-mine vegetation is likely to succeed post-mine in the same climate, a joint MSU/Montana Department of Environmental Quality/ Mining Community project has ordinated/classified pre-mine vegetation to identify pre-mine native vegetation types (Weaver and Aho 2006). Species lists and cover estimates for these communities provide a basis for seeding post-mine sites.

We hypothesize further that, because climate is not changed by mining, each vegetation type is most likely to succeed in sites similar to those occupied pre-mine, that is, on sites with similar slope, aspect, and soils. The object of this pilot project is, thus, to determine the range of conditions each pre-mine community can occupy.

Our project considered two major tasks testing our capacity to correctly predict pre-mine vegetation from pre-mine environmental data (vegetation habitat association). The first tested creation of an approximate prediction on a regional scale (SE Montana, Chapter 1). And the second tested the possibility of making a more precise prediction on a local scale (Absaloka Mine). The regional analysis was based on correlation of vegetation with measurements of vegetation and environment (precipitation, aspect, and slope position) coarsely measured from aerial photographs located in three rainfall belts (13", 15', and 17"/ year) on a homogeneous substrate (Fort Union Formation) in SE Montana.

The local analysis explored the use more sophisticated analysis on finer data (ie vegetation and environmental measurements made at GPS precise points studied at a single mine site (Absaloka) in SE Montana. The work was subdivided into five tasks considered in Chapters 2-6. Pre-mine vegetation was classified and described on the basis of approximately 800 points (Chapter 2). Environmental data was catalogued (Chapter 3); the catalogue included ground truth data (from private company (DC) measurements of GPS position, slope-aspect, landscape position and soil texture), and data from the public domain (DP for landscape characteristics including slope, aspect, position, range site, and soil texture). We interrupted our analysis to evaluate public data for present and future applications (Chapter 4); comparison of public data (DP) with ground truth (DC) raises questions about use of public data at our scale of interest. We described the environment of each vegetation type, factor-by-factor and compare results based on public (DP) and private data (DC, Chapter 5). Finally we test three methods for correlating vegetation with multiple environmental qualities (Chapter 6). A unique graphical method is used to demonstrate the range of slope-aspect conditions occupied by a vegetation type and/or compare it with the range of another community. Logistic regressions based on slope/aspect/ derived qualities suggest siting requirements for an especially desirable vegetation type. And CART analyses prescribe an optimal vegetation type for segments of a pre-mine/post-mine surface.

Acknowlegements. Our examination of vegetation habitat association (VHA) involved several parties. S Regele (Montana Department of Environmental Quality) did preliminary studies (Regele and Reichert 1998) and promoted the project. S Regele and T Weaver received funding from USDI Office of Surface Mines (OSM). The Absaloka Mine (D Myran and Westech/K Skow) provided pre-mine vegetation and environmental data. F Dougher (MSU/LRES Dept) gathered and manipulated public data. S Wood gathered regional data from digital color aerial photos NAIP 2005 images provided by L Temple (USGS). K Aho performed ordination/classification and regression analyses. T Weaver managed the project and drafted the report.

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Chapter 1, VHA task 6.

CORRELATION OF VEGETATION TYPES WITH PRECIPITATION, ASPECT, AND LANDSCAPE POSITIONS,SE MONTANA--A GUIDE TO RECLAMATION OF DISTURBED SITES

INTRODUCTION.

Vegetation of semi-arid SE Montana seems to vary with precipitation, aspect, and position. Variation in vegetation with rainfall should parallel that documented internationally (e.g. Holdridge 1947) and regionally (Weaver 1980), i.e. steppe vegetation is on drier sites and woodland vegetation is on moister sites. Where water is a limiting factor, differentiation of vegetation in a single landscape probably reflects differences in water availability among component microsites. Aspect effects are demonstrated in SE Montana by the fact that, within a rainfall zone, drought tolerant steppe vegetation tends to occupy south slopes and woodland vegetation tends to occupy north slopes. Effects of landscape position on vegetation are more complex as position may affect radiation, redistribution of water, water distribution in the soil profile, or the probability of fire. While, in the mine reclamation context rainfall is not manageable, aspect and position effects may be.

Reclamation of disturbed lands -- mines, roadsides, gas wells, burns -- will succeed only if plantings are compatible with the site's macro- and micro- environment (habitat). When natural vegetation is the reclamation target, we assume that the community/vegetation most suitable for a site (and sites suitable for desired communities) can be identified by correlating communities and environments occurring together in undisturbed landscapes. Once identified, these can be reestablished in the reclamation landscape.

Given this, our objectives are to…

1) determine what natural communities tend to dominate in the three rainfall belts (13, 15, and 17" per year) common in the region. Intermediate communities are expected under intermediate precipitation levels.

determine how communities of a single precipitation zone vary among aspects, i.e. which communities are broadly distributed and which are more strongly associated with north or south slopes.

determine how communities on natural sites in a precipitation zone and aspect distribute themselves among landscape positions. Application of knowledge about position effects will require investigation to determine the extent to which they are due to such factors as radiation load, distribution of organic matter and seeds, lateral redistribution of water, vertical storage of water, and fire.

METHODS.

We expect (hypothesized) that the distribution of vegetation at the landscape level in SE Montana is determined by variation in three primary environmental gradients: precipitation, aspect and position. To test/demonstrate this we sampled a 'natural experiment' - - as described below- - to determine the correlation of vegetation type and environment at representative 'nodes' of the gradients.

A uniform background was required to minimize variation caused by factors other than those studied. To minimize substrate effects, we located three field sites on the Ft. Union formation (App. Fig 1, USGS 1999 or NRIS 2006), an early Cenozoic sedimentary formation containing layers of sandstone, shale, and coal (Stricker and Ellis 1999). The required uniform background flora is assumed because the barrier-free area has been occupied by steppe/pine savanna for thousands of years.

Three precipitation treatments, representing the range of rainfall in SE Montana, were imposed by selecting a site in each of three rainfall belts (App Fig 1, NRIS 2006) and, of course, on the Fort Union: 13,15, and 17" per year (App. Fig. 1, NRIS 2006) . Because the precipitation treatments are unreplicated (as contracted), our results could be bolstered by adding two or more replications. The Kinsey site (13") has a badlands appearance with open vegetation on uplands, sparse juniper on north slopes, and patches of grass/shrub in bottoms. At the Absaloka site (15”) the upland is dominated by pine savanna/ forest on ridges and mesas and bottoms are shortgrass/sagebrush. The Otter Creek site (17”) has narrower bottoms (less riparian than Absaloka) and is mostly covered by pine savanna/forest.

Vegetation and environments of the three rainfall zones were sampled simultaneously for aspect and position effects (correlations) on aerial images described below and replicated in (Appendix Figures 2-7). One image came from each rainfall zone. Points sampled in each image were intended to represent fourteen different environmental types, to be equal in number among types, and to be well dispersed (stratified random) over the site. To achieve this each ‘precipitation’ site was ‘striped’ border to border (E-W) with 100 transects each approximately 100m from its neighbor (Table 1). Every fifth transect was sampled. On each line (block) we sought one example of fourteen environments [four aspects (N, S, E, W) x three positions (shoulder, slope, and toe) plus ridge and bottom which don’t have aspects per se]. The points were located by beginning at a random point on each line and heading east, taking the first example of each environment encountered. If any of the 14 environments were still missing at the end of the transect, we circled back to its west end and continued east again in search of the remaining environments. Because some transects did not contain all the topographic environments sought, our pilot project data set is not completely balanced (Table 1). Obviously disturbed sites (e.g. agricultural fields, mines or roadsides or areas recently affected by wild fire) were excluded from analysis.

Sample units were described with respect to aspect, position and vegetation type present. Sample units were 100 $m^{2,}$, i.e. 5.6 m in radius. Their aspects were assigned to cardinal positions. Positions (ridge, shoulder, slope, toe, and bottom) at sample points were subjectively estimated. This was justified since the resolution of aerial photos was much higher than the resolution of 10m or 30m DEMs (Jensen 1996). Vegetation cover at sample points was subjectively identified. The subjective identifications were calibrated by examining sample points classified on the ground at Absaloka (Westech 1992), visiting the three sites in the field, and comparing the appearance of the types across the three images. See Table 2 for description of vegetation types identified in images. Table 2 lists the vegetation types recorded and provides brief descriptions of them. Though recorded, the exposed bedrock data (+/-) has not been analyzed

The images sampled were natural color digital aerial photographs drawn from the National Agricultural Imagery Program (NAIP 2005) files. Thanks to L Temple of the USGS Northern Rocky Mountain Science Center, Montana State University. They were captured in 2005, ortho-rectified and registered to the Universal Transverse Mercator (UTM) coordinate system, NAD83, and had a ground resolution of one meter. Each image was clipped to the area of a USGS 7.5' topographic quadrangle and is replicated in Appendix Figs 2-4. Upper left (NW) and lower right (SE) bounding coordinates for the 3 images are listed in Table 1.

Details of the sampling follow. Equally spaced transects were located with ArcGIS 9.1. Each was divided into 100 possible starting points, of which one was randomly selected with Excel. Transect width varied due to variation in the length (N-S) of the image width- - transects were 95, 143 and 122 meters wide on the Kinsey, Absaloka,and Otter Creek sites respectively. We sampled 34 transects at Kinsey and Absaloka and 27 transects at Otter Creek. The realized sample numbers were less than the expected 14 environments x number of transects - - due to the absence of particular environments on transects selected. Realized/ expected sample sizes were 456/476 for Kinsey , 419/476 for Absaloka, and 343/378 for Otter (Table 1).

The data are summarized in Table 3 which compares the vegetation, type-wise, across rainfall regimes (between tables) and slope/position combinations (within tables). The most basic presentation is one of raw data and our presentation is based on it. Though not available, we would have prefered a presentation based on equal numbers of points in each stratum. As a result we tried to normalize the data between sites (Appendix Table 1), between aspects (Appendix Table 2), and between positions (Appendix Table 3). But because we are unable to normalize between all environmental characteristics simultaneously and because the conclusions drawn are identical, we present the most basic (unmodified) data.

RESULTS

Hypothesis. Four distinct landscape factors are distal controls of the distribution of vegetation in SE Montana coal/gas lands: precipitation, aspect, slope, and soil. In our semi-arid environment their primary controlling action is through their effects on water availability. The effects of temperature and nutrients are much less important.

Precipitation. Local-regional precipitation determines the catena/spectrum of vegetation types present at a site. In the 13” rainfall belt, the zonal vegetation (the major precipitation determined vegetation, Daubenmire 1968) is mesic grassland *(Artemisia* grassland &, herbaceous grassland), with significant amounts of xeric vegetation (dry scrub, juniper forest and sparse vegetation) on micro/meso-sites. There is no ‘moister’ vegetation. In the 15” rainfall belt, the zonal vegetation includes both mesic grassland (Artemisia-grass& Grass-herb) and moister types *(Pinus* and *Rhus).* There is very little xeric vegetation. In the 17” rainfall belt zonal vegetation includes some mesic grassland (Grass-herb, not Artemisia-grass), but mostly moister vegetation (mostly pine, little *Rhus).* There is very little xeric vegetation.

Aspect. One expects vegetation cover on slopes to vary with aspect, supposedly because southerly aspects are most radiated, driest, and warmest. In the 13” rainfall belt, the moister grasslands and dry scrub are uniformly distributed, the xeric sparse vegetation appears on south slopes, and xeric juniper forest appears on north slopes (Table 3). Data not presented show that within the juniper type forest density is highest on the most northerly sites. In the 15” zone mesic grasslands *(Artemisia*-grass and Grass-herb) are uniformly distributed while moister vegetation is partitioned i.e. *Rhus* occupies south slopes while sparse pine and especially dense pine forests (>50% cover) occupy north slopes (Table 3). In the 17” zone, mesic grassland and moist pine (<50% cover) seem little affected by aspect, but sparse vegetation and *Rhus* appear on southerly slopes while moister pine forests (> 50% cover) appear on northerly slopes. Closer inspection of open pine and grassland frequencies show biases toward north and south slopes respectively (Table 3). Due to negligible slope, flat tops and bottoms are aspect free and are so discussed with position below.

Position. Vegetation might vary with position due to radiation/slope, redistribution of water, and substrate effects. On slopes in the 13” zone, mesic *Artemisia*-grassland and xeric juniper are evenly distributed, other xeric vegetation (sparse and dry shrub) prefer upper slopes, and riparian snowberry prefers lower slopes (Table 3). On slopes in the 15” zone, mesic grasslands prefer lower slopes while moister *Rhus*/pine prefer upper slopes. In the 17” zone, mesic grassland prefers lower slopes and moister *Rhus*/pine prefers upper slopes (Table 3).

Flat hill tops might have zonal vegetation since they are influenced by neither slope nor aspect. This is true for 13” and 15” zones, but not for the 17” zone. In the 13” zone moist grasslands *(Artemisia*-grass and Grass- herb) dominate and xeric vegetation is poorly represented (Table 3). In the 15” zone flat uplands are mostly pine dominated with a little mesic grassland (mostly

Artemisia-grass). In the 17" zone, herb grassland dominates in spite of the high rainfall (Table 3). There may be considerable soil texture variations between hill top sites.

Vegetation-environment relations in aspect-free bottoms might parallel aspect-free tops, except where bottoms receive significant amounts of run-off water. In the 13" zone mesic grasslands (both types) dominate and sparse vegetation appears on eroded sites, as if runoff is unimportant. In the 15" zone, mesic grassland, dry riparian shrub *(Symphoricarpos)* and mesic riparian shrub (half short and half tall) occupy bottoms, as if runoff is more important (Table 3). In the 17" rainfall belt grassland (Grass-herb, not *Artemisia*-grass) and tall shrubs occupy bottoms.

DISCUSSION.

Precipitation. As expected, zonal vegetation (Daubenmire 1968) changes from grassland to forest when climate dries from 13 to 17" (Weaver 1980, 1994). Grassland vegetation is the sole zonal vegetation in the 13" precipitation zone, a core (major) cover in the 15" zone, and no core cover in the 17" zone. Inversely pine vegetation is not core at 13", a partial core at 15" and primary core at 17". The fact that zonal vegetation is bimodal (mesic and moist) in the 15 and 17" zones suggests that differences in substrate in an ecotonal zone might be responsible for large differences in vegetation type.

Aspect. Zonal vegetation changes from steppe to forest as one moves from south to north slopes. In the 13" zone, sparse vegetation is on south slopes and juniper is on north slopes. In the 15" zone *Rhus* is on south slopes and juniper is on north slopes. In the 17" zone grass-herb is on south slopes and closed pine is on north slopes. The effect of south slopes is surely due to its high radiation. This radiation probably affects plants through drought since, in our region summer drought is far more likely to limit plant performance than warmer temperatures, regardless of season. One might marvel at the fact that radiation differences so slight as demonstrated in chapter '3' can influence vegetation distribution.

Position. On slopes grasses occupy toes while deep rooted woody vegetation occupies shoulders (Table 3). In the 13" zone *Artemisia*-grass vegetation is on toes while dry shrubs and sparse vegetation occupy shoulders. In the 15" zone, *Artemisia* grassland is on toes while *Rhus* and pine are on shoulders. In the 17" zone Grass-herb is on toes while open pine is on shoulders (Table 3).

We offer two non-exclusive hypotheses for the tendency of toes to be grassier than shoulders. 1) Soil water is at the surface on toes and at depth on shoulders. This is because erosion of fine soils from shoulders to toes, makes shoulders and toes relatively rocky/gravely and clay-rich respectively. Rock-free toes are grassy because the diffuse root system of grasses are favored in this system. And shoulders are lignaceous because tap-rooted trees and shrubs use deep water without the competition of grasses (Walter 1973). 2) Fire favors plants investing little in aboveground parts, i.e. grasses over shrubs/trees. Fire is greater on toes than shoulders for two reasons. First, fire travels more easily across rock-free toe than rocky shoulder surfaces due to the higher density of ground-level fuel. Ground-level fuel is relatively thick on rock-free toes both because grass density is high and because rock surface is low. Second, relative to toes and upwind-shoulders, down-wind shoulders are sheltered by their position from wind-driven fire.

The vegetation of ridge tops is expected to follow zonal vegetation when/if soils are deep and level. In the 13” zone grasses dominate and in the 15” zone either grasses or pines do dominate (Table 3). In the 17” zone grasses, rather than the expected pines, dominate. While we offer no specific no specific hypothesis, this deviance is likely substrate determined.

Vegetation of bottoms becomes more robust with increasing precipitation. Where it occurs, riparian vegetation is low (snowberry) in the 13” zone (Table 3). It can be either low or high in the 15” zone. And it is high *(Prunus* or cottonwood) in the 17” zone. The difference is probably due to increasing downslope runoff volume and dependability in higher precipitation zones. The quantity (frequency) of riparian vegetation at 13” and 17”, is lower than at 15”; we attribute the difference to unrelated differences in landform.

The sample. Conclusions drawn here are based on patterns in the raw data (Table 3). While our sample ‘should’ contain equal samples (numbers of points) in each cell (34), some points are absent (Table 1) because these environments didn’t appear on every sample transect. Our conclusions are based on the assumption that our sample is adequate, i.e., that missing points would have been distributed among slope/aspects in proportion to those seen in the existing sample.

Implications for reclamation. With regard to reclamation, we deduce that target types will vary according to precipitation belt and that the target vegetation for a mine can be estimated from its precipitation by either using one of our zones or by interpolation between them. The suitability of vegetation for installation across aspects can be similarly estimated.

Estimation of target vegetation for specific positions is less straight-forward. If position represented slope alone, the slope-vegetation of shoulders and toes should be similar. It is not. And the difference is not likely due to water transport, because drier grassy vegetation occurs on 'run-in' toe slopes. We postulate, instead, that 'soil texture/quality' is a major factor. If so, normal 'top-soiling' in reclamation will replace deep rooted woody plants (pine and shrub) normal to upper slopes with grasses. To successfully implant woody plants one must provide a rocky surface/profile. Thus, the reclamation ecologist can target for the vegetation of his choice by manipulation of surface deposits -- a deviation from the common practice of using loamy homogenized surface layers throughout reclaimed tracts.

Based on summary of data from our pilot study, we make tentative recommendations targetting vegetation types for reclamation on particular surfaces at a site in the 15" rainfall zone of SE Montana (Table 4, 5). We recognize two situations parallel to those where modern agriculturalists install different crops, seeding rates, or fertilization rates in different landscapes (Carr et al 1991, Keck et al 1993, Nielsen et al 1993). First, where a site is already re-contoured, it may be subdivided into landscape units, each to be planted with communities most likely to survive/thrive there. And, second, if, at an earlier stage in the reclamation process one chose to create a surface suitable for a particular community he wished to install. In the first case, the reclamation ecologist might tentatively choose vegetation types appropriate for particular landscape segments from Table 4, noting that less likely alternatives can be found in Table 3 and that the material in both tables is uncertain if post-mine soil conditions vary from the pre-mine soils naturally associated with the community. In the second case, the reclamation ecologist will refer to Table 5 to determine the environment best suited for the community he seeks to install. While the qualifier for soil condition may at first seem irksome, the skilled ecologist/engineer will recognize that he can modify environments to his advantage by modifying soil qualities. Modifiable qualities include those which affect runoff, vertical distribution of retained water, and vegetation flammability.

CONCLUSIONS

We show that the prairie/steppe vegetation is correlated with precipitation zone, aspect, and position. Study of natural vegetation environment correlation (VHA) predicts the vegetation most likely to succeed in a particular precipitation zone and aspect. Alternatively it suggests environmental qualities to emphasize in creating sites for particular vegetation types. In contrast we suspect that position effects are more difficult to interpret. They are probably due more to substrate than to slope and thus vegetation will follow the 'topsoil' installed, whether it is the traditional loam (favoring grasses) or a rockier mixture (favoring trees and shrubs).

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Table 1. Characteristics, location, and sampling of the study sites.

	Kinsey	Absaloka	Otter Creek	Source
Substrate	Ft Union	Ft Union	Ft Union	1
Ave ann pptn.	13"	15"	17"	1
Ave ann temp. (°C)				1
Ave Jan max/min (°C)				
Ave July max/min (°C)				
Regional vegetation	Bogr	Mixed	Pine	2
Air photos	(NAIP). 2005	(NAIP). 2005	(NAIP). 2005	
USGS quad cover	Kinsey	Wolf School	Otter	
NW corner				
UTM northing	5,163,795	5,082,579	5,012,245	
UTM easting	442,548	334,904	400,860	
SE corner				
UTM northing	5,149,749	5,068,057	344,999	
UTM easting	452,084	4,995,372	413,091	
Sample strip interval (m)	95m	143m	122m	
Points				
Total	476	419	343	
Top	25	29	25	
N shoulder	29	30	23	
N slope	35	35	28	
N toe	19	35	24	
E shoulder	27	34	23	
E slope	35	34	29	
E toe	30	33	20	
W shoulder	33	36	25	
W slope	33	36	27	
W toe	39	32	23	
S shoulder	28	31	20	
S slope	27	32	28	
S toe	26	26	21	
Bottom	33	33	27	

[1] Natural Resource Information System (NRIS). 2006. Montana Geographic Information Clearinghouse. http://nris.mt.gov/gis/.

[2] Kuchler 1964 Kuchler, A. 1964 Potential natural vegetation of the conterminous US. Amer Geogr Soc Special Pub 36.NY, 116 pgs.

[3] National Agricultural Imagery Program (NAIP). 2005. USDA Farm Services Agency Aerial Photography Field Office. http://www.apfo.usda.gov.

Table 2. Vegetation types observed/recorded in three precipitation zones, 13” (Kinsey), 15” (Absaloka), and 17” (Otter Creek)

Vegetation Type	**Description**	**Sites Where Present**
Sparse vegetation	Mostly bare soil or rock, <10% total vegetation cover.	13”, 15”, and 17”
Juniperus 1	<50% cover, open canopy, grass/forb or shrub understory.	13”
Juniperus 2	>50% cover, closed canopy, grass/forb or shrub understory. This type is rare (points), more north facing than juniper 1, and is therefore pooled with juniper 1.	13”
Dry shrub	This vegetation may include A. cana, A. tridentata, Atriplex sp., Sarcobatus vermiculatus, Rhus trilobata, Juniperus horizontalis and/or scattered Juniperus scopulorum . Dry shrub is distinguished from the Artemisia/ grass by its low (<20%) vegetation cover. While the type undoubtedly contains distinct sub-types, we could not confidently distinguish communities dominated by different shrub species on our images.	13”
Artemisia/grass	Either A. cana or A. tridentata is dominant (approximately >20% cover), with grass/forb understory. This class has higher cover than the preceding “dry shrub” class.	13”, 15:, and 17”
Grass/herbaceous	Grass or forbs are dominant and tree/shrub cover is <20% .	13”, 15:, and 17”
Rhus trilobata	Rhus >20% cover with other shrub species often present but with less cover. Grass/forb understory.	15” and 17” , if 13” recorded in dry shrub
P. ponderosa 1	Pine <50% cover, open parklike canopy, grass/forb or shrub understory.	15’ and 17”
P. ponderosa 2	Pine >50% cover, relatively closed canopy, grass/forb or shrub understory.	15” and 17”
Riparian herb	This type contained five points, is not distinguishable from grass-forb, and was therefore pooled with grass-herb..	15”
Riparian low shrub	Symphoricarpos occidentalis is dominant.	15” and 17”
Riparian tall shrub	Prunus virginiana and/or Crataegus sp. dominant, might be some Salix sp.	15” and 17” check Kinsey
Riparian deciduous	Fraxinus pennsylvanica, Acer negundo, and/or Salix amygdaloides trees dominate. This contains few ( ) points and is therefore pooled with tall shrub.	15” and 17” check Kinsey

Table 3. Location of major vegetation types in fields of precipitation (13”, 15”, and 17”), aspect (N,E,W,S, and level), and landscape position (top, shoulder, mid-slope, toe, and bottom), SE Montana. (RAW DATA). Cell contents record actual frequencies of vegetation in each precipitation, aspect, position. Expected frequencies are higher (see text)

	XERIC															MESIC									
	Juniper					Dry shrub					Sparse					Artemisia-grass					Grass-herb				
POS	N	E	W	S	0	N	E	W	S	0	N	E	W	S	0	N	E	W	S	0	N	E	W	S	0
Kinsey, 13" ppn.																									
Top	.	.	.	.	.	.	.	.	.	3	.	.	.	.	3	.	.	.	.	11	.	.	.	.	8
Shoulder	8	1	1	.	.	7	8	12	9	.	4	5	4	9	.	8	9	14	7	.	2	4	1	3	.
Mid	9	.	3	.	.	5	3	7	4	.	.	3	3	5	.	15	23	13	10	.	4	6	6	8	.
Toe	10	3	.	1	.	1	1	3	7	.	.	1	3	5	.	6	19	24	9	.	1	4	8	1	.
Bottom	.	.	.	.	1	.	.	.	.	.	.	.	.	.	7	.	.	.	.	15	.	.	.	.	10
Absaloka, 13" ppn.																									
Top	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	5	.	.	.	.	3
Shoulder	.	.	.	.	.	.	.	.	.	.	.	2	1	4	.	3	4	1	2	.	.	1	.	.	.
Mid	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	7	19	10	14	.	1	3	2	2	.
Toe	.	.	.	.	.	.	.	.	.	.	.	2	.	3	.	7	9	10	7	.	4	2	3	5	.
Bottom	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8	.	.	.	.	9
Otter Cr. 17" ppn.																									
Top	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	.	.	.	.	19
Shoulder	.	.	.	.	.	.	.	.	.	.	.	1	.	9	.	.	.	.	.	.	.	3	1	3	.
Mid	.	.	.	.	.	.	.	.	.	.	.	.	1	8	.	.	2	1	.	.	1	7	9	9	.
Toe	.	.	.	.	.	.	.	.	.	.	.	.	.	5	.	.	.	.	2	.	8	11	14	11	.
Bottom	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	19

	MOISTER															RIPARIAN									
	Rhus					Pine >50% cvr					Pine <50% cvr					Ripr., short shrb					Ripr., tall shrb				
POS	N	E	W	S	0	N	E	W	S	0	N	E	W	S	0	N	E	W	S	0	N	E	W	S	0
Kinsey, 13" ppn.																									
Top	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Shoulder	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.
Mid	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	.	1	.	.	.	.	.	.	.
Toe	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	2	1	3	.	.	.	.	.	.
Bottom	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Absaloka, 13" ppn.																									
Top	.	.	.	.	3	.	.	.	.	.	.	.	.	.	17	.	.	.	.	1	.	.	.	.	.
Shoulder	2	5	14	15	.	5	.	.	.	.	20	22	20	10	.	.	.	.	.	.	.	.	.	.	.
Mid	.	4	5	13	.	6	.	1	.	.	21	8	17	3	.	.	.	1	.	.	.	.	.	.	.
Toe	.	.	1	3	.	3	1	1	.	.	13	3	6	3	.	4	12	5	3	.	4	4	6	2	.
Bottom	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8	.	.	.	.	8
Otter Cr. 17" ppn.																									
Top	.	.	.	.	1	.	.	.	.	.	.	.	.	.	3	.	.	.	.	.	.	.	.	.	.
Shoulder	.	2	2	2	.	11	3	1	.	.	12	14	21	6	.	.	.	.	.	.	.	.	.	.	.
Mid	.	1	.	5	.	13	2	3	.	.	14	17	13	6	.	.	.	.	.	.	.	.	.	.	.
Toe	.	.	.	1	.	8	3	2	.	.	7	6	6	2	.	.	.	.	.	.	1	.	1	.	.
Bottom	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8

[1] Samples were taken on sites with little disturbed vegetation/ soils on a single geologic formation (Ft Union) near Kinsey (13”), Absaloka (15”) and Otter Creek (17”) Montana.

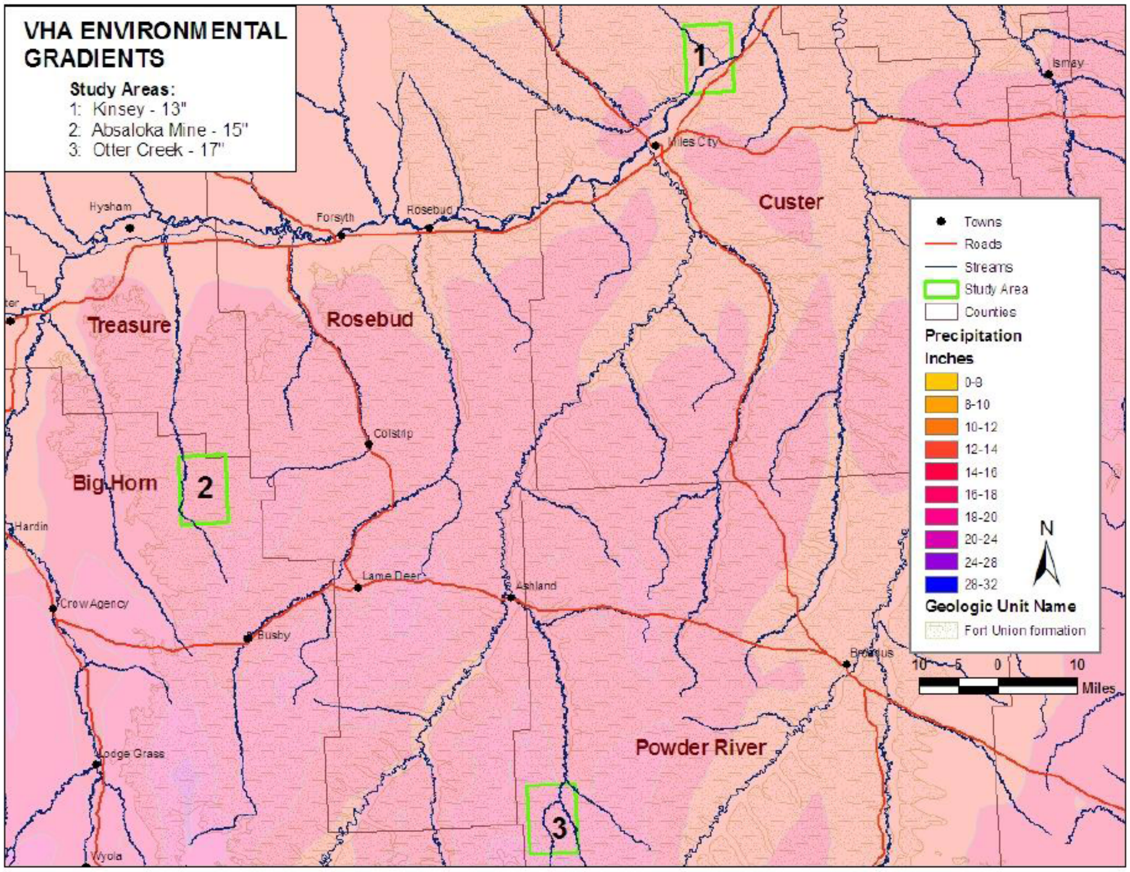
Table 4. Most likely vegetation choices for fourteen landscape segments, on natural soils in the 15" rainfall belt, SE Montana. See notes below[1,2].

Position[1]	Aspect[1]	Cli-vegetation I[2]	Cli- vegetation II[2]
Top	0	Pine <50%	--
Shoulder	N	Pine <50%	--
	E	Pine <50%,	Rhus
	W	Rhus	Pine <50%
	S	Pine <50%	--
Mid	N	Pine <50%	--
	E	*Artemisia*-grassl	Pine <50%
	W	Pine <50%	*Artemisia*-grassland
	S	*Artemisia*- grassland	Rhus
Toe	N	Pine <50%	*Artemisia*-grassland
	E	Pine <50%	SRS (snowberry) or *Artemisia*- grassland
	W	*Artemisia*-grassl	Pine <50%
	S	*Artemisia*-grassl	--
Bottom	0	Grass-herb	[Riparian, short or tall]

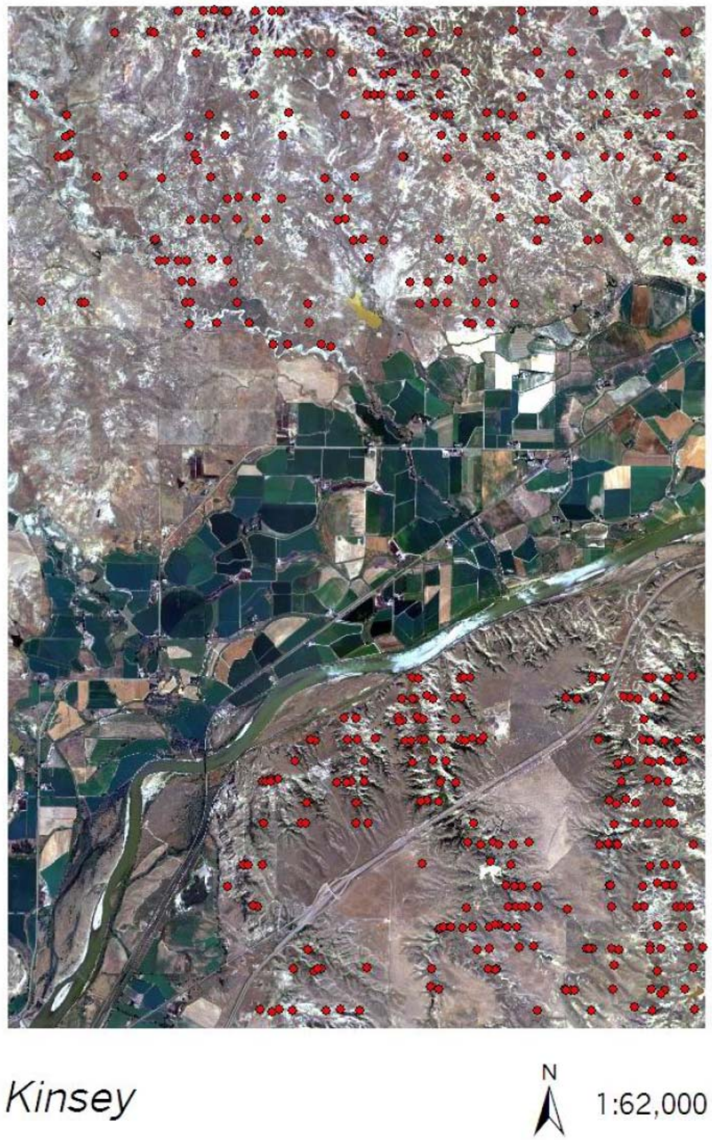
[1]Landscape segments are compounds of position (top, shoulder, mid slope, toe, and bottom) and aspect (N,E, W, S, and level).
[2]The pre-mine vegetation (Cli I) most likely on a site is specified. The most likely alternate is also specified (Cli II). Other less likely alternates may be available, see Table 3. Pre-mine soil quality is confounded with position and aspect.. The vegetation best suited for a position in a post-mine landscape unit may be modified if soil quality is modified.

Table 5. Most favorable sites for installation of SE Montana vegetation types in the 15” rainfall zone. It is assumed (perhaps falsely) that post-mine soils are like pre-mine soils. Selection among the choices offered (and others) will be facilitated by review of Table 3. The site best suited for a vegetation type may be modified if soil quality is modified.

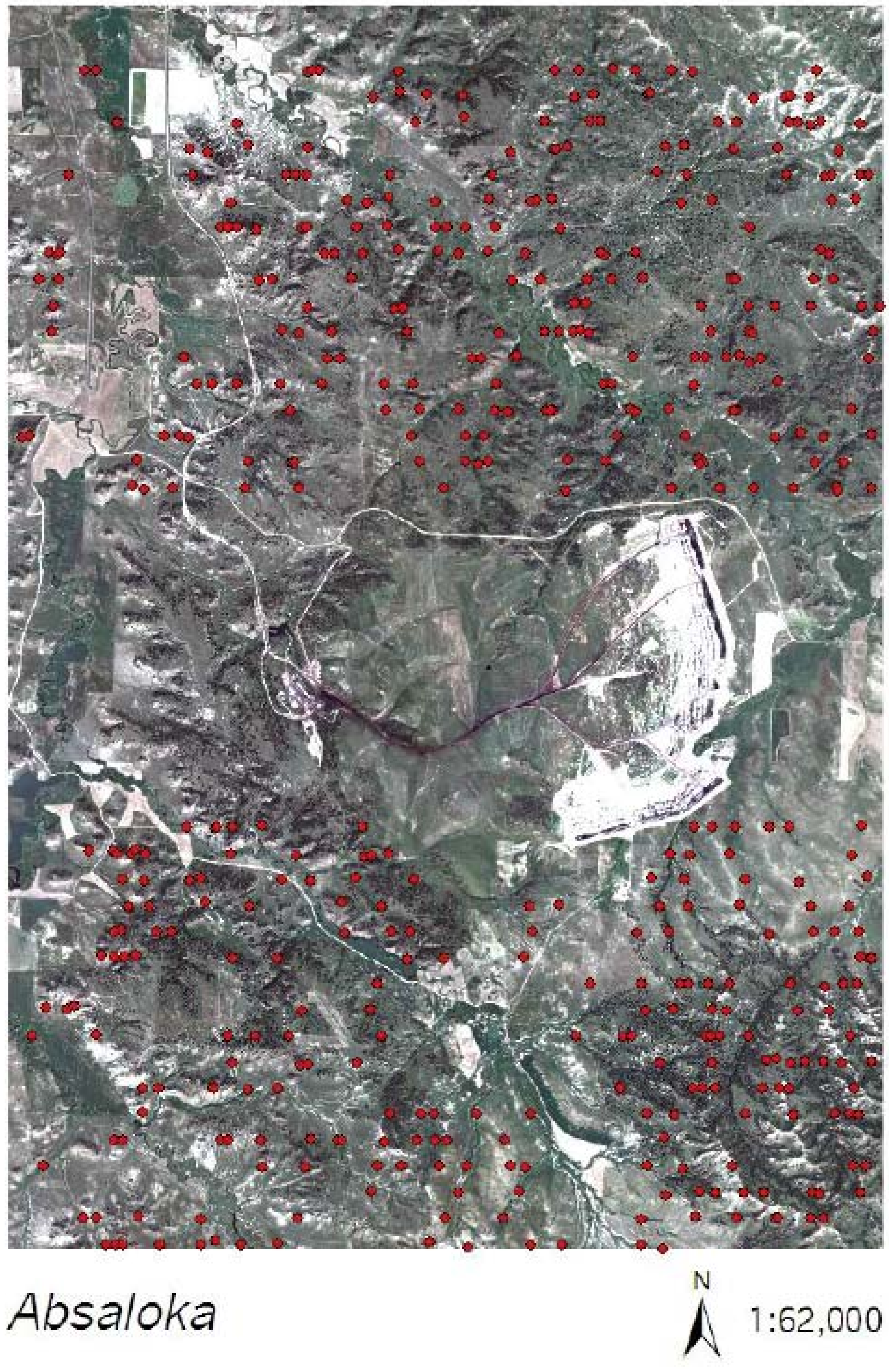
Vegetation type.	Landscape position and aspect.
Juniper	- -
Dry shrub	- -
Sparse	Shoulder, south or east
Artemisia-grass	Mid-slope and toes, E, W or S.
Grass-herb	Bottoms
Rhus	Soulders and slopes, W or S.
Pine >50%	Mid-slope especially N
Pine <50%	Mid-slopes and shoulders, esp North facing
	Upper lopes, especially N,E, and W
Low riparian (snowb)	Toes (E) and bottoms.
Tall riparian (Prunus)	Bottoms and toes.



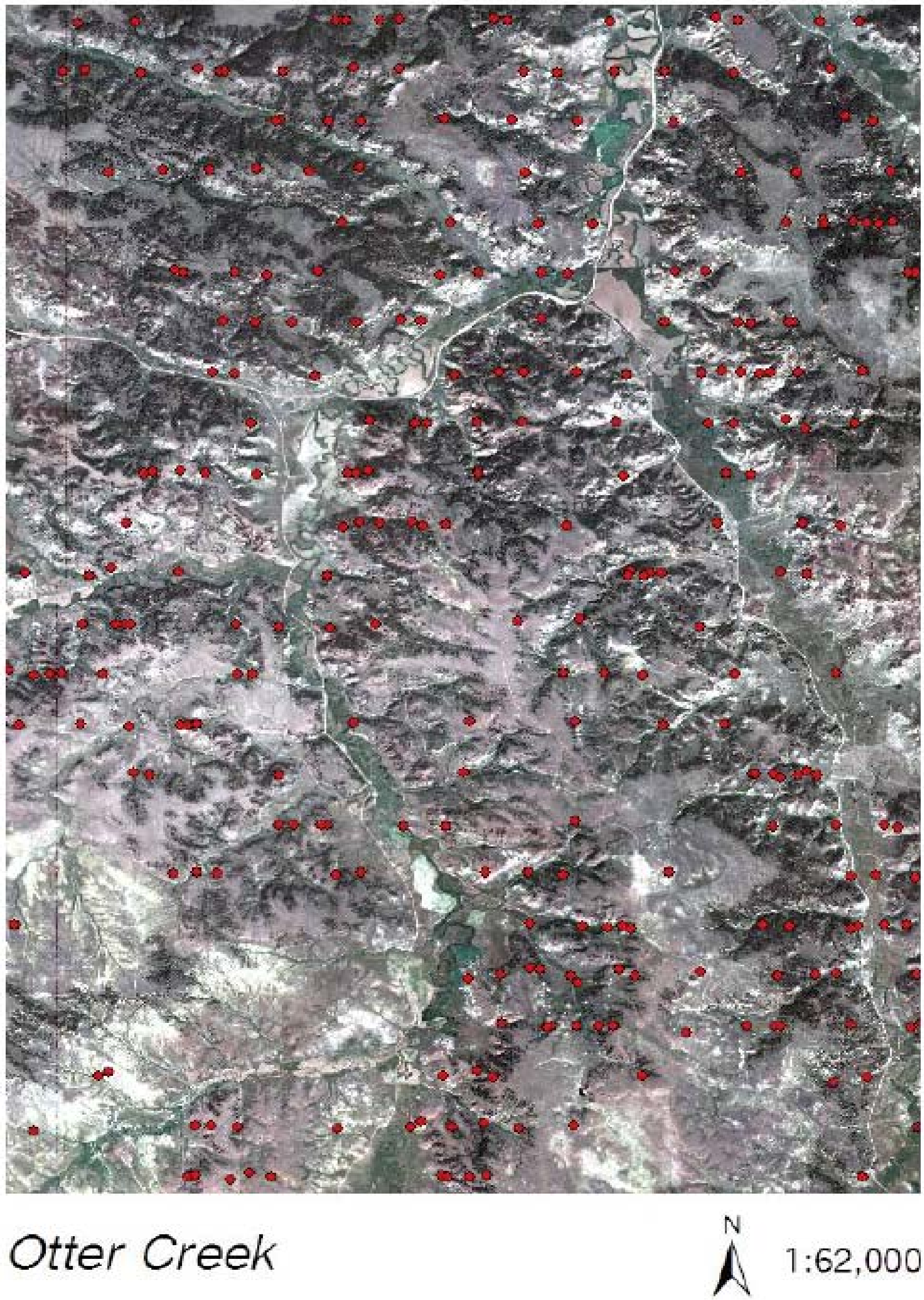
Appendix figure 1. Location of the sample sites in fields of geology and precipitation. Sites 1, 2, and 3 are Kinsey, Absaloka, and Otter Creek. All lie on the Fort Union formation (hatched). Colors indicate rainfall belts for Kinsey (13"=tan), Absaloka (15"=pink), and Otter Creek (17"=lavender).



Appendix figure 2a. Remote image of the 13” site (Kinsey). The shaded background shows the landform and faint points locate the actual 100m^2 study plots. Irrigated and riparian sites near the Yellowstone river (center) were not sampled.



Appendix figure 2b. Remote image of the 15" rainfall site (Absaloka). Disturbed areas associated with the mine were not sampled. Actual 100 m^2 sample points are indicated.



Appendix figure 2c. Location of the study points at the 17" (Otter Creek) site. The shaded background shows the landform and faint points locate the actual 100m^2 study plots.

Chapter 2, VHA task 1.

CLASSIFICATION OF VEGETATION AT THE ABSALOKA MINE- - A PRELUDE TO VHA ANALYSIS.

T. Weaver and K. Aho

12 April 2006

INTRODUCTION.

Understanding the influence of environment on vegetation (vegetation-habitat-association) is needed both to choose vegetation most likely to succeed in particular facets of the landscape (meso-environments). And to create sites (meso-environments) needed to establish specific vegetation types desired.

Analysis of vegetation-habitat-association must begin with identification of pre-mine vegetation types occupying the area. It will then progress to correlating (modeling) the presence of vegetation types, one-by-one, with landscape factors or factor complexes. Landscape factors are land features (e.g. slope, aspect, and soil type) which determine proximal physiologic factors (e.g. water and nutrient availability).

Objective one (Task 1) of our project is to classify the vegetation of the Absaloka site (our VHA test area) as a basis for correlating each vegetation type present with landscape factors which support it/allow it. The classification is to be based on community composition (species presence and cover) of vegetation measured at over 800 points, an outstanding sample. This report describes our methods and results.

METHODS.

Study area. Our study area includes the 1991 Absaloka Tract 3 East, 2003 Tract 3 South, and 2005 south extension baseline study areas. The combined (three) datasets filled a data matrix with 810 plots and 357 species.

Sampling. Western Technologies (Westech), Helena MT., was contracted by Westmoreland Resources to inventory vegetation from the study area. A large number of community types (§50, Appendix 1) were subjectively identified by the consultants at the three sampled areas. Sample sizes for communities were based on professional judgment and sample adequacy formulae (Westech 1992). Ocular estimation of canopy cover for species was made using 0.1 acre circular plots, each centered on a randomly selected point in a prescribed community type. Tree density was measured by recording all individuals by species and class sizes in 0.1-acre circular plots encircling the same random point used for canopy estimates. Shrub density was estimated by six 0.001 acre circular plots distributed randomly within the 0.1-acre plot used for tree densities measurements.

Ordination. Non-Metric Multidimensional Scaling (NMDS, Kruskal 1964) was used to create ordinations from canopy cover data. Although random starting points were also tried, lowest stress non-metric multidimensional (NMDS) solutions resulted from using PCoA (Principal Coordinates Analysis) scores as initial starting points (cf. Roberts 2005). Bray-Curtis dissimilarity (Faith et al. 1987) was used to create the dissimilarity matrix. A tolerance of 10^{-7} was used with 200 iterations (cf. McCune and Grace 2002). Additional ordination dimensions are not used after the final stress of an NMDS solution drops below 21 (McCune and Grace 2002). Stress is the departure from monotonicity in the plot of distance in the original *n*-dimensional space versus distance in the NMDS ordination space (McCune and Grace 2002). NMDS ordinations were run in R using MASS (Venables and Ripley 2005) and vegan (Oksanen 2005) packages.

Classification. Flexible β hierarchical agglomerative clustering was used to classify the data (Aho et al. 2005a, Aho 2006, and Aho et al. 2006). The value β = -0.25 was used to yield results similar to Ward's method (Ward 1963), which is effective and space-conserving, but is incompatible with non-Euclidean distances (McCune and Grace 2002). Bray-Curtis dissimilarity (Faith et al. 1987) was used to create the dissimilarity matrix. Wishart's objective function (Wishart 1969) was used to scale the cluster dendrogram. Classifications were run using PC-ORD software (McCune and Mefford 1999).

<u>Pruning analysis.</u> Heirarchical trees were pruned at optimal pruning levels (i.e. optimal numbers of clusters),based on the consensus of eight different classification evaluators. These were: Average silhouette width (ASW, Rousseeuw 1987), PARTANA ratio (Roberts 2005), C-index (Hubert and Levin 1975), gamma (Goodman and Kruskal 1954), point-biserial correlation (Brogden 1949), indicator species analysis (ISA) average *p*-value (Dufrêne and Legendre 1997), and ISA significant indicators (Dufrêne and Legendre 1997), an adapted form of Morisita's index (Horn 1966), and indicator species analysis minimizing intermediate constancies (ISAMIC, Roberts 2005). These algorithms are thoroughly explained in Aho et al. (2006). Their uses as pruning evaluators are explained in Aho (2006) and Aho et al. (2005a, 2005b). The pruning algorithms were coded using the R language (R development core team 2006).

RESULTS

Communities of the Absaloka area vary as their environments range from very dry to very wet. And within this sequence vegetation is apparently further differentiated by soil texture and slope position (runoff). We hypothesize that the availability of water is determined by energy availability (slope/aspect), slope position (run-off), and reservoir quality (soil texture).

An ordination of the community data shows a diffuse, but structured cloud (Fig 1a) and is statistically sound. 1) Communities at its top form an arc in which open pine forests with understories of either FIED *(Festuca idahoensis)* or AGSP *(Agropyron spicatum)* appear on the left. AGSP fades into dry grasslands (STCO, *Stipa comata)* at the apex. *Stipa* fades down and to the right into slope-toe AGSM-STVI (Agropyron smithii-Stipa viridula) and seemingly on into old field vegetation. At the center of the cloud the *Symphoricarpos* (SYOC) community connects the dry grasslands (STCO and AGSM-STVI) to wet communities below, i.e. stream bottom (PRVI = *Prunus virginiana)* and ponded (SPPE = *Spartina pectinata).* The series arches because the SYOC community is bound (loosely) to the pine complex as well as to the dry slope-toe community. While the old field community seems to be tied to the STCO and AGSM communities, inspection of the second plane shows it to be the most discrete community cluster

(Fig 1b). 2) Stress for the NMDS ordination was surprisingly low (17), particularly given the size of the dataset, and indicated a usable projection with little risk of drawing false inference (Fig 1).

A hierarchical (flexible beta) classification of the data was used to segment the variation shown in the ordination (Fig 2c). The classification divided it stepwise into segments, i.e. first two, then successively more.

Eight objective tests were used to determine an optimal number of classes. An optimum recognizes basic variation, but without dividing the spectrum into an unmanageable number of indistinguishable types. We judged that optimum to be eight classes (Fig 2a). Our pruning was mechanically performed using standard evaluation techniques as refined by Aho (2006). The eight evaluators were transformed (to standardize maximum scores as optimum) and normalized (to facilitate comparison and allow averaging). In the simplest treatment the optimum pruning level(s) is shown as a peak(s) in a graph(s) of 'evaluation score' against cluster number (Fig 3a). We tried integrating evaluator opinion by averaging the standardized scores across evaluators (Fig 3b). This averaging of direct (raw) evaluator scores is problematic because the evaluators fall into two groups, those in which scores rise or fall at across class number at higher levels. Thus, we prefer a somewhat more complicated 'detrended' approach. The divergence was eliminated by graphing the quantity (divergence of evaluator score from a regression of score against cluster number) against cluster number (Fig 4), for both single (4a) and averaged evaluator scores (4b). Vertical dashed lines in both methods (Fig 3b and Fig 4b) indicate that the simplest adequate and optimum solution is eight clusters (Fig 3b and 4b). Note that solutions near twelve clusters are poor (Fig 4b) and that there is a secondary optimum near sixteen clusters (Fig 4b).

While we have pruned the classification at eight types (Figs. 2-3), the communities identified are not perfectly homogeneous. This may be demonstrated by examining the driest and wettest types (Tables 2-4). While appearance (physiognomy) of the driest type is determined by a few ever-present species (STCO, BOGR, *Spharalcea coccinea)* some plants present indicate relatively dry examples (e.g. *Opuntia fragilis)* and some indicate relatively moist examples (e.g. ANGE). While members of the wettest community are united by the presence of *Spartina pectinata* (mostly), the driest third *(Hordeum jubatum)* and wettest third *(Equisetum laevigatum* and *Scirpus americana)* are 'abnormal'. We respect the work of a splitter (K. Skow, Westech) who, in examining the same data set, subjectively recognized fifty community types (Appendix 1), a number which simultaneously describes variation in the vegetation in more detail and recognizes more community types than the reclamation ecologist wishes to install. The paradox of micro/macro communities may be best solved by planting diverse seed mixes appropriate to specific meso-environments and providing time for differentiation of the appropriate community variant.

We introduce the eight communities recognized with an outline key (Table 1.) The key arranges natural vegetation on a dry-wet gradient and segments the gradient by environmental family, e.g. upland, mesic, and hydric.

Table 1. Outline key to the eight community types identified.

A_1. Union I (AGCR and BRJA) well represented.	*OLD FIELD*
A_2. Union I poorly represented.	
B_1. Union C (e.g. STCO, BOCU,SPCO, GACO) well represented.	**Grassland**
C_1. Union G (e.g. POPR, ALAL, RACO, SYOC) absent.	**Upland grassland**
D_1. Trees and shrubs (e.g. PIPO, RHTR, YUGL absent)	*STCO.*
D_2. Trees, shrubs and FEID or AGSP present	**Savanna or grassland.**
E_1. AGSP present, FEID slight, PIPO & RHTR present.	*AGSP savanna*
E_2. FEID present, PIPO &RHTR present	*FEID savanna*
C_2. Union G (e.g. POPR, ALAL, RACO, SYOC) present.	*AGSM/STVI.*
B_1. Union C (e.g. STCO, BOCU,SPCO, GACO) poorly represented.	**Mesic/hydric**
C_1. Shrubs well represented	
D_1. Short shrubs only (e.g. SYOC and ROWO.)	*SYOC*
D_2. Taller shrubs (e.g. *Prunus, Ribes, Crategus*), even ACER	**Riparian**
C_2. Shrubs poorly represented (except Rosa), *Spartina* present.	*SPPE 'ponds'*

To facilitate discussion, we ordered the eight community types recognized linearly on a hypothetical water gradient. 1) Upland grassy communities range from STCO through AGSP/PIPO to FEID/ PIPO (Tables 3-4). Each upland community type contains several species (a union, defined below) which are significantly more common in it than in the other two grasslands. We hypothesize that *Pinus ponderosa* in two of the grassy types is associated with increased effective (deep/total) water availability due to coarser soils (deeper penetration and perhaps greater storage) and/or cooler conditions (reduced consumption). 2) The AGSM type stands between the upland grassy communities and the lowland types. It has no unique species. Run-in water likely imports clay (relating it to the STCO community and wets its soils (relating it to the riparian). 3) Three lowland communities, each with semi-unique subdominants, receive still more run-in water. They seem to be differentiated by (are correlated with) differences in the reservoirs that hold their water: deep soil (SYOC), gravel (PRVI), and ponds (SPPE). Finally, the eighth community type (AGCR) occupies old fields and or mine reclamation seeded to this exotic species. 4) *While some of the hypotheses presented are 'old standards' VHA will subject them to 'best ever' tests by calculating community/environmental correlations with the proposed conditions.*

The community types are best [= most easily] described by reference to nine unions (groups of species in groups 'A-I' in Table l. 1) Unions are groups of species tending to be found together, presumably due to common environmental requirements. 2) For example, the union 'C' uniting the grasslands includes *Stipa comata* and *Bouteloua curtipendula*. The grasslands are united with each other and with the driest riparian type by union 'D' which includes plants with slightly greater water demands (e.g. *Agropyron smithii, Stipa viridula* and *Artemisia ludoviciana*). 3) The three upland prairie types are distinguished by unions 'A' and 'B.' Union 'A' (e.g. *Opuntia fragilis*) is most prevalent in dry *Stipa* grasslands. Shaded species in union 'B- column 2' (e.g. *Agropyron spicatum, Rhus trilobata*, and *Pinus ponderosa*) characterize the *Pinus/Agropyron* community. Shaded species in union 'B- column 3' (e.g. *Festuca idahoensis, Rhus trilobata,* and *Pinus ponderosa*) characterize the *Festuca/Pinus* community. 4) Slope toe grasslands are recognized by high *Agropyron smithii* cover, plants of union 'E', and the appearance of plants of union 'F' (e.g. *Poa pratensis**, Ratibida columnifera, and Alyssum alyssoides*). The plants of union 'E' as well as *Bouteloua gracilis*, Poa secunda, *Sphaeralcea coccinea* and *Gaura coccinea* of union 'C', link slope toe and *Stipa comata* grasslands, probably because the clay-rich soils of their environments hold water within reach of these shallow rooted plants. 5) Mesic-hydric communities are linked by species of union 'G'. The streamside community (*Symphoricarpos* is dominated by S*ymphoricarpos occidentalis, Rosa woodsii,* and *Poa pratensis** The instream community *Prunus virginiana* contains these species (union 'F') as well as shrubs of union 'G' (e.g. *Prunus, Ribes*, and *Crategus*). The seasonally flooded *Spartina* community includes species of union 'H' (e.g. *Spartina pectinata, Hordeum jubatum,* and *Equisetum laevigatum*). 6) Old fields are dominated by the exotics *Agropyron cristatum* and *Bromus japonicus*.

<u>The communities.</u> The eight communities recognized are elaborately described with species lists quantified with constancy and frequency data (Tables 3a, 3b, and 4). The codes corresponding to a species (e.g. 6E) indicate their constancy and cover (see Tables 3a, 3b, and 4). Constancy (the numeric code) measures the universality of the species, i.e. the percentage of samples within a community which contain the species. Cover (the alphabetic code) is the average, over all examples of the community, of the percent of the ground covered (vertical projection) by the species. The constancy and cover classes are keyed at the bottom of Tables 3-4. Asterisked species in the community descriptions below are exotic.

STCO. The STCO community aspect is determined by Stipa comata (const >90,cvr > 25%), other grasses (e.g. *Bouteloua curtipendula, Bouteloua gracilis, Agropyron smithii, Carex pennsylvanica,* and *Bromus japonicus*) , low cover forbs including *Sphaeralcea conccinea,* and a union (A) of relatively high fidelity herbs (A) including *Andropogon scoparius*. While weeds colonize newly established stands, established communities support few weeds aside from *B. japonicus* and *Tragopogon dubius* (Table 3). This association corresponds to Kuchler's type 64. We expect the VHA model to demonstrate that soils of this type are rock free and high in clay.

AGSP/PIPO. The AGSP community is determined by *Agropyron spicatum* (const >90%, cvr 5-25%) other grasses (*Bouteloua curtipendula* and *Bromus japonicus* (E)), low cover forbs (*Phlox hoodii, Achillea millefolium, Tragopogon dubius**), woody plants (*Pinus ponderosa* const >70%, cvr 5-25% and Rhus *trilobata* const >60%, cvr >2%), and species associated with the pines (Union B). Weeds are few but include *Bromus japonicus** and *Tragopogon dubius**). This type corresponds to Kuchler's (1964) types 63 and 16. The VHA model will likely show that soils of this type are relatively rocky/sandy.

FEID/PIPO. The FEID community is determined by *Festuca idahoensis* (const > 70%, cvr 5-25%), woodies (*Pinus* ponderosa (const.90%, cvr >25%) and *Rhus trilobata* (const> 50%, cvr 2-5%) and species associated with the woodies (Union B). Weeds are few (e.g. *Bromus japonicus** and *Tragopogon dubius**). This type corresponds to Kuchler's (1964) types 63 and 16. The VHA model will surely show that soils of this type are relatively rocky/sandy.

AGSM/STVI. The AGSM type is determined by *Agropyron smithii* (const >80%, cvr 5-25%), other grasses (e.g. *Bouteloua gracilis*), forb/shrub with low cover (*Artemisia cana*, *Sphaeralcea coccinea*, *Gaura coccinea*), and available plants of unions E-F (*Plantago patagonica*, *Poa pratensis**, *Alyssum alyssoides**). Woodies are notably absent, perhaps because clay-rich run-in sites have sparse deep water reserves. In addition to exotics of upland grasslands (e.g. *B. japonicus** and *T. dubius**), shallow rooted exotics (e.g. *Poa pratensis** and *Alyssum alyssoides**) absent from higher/drier sites appear here, perhaps supported by water stored in fine textured surface soils. While the type appears in drainages everywhere, bands are two narrow to map, except perhaps as a component of the 'riparian' complex of seasonal streams.

SYOC. SYOC is characterized by low shrubs (*Symphoricarpos occidentalis* (const >90%, cvr>25%) often with *Rosa woodsii*), run-in grasses (Unions D-E, including *Agropyron smithii,* *Stipa viridula, Poa pratensis**, and *Bromus japonicus* *). Forbs include *Ratibida columnifera, Achillea millefolium, and Tragopogon dubius*. Exotics include *Poa pratensis*, Bromus japonicus**, and *Tragopogon dubius**.

PRVI. PRVI is an 'in-stream community' characterized by taller shrubs (Union F, *Prunus* (const>60%, cvr 5-25%), *Ribes*, and *Crategus*). It also contains shorter *Symphoricarpos* and *Rosa* from drier sites, and sometimes taller *Acer* (boxelder) trees. Its understory includes rhizomatous grasses (*Poa pratensis** *Elymus virginiana*, and *Bromus japonicus**), as well as coarse forbs such as *Arctium minor**.

SPPE. SPPE usually contains *Spartina pectinata* (const>70%/cvr >25%), and less consistently, graminoids (*Hordeum jubatum* and *Scirpus Americana*) and forbs of Union H. The community is linked to the slope-toe and riparian communities by Agropyron trachycaulum and Poa pratensis. Exotics which occur in more than 30% of the plots examined are *Bromus japonicus**, *Poa pratensis**, *Thlaspi arvensis**, *Melilotus officinalis**, and *Cirsium arvense**.

AGCR. AGCR is the old field community. Its two variants (both visible in a 16 community classification) are dominated by *Agropyron cristatum** (const>90%/cvr >25%) or *Agropyron intermedium**, whichever it was seeded to. Most species of upland grasslands and moister slope-toe and SYOC communities (both native and exotic) occur in old fields. This suggests that they may be 'reclamation candidates' tolerant of upland conditions but excluded by the resource/allelopathic competition of *Agropyron cristatum*.

DISCUSSION.

We have examined variation in the vegetation of the Absaloka site (NMDS ordination, Kruskal 1964), segmented the variation in a hierarchical tree (flexible β agglomerative classification, Lance and Williams 1967), objectively pruned the tree to yield eight types, and compared/ characterized the types with a relevé table and summarized relevé information in capsule descriptions of the communities.

We review the ordination, classification, and especially the pruning methods. Ordination and classification were conducted with techniques which are all established and familiar to us (Aho et al. 2005a, 2005b). Pruning was based on a consensus of eight indicators which are well established and familiar to us (Aho et al. 2006 and Aho 2006). Our agglomerative method combines vegetation samples (plots) in pairs (according to their similarity) and combines pairs/populations successively until, after many steps, all samples are combined into one heterogeneous regional type.

A hierarchical tree must be pruned at an optimal level. Single plot samples, or pairs of samples are useless (as subjects of environmental relations or as guides to planting) because they are too site specific and have too little generality At the other extreme, lumping all plots into one 'regional' type provides no basis for selecting a group of organisms especially fit for an environmentally distinct facet (segment) of the SE Montana landscape. An intermediate eight community pruning best represents the vegetation of the Absaloka site. It segregated the principle vegetation types without excessively subdividing the sample population into groups which are effectively indistinguishable without clear correlation to landscape factors of natural or reclamation landscapes.

At the sub-optimal simplest, our classification recognizes three upland types (STCO, AGSP, and FEID), an intermediate AGSM-STVI type, three lowland types (SYOC, *Prunus,* and *Spartina),* and planted old field vegetation. The four broad types are subdivided into eight optimal (narrower) types (Fig. 4a) indicated parenthetically in the preceding sentence. The relative homogeneity of the eight types is demonstrated by splitting supra-optimally to sixteen types (Fig. 4b) and observing which of the eight types is subdivided: STCO (3x the number of branches), AGSP-PIPO (1), FEIDPIPO (2x), AGSM (1), SYOC (1), *Prunus (3x), Spartina (2x),* and Old field (2x). That is, the STCO and PRVI types contain more internal variation than do the

AGSP, AGSM, and SYOC types. Supra-optimal splitting can be continued to ridiculous 810 member types (Fig. 4c).

In the VHA analysis we will measure the correlation of one or more landscape features (e.g. slope, aspect, and soil) with each of the eight vegetation types. High correlation will suggest that that landscape factor(s) is necessary for (or prevents) success of the vegetation type. We assume that the high correlation with the landscape factor is due to linked proximal physiological factors, rather than unrelated correlates.

Given more time/resources, one might profitably re-type the vegetation physiognomically, determine whether the vegetation samples were similarly classified, and determine the degree to which responses to the environment are parallel. This is desirable and may be explored, but is not contracted.

We note that while this classification was made for VHA application, it can and may be used for non-VHA projects. 1) I might be used to suggest dominants and codominants for reclamation seeding. Dominants will be native grasses, and since they will probably compete poorly with initially more aggressive domestics, the successional trajectories of various native/domestic mixes should be tested before seeding them. A list of 'companions' will press us to develop appropriate seed sources. 2) Examination of old field communities will suggest which species will (and won't) establish well in reclamation plantings, intended to be seral communities eventually yielding to climax communities. 3) Study of exotic distribution in the relevé table may suggest control strategies possibly involving pre-emergent herbicides, season of planting, and resource enrichment.

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Chapter 3, VHA task 2

GIS OF THE ABSALOKA MINE.

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Abstract. This report provides a pilot project GIS for the Absaloka mine area (73 km^2), SE Montana (45^o 48’ N Latitude, 107^o 2’ west Longitude). The primary layers include three indicators of vegetation type (Absaloka subjective and 8-16 type computed), four field-measured environmental qualities (GIS location, slope, slope position, aspect, soil texture), several more environmental measurements drawn from the public domain (e.g. slope, aspect, soil type, clay content, soil water storage capacity, and range site) and a calculated slope position. This information will be used to model relationships between plant communities and environmental correlates (‘factors’, VHA tasks 4 &5). In addition we will use redundant data on slope and aspect derived from field measures, a 10m DEM, and a 30m DEM to determine the applicability of relatively coarse data drawn from the public domain to fine scale reclamation tasks (VHA, task 3).

Key words: Absaloka GIS, SE Montana, steppe vegetation, forest vegetation, environment, vegetation- habitat-association (VHA), reclamation of disturbed vegetation, coal mining, gas/oil drilling. vegetation types (Agsm, Stco, Agsp, old field, Pipo-Agsp, Pipo-Feid, Syoc, Prvi and Sppe etc) and controlling factors (e.g. slope, aspect, and soil water storage capacity)

INTRODUCTION.

The object of VHA analysis is to relate (correlate) late seral (climax) vegetation types to the environments they occupy. We have chosen the area surrounding the Absaloka mine as a pilot project 'test site', because the area has an especially large set of readily available pre-mine samples gathered by one firm and using one set of methods (WESTECH 1992, 2004, 2006).

We make these correlations as a basis for siting of 'reclamation' vegetation types in the post-mine landscape *(i.e.* vegetating a particular site or providing the environment for a particular community). In doing so we assume that vegetation and environment have a 1:1 relationship. The assumption is based, in turn, on the belief that every vegetation type requires certain conditions and cannot survive without them *(cf.* Daubenmire 1968, Holdridge 1947). At the physiological level the required conditions include suitable supplies of material *(e.g.* water and nutrients) and energy (e.g. heat and light). At the landscape level these conditions include landscape features that determine the availability of required materials (e.g. inputs of rain and losses related to slope, aspect, and deep drainage) and energy *(e.g.* slope and aspect). We offer two qualifiers. First, in addition to the requirements for a particular resource, the 1:1 relationship could be determined by an influence of the community on its environment *(e.g.* modification of landforms and substrates by vegetation-induced reduction of erosion, vegetation induced deposition, or vegetation induced improvement of nutrients or soil water storage capacity by deposition of organic matter). Second, while the 1:1 relationship holds for most near-climax vegetation, early seral vegetation is less responsive to its environment. This is true because seral vegetation is adapted to opportunistically occupy disturbed sites at least temporarily and it survives, in part, due to the broad tolerances of its plants. The second qualifier is less important in little disturbed landscapes *(e,g.* mountainous areas with naturally disturbance/fire-protected areas) than in heavily disturbed areas *(e.g.* in grasslands where fires travel long distances, grazing is routine and often intense and a large percentage of the landscape may be covered by seral vegetation).

The Absaloka GIS has been constructed to compile four sorts of data needed to develop the VHA analysis (Task 4). 1) It locates ~ 800 points being studied. 2) It identifies the vegetation of those ~800 points, points well distributed (stratified) over geography (segments of the mine) and vegetation types appearing within the geographic segments. 3) It files, for the same points, environmental qualities (presumptive landscape level factors) we have contracted to correlate with vegetation. These include field-gathered slope, aspect, position and soil texture data. 4) It files, for the same points, data on other possible factors for which information is available in the public domain. These include slope and aspect, NRCS soil types, NRCS soil water storage capacity, and depth to bedrock.

Note that the GIS contains some 'redundant' measures to be used for evaluating/ comparing the value of different pilot project data sets. Most important are measures of environmental quality (slope, aspect and soil texture) measured on the ground and derived from digital elevation models (DEMs). In VHA task 3, we will regress measures of environmental quality drawn from 'public' data against on-the-ground measures to determine the applicability of data drawn from the public domain for use in siting vegetation on a fine scale in mine reclamation.

METHODS.

The study site. The Absaloka mine (Westmoreland Coal Company, PO Box 449 Hardin MT, 59034) is located at 45°48'16" N 107° 2'59" W, elevation 1117m, between Colstrip and Hardin MT. Annual precipitation averages 13.9 ", with 6.6" falling in March- June (in-mine data). Average temperatures (mean/high/low) at nearby Colstrip are in January 22/37/14F and in July 71/85/55 (USDC 2003). Climatic data for the region are more generally summarized by Weaver (1980). Soils are in the Wibaux-Thedalund-Spearman association; they are 8-40 inches deep, loamy with 0-35% rock (>3"), and mildly alkaline (pH 6.6-7.8) (USDA 1977). Bedrock is shale/sandstone of the of the Fort Union formation (USGS 1999).

Vegetation. Vegetation data was collected by Westech Inc. in 1991, 2003, and 2005 from three segments of the mining permitted area, that is, Tract 3E (254 samples, 1991), Tract 3S (279 samples, 2002) and Tract 3S, south extension (278 samples, 2005). Stratified random sampling was used. The vegetation was subjectively classified and multiple 'random' point locations were chosen from each type. The 'randomization' included the requirement that the position of the plots be shifted slightly, if necessary, to avoid within-plot heterogeneity and to eliminate obviously disturbed sites (K. Scow, pers com). The sample sizes for each community were based on 'professional judgement and sample adequacy formulae' (Westech 1992).

The vegetation at each location was sampled with a 0.01acre circular plot (radius 11.8 ft). All plants contained in the plot were listed; nomenclature followed Dorn (1984) as confirmed by the floras of the Pacific Northwest, the Great Plains and the Intermountain area. The canopy cover of all species was ocularly estimated (Brown 1954, Daubenmire 1957, 1968 and Bonham 1989).

NOTE: While data on densities of woody plants were not used in our pilot project classifications, one could use density in constructing a physiognomic classification and in characterization of the vegetation types. Shrub density (stems/acre) in the 0.01acre plot was variously estimated and omitted as not comparable among tracts. Tree density was measured in 0.01 and 0.1 acre (radius 37.2 ft) plots by recording all individuals, by species and size class. Tree cover was estimated as % cover over the 0.01acre perimeter. While possibly useful, neither tree cover nor density were entered.

Vegetation stands were compared (Bray-Curtis dissimilarity, Faith et al. 1987), ordinated , and classified with Flexible β (β = -0.25) hierarchical agglomerative clustering as described by Aho et al. (2005), Aho (2006), and Aho et al.(2006). Classifications were run using PC-ORD software (McCune and Mefford 1999). Wishart's objective function (Wishart 1969) was used to scale the cluster dendrogram. The heirarchical trees were pruned at optimal pruning levels (i.e. optimal numbers of clusters) based on the consensus of eight different classification evaluators. These algorithms are reviewed by Aho et al. (2006). Their uses as pruning evaluators are explained in Aho (2006). The pruning algorithms were coded using the R language (R development core team 2006). Our VHA Task 1 report mentions the (desirable) possibility of extending the project to explore other uncontracted classifications, especially a physiognomic one.

Environment. The location and environmental qualities at the points was recorded in the field. Locations (for 2002 and 2005, not 1991 data) were GPS located. Slope (%), aspect (degrees from north), texture, configuration and topography were recorded (Brunton compass) for all plots. Sand/silt/clay were determined by hand texturing and the presence of gravel was noted.. Bedrock (depth not recorded) was Ft Union shale/sandstone (USGS 1999).

Additional location/environmental data for the points were drawn from data in the public domain (Table 1). 1) A 10m resolution elevation model was derived from CAD hypsographic data commissioned by the mine. Raster elevation data were interpolated from the hypsography using ESRI software. And slope and aspect data were then calculated from the 10m elevation data. 30m resolution USGS DEMs were acquired for the study area, and slope and aspect based upon these models were similarly calculated. 2) Records of soil properties *(e.g.* map unit name, clay content and soil water storage) were obtained from public domain NRCS SSURGO data (Table 1). Water storage was calculated by NRCS, methods not available. Many other soil properties *(e.g.* horizon thickness, stone content, texture, pH, and range site) are 'nested' in map unit names and can be extracted from them. Because they are confounded, individual effects and interactions among them cannot be studied in this pilot work. It may be possible, however, to compare public and field measures of soil texture and to examine interactions of slope and aspect with soil type (or a nested soil quality of soil type such as texture, depth, or organic matter).

RESULTS AND DISCUSSION.

The Absaloka mine is located in Bighorn County in the Wolf Creek School and the 'Jeans fork NE quadrangles (USGS 1999). Our pilot project GIS summarizes data relevant to coal mine reclamation in this area.

Most of our twenty-seven GIS layers are presented in Appendix figures/ subfigures 1-13. Some GIS layers, including all of the 'public domain' data, cover the entire quadrangle. Others cover only the area surveyed by the mine for permitting/management purposes. Contracted point sample data, presented in data files, include location, vegetation type, field environment (slope, aspect, and soil texture). We have added (uncontracted) data from the public domain, and may add more in post-pilot work , in the hope that the additional data will be useful in the identification of environments occupied by pre-mine vegetation types.

The GIS includes information on vegetation and environment (Table 1) that are to be correlated/ used to construct the VHA model **(VHA, task 4).** 1) Vegetation layers identify the vegetation at each of the 811 points, as determined by objective/computer classifications (8 and 16 types VHA, task 1) and by the subjective classification used in Westech's choice of sample locations. 2) We hope field measured environmental data will provide a basis for siting major vegetation types, and/or for creating environments conducive to establishment of targeted vegetation types. Layers for slope, aspect, and soil texture summarize the data for which correlation/ association is contracted, one by one or in combination. 3) We will test (uncontracted) inclusion of other layers (perhaps soil type, soil water storage capacity, range site, bedrock depth, etc) to improve predictions of pre-mine vegetation. While inclusion of these factors may improve predictions of pre-mine vegetation they may be less applicable to siting of post mine vegetation because soil and bedrock quality are modified in the mining/reclamation process.

The GIS also includes information to be used to test the applicability of data from the public domain to our problem. Field sampling and reconstruction is conducted on a relatively fine scale, while 'public' data is often gathered/ distributed on a coarser scale (e.g. 10m-30m). To determine whether the public data is too coarse for VHA use we will regress slope, aspect, and soil texture values from 'public' data against ground truth measures made in the field (VHA, task 3).

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The Absaloka mine (Westmoreland Coal Company, PO Box 449 Hardin MT, 59034) and its contractor (K Scow, Westech, PO Box 3005 Airport Rd. Helena MT, 59601) provided the underlying field data. F. Dougher formatted all of the GIS layers. This included entering field data, gathering public domain data, and creating the 10m DEM from the topographic map provided by the mine. K Aho used field data to perform vegetation classifications which provide the basis for the vegetation layers (mechanical I & II and subjective). T. Weaver organized the reporting. S. Regele (Montana Department of Environmental Quality) and USDI Office of Surface Mining (OSM, T. Blackburn) provided impetus, encouragement and funding for the project. Thanks to all. OSM, through Montana Dept. Envt. Quality, provided monetary support for the work. Thanks to all.

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Table 1. Data layers presented in the Absaloka geographic information system and their sources.

Character	Figure/Table	Source	Comments	Citation/address
		SITE DATA		
Basemap	1	USGS	DOQ	http://nris.state.mt.us/
Man-made features	1	Abs/WESTECH	from CAD data	
Data points	2	Abs/WESTECH		
		VEGETATION		
Vegetation types	t3	Abs/VHA task 1		
		TOPOGRAPHY		
Topographic map	3	Abs/WESTECH	CAD topo lines	
Elevation 10m	4a	Derived, Fig 3		
Elevation 30m	4b	USGS		http://nris.state.mt.us/
Abs point aspect		Direct	Abs/WESTEC	Abs point survey
10m aspect	5a	Derived, Fig3	ArcInfo Interpolation	
30m aspect	5b	USGS		http://nris.state.mt.us/
Abs point slope		Direct	Abs/WESTEC	Abs point survey
10m slope	6a	Derived, Fig 3	ArcInfo interpolation	
30m slope	6b	USGS		http://nris.state.mt.us/
Slope position	6c	Derived, Fig 3		http://www.wsl.ch/staff/niklaus.zimmermann/progs.html
		SOIL QUALITY/POTENTIAL		
Mine generated geol map.		Abs/Mont DEQ	Not available.	
NRCS soil units	7	NRCS	SSURGO Data	http://www.ncgc.nrcs.usda.gov/
Mine generated soil types		Abs/Mont DEQ	Not available	
Soil characteristics	t#	Abs/NRCS	SSURGO/Direct data	
Solum thickness	8	NRCS	SSURGO Data	http://www.ncgc.nrcs.usda.gov/
Soil % clay	9	NRCS	SSURGO Data	http://www.ncgc.nrcs.usda.gov/
Abs point texture		Abs/WESTECH	Not available, not comparable.	
Soil water storage				
0-25cm	10a	‘Available soil water’		
0-50cm	10b	NRCS	SSURGO Data	http://www.ncgc.nrcs.usda.gov/
0-100cm	10c			
0-150cm	10d			
Range site	11	‘Precipitation x water storage’		
		NRCS	SSURGO Data	http://www.ncgc.nrcs.usda.gov/
		SITE POTENTIAL (yield)		
Range yield		NRCS	SSURGO Data	http://www.ncgc.nrcs.usda.gov/
Wet yr	12a			
Ave yr	12b			
Dry yr	12c			
Alfalfa yield		NRCS	SSURGO Data	http://www.ncgc.nrcs.usda.gov/
Ave yr	13a			
Irrigated	13b			

Table 2. Vegetation types identified in the Absaloka mine (VHA, I). The assignment, for points at the Absaloka mine, to the types of each classification is reported in Appendix 1.

Classification	8-type[1]	16-type[2]	List of Absaloka types[3] included.
DRIER TYPES			
Stipa comata	Stco (2)	2a 2b	
A spicatum	Agsp (3)	3	
P ponderosa	Pipo (4)	4a 4b	
MOISTER TYPES			
A smithii- S viridula	Agsm-Stvi (1)	1a 1b	
Prunus virginiana	Prvi (5)	5a 5b 5c	
Symphoricarpous oc	Syoc (6)	6	
Spartina pectinata	Sppe (7)	7a 7b	
Old field[4]	OField (8)	8a 8b	

[1]Vegetation types in the 8-type classification, listed (except old field) from dry to wet environments. Names are preliminary.
[2] Vegetation types in the 16-type classification listed from dry to wet. These types are un-named because the fine division is not justified. Sub-types may not be correctly ordered on the water gradient.
[3] Lists of Absaloka types have not been made.
[4] The old field is mechanically grouped with the moist sites- - perhaps because the thin vegetation provides resources to plants that could not otherwise survive in the STCO and AGSP types.

Table 3 Soils of the Absaloka Mine area, Bighorn Co, Mt. App 2.

Soil characteristics are depth to bedrock (in), % coarse sand (4.75mm) or finer, % fine sand (0.36mm) or finer, permeability (in/hr), range site (textural class and rainfall--10-14in/yr or followed by plus, 15-19 in/yr) textural abbreviation (unified), texture, slope, and notes.

Name	Depth inches	>3" %>3"	Sieve #4 4.75mm	Sieve #40 0.36 mm	Perm in/hr	Range site**	Txt-abbr	Texture	Slope	Note
ALLENTINE	>60	0	100-	95-100	>0.06	clay	cl or ch	CLAY		
ALICE	>60	0	100-	95-100	0.06-0.2	sand	sm	FINE SANDY LOAM	4 TO 15	
ASCALON	>60	0	85-100	60-70	2.0-6.0	sand	sm	SANDY LOAM	4 TO 8	
BELFIELD	-	0	100-	95-100	0.2-0.6	silt+	cl	SILT LOAM		GENTLE UNDUL
CHUGTER COMPLEX	>60	0	95-100	80-90	0.6-2.0	silt		SILTY CLAY LOAM	2 TO 15	
CUSHMAN	20-40	0	100-	90-100	0.6-2.0	silt	ml	LOAM		UNDULATING
FARNUF	>60	0	100-	85-95	0.6-2.0	silt+	ml-cl	LOAM	2 TO 4	
FARNUF	*>60*	*0*	*100-*	*85-95*	*0.6-2.0*	silt+	*ml-cl*	LOAM	4 TO 8	
FT COLLINS	>60	0	85-100	80-95	0.6-2.0	silt	cl	LOAM	2 TO 4	
FT COLLINS	*>60*	*0*	*85-100*	*80-95*	*0.6-2.0*	silt	*cl*	LOAM	4 TO 8	
FT COLLINS	*>60*	*0*	*85-100*	*80-95*	*0.6-2.0*	silt	*cl*	LOAM	4 TO 8	CHANNELED
FRAZER	>60	0	100-	95-100	0.06-0.2	clay+	cl	SILTY CLAY LOAM		
GLENBERG	>60	0	100-	60-70	2.0-6.0	sand	sm	FINE SANDY LOAM	2 TO 4	
HARVEY	>60	0	70-100	65-95	0.6-2.0	silt	cl	LOAM		ROLLING
HARVEY	*>60*	*0*	*70-100*	*65-95*	*0.6-2.0*	silt	*cl*	LOAM		UNDULATING
HAVERSON	>60	0	100-	85-95	0.6-2.0	saline low		LOAM	0 TO 2	
HAVERSON	*>60*	*0*	*100-*	*85-95*	*0.6-2.0*	clay	*ml-cl*	LOAM	2 TO 4	
HAVERSON-LOHMILLER	*>60*	*0*	*90-100*	*85-100*		silt				CHANNELED
HAVERSON-LOHMILLER	*>60*	*0*	*90-100*	*85-100*		overflow				FREQ FLOODED
HAVERSON-LOHMILLER	*>60*	*0*	*90-100*	*85-100*		saline low				WET
HELDT	>60	0	90-100	90-100	0.6-2.0	clay	cl	SILTY CLAY LOAM	0 TO 2	
HELDT	*>60*	*0*	*90-100*	*90-100*	*0.6-2.0*	clay	*cl*	SILTY CLAY LOAM	2 TO 4	
HELDT	*>60*	*0*	*90-100*	*90-100*	*0.6-2.0*	clay	*cl*	SILTY CLAY LOAM	4 TO 8	
HYDRO	>60	0	100-	90-100	0.06-0.2	silt	cl	LOAM	0 TO 8	
HYDRO-ALLENTINE	*>60*	0	100-	90-100		pan spots			fix	
HYSHAM	>60	0	100-	95-100	0.06-0.2	silt	cl	LOAM	0 TO 2	

LOAM

KIM	>60	0	100-	85-95	0.6-2.0	silt	ml	LOAM	4 TO 15	
KORCHEA	>60	0	100-	85-95	0.6-2.0	silt+	ml	LOAM	0 TO 2	
KORCHEA	*>60*	*0*	*100-*	*85-95*	*0.6-2.0*	silt+	*ml*	LOAM	2 TO 4	
KYLE	>60	0-25	65-100	60-100	<0.06	clay	ch	SILTY CLAY	0 TO 2	
KYLE	*>60*	*0-25*	*65-100*	*60-100*	*<0.06*	clay	*ch*	SILTY CLAY	2 TO 4	
LISMAS	10-20 shl	0	85-90	80-90	<0.06	shallo clay	cl-ch	CLAY	>15	
LISMAS-SHALE OUTCROP	10-20 shl	0	85-90	80-90	<0.06	shallo clay	cl-ch			STEEP
LOHMILLER	>60	0	90-100	85-100	0.2-0.6	clay	cl	SILTY CLAY LOAM	0 TO 2	
LOHMILLER	*>60*	*0*	*90-100*	*85-100*	*0.2-0.6*	clay	*cl*	SILTY CLAY LOAM	2 TO 4	
LOHMILLER	*>60*	*0*	*90-100*	*85-100*	*0.2-0.6*	clay	*cl*	SILTY CLAY LOAM	4 TO 8	
LOHMILLER	*>60*	*0*	*90-100*	*85-100*	*0.2-0.6*	clay	*cl*	SILTY CLAY LOAM	8 TO 15	
LOHMILLER	*>60*	*0*	*90-100*	*85-100*	*0.2-0.6*	saline low	*cl*	SILTY CLAY	2 TO 4	SALINE
LOHMILLER-MIDWAY		0				clay		SILTY CLAY LOAM		UNDULATING
MCRAE	>60	0-10	80-100	75-95	0.6-2.0	silt	ml	LOAM	0 TO 1	
MCRAE	*>60*	*0-10*	*80-100*	*75-95*	*0.6-2.0*	silt	*ml*	LOAM	1 TO 4	
MCRAE	*>60*	*0-10*	*80-100*	*75-95*	*0.6-2.0*	silt	*ml*	LOAM	4 TO 8	
MIDWAY	10-20 shl	0	70-95	75-85	0.6-2.0	clay	cl	SILTY CLAY LOAM		ROLLING
MIDWAY	*10-20 shl*	*0*	*70-95*	*75-85*	*0.6-2.0*	clay	cl	SILTY CLAY LOAM		UNDULATING
MIDWAY-LISMAS	10-20 shl	0	75-95							ROLLING
MIDWAY-SHALE OUTCROP		0								STEEP
MIDWAY-THEDALUND	10-40-	(0-30)	70-100	65-95	0.6-2.0	thin hill				HILLY
MIDWAY-THEDALUND	10-40 shl	(0-30)	70-100	65-95	0.6-2.0	clay				ROLLING
NELSON	20-40 snd	0	75-100	50-70	2.0-6.0 clay	sand	sm	FINE SANDY LOAM		UNDULATING
NELSON-ALICE		0				sand	sm	FINE SANDY LOAMS		ROLLING
NELSON-GLENBERG		0		50-70	2.0-6.0		sm	SANDY LOAMS		UNDULATING
NUNN	>60	0	85-100	85-100	0.2-0.6	clay	cl	SILTY CLAY LOAM	0 TO 1	
NUNN	*>60*	*0*	*85-100*	*85-100*	*0.2-0.6* sand	clay	*cl*	SILTY CLAY LOAM	1 TO 4	
NUNN	*>60*	*0*	*85-100*	shale *85-100*	*0.2-0.6*	clay	*cl*	SILTY CLAY LOAM	4 TO 8	
NUNN-MIDWAY		0			0.2-0.6	clay	cl	SILTY CLAY LOAM	4 TO 15	
RICHFIELD	>60	0	100-	95-100	0.2-0.6	silt	cl	SILTY CLAY LOAM	0 TO 2	
SALINE LAND		0				saline low				
SAVAGE	>60	0	100-	95-100	0.2-0.6	clay	cl	SILTY CLAY LOAMS	4 TO 15	
SAVAGE-WAYDEN			100-	95-100		clay	cl	SILTY CLAY LOAM		
SPEARMAN	20-40 shl	*	85-100	80-95	0.6-2.0	silt	cl	LOAM		UNDULATING
SPEARMAN-WIBAUX	8-40 shl	*			0.6-2.0	silt				ROLLING
TALAG	>60	0	100-	90-100	<0.06	clay	cl-ch	CLAY	0 TO 8	
TERRACE ESCARPMENTS		0				thin hill		LOAMY		

THEDALUND	20-40 shl	0-30	70-100	65-95	0.6-2.0	silt	ml or sm	LOAM		UNDULATING
THEDALUND-CUSHMAN	20-40	(0-30)			0.6-2.0	silt		LOAMS		UNDULATING
THEDALUND-FT COLLINS		(0-30)			0.6-2.0	silt				ROLLING
THEDALUND-MCRAE		(0-30)	70-100		0.6-2.0	silt				DISSECTED
THEDALUND-MCRAE		(0-30)	70-100		0.6-2.0	silt				ROLLING
THEDALUND-MIDWAY		(0-30)	70-100		0.6-2.0	silt				ROLLING
THEDALUND-NELSON	20-40 shl	(0-30)	70-100			silt				ROLLING
THEDALUND-ROCK OUTCROP						thin hill				HILLY
THEDALUND-WIBAUX		(0-30)			0.6-2.0	silt				ROLLING
THEDALUND-WIBAUX		(0-30)			0.6-2.0	thin breaks				VERY STEEP
THEDALUND-WIBAUX		(0-30)			0.6-2.0	thin hill		STONY LOAMS		HILLY
THURLOW	>60	0	100-	95-100	0.2-0.6	clay	cl	SILTY CLAY LOAM	0 TO 1	
THURLOW	*>60*	*0*	*100-*	*95-100*	*0.2-0.6*	clay	*cl*	SILTY CLAY LOAM	1 TO 4	
THURLOW	*>60*	*0*	*100-*	*95-100*	*0.2-0.6*	clay	*cl*	SILTY CLAY LOAM	4 TO 8	
THURLOW-MIDWAY	*>60*	*0*	*100-*	*95-100*	*0.2-0.6*	clay	*cl*	SILTY CLAY LOAMS		
TULLOCK	20-40 snd	0	100-	65-75	6-20-	sand	sm	LOAMY FINE SAND		ROLLING
WAGES LOAM	>60	0	100-	85-100	0.6-2.0	silt	ml-cl		2 TO 4	
WAGES LOAM	*>60*	*0*	*100-*	*85-100*	*0.6-2.0*	silt	*ml-cl*		4 TO 8	
WAYDEN	10-20 shl	0	*100-*	*95-100*	*0.6-2.0*	clayey+TH	*cl*	SILTY CLAY LOAM		
WAYDEN-REGENT	10-20 shl	0	100-	95-100	0.6-2.0	thin hill+	cl	SILTY CLAY LOAMS		HILLY
WAYDEN-ROCK OUTCROP						clay				ROLLING
WAYDEN-SHALE OUTCROP										VERY STEEP
WIBAUX	8-20 shl	15-35%	35-65	15-50	0.6-2.0	shallow	gm	CHANNERY LOAM		

shale

Alll data from J Meshnick et al. 1977. Supporting data are found at the two Web sites cited.
J Meshnick, J Smith, L lGray, R Peterson, D Gentz, and R Smith 1977 Soil Survey of Bighorn Co Area, MT. Govt Print Off, Wash DC. __ pgs.
http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx - Web Soil Survey
http://soildatamart.nrcs.usda.gov/Default.aspx - Soil Data Mart
Hansen, Michael - Bozeman, MT
<Michael.Hansen@mt.usda.gov> 587-6813

To learn about soil water holding capacity see NRCS access site MUAGGATT= map unit aggreagated attributes.

Roman data come from Soil Survey of Bighorn Co Area MT. White, central to analysis.
Italic data copied from 'typical level site data' to units of greater slopes. Yellow, included in analysis.
Complex data entered where there is agreement between the soil units included. Red, not included in analysis.

Soil characteristics are depth to bedrock (in), % coarse sand (4.75mm) or finer, % fine sand (0.36mm) or finer, permeability (in/hr), range site (textural class and rainfall--10-14in/yr or followed by plus, 15-19 in/yr) textural abbreviation (unified), texture, slope, and notes.

Range sites include a textural class and a pptn range: 10-14"/year (unmarked) and 15-19 ('+')

** Spearman 0-15% >3" at 15-23", Wibaux 15-35% >3" at surface.

Table 4. Names of the range sites in the area permitted to the Absaloka mine (*) and immediately surrounding areas.

Texture	Precipitation zone	Province	
Shale *	15 to 19 inches	N R Mtn foothills, S	ORANGE OR GREY?
Shallow Clay *	10 to 14 inches	Sediment	LT BLUE
Clayey-Steep *	10 to 14 inches	Sediment	LT BLUE
Dense clay	10 to 14 inches	Sediment	
Sands *	10 to 14 inches	Sediment	YELLOW
Sandy *	10 to 14 inches	Sediment	
Sandy	15 to 19 inches	N R Mtn foothills, S	
Silty *	10 to 14 inches	Sediment	BROWN
Silty *	15 to 19 inches	N R Mtn foothills, S	BROWN
Silty-Steep *	10 to 14 inches	Sediment	LT BROWN
Thin silty	15 to 19 inches	N R Mtn foothills, S	
Overflow *	10 to 14 inches	Sediment	PINK, DULL
Saline Lowland *	10 to 14 inches	Sediment	RED OR WHITE

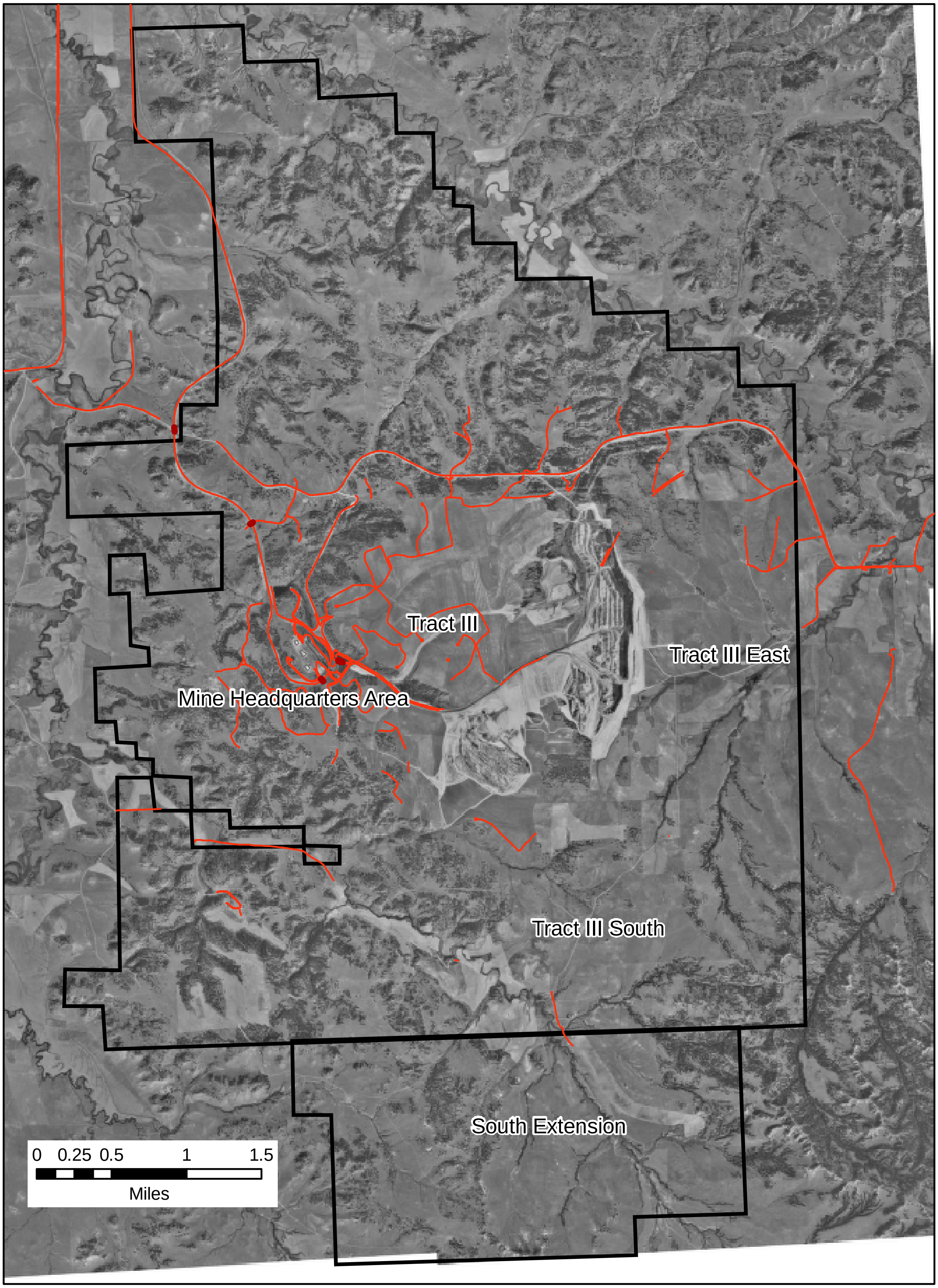

Fig 1. The Absaloka study area (ASA) . The area covered by the GIS, boundaries of permitted mine areas, and included roads all superimposed on a Digital Orthophoto Quad (DOQ). The Absaloka mine is located between Hardin and Colstrip, south-central, Montana (45^{o}48'N 107^{o}2'W).

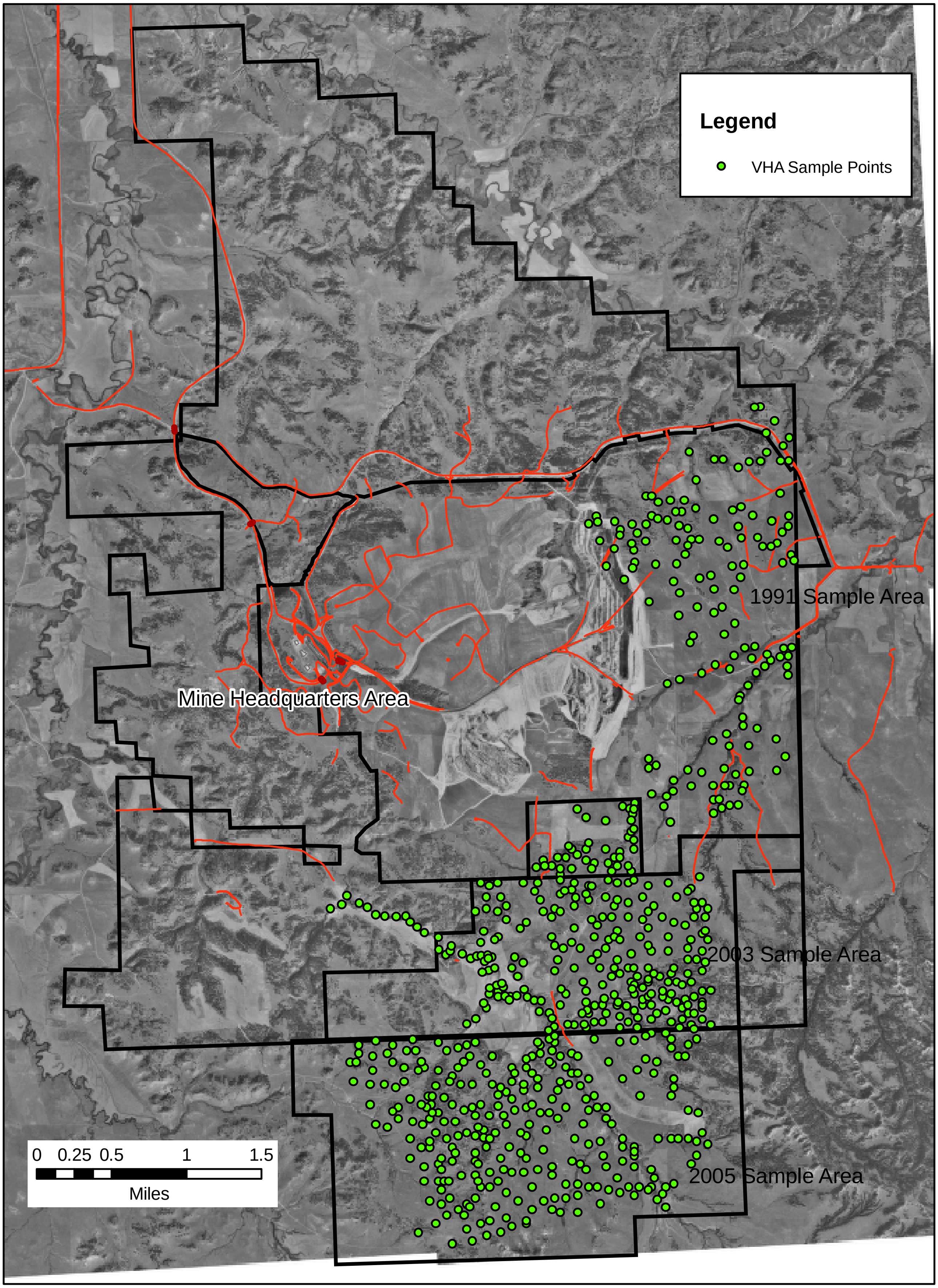

Fig 2. The Absaloka study area showing points sampled for vegetation and environment (slope and aspect) in support of the permit application. Soil characteristics at these points are presented in Table 2.

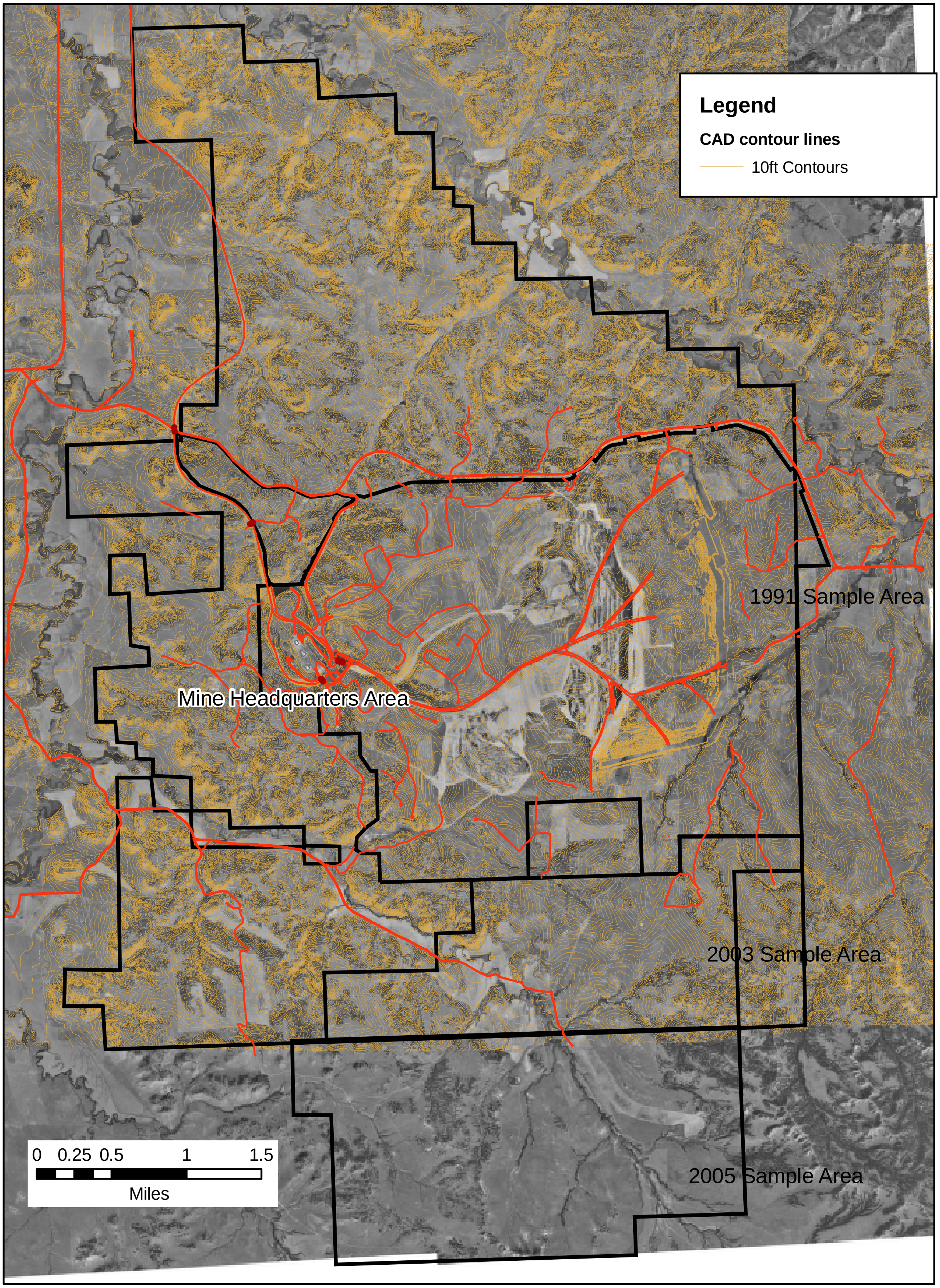

Fig 3. Topographic 10 ft interval contour map of the area as surveyed by the mine.
From Absaloka Mine data.

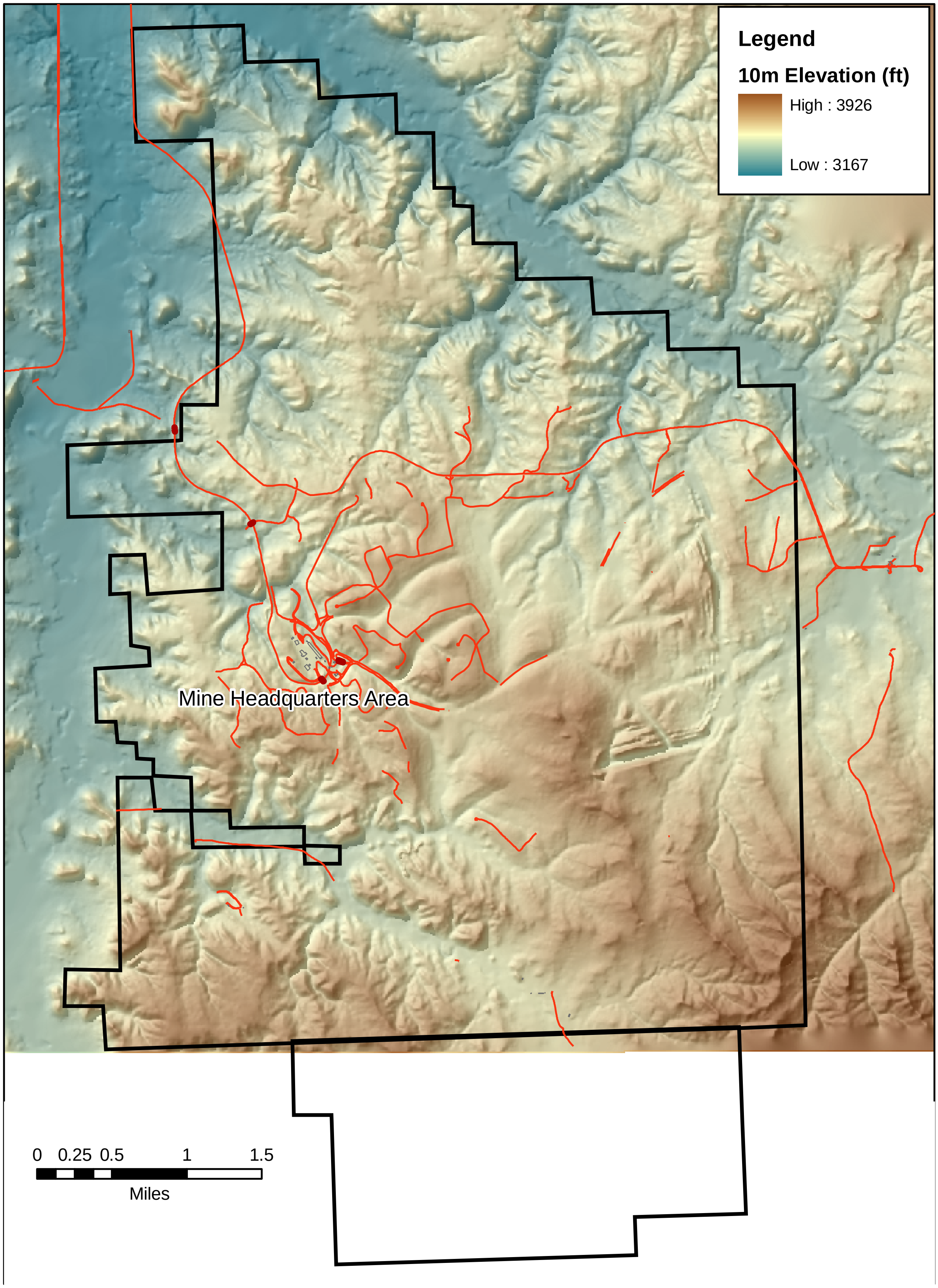

Fig 4a. Elevations of ASA derived from a 10x10M DEM (see text). No ground truth, not used in VHA. Derived from Absaloka Mine data.

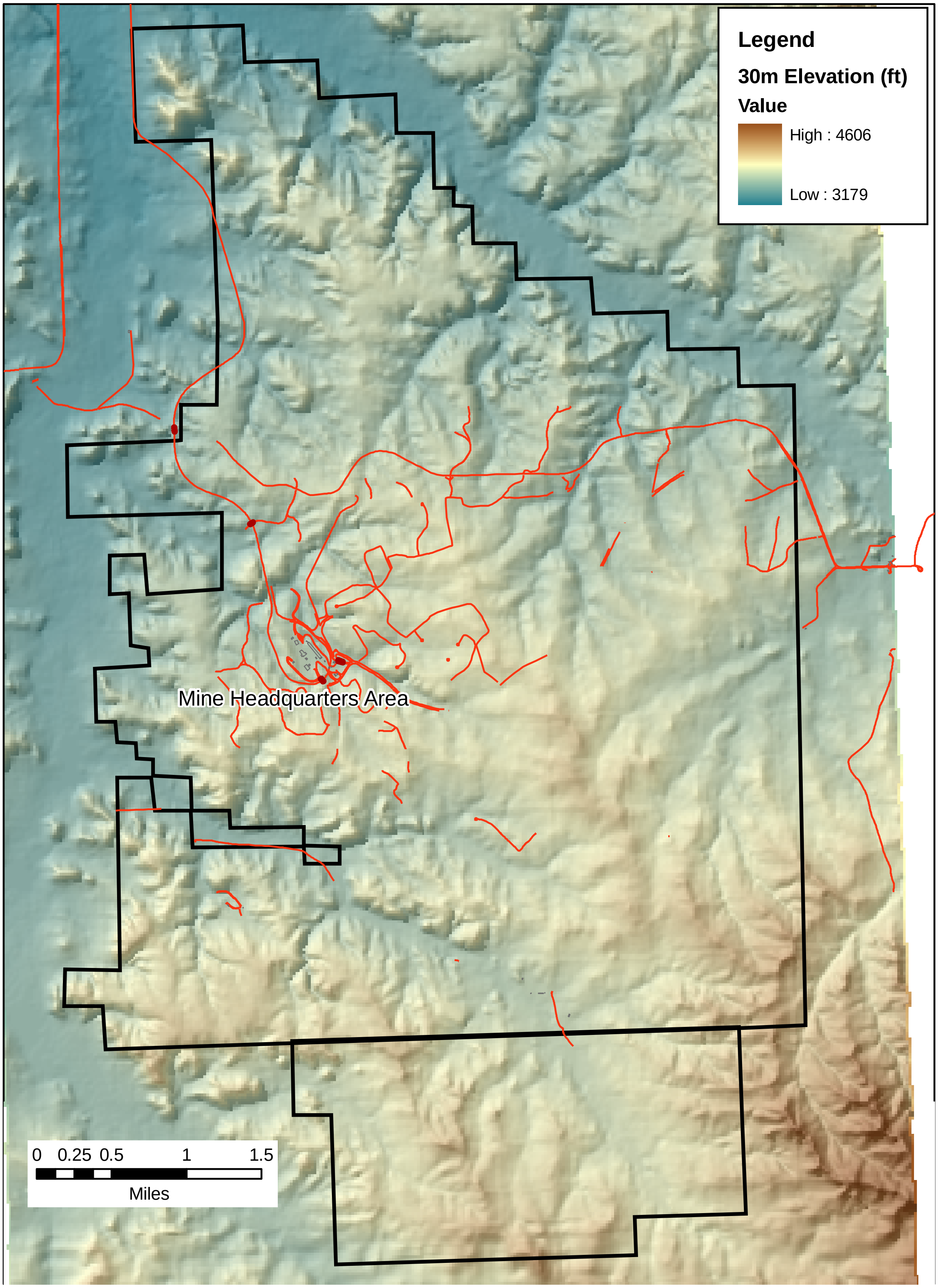

Fig 4b. Elevations of ASA derived from a 30x30M DEM (USGS). Compare with Fig 4a to see how averaging diffuses upland relief and waterways. No ground truth., not used in VHA.
From public data.

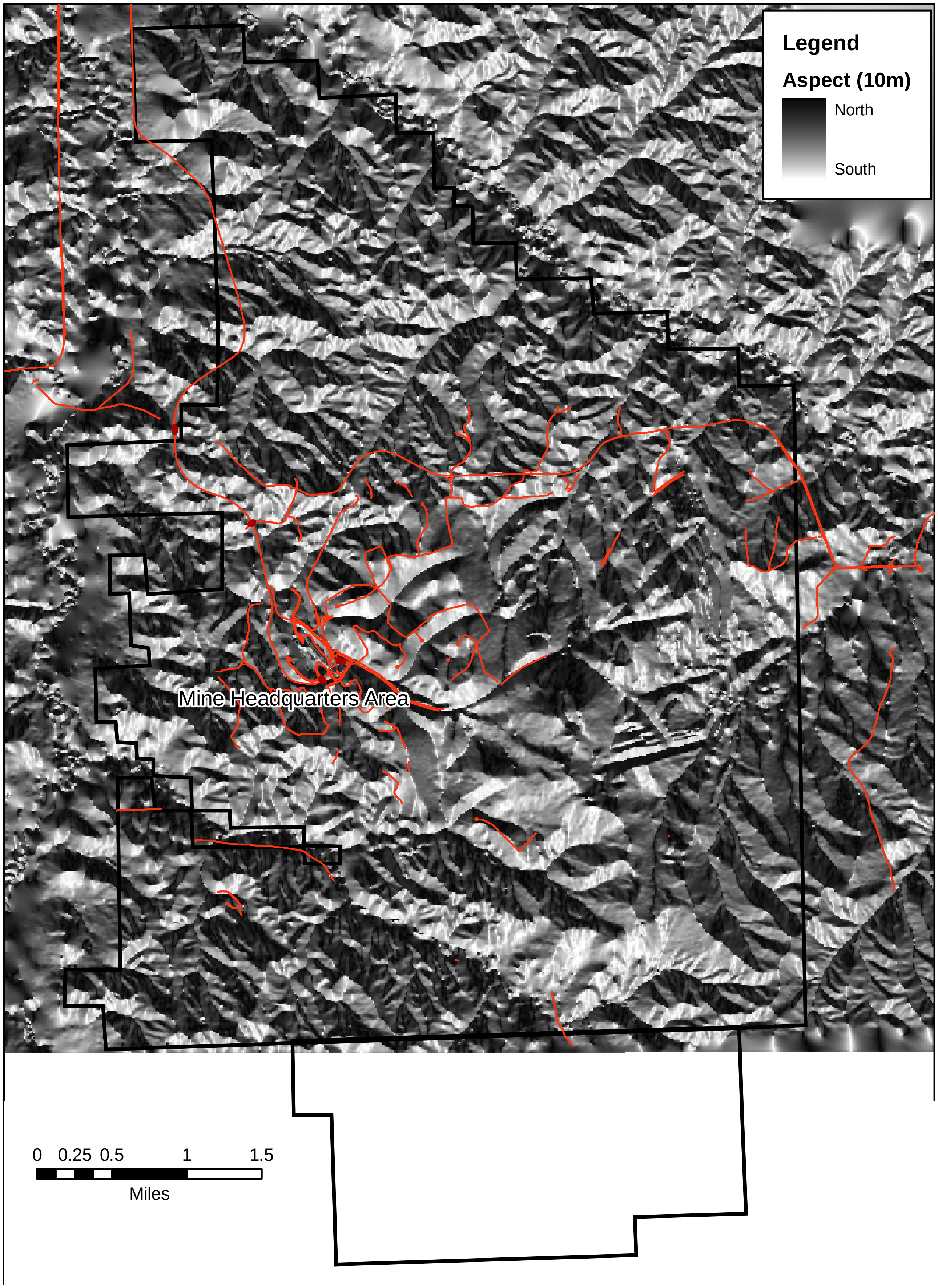

Fig 5a Aspect of ASA (degrees from north) derived from the 10x10m dem. (see text). Used both in evaluation and VHA. Dark areas are North facing (~315^{o} - 45^{o}), light areas are South facing (~135^{o} - 225^{o}), and grey areas are intermediate.

Derived from Absaloka Mine data.

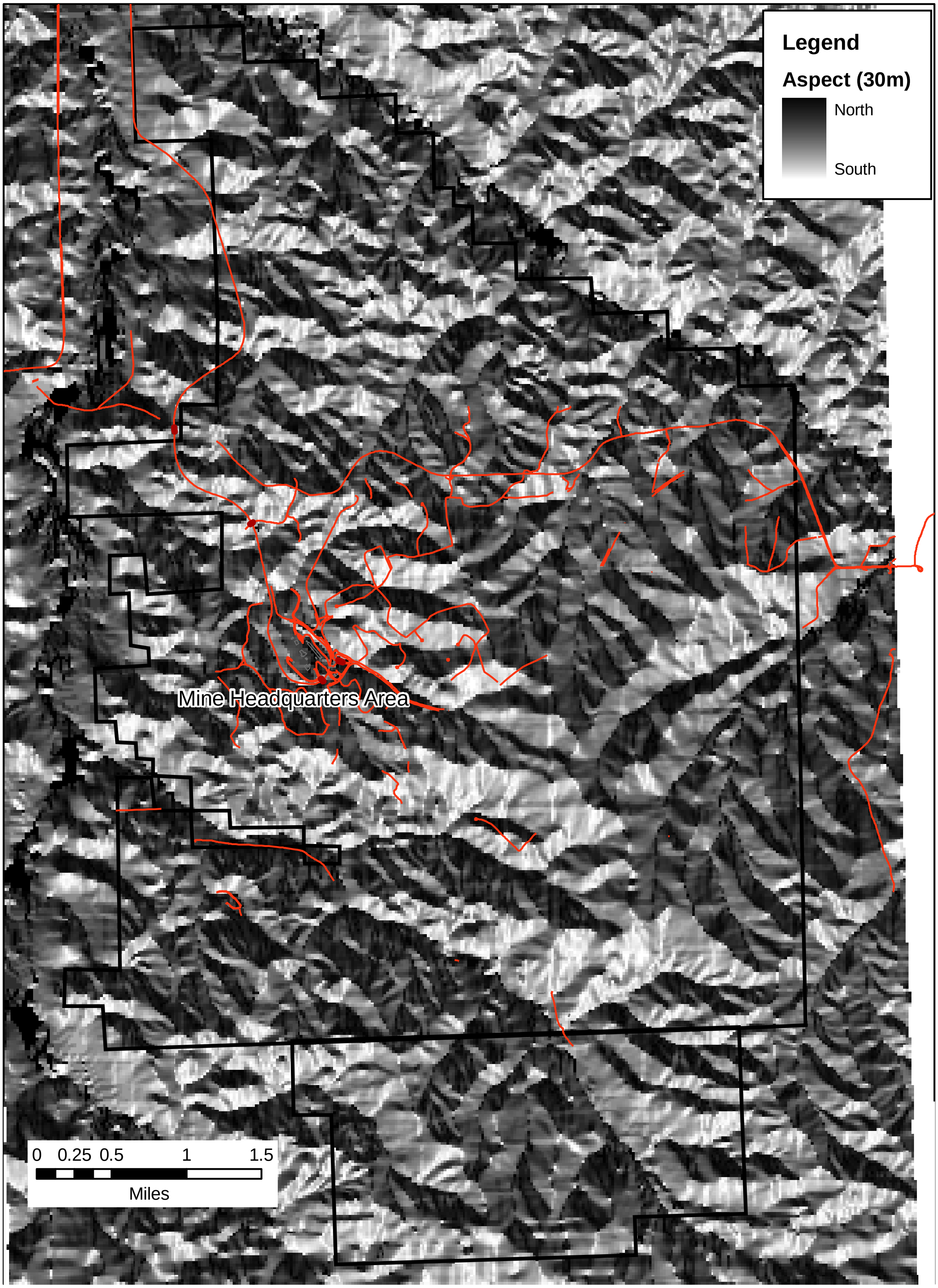

Fig 5b. Aspect of ASA (degrees from north) derived from the 30x30m dem. (USGS). Dark areas are North facing (~315o - 45o), light areas are South facing (~135o - 225o), and grey areas are intermediate. Averaging demonstrated by the large angular pixels. Used in evaluation and possibly VHA.
From public data.

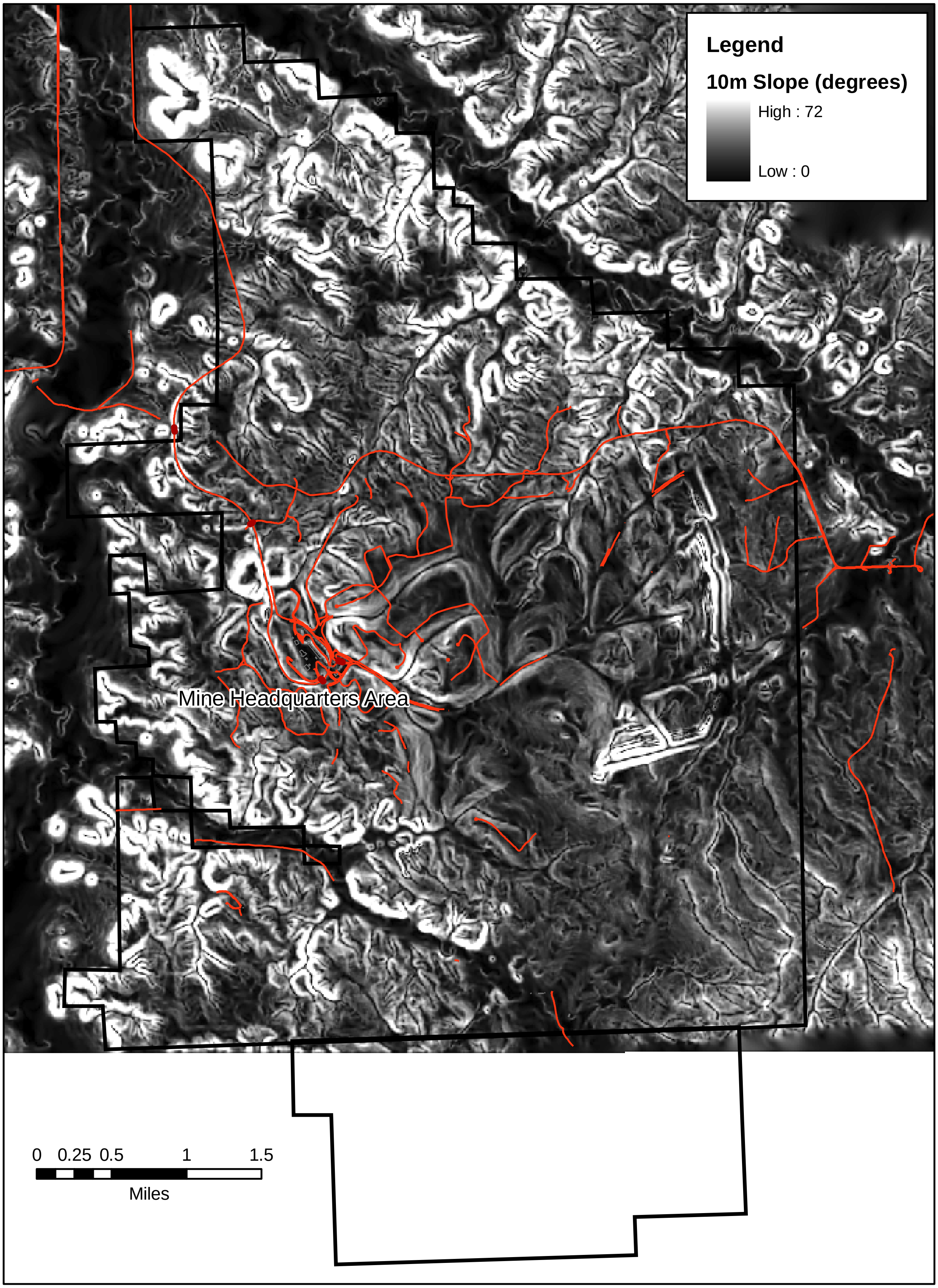

Fig 6a. Slope of ASA derived from a 10x10m DEM (see text). Grey hilltops (slight slope) grade downhill to steep slopes (bright), gray toe slopes, and flat bottoms (dark). Note riverbanks. Used in evaluation and VHA.

Derived from Absaloka Mine data.

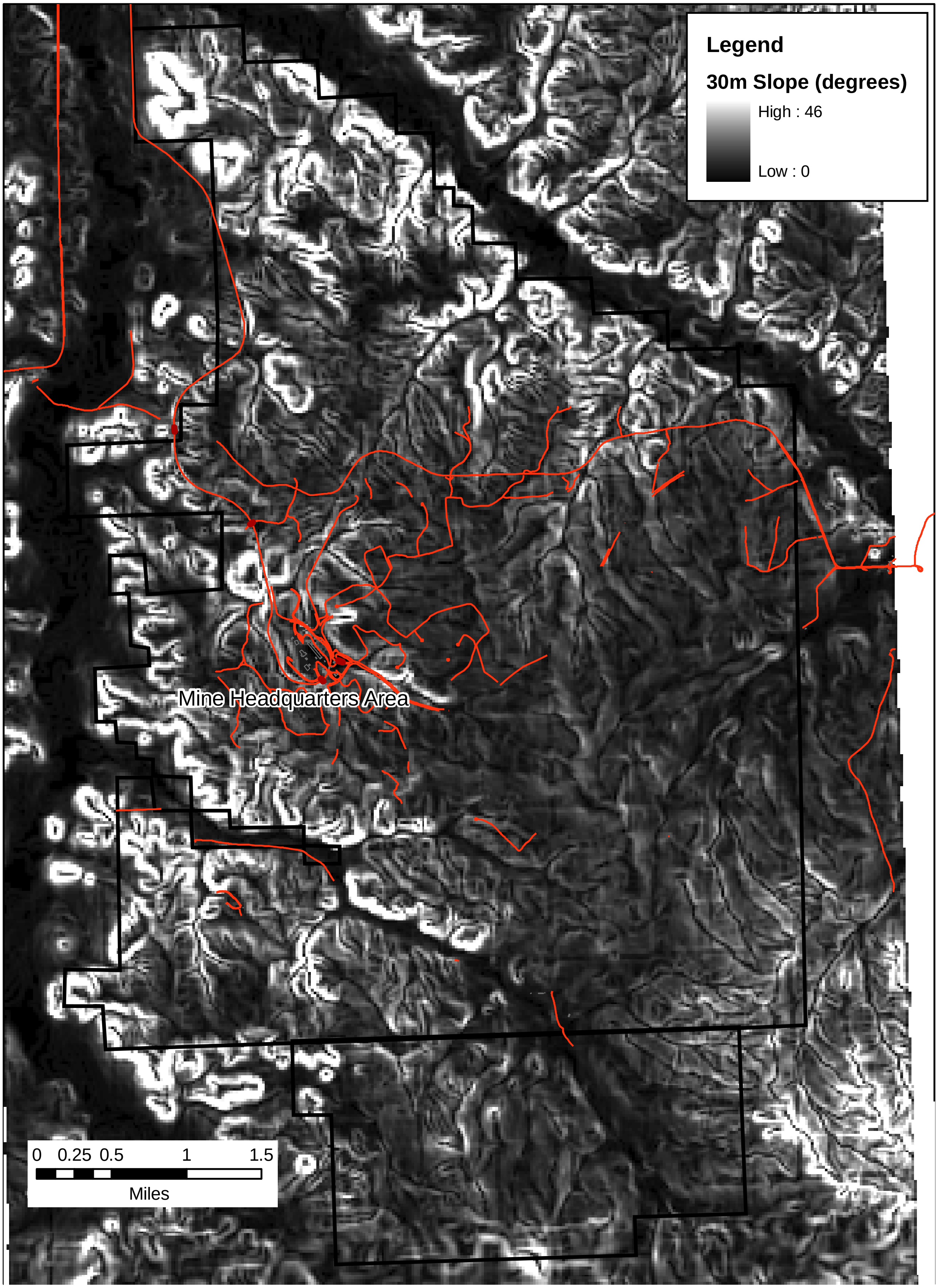

Fig 6b. Slope of ASA derived from 30x30m DEM (USGS). As in figure 6a, except that pixel corners (indicating averaging) are evident. Used in evaluation and possibly VHA.
From public data.

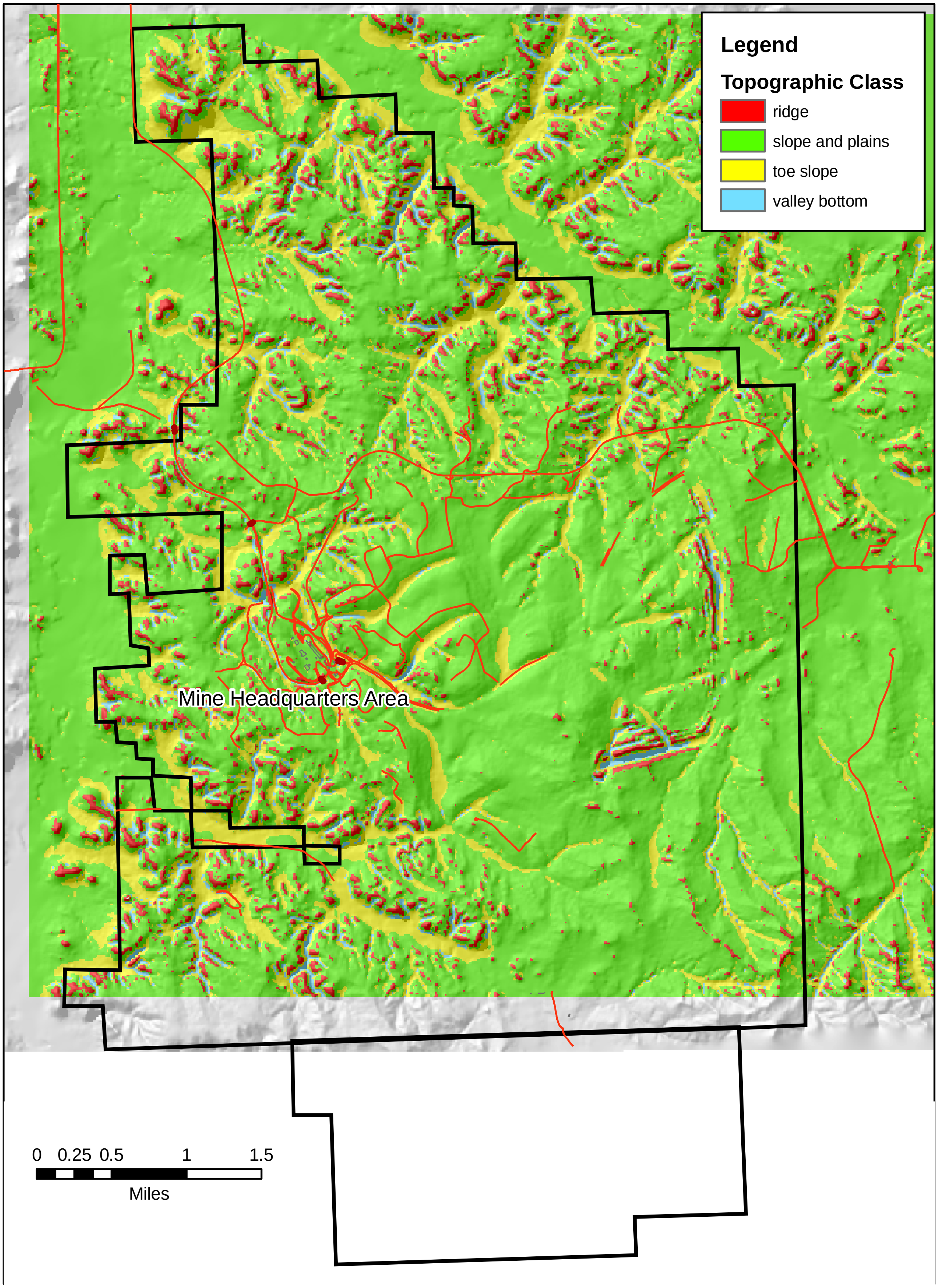

Fig 6c. Topographic classes (http://www.wsl.ch/staff/niklaus.zimmermann/programs/aml4_2.html) of ASA. These mathematically describable units should be comparable to these seen in Fig 6a and 6b. The model seems to show too much green slope, see, for example in the flood plains.

Derived from Absaloka Mine data.

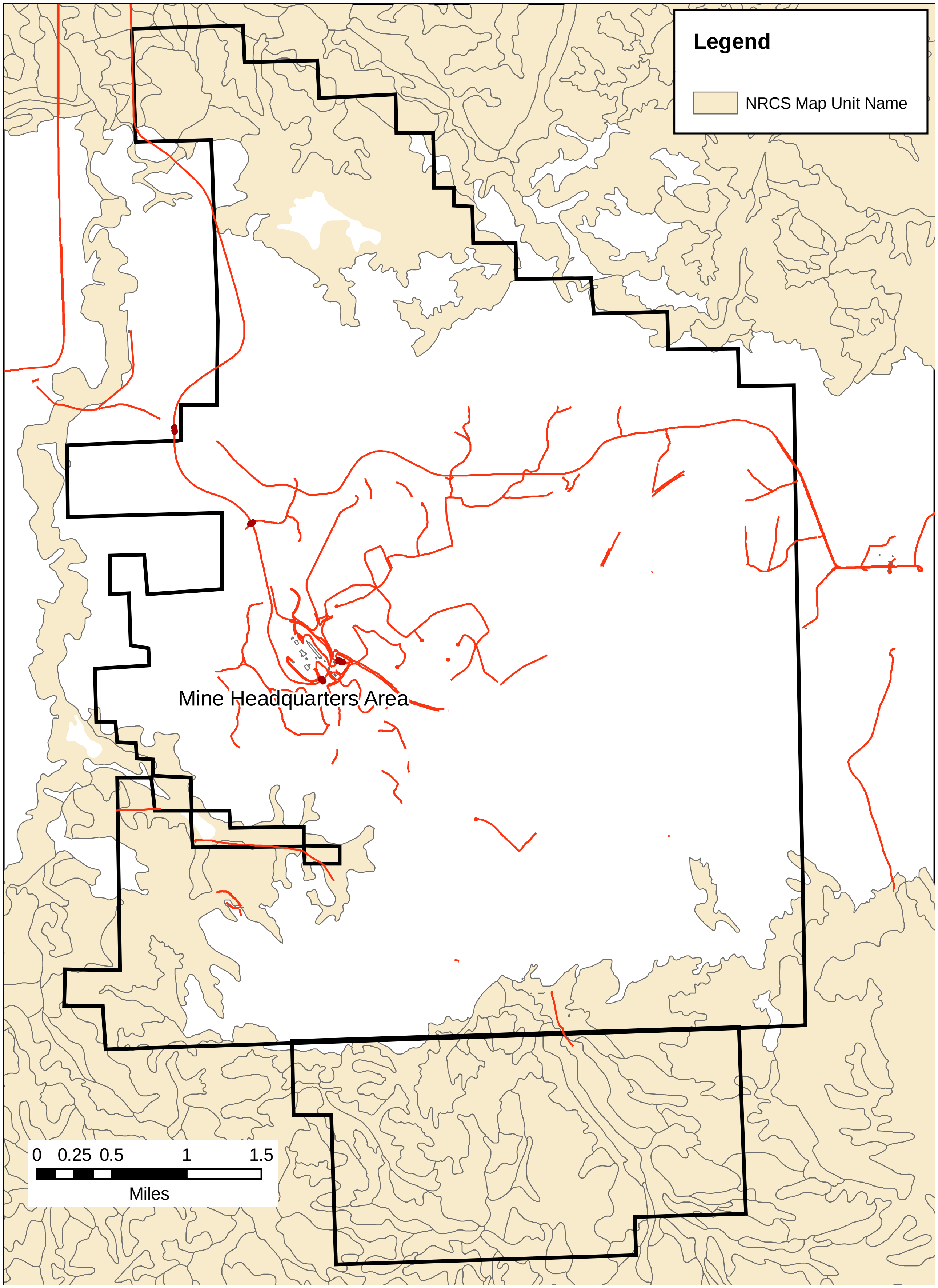

Fig 7. NRCS/SCS soil units. The units are outlined, but named only in the included ArcGIS dataset. The names are listed in Table 2.
From public data.

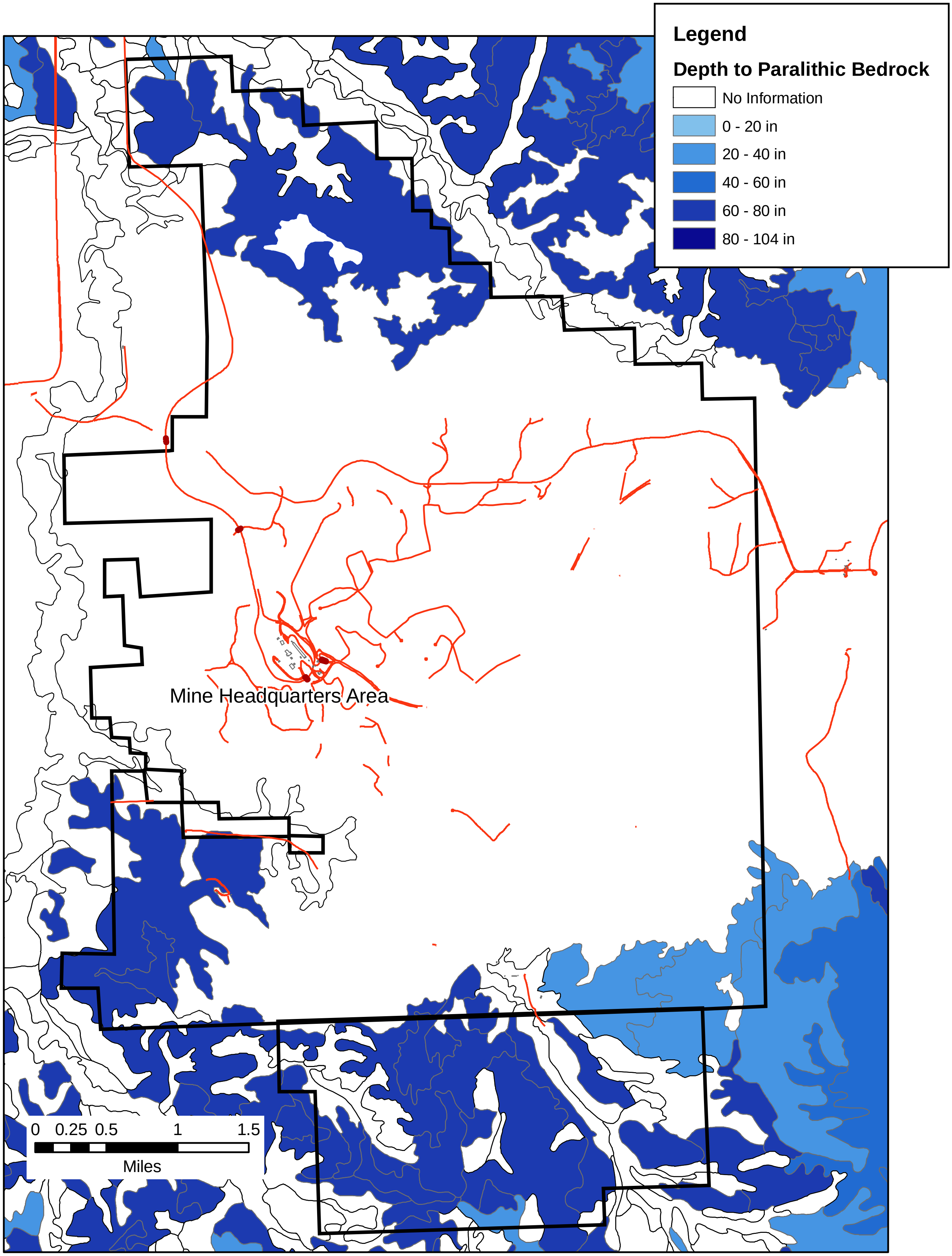

Fig 8. Solum thickness at ASA. Soil thickness is usually deep (60-80 inches) on uplands and not measured in valley bottoms. Drawn from NRCS/SCS. No ground truth.
From public data.

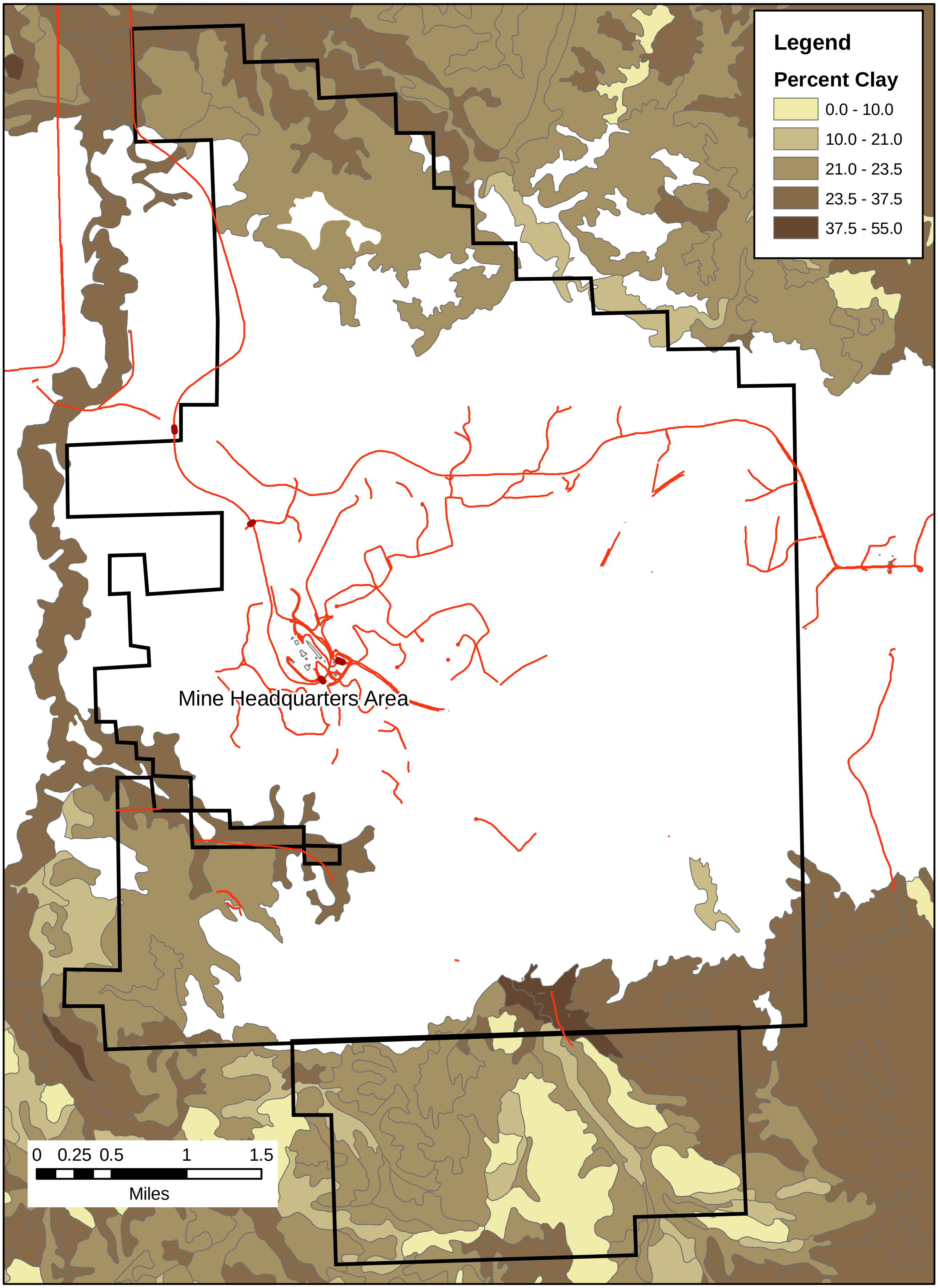

Fig 9. Soil clay content (%) at ASA. Clays are eroded from uplands and deposited on slope toes and river terraces. Drawn from NRCS/SCS, no ground truth. Soil textures for field points are found in Table 3. From public data.

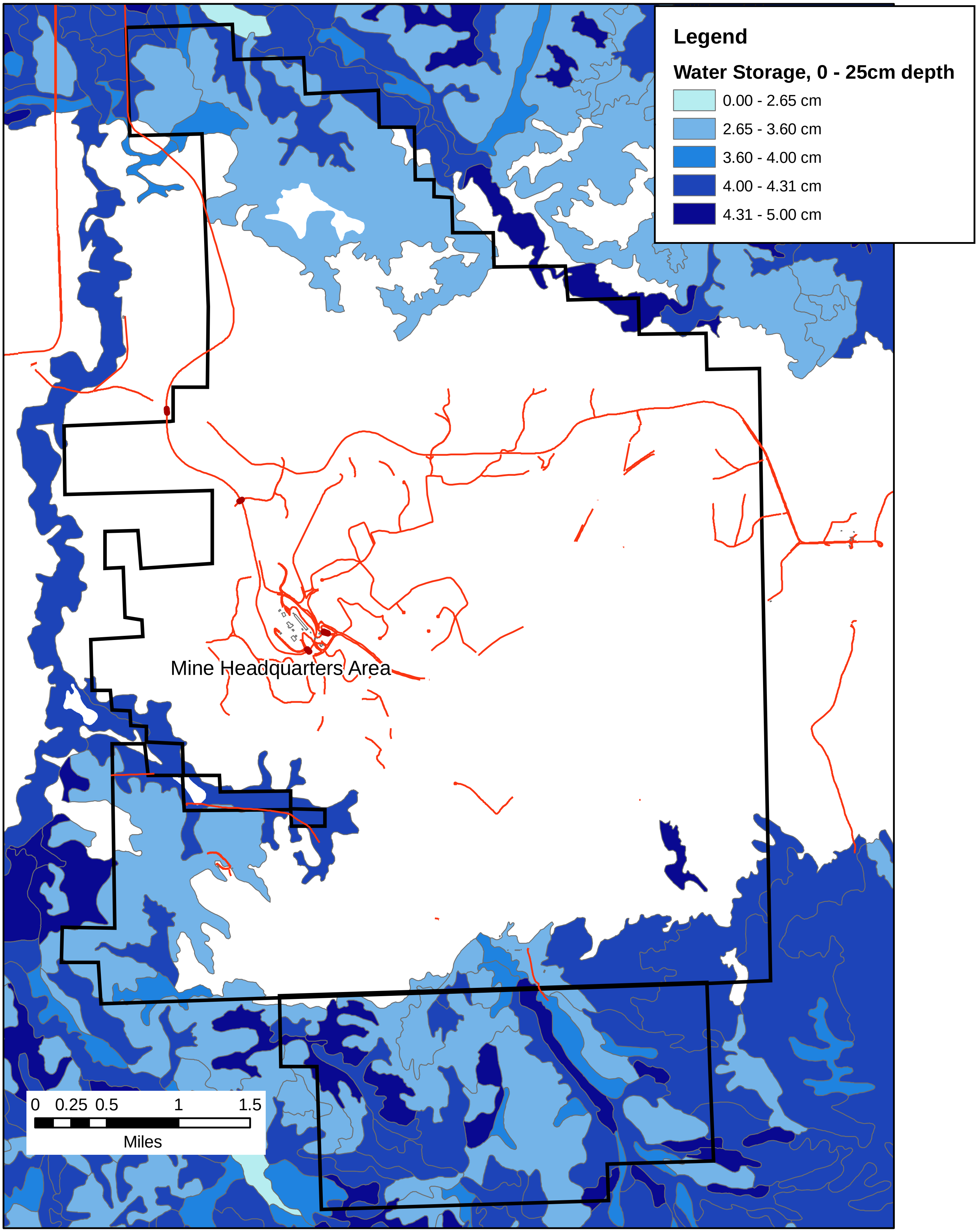

Fig 10a. Water storage, 0-25cm (NRCS 'available water') at ASA. Shallower soils of uplands have little water storage capacity (0-2.5 cm / 25cm), while soils of flats and river terraces have more (3.5-4.5 cm/25cm). Drawn from NRCS/SCS, no ground truth. Useful in VHA engineering.
From public data.

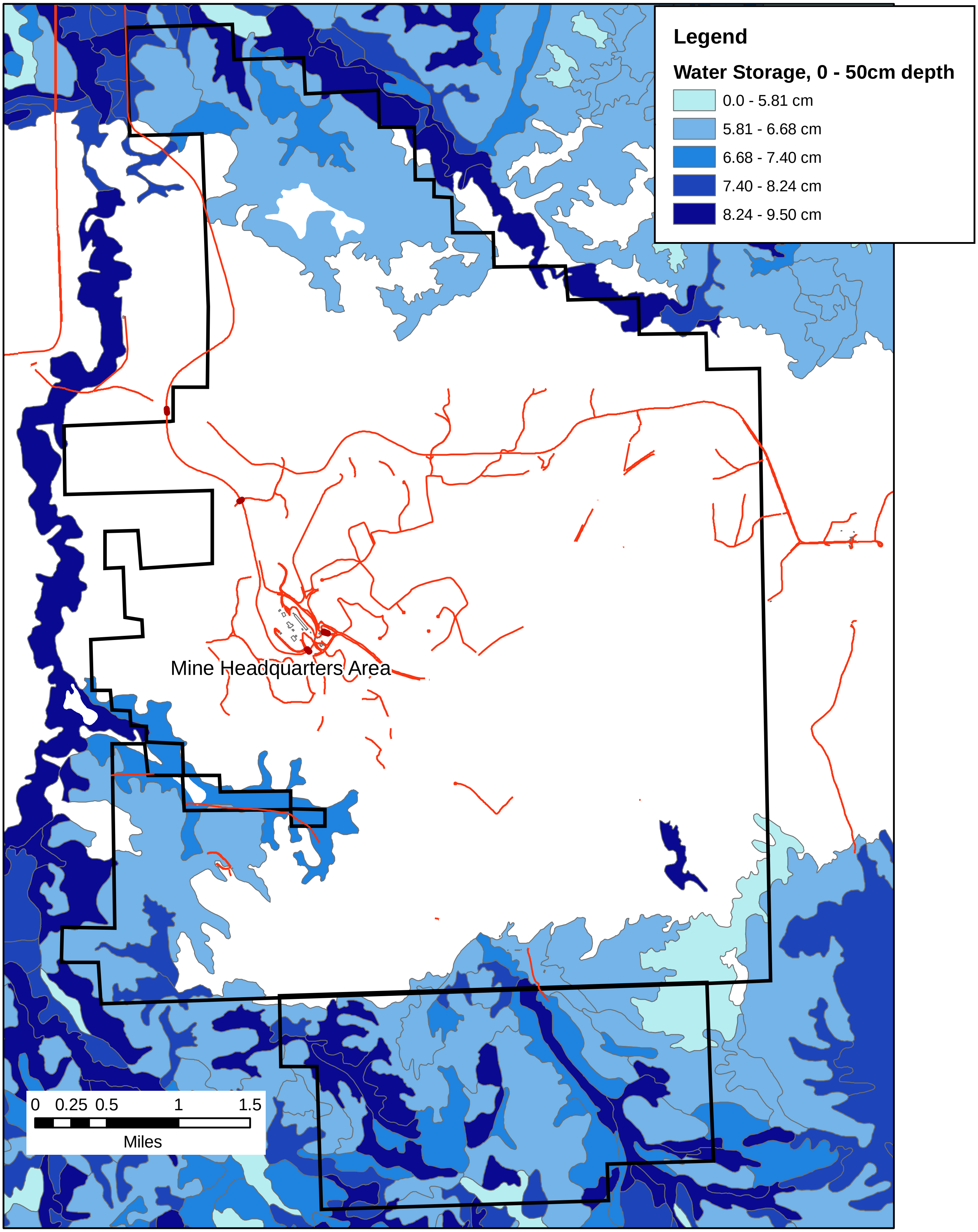

Fig 10b. Water storage, 0-50cm (NRCS 'available water') at ASA. Shallower soils of uplands have little water storage capacity (0-6cm/50cm), while soils of flats and river terraces have more (6.6-8.2 cm/50). Drawn from NRCS/SCS, no ground truth. Useful in VHA engineering.

From public data.

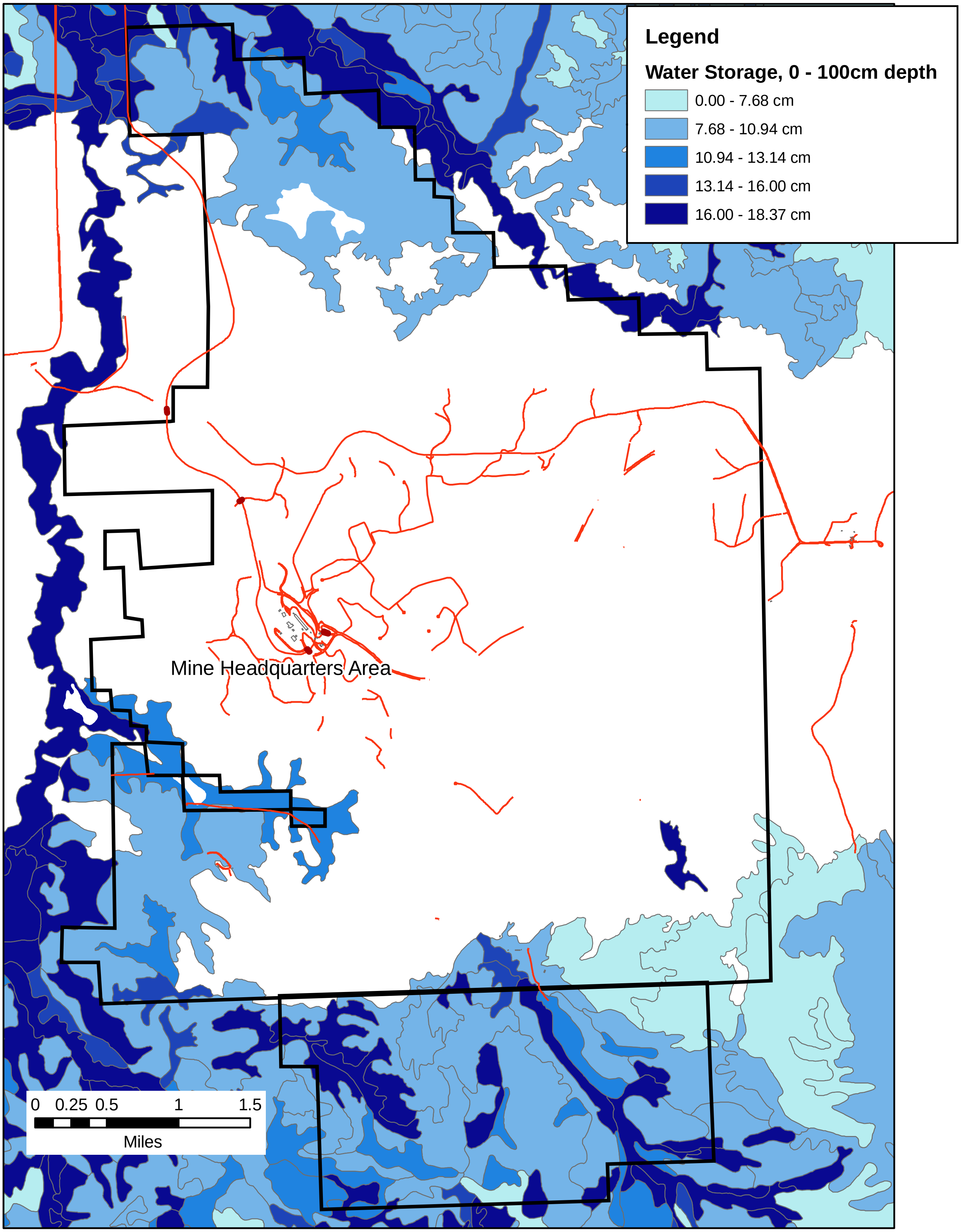

Fig 10c. Water storage, 0-11/100cm (NRCS 'available water') at ASA. Shallower soils of uplands have little water storage capacity (0-7.5 cm/50cm), while soils of flats and river terraces have more (13-16cm /100). No ground truth. Useful in VHA engineering.
From public data.

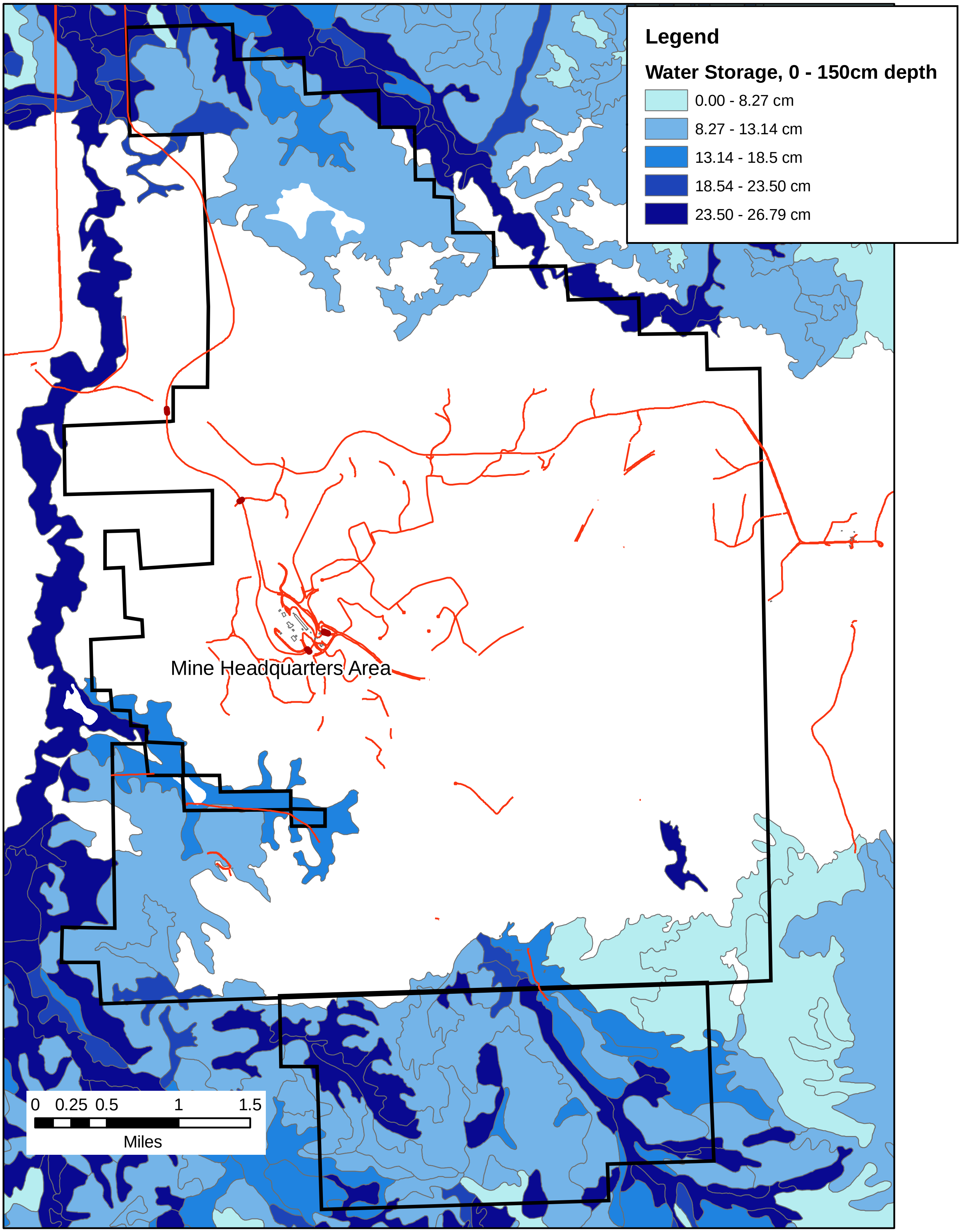

Fig 10d. Water storage, 0-150cm (NRCS 'available water') at ASA. Shallower soils of uplands have little water storage capacity (0-8 cm/150cm), while soils of flats and river terraces have more (18-28cm/150). Drawn from NRCS/SCS, no ground truth. Useful in VHA engineering.

From public data.

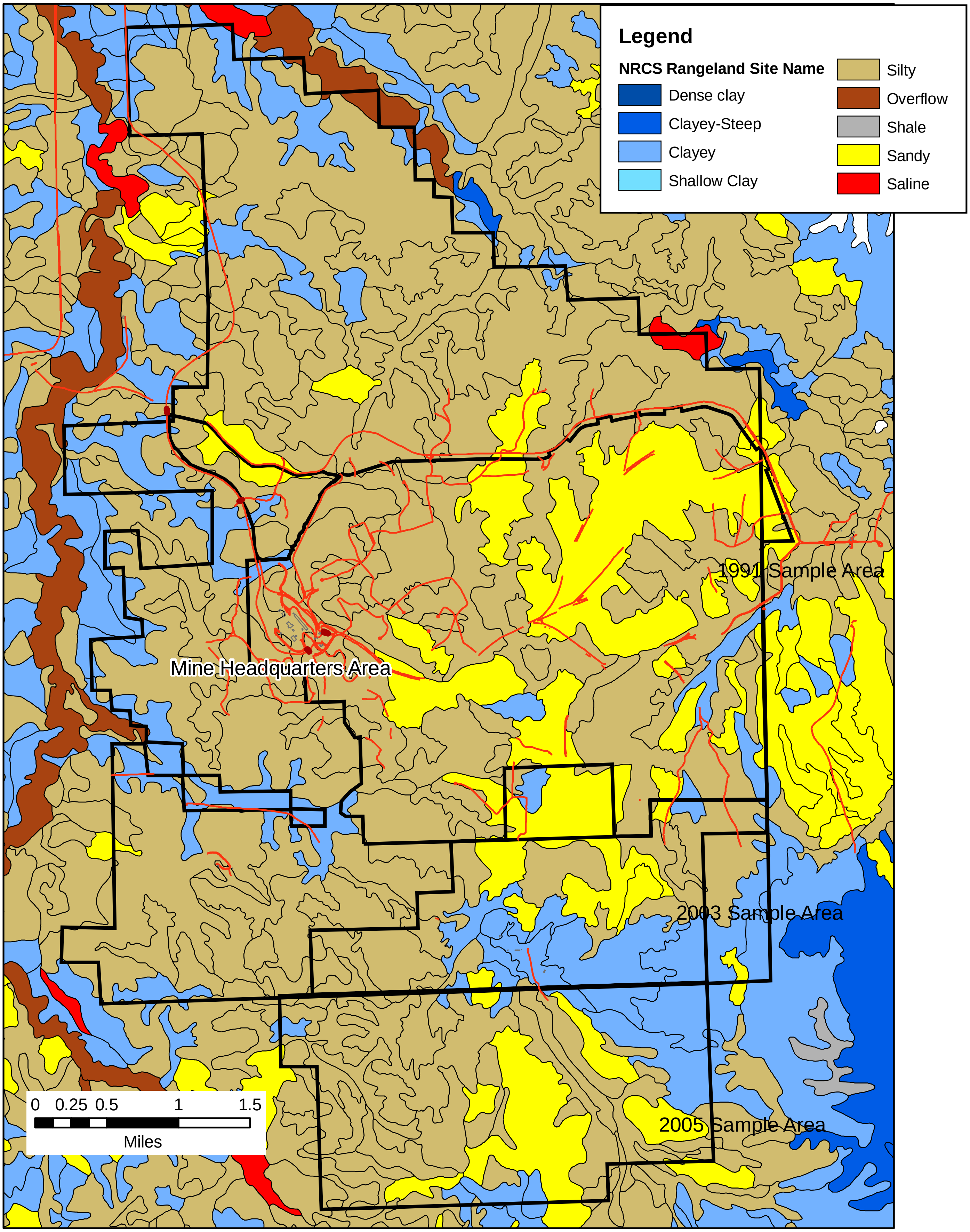

Fig 11. NRCS/SCS range sites for ASA. Range site definitions integrate surface soil texture and average precipitation to estimate normal available water (ie plant survival and production). They tend to parallel water storage capacity, but are more easily estimated in the field. The units are outlined and shaded by range site class. The units are named in Table 2, but only identified in the electronic version of the map. Drawn from NRCS/SCS, no ground truth. Useful in VHA engineering. From public data.

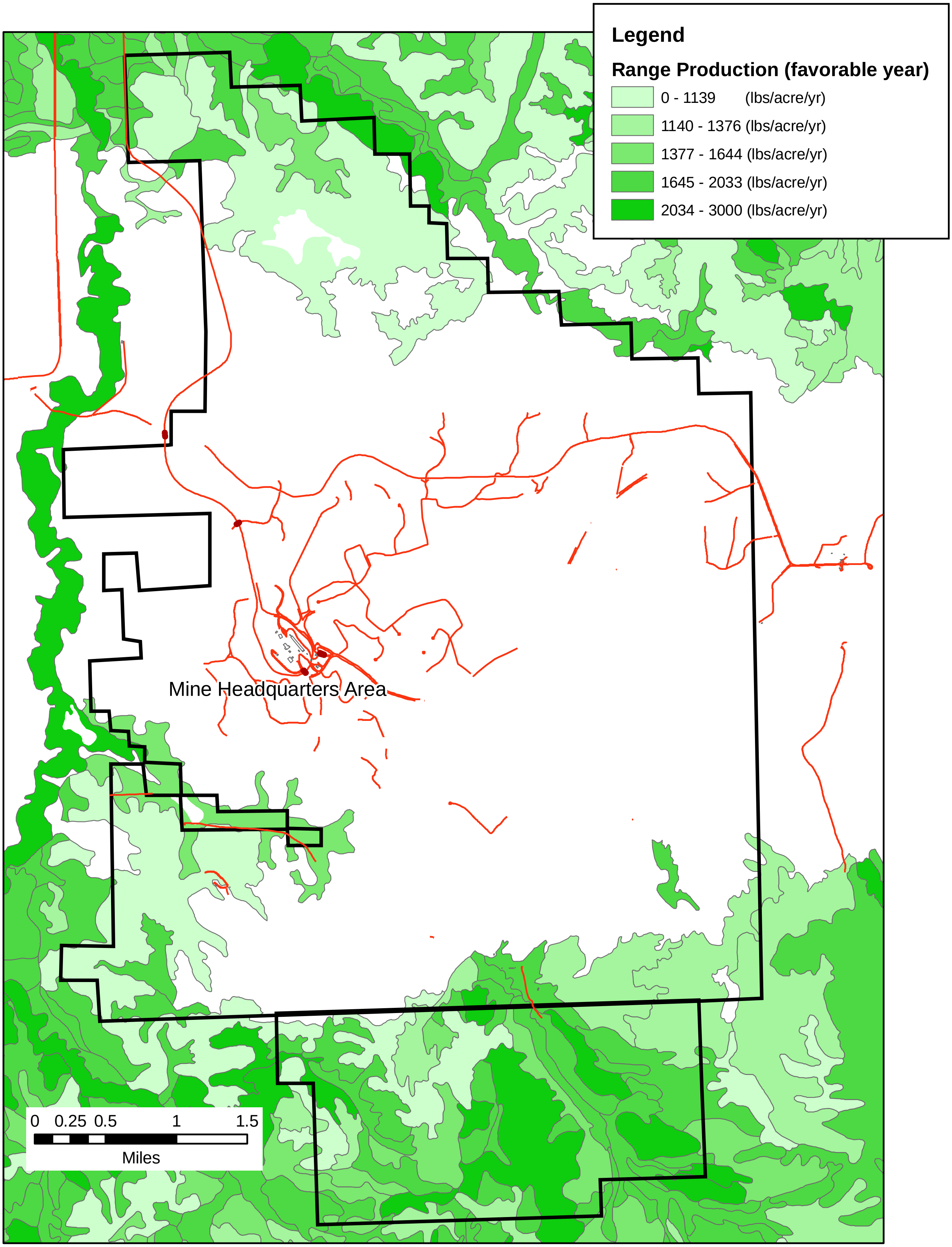

Fig 12a. Productive capacity of pre-mine ASA lands (non-irrigated). Range production in a favorable year (lbs/acre/yr x 0.112= gm/m2/yr.) Drawn from NRCS/SCS, no ground truth.
From public data.

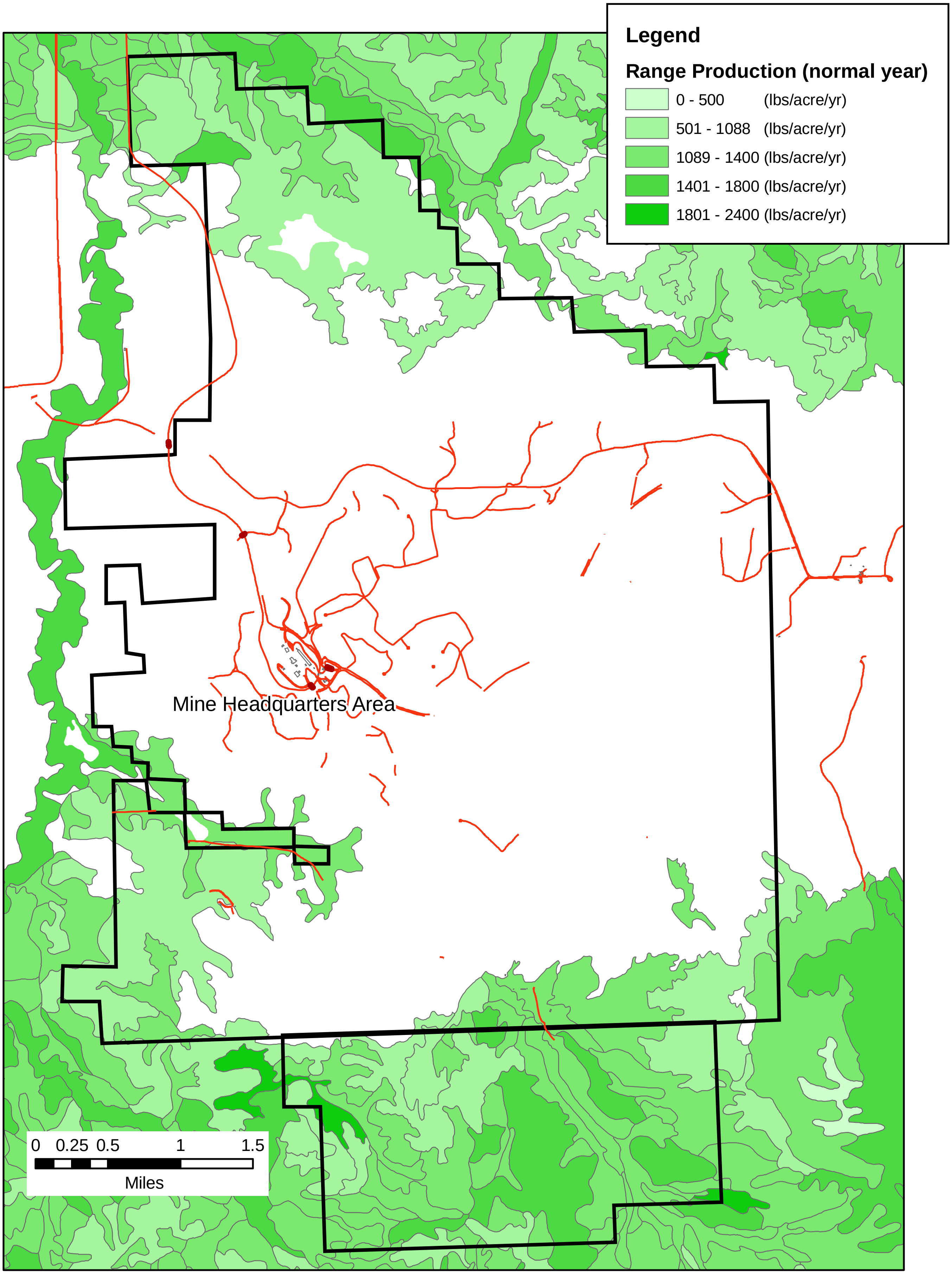

Fig 12b. Productive capacity of pre-mine ASA lands (non-irrigated). Range production in an average year (lbs/acre/yr x 0.112= gm/m2/yr.) Drawn from NRCS/SCS, no ground truth.
From public data.

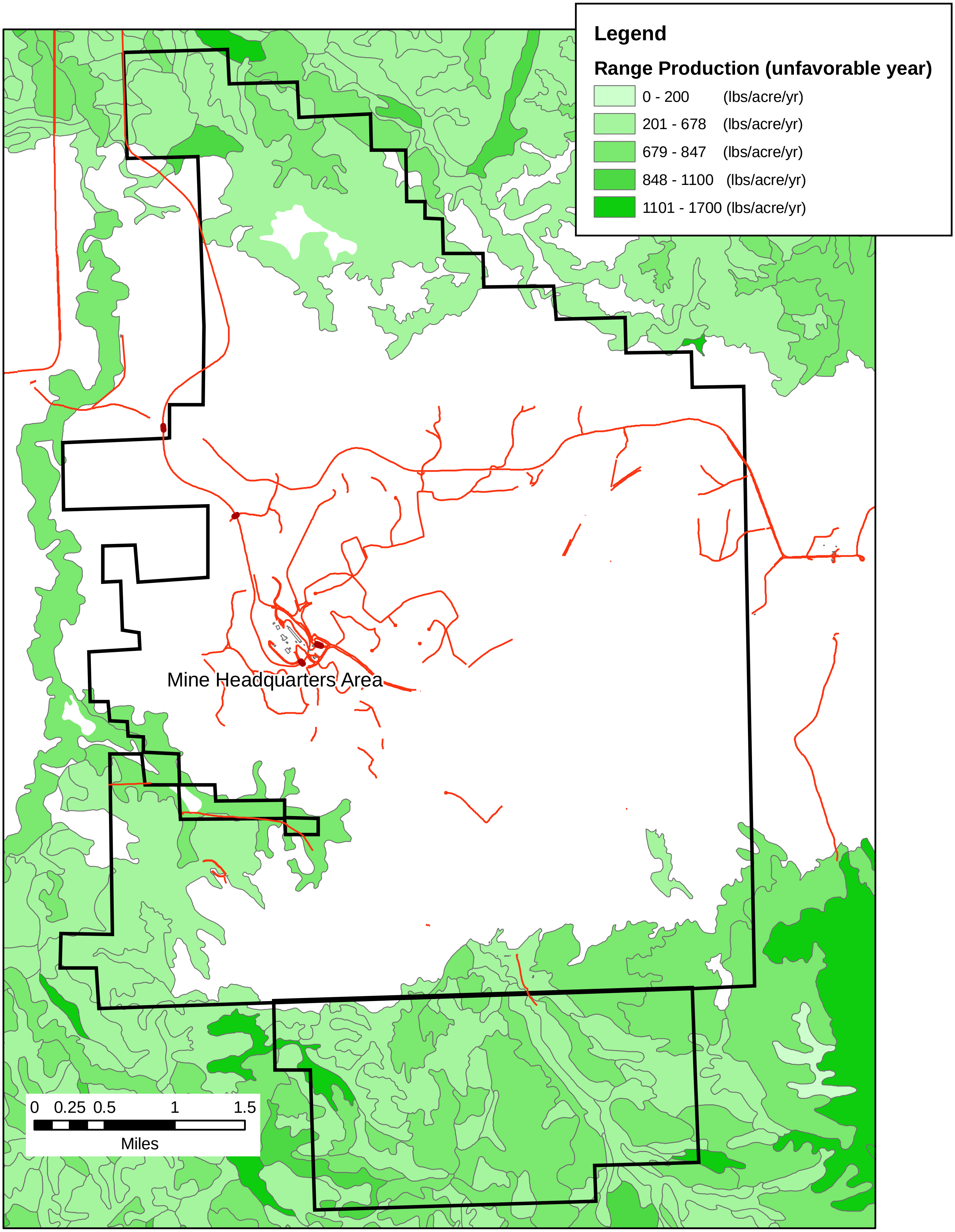

Fig 12c. Productive capacity of pre-mine ASA lands (non-irrigated). Range production in a dry year (lbs/acre/yr x 0.112= gm/m2/yr.) Drawn from NRCS/SCS, no ground truth.
From public data.

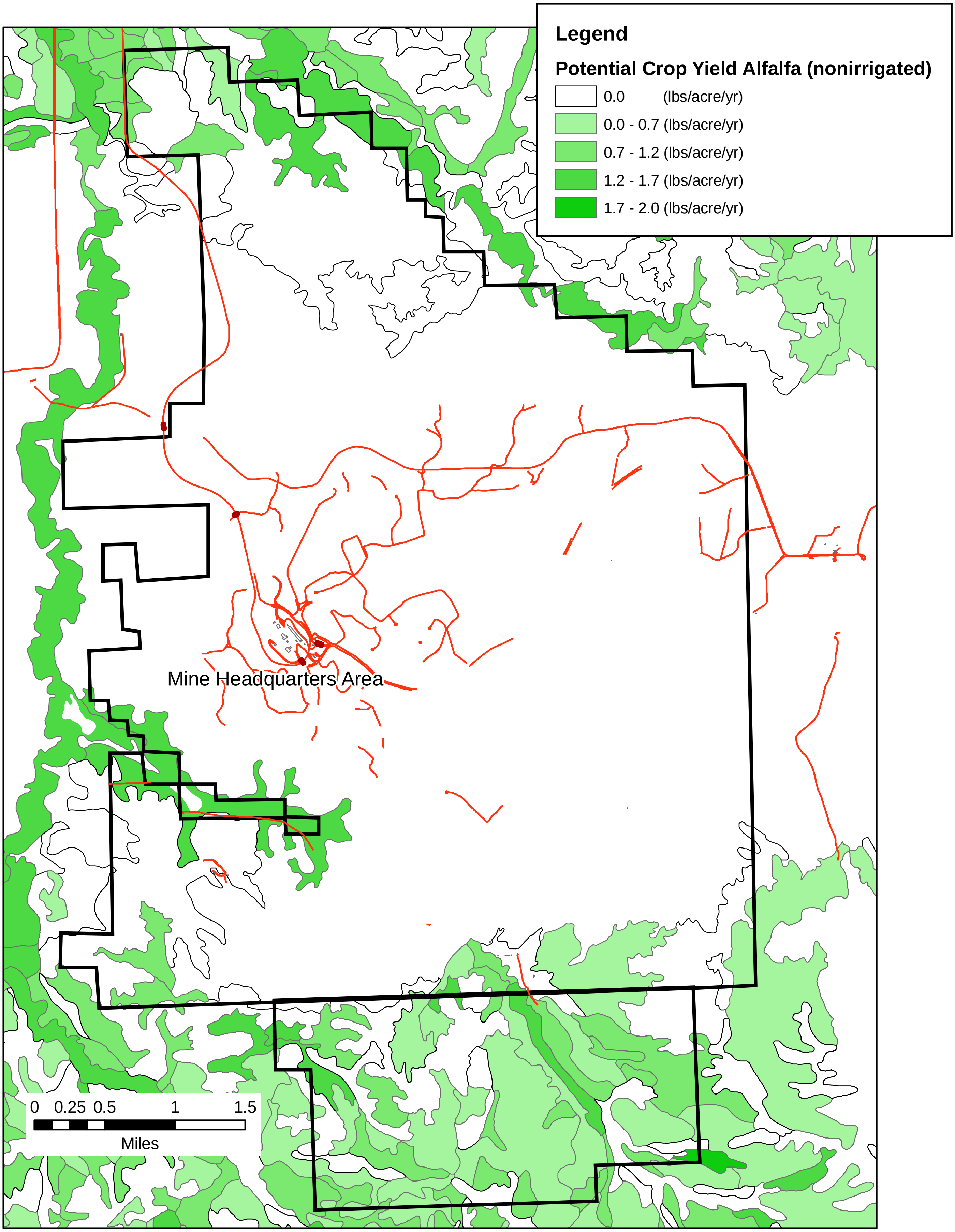

Fig 13a. Productive capacity of pre-mine ASA lands (non-irrigated). Production of alfalfa in an average year (lbs/acre/yr x 0.112= gm/m2/yr.) Drawn from NRCS/SCS, no ground truth.
From public data.

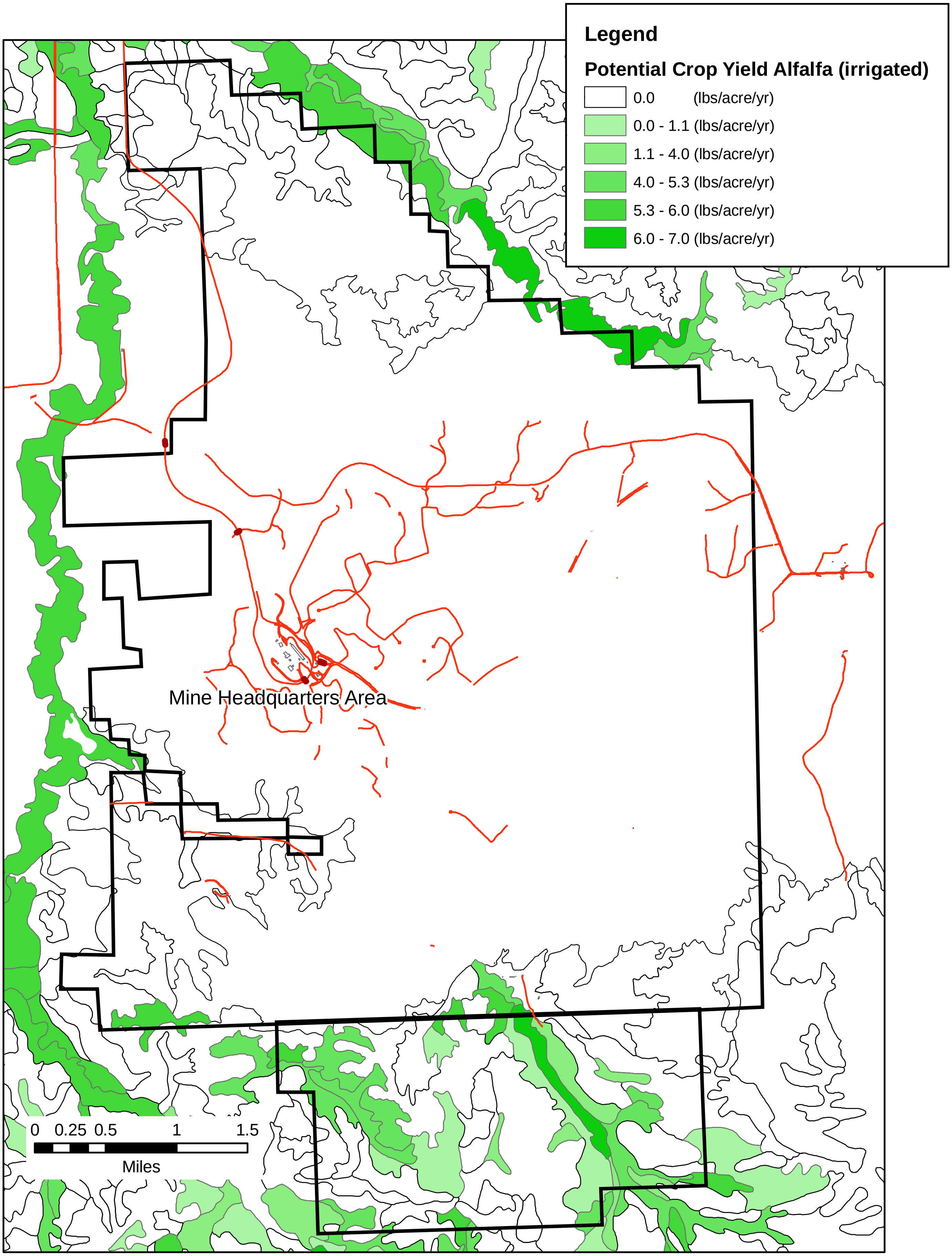

Fig 13b. Productive capacity of irrigated ASA lands. Production of alfalfa in an average year (lbs/acre/yr x 0.112= gm/m2/yr.)
From public data.

Chapter 4, VHA task 3

EVALUATION OF PUBLIC DATA (PD) VS. PRIVATE COMPANY (PC) DATA
that is,
SUITABILITY OF LARGE GRAIN DATA FOR FINE GRAIN MANAGEMENT- -
SUCH AS [POST MINING] REVEGETATION

INTRODUCTION

Landscapes are modeled for various reasons. To estimate runoff quantity and patterns . To map meso-environments which influence crop establishment and yield (Carr et al 1991, Nielsen and Bouma 1993). Or in re-vegetation (reclamation) of disturbed lands, to map micro-environments in which a (natural) community planted is likely to establish/perform well.

Landscape analysis can be used in at least two stages of post-mining (or post fire etc) reclamation. 1) First, in identifying (natural) vegetation suitable for particular landscape facets. And 2) second, to map facets of the disturbed landscape where each vegetation type is likely to establish.

To identify the environmental qualities necessary for a (each) community of concern this pilot project correlated vegetation presence/performance with qualities of the environment (landscape factors) it occupies, that is, by vegetation habitat association/analysis (VHA). Knowledge of community niches defined with landscape factors (slope, aspect, soils) will support installation of communities well suited for sites created and/or will support design of sites suitable for particular communities. In our primary analysis (step 1) we would ideally identify plant communities at specific points (visited remotely or in the field) and correlate the presence/performance of each vegetation type with associated habitat characteristics (eg slope, aspect, soil water holding capacity) drawn from 'public data'. We ask here, however, whether the precision of public data is suitable for the task.

In this (and other) contexts community sharing of (public) data on landscape attributes has obvious (economic and possibly quality) benefits in both private and public applications. As a result, many data on landscape attributes have been made available and others are being added. For example, slope and aspect are drawn from digital elevation models developed from topographic maps or simulated 'air photos' based on 30m and finer 2m (Ikonos) satellite images. Landscape positions are also mapped from the same DEMs (Zimmerman 2006). And conditions in landscape segments are sampled and extrapolated by mapping to similar areas (e.g. SCS/NRCS and NRIS).

In considering the correlation of vegetation with public measures of environmental quality, we note that, when public data is created, map units average the qualities of their subunits. We expect such averaging to affect topographic measures (e.g. slope/ aspect) and site quality (eg soil quality) measures; examples follow. 1) In our relatively level foothill environment, slopes at points described from 30x30 m DEMs (measured across 90x90m areas) are probably less than ground truth slopes because slopes of steeper microsites are averaged with those of gentler microsites. 2) Similarly, because aspects of slopes are measured on 30x30m DEMs (ie across 90x90m plots), an estimate of the aspect at a point deviates from ground truth to the degree that its aspect deviates from the average aspect in the 30x30m plot which includes it. 3) Similar error is included in other measures of topography made by comparison of adjacent pixels, eg position measures made by comparing elevations across strings of three pixels (eg Zimmerman 2006). 4) When soil quality is mapped, whether from field data (eg texture, water holding capacity) or mechanically (e.g. reflection or photosynthesis) mapping is done at a specified scale. Thus, ground-truth units smaller than the smallest mapping unit (2-5 acres for NRCS) may be mis-described by immersion in the dominant quality, i.e. ignored.

The object of this pilot project paper is to test for/ measure the error associated with use of public data , (e.g. DEMs based on 10-30m (pixel) units or 2-5 acre NRCS units) to estimate environmental quality of points ($100m^2$) in a mountain foothills environment. Specifically we will test effects of using larger map units (pixels) or mechanically mapped topographic characteristics (slope, aspect, slope position, radiation) and more subjectively mapped soil qualities (eg texture, rock content, depth to bedrock). That is, we will compare measures made from DEMS (10 and 30m) or published soil data (NRIS/SCS-NRCS) with (PC) ground truth.

METHODS.

We seek to measure slope, aspect, landscape position and soil properties of specific points for correlation with vegetation types present at those points. Conventionally, vegetation and environmental data have been gathered concurrently for this purpose. It is generally assumed that the process would/might be more efficient/less expensive if the environmental data were gathered, instead, from coarser grained public data (eg remotely sensed images, digital elevation models (DEMs) constructed from these images, or the soil maps of SCS/NRCS). One might doubt, however, that suitable point data can be read from data previously integrated over relatively large areas (0.1- 2 ha). The object of our project is to estimate such losses, ie to evaluate the large scale (large pixel) public data as a source of small scale (point/ small pixel) information. We do so by comparing (PC) values of environmental factors measured at points in the field and re-measured from coarser public data. In evaluating any non-concurrence the user will have to determine the scale appropriate for his application, e.g. mine reclamation.

Fine scale data gathered for permitting at the Absaloka coal mine provided excellent material for evaluating relatively coarse data (USGS and NRIS) for possible use in management at a finer scale. That is, GPS-ed pre-mine characterization points from the Absaloka mine provide ground truth for comparison with data drawn from coarser grained public data sets. The Absaloka Mine is located east of Hardin, SE Montana (45° 48' N, 107° 2' W; elev. 1120m) in the ecotone between great plains steppe vegetation and eastern ponderosa pine forests (Kuchler 1964).

Our 556 primary points were collected in 2003 (279) and in 2005 (277) and located with *Trimble Geoexplorer GPS and Trimble XT GPS* instruments. 254 accessory points were sampled in 1991 but excluded because they were located, less precisely, from topographic maps. In all three cases Westech selected the points as a stratified random sample of the pre-mine landscape; the area map was divided into vegetation units and each was sampled with one or more random points. Locations of the points and corresponding vegetation and environmental data (Westech 1992, 2004, and 2006) were provided by the Absaloka mine (D Myran, 2006 personal communication) and the contractor who chose and characterized them *(Western Technology and Engineering Inc., WESTECH, 3005 Airport Rd., P.O. Box 449, Helena MT, 59601)*

We discuss below other criteria for selection of points for particular tests, eg exclusion of soil units comprised of two (or more) soil types to simplify comparison of field data and public data.

We determined the accuracy with which **slope** at a point can be read from 10m and 30m DEMS by plotting the DEM slope against ground truth. Slope is defined as the angular deviation of a slope from a level plane. PC field measures were made with a clinometer and converted from percent measured to degrees by use of the formula $DS = ARCTAN(PS / 100) \times (180 / ð)$ where DS = slope measured in degrees and PS = slope measured as a percent. DEM slopes were estimated from 3x3 pixel units, i.e. over 30 x 30 m or 90 x 90m land units with arcinfo spatial analyst.. The 10m DEM was constructed from a mine-supplied high resolution topographic map by use of ARCINFO spatial analyst tools. The 30m DEM was available from USDI. We present slopes in degrees, which are convertible to percent by the formula above. The relationship between the calculated slopes and ground truth is described with two regressions, an unrestricted least squares regression and a linear regression forced through the origin. Five deviant points indicated in Fig1a and Fig 2a were eliminated from the regressions as missampled/mis-recorded. The fact that all were described in the same vegetation type at the same time bolsters our suspicion that they are erroneous.

We determined the accuracy with which **aspect** at a point can be determined from 10 x 10 and 30 x 30 m pixels by plotting the DEM aspect against ground truth. Aspect is the direction an observer is facing if his back is tangent to a topo-line behind him. Field measurements were made with a forester's cruising compass (Silva). DEM aspects are estimated from 3x3 pixel units, ie over 30x30m and 90 x 90 m land units. Aspects were calculated with ARCINFO spatial analyst from the same 10m and 30m DEMs used for measurement of slopes (see above). Aspects are presented as degrees from true north (N=0, E-W= 90, S=180) to index energy loads. The relationship between the calculated slopes and ground truth is expressed with two regressions, an unrestricted least squares regression and a linear regression forced through the origin, both explained in the statistics section below.

To determine the accuracy of landscape analysis for estimating actual **landscape position**s (ridge, slope, toe, flat) we compare positions recorded in the field with positions calculated from the DEM. The field position was ocularly estimated and the results were simplified into Zimmerman's four classes for comparison. Position was calculated from the 10m DEM (constructed from the mine's topographic map), but not from the 30m DEM, by the method of Zimmerman (2006). Data are presented in a contingency table (Table 3) with actual (PC field observed) values in the left column and values predicted from 10m DEM across the top, and a tally of concurrence in the matrix cells resulting. If PC field and DEM predicted values are in complete concurrence only diagonal cells will be filled and, assuming random sampling of the landscape, numbers of concurrences will be proportional to the area of each topographic class in the landscape. Agreement of the categorical assignments was summarized with total percent agreement and a kappa statistical summary (Jensen 1996) as explained the statistics section below.

To determine the accuracy with which we can determine **soil properties** of a point included in a coarsely mapped public data (SCS/NRCS-NRIS), we compared legend information from a soils map with field observed data (Westech). Soil qualities studied were quantity of cobble, quantity of gravel, and soil texture (sand/silt/clay content). PC Field determination of soil quality included a qualitative estimate of cobble-gravel presence (+/-) and a simple hand texturing. 'Public domain' descriptions of each soil were made by determining the soil type of each point studied and reading the cobble (2 classes), gravel (3 classes), and texture of each point from the SCS/NRCS soil type descriptions (Meshnik et al 1977). For both data sets, the clay content of surface soils at the points sampled was estimated as the midpoint of clay contents in the texture class assigned (Gee and Bauder 1986). Agreement of all three categorical assignments is described with total percent agreement and a kappa statistical summary (Jensen 1996), as explained in the statistics section below.

Accurate prediction of soil properties depends on two factors- - rather than one as used in determining slope, aspect, and position. 1) First, it is intuitively obvious that in complex units, estimation of soil quality depends on determination of the sub-unit from which soil properties will be read and that that determination for a random point will only be correct in proportion to the area of the subject unit relative to the area of the complex unit. To minimize 'identity error' we omitted all points located in complex map units. Identity error was still not eliminated completely because most simple units contain some foreign inclusions. 2) Second, dismissing the intuitively obvious, we consider the possibility that the value of one-on-one comparisons is diminished by imperfect measurement of soil quality by those who did the field sampling. Soil quality in the public units was estimated by SCS/NRCA professionals using coarse quantitative categories. Field measures were made by less experienced contractors with solid methods, but using less well defined categories and less practiced determination. Future use of simple and inexpensive quantitative methods (Boyoucos, Gee and Bauder 1986) is recommended to eliminate this source of error.

STATISTICS. Remotely measured slope and aspect PD data were compared with PC ground truth by regressing the remotely sensed variable against ground truth. Two linear regressions were tested, an unguided regression and a regression forced through the origin. R2 on the guided regressions was calculated with the following formula: $r^2 = corr(\hat{y}_i, y_i)$. Categorical public data and parallel field data were compared by tabling them against each other in contingency tables. These data include landscape position and substrate quality (ie cobble, gravel, and fine particle (sand, slit, clay) content). Agreement (%) was calculated as an overall measure of concurrence. The kappa statistic (cf. Jensen 1996) was also used as a more conservative measure of agreement, because it separately considers categorical disagreement from the perspective of ground truth data and the public data (i.e. errors of omission and errors of commission). Note that in the producer/consumer/kappa analysis we treated the ground truth as correct (i.e. reference). This is correct for landscape position, but not likely true for soil particle distributions.

RESULTS.

SLOPE. DEM derived slope (PD) was plotted against PC ground truth for both 10m (Fig 1a) and 30m (Fig 1b) 2003-2005 data. While the 1991 data were eliminated, because they lack the precision of GPS-ing, results are parallel and can be seen in appendix figures 1a&b. The data in each graph is described with two linear regression lines, one unguided and one forced through the origin. Equations, probabilities, and r^2 for these lines are recorded in the figures and again in Table 1. In our discussion we will dismiss the 10m data, recognize that estimates made from the 30m DEM are very low (~25%) relative to ground truth, prefer the unguided regression, wonder at the high intercept (3^o), and note that the scatter is large.

ASPECT. DEM derived aspect was plotted against ground truth for both 10m (Fig 2a) and 30m (Fig 2b) 2003-2005 data. While the 1991 data were eliminated because they lack the precision of GPS-ing, the results are parallel and can be seen in appendix figures 2a&b. The data in each graph is described with two linear regression lines, one unguided and one forced through the origin. Equations, probabilities, and r^2 for these lines are recorded in the figures and in Table 2. In our discussion we will recognize that average estimates made from the DEMs are very similar to ground truth (96-97%), prefer the guided regression, and note that scatter is both large and asymmetric, that is, that it has a deficiency of south-facing outliers.

TOPOGRAPHIC POSITION. To evaluate the accuracy of publicly available slope positions, we tabled them against ground truth. Public landscape positions (bottom, toe-slope, slope, and ridge) were calculated from the 10m DEM only (sadly), by a popular method (Zimmerman 2006). The analysis was based on 2003 data only, because 1991 data was not GPS-ed and because 2005 field data were not available. Landscape positions recognized in the field were grouped into the four types calculated (cf Table 3). The contingency table comparison (Table 3a) shows good agreement on slopes, but strongly misclassifies much rarer bottoms, toe-slopes, and ridges into the slope category. Total agreement was 60% (Table 3b) and error matrix analysis with kappa analysis (Jensen 1996, Table 3) support the conclusion that calculated positions are only loosely related to PC ground truth.

SOIL COMPOSITION. Large (cobble >7.5cm), medium (gravel <7.5cm and >2mm) and small (sand/silt/clay <2mm) particle contents of the soils classified from Westech field analysis and SCS/NRCS data were compared separately. Contingency tables (Table 4,5, and 6.) present differences/similarities. Companion tables present percent agreement and error matrix analysis with kappa analysis (Jensen 1996)

COBBLE. Field and SCS designations were compared on a presence/absence basis (Table 4). The data sets agreed that cobble-free sites are the norm (92%). Discouragingly, they are in complete disagreement as to which of the sites are cobbly (Table 4) While agreement is = 92.7%, a particulary low kappa statistic (-2.3) demonstrates, nevertheless, the complete lack of agreement between the measures. Note that the entire calculation is based on the questionable assumption that Westech data is more true than SCS/NRCS data.

GRAVEL. According to SCS/NRCS (Meshnik et al 1977) gravely soils contain 0-35% gravel, no described soils have gravel contents in the 0-10% range, and gravel-free soils contain less than 10% gravel (Table 5). Westech compositional boundaries are undefined. The classifiers agreed in only 29% of the cases. While SCS classified 72% of the soils gravely, Westech called 28% of the soils gravely. 28% of the soils were called non-gravely by both classifiers. A low Kappa statistic (1.2), based on the questionable assumption that Westech data is more true, emphasizes the poor agreement.

SOIL TEXTURE. Of the twelve classes in the textural triangle (Gee and Bauder 1986, Brady and Weil 2000) three were recognized by both SCS/NRCS and Westech and nine were recognized by one or the other (Table *6abc).* Agreement was only 33%. A low Kappa statistic (8), based on the questionable assumption that Westech data is more true, emphasizes the poor agreement. However,if one considers all cases off by only one textural class (ie, near-misses) as matches, agreement is considerably better (83%, Table 7).

Placement of a soil in the soil triangle depends on estimates of sand, silt, and clay contents which were not quantified by either party. To simplify the classification we ask whether the parties agree on in their estimates of clay content, the primary determinant of soil water and nutrient holding capacity, and the most easily field estimated. We estimated the clay content of each sample from the textural triangle as the midpoint in clay content for the class named. Using a three level classification (Table 7, clay >50%, 18-50%, and <17%) agreement was much better (65%= 160/246) than with the textural classes (33%). Using a two level classification (Table 7) improved agreement slightly, to 69%= 169/246.

DISCUSSION.

To evaluate public data (pilot project) we compared characterizations of points made from PC field data and public data captured from remote sensing or synthetic mapping. Our object was to determine whether relatively coarse public data are dependable at the mine-reclamation scale. Specific comparisons were made for three landscape characteristics likely important in mine reclamation/ revegetation (ie slope, aspect, topographic position) and three soil qualities (cobble, gravel, and texture)

SLOPE. Slope is important primarily as an influent of water capture (runoff), as a determinant of evapo-transpiration (energy capture), as a correlate of stability, and, in the pre-mine state, often as a correlate of rockiness (water infiltration and fire danger). While ground truth is clearly the reference at the reclamation scale, calculated slopes may accurately describe the landscape at a larger/smaller scale of no currently identified use.

Our PD sample strongly over represents low slopes. We deduce, never-the-less that slopes measured from DEMs underestimate actual slopes considerably. Slopes measured from the 30m DEM (Fig 1, Table 1) are less than half of those measured in the field whether unrestricted (y= 0.25+3, r^2= 0.31) or forced through the origin (y= 0.50x +0, r^2= 0.31). We offer four observations on slopes measured from the 30m DEM. 1) The lesser slope shown by remotely sensed data surely occurs because its large pixels average steeper and shallower topographic portions of the generally more level remote observational unit, ie 90x90m (0.8 Ha). 2) The concentration of low slope points above the origin in the graph of the guided model (dashed line, Fig 1) suggests acceptance of the unguided (solid) regression. 3) Variances of the regressions are high and equal (r^2= 0.31LS and 0.31guided). Underestimates occur when steep sites are imbedded in shallow pixels. Accurate estimates occur when local slopes and land slopes are equal. And overestimates occur when shallow sites are imbedded in steeper landscape facets. 4) The intercept of the unguided estimate is 3^o but, while an (apparent) 3^o underestimate in field might have been made on low slopes, it is surprising that the bias extended across all slopes.

We reject the results of our analysis of the 10m DEM (Fig 1, Table 1). Because, while larger pixels must generally level a landscape (as with the 30m DEM), our analysis, that the DEM estimates of slope are always higher than ground truth (y=1.75x +0, r^2= 0.41 Lin and y=1.02x + 9, r^2 =0.41), is obviously incorrect. We have not found the source of this error, but offer three possible explanations. Possibly there was error in generation of the topographic map from which the slope estimates were made. Possibly the program used to create the DEM from topographic maps is incorrect or was incorrectly applied.

Similar conclusions would be drawn if we included (1991) data from non-GPS-ed points (Table 1 or App 1).

ASPECT. Aspect is important primarily as an influent of evapotranspiration (incoming radiation). While ground truth is clearly the reference for our scale, calculated aspects may accurately describe the landscape at a larger/smaller scale.

We deduce that, while aspect measured from the DEMS varies considerably around the true aspect, measurements are, on average, accurate. Five observations elaborate. 1) Our sample was well distributed around all aspects. 2) When plotted against PC ground truth, both 10m and 30m data are concentrated on the 45^o axis of equality. Thus regression lines forced through the origin describe the data graphed well, ie that of the 10m data ($y= 0.97x+0$, $r^2= 0.50$, Fig 3) and 30m data ($y=0.96x+0$, $r^2= 0.36$). 3) Variation around the guided regression lines is high ($r^2= 0.50$ and 0.36 for 10 and 30m DEMs respectively), indicating that while the aspects measured are well correlated on average, deviation can be very large (eg 50^o). It seems obvious that error is more often toward a more southerly estimate than a northerly one. We have not formally tested this hypothesis. This bias may indicate a southerly aspect at a scale larger than that observed by the PC field samplers. 4) We reject the unguided regression because the preponderance of south facing outliers twists it away from the concentration of points. 5) Similar conclusions would be drawn if we included data (1991) from non-GPS-ed points (Table 2 or Appendix 2)

LANDSCAPE POSITION. Landscape position is relevant to vegetation distribution/choice of revegetation community- - primarily because it affects plant water relations through wind driven evapo-transpiration (ridges vs bottoms) and redistribution of water from high to low sites (run-off of rain and blow-off of snow). As a result, vegetation surveyors record the positions of their sites and modelers calculate corresponding positions from DEMs. Because PC field classification is straight-forward we see the field data as true for the scale of interest. Thus correlation of PC field data with calculated data should provide a test of a particular landscape model (Zimmerman 2006) in a prairie/foothill landscape.

Using the 10x10m DEM there is 65% agreement between the model and PC field observations. But because we doubt slope estimations from the 10m DEM we cannot deduce that the Zimmerman model has failed. Agreement in identification of sloping sites, the most common position type, was strong (196/216=91% correct). Sites occupying a small fraction of the landscape, however, were poorly identified by the model. For ridge, toe slope, and valley bottoms- - only 1/26= 4% , 2/12= 17%, and

6/82= 7%, respectively- - were correctly identified (Table 3). Figure 6c in the GIS chapter shows/illustrates the poor performance of the landscape model on valley bottoms; most are mis-classifed as sloping land.

Given post-pilot project resources, we would re-test, using the ‘more dependable/certain’ and broadly applied 30m DEM. Logic suggests that when large pixels are used, ridges, toes, and all but the broadest bottoms would be underestimated- - due to averaging with the common slope type- - as they were in the 10m DEM. Slopes misclassified must fall into slopes. Thus, while we doubt the 10m DEM, we expect results parallel to those deduced from it.

SOILS. Field measures were compared with SCS/NRCA data for three soil characteristics.

COBBLE AND GRAVEL. Cobble and gravel are potential determinants of tree-shrub performance because they support woody plants both by minimizing the travel of fire and by supporting water drainage through the grass rooted zone to reservoirs used mostly by trees and shrubs. SCS/NRCS and Westech usually agreed (72%) on cobble contents because cobbly soil surfaces are rare in the area. However, because cobbles are so distinct, it is surprising that Westech and NRCS cobble designations never coincide (Table 4). Some of the confusion may arise because, while NRCS defines ‘cobbly’ as >35% % cover of rocks >7.5cm in diameter, Westech (undefined) may have required a higher cobble content for this designation.

SCS/NRCS and Westech agreement was only 29% on gravel contents (Table 5). The classifiers agreed on a few (4/254= 2%) gravely sites and a few no-gravel sites (70/254= 28%). Many sites (180/254=71%) classified as gravely by SCS, were called gravel-free by Westech. This difference might be explained in two ways. Relative to SCS/NRCS, Westech may have required a higher gravel content for the ‘gravely’ designation. Or Westech’s more surface-based examination may have missed gravel and classified, for example, needle littered gravely sites as non-gravely.

TEXTURE. Texture is a determinant of vegetation habitat and re-vegetation planning because sandy soils capture water (high permeability) and store it in deeper layers more available to trees and shrubs than to grasses. In contrast, clay rich soils shed water from heavy showers (runoff) and store most of the remainder in surface layers where it is available to grasses.

Absolute agreement on soil texture between SCS/NRCS and Westech was poor (72/246=29% , Table 6). Agreement improves if one softens the standard. If one accepts as identical Westech textures within one class of SCS classes, agreement is 204/246= 83%% (Table 6). Alternatively, if one assumes that clay content is the active property in soil texture, he might compare soil clay contents by assuming that clay content is at the middle of the clay range in the soil texture considered. If clay contents are defined as three classes (>50%, 50-18%, and <17%) agreement is 160/246= 65%. If clay content is defined as >50% and <30% (???) agreement is 169/246= 69% (Table 7).

ERROR. The over-all poor agreement between PC field and SCS/NRCS data makes it difficult to use either with confidence. Because the field data was gathered by contractors with less expertise in soil science, one could to attribute all the 'error' to them. For example their measures may be more concentrated on surface conditions and their texturing may be less precise. On the other hand, because public data is mapped in relatively large units and each is characterized by description of its dominant soil, the soil of any sample occupying an inclusion (distinct sub-unit) is automatically mis-characterized. While we minimized the likelihood of this 'wrong soil' problem by omitting all units designated/mapped as compound, such error is still expected in proportion to the area of 'odd' inclusions in the mapped unit.

DISAGREEMENT. We see three sources for disagreement between public data and PC ground truth: Scale, precision, and observation method.

SCALE. The disagreement between public and ground truth data for landscape characterization may be due to difference in scale rather than 'right-wrong'. DEM slope and aspect describe landscape at a larger scale (of broader units) than at that sampled by pre-mine contractors. Zimmerman's (2006) landscape model may similarly apply to a larger scale, with its over-detection of slopes (and under-detection of other positions) due to the averaging of ridges, toe-slopes, and even broad river bottoms into adjacent slopes.

If disagreement is due to scale, we should use the scale most appropriate to our objectives, that is, characterization of micro- or mesoenvironments for use in describing them and relating them to vegetation that can or does occupy them. Such disagreements might not exist in two circumstances. In a gentle plain (e.g. the 'monotonous' western plains) where the environments of small sample units don't vary among small companion units or between the small units and larger landscape units that include them. Second, from the stand-point of vegetation, disagreements might not exist where a broadly tolerant vegetation type (seral or climax) in the center of its environmental range (e.g. in the center of a Holdridge (1947) cell) thrives in somewhat different environments of adjacent micro-sites.

Neither possibility is available in the broken landscape of our ecotone between grassland and pine forest, where small differences in environmental conditions cause marked change in vegetation. Ecologists of the area- - academics, mine operators, and state regulators- - have subjectively chosen small sample units (~100m^2), rather than the larger sample units of a 30m DEM (~8000m^2= 0.8Ha) for characterization of vegetation and its environment. A serious test of this subjective choice could be made by comparing the correlation, at several scales, between a vegetation type and a likely landscape factor (eg slope, aspect, % clay). Such a test might be elaborated by examination of multiple vegetation types and multiple factors or factor combinations. While most ecologists opt for small units, there may be uses for larger ones: perhaps in the description of vegetation at a regional scale or in the examination of geomorphology.

PRECISION. The number of distinct inclusions must increase as detailed maps are summarized into maps with coarser units. And with that growth/increase, the probability that the environment/vegetation of a micro-site (ground truth) will match that of an encompassing unit will fall. Matching of vegetation with public domain site characteristics is best when the points considered are GPS referenced. When they do not match, the comparison is obviously inappropriate. The error associated with mismatch will probably grow with offset and to be greater in heterogeneous than homogeneous environments.

CHARACTERIZATION METHODS. Use of different methods or subdividing continuous scales inconsistently can also cause disagreement. Thus, both less (consultant) and more (SCS/NRCS) expert observers of soil (or vegetation) may profit from the use of quantitative measures and standardized definitions. For example, cobbly and gravely might be easily estimated ocularly or with a point method. Clay content and soil texture are easily measured with the Boyoucos method (Gee and Bauder 1986). Quantitative measures, will circumvent difficulty in defining/ applying ‘classes’ (e.g. cobble status or soil texture) which may have confused comparisons of soils in our study.

CONCLUSIONS.

Estimates of slope, aspect, landscape position, and soil quality made from publicly available data usually agree poorly with measures made on the ground (e.g. PC). The differences may be due to scale effects and/or measurement error.

On average, slopes calculated from 30m (PD) DEMS greatly underestimate (25%of ground truth) slopes measured on the ground (PC). Variance associated with this mean is large, and is symmetrical around the regression line. We reject correlations drawn from our not-credible 10m DEMs.

On average, aspects calculated from 10-30m DEMs were comparable to those measured on the ground. Variation associated with this mean was large (r2= 0.5 and 0.36) and the error was strongly biased toward south-facing slopes.

Landscape position classification based on our 10m DEM and the Zimmerman (2006) method was in poor agreement. While the errors were those expected, conclusions are withheld due to skepticism about the underlying data set.

The disagreement between measures of slope, aspect, and perhaps position may express real scale differences. If so, the patchiness observed in the landscape suggests that the smaller scale is most appropriate for identification and replacement of vegetation. Are there useful applications for the larger scale?

Agreement between public and Westech data is poor for cobble, gravel (29%) and texture (30-60%). While we see the ground survey as defining vegetation relevant truth in the study of slope, aspect, and position, it is not clear what is the standard in the examination of soils. Because soil quality affects water availability and fire behavior we encourage simple quantification cobble, gravel, sand, silt, and clay contents.

LITERATURE CITED.

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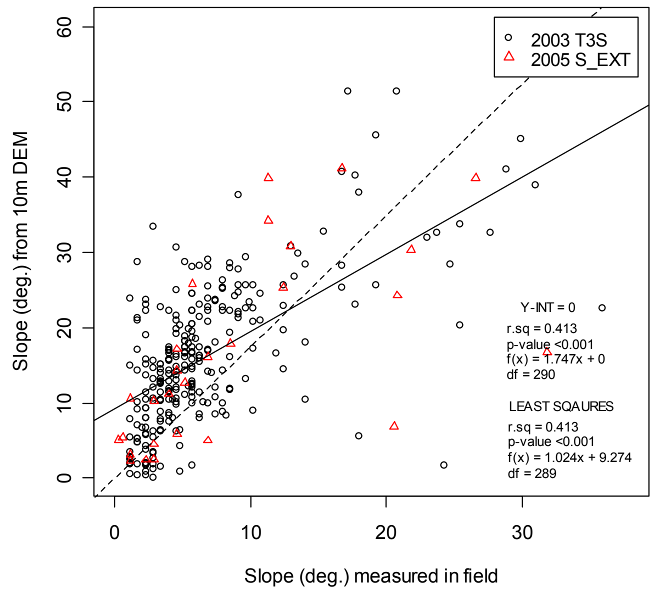


Figure 1a. Comparison of ground-truth slope and slope estimated from the 10m DEM, 2003-2005 data.

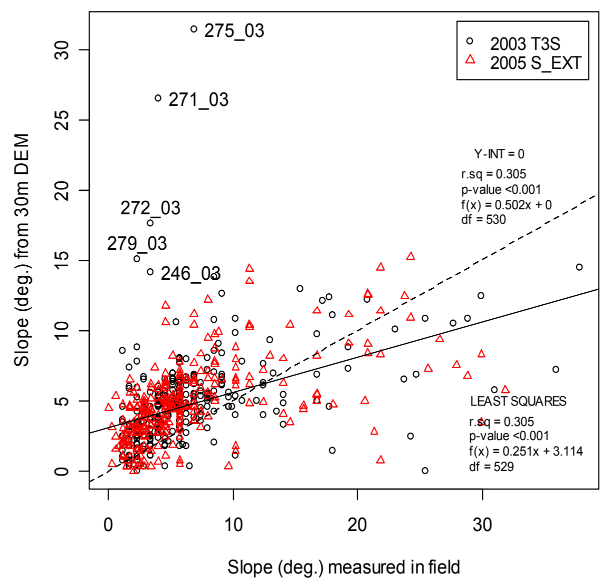


Figure 1b. Comparison of ground-truth slope and slope estimated from the 30m DEM, 2003-2005 data. The numbered points were eliminated as somehow in error.

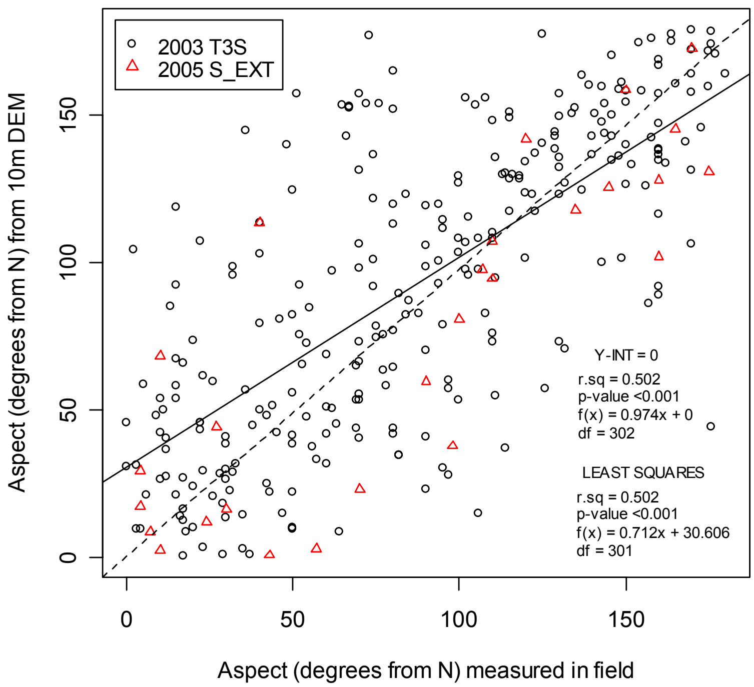


Figure 2a. Comparison of ground-truth aspect and aspect estimated from the 10m DEM, 2003-2005 data.

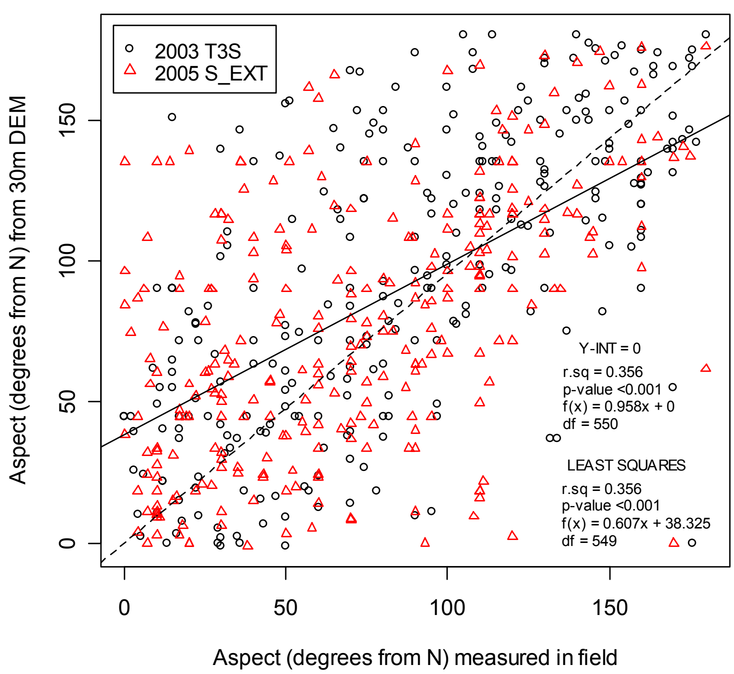


Figure 2b. Comparison of ground-truth aspect and aspect estimated from the 30m DEM. 2003-2005 data.

Table 1. Relation of predicted slope to ground truth. Regressions treat 1999, 2003, 2005, and composite data. Regressions are of two forms, unguided and guided, i.e. , with the line forced through the origin.

	Coef.	Y-int.	DF	R^2	*p*-val
Unrestricted regression					
All data_10m	0.90	10.92	442	0.205	<0.001
2003-2005 data_10m	1.02	9.27	289	0.413	<0.001
All data_30m*	0.25	3.14	682	0.241	<0.001
2003-2005 data_30m*	0.25	3.11	529	0.305	<0.001
1991_10m	0.05	16.6	151	0.0002	0.877
1991_30m	0.04	4.02	151	0.002	0.595
2003_10m	1.06	9.23	261	0.426	<0.001
2003_30m*	0.24	3.15	261	0.294	<0.001
2005_10m	0.90	8.34	26	0.377	0.001
2005_30m	0.26	3.09	271	0.315	<0.001
Regression forced through origin					
All data_10m	1.877	0	443	0.205	<0.001
2003-2005 data_10m	1.747	0	290	0.413	<0.001
All data_30m*	0.516	0	683	0.251	<0.001
2003-2005 data_30m*	0.502	0	530	0.305	<0.001
1991_10m	2.552	0	152	0.0002	0.877
1991_30m	0.640	0	152	0.002	0.595
2003_10m	1.813	0	262	0.426	<0.001
2003_30m*	0.4964	0	257	0.294	<0.001
2005_10m	1.3996	0	27	0.377	0.001
2005_30m	0.5071	0	272	0.315	<0.001

*Outliers excluded.

Table 2. Relation of predicted aspect to ground truth. Regressions treat 1999, 2003, 2005, and composite data. Regressions are of two forms, unguided and guided, i.e. , with the line forced through the origin.

	Coef.	Y-int.	DF	R^2	*p*-val
Unrestricted regression					
All data_10m	0.533	43.34	454	0.291	<0.001
2003-2005 data_10m	0.712	30.61	301	0.502	<0.001
All data_30m	0.473	47.61	702	0.220	<0.001
2003-2005 data_30m	0.607	38.33	549	0.356	<0.001
1991_10m	0.07	69.6	151	0.005	0.390
1991_30m	-0.07	80.0	151	0.006	0.360
2003_10m	0.71	31.8	273	0.499	<0.001
2003_30m	0.66	38.4	273	0.409	<0.001
2005_10m	0.7	19.5	273	0.546	<0.001
2005_30m	0.51	40.6	274	0.267	<0.001
Regression forced through origin					
All data_10m	0.919	0	455	0.291	<0.001
2003-2005 data_10m	0.974	0	302	0.502	<0.001
All data_30m	0.473	0	703	0.220	<0.001
2003-2005 data_30m	0.958	0	550	0.356	<0.001
1991_10m	0.7603	0	152	0.0049	0.3904
1991_30m	0.7242	0	152	0.0055	0.3603
2003_10m	0.9859	0	274	0.4993	<0.001
2003_30m	0.9901	0	274	0.4087	<0.001
2005_10m	0.8579	0	27	0.5457	<0.001
2005_30m	0.9130	0	275	0.2665	<0.001

*Outliers excluded.

Table 3a. Comparison of topographic designations of sites by Westech and classes created using the Zimmerman (2006) method. Note, analyses are based on 1991 and 2003 data, because the 2005 data did not fall into the region of the 10m DEM.Westech classes not available.

		Westech (reference)			
		Ridge	Slope	Toe Slope	Valley Bottom
ZIMMERMAN/ DEM	Ridge	1	9	0	1
	Slope	25	196	10	53
	Toe Slope	0	9	2	22
	Valley Bottom	0	2	0	6

Table 3b. Agreement in topographic class assignments of sites made by Westech and classes created using the Zimmerman (1996) method. Classes are slope, ridge, toe slope, and bottom, as above.

	Agreement between ground truth and 10m DEM topographic categories (%)	*p*-value[1]
All data	61.0	0.039
1991 data	60	0.828
2003 data	61.7	<0.001
2005 data	NA	NA

P-values are type-I errors for tests of the H_0 "The agreement of categorical assignments is no greater than expected by chance". *P*-values were obtained with a Monte-Carlo randomization of categorical assignments using 1000 permutations.

Table 3c. Error matrix analysis of topographic assignments of sites, including kappa statistics. 1991 and 2003 data were used. Westech data were used as reference data in user and producer calculations.

Accuracy	Ridge	Slope	Toe Slope	Bottom	Kappa statistic
1991 and 2003 data					
User	3.8	90.7	16.7	7.3	12.3
Producer	9.1	69	6.1	75	
1991 data					
User	0	86.7	40	3.2	0.7
Producer	0	65.5	22.2	33.3	
2003 data					
User	5.9	93.7	0	9.8	18.8
Producer	14.3	71.5	0	100	

Table 4a. Comparison of 'cobbly' designation of sites by Westech and SCS/NRCS public data1991 data and outliers in 2003 data (cf. Figs. 2 and 6) were omitted.

		Westech	
		Cobble	No Cobble
SCS/NRCS	Cobble	0	17
	No Cobble	4	233

Agreement (%) = 91.7

Note: This analysis assumes no 'soil typing error' because only 'simple' units were selected.
For NCS/NRIS categories cobbly is defined as a soil type containing rocks larger than 75mm diameter.
Westech designations are undefined.

Table 4b. Comparison of 'cobbly' designation of sites by Westech and SCS/NRCS public data, kappa analysis. Perhaps inappropriately, Westech data was used as reference data in the user and producer calculations.

Accuracy	Cobble	No Cobble
User	0.0	98.3
Producer	0.0	93.2

Kappa statistic = - 2.6

Table 5a. Comparison of ‘gravelly’ designation of sites by Westech data and publicly available SCS/NRCS data, contingency table. 1991 data, and 2003 outliers noted in Figs. 2 and 6 were not used in analysis.

		Westech		
	(cover)	Gravel	Intermediate Gravel	No Gravel
SCS	Gravel (0-35% gravel)	4	0	180
	Intermediate Gravel (0-10%)	0	0	0
	No Gravel (0%)	0	0	70

Agreement (%) = 29.1

Table 5b. Comparison of ‘gravelly’ designation of sites by Westech and publicly available SCS/NRCS data, kappa analysis. Perhaps inappropriately, Westech data was used as reference data for user and producer calculations.

Accuracy	Gravel	No Gravel
User	2.2	100.0
Producer	100.0	28.0

Kappa statistic = 1.2

Table 6a. Comparison of soil texture[1] designation of sites by Westech and publicly available SCS/NRCS data[2]. The agreement column specifies agreement when 'agreement' is defined as 1) perfect agreement, 2) near miss= 1 class, and 3) large error= 2 class. SCS and Westech totals sum the examples of any texture without regard for the opinion of the competing classifier.

Westech textures

		% clay	Cl	SiCl	ClL	SaClL	SiClL	L	SiL	SaL	LSa	SCS total	% Agreem.[3] 1	2	3
SCS/NRCS textures	Cl	77			2	2	**4**	0	**3**	**6**	0	17	***0***	***35***	***65***
	SiCl	50			0	0	1	0	**6**	0	0	7	***0***	***14***	***99***
	ClL	35													
	SaClL	32													
	SiClL	32			0	1	1	0	**4**	**7**	0	13	***8***	***38***	***46***
	L	16			3	8	**21**	0	**17**	**32**	1	82	***0***	***27***	***99***
	SiL	12													
	SaL	10			2	6	11	2	**21**	**81**	4	127	***64***	***90***	***90***
	L-Sa	8													
Westec total					7	17	38	2	51	126	5	246			

Footnotes:
[1]Soil textures are Cl=clay, SiCl=silty clay, ClL=clay loam, SaClL=sandy clay loam, SiClL=silty clay loam, L= loam, SiL=silt loam, SaL=sandy loam, LSa=loamy sand

[2]1991 data outliers in 2003 data (cf Figs. 2 and 6) were omitted from the analysis.

[3]The agreement column specifies agreement when 'agreement' is defined as 1) perfect agreement, 2) near miss= 1 class, and 3) large error= 2 class.

Table 6b. Comparison of soil texture designation of sites by Westech and publicly available SCS data, kappa analysis. Perhaps inappropriately, Westech data was used as reference data for user and producer calculations.

Accuracy	Cl	ClL	L	LSa	Sa	SaClL	SaL	SiCl	SiClL	SiL
User	NaN	0	0	0	NaN	0	64.3	NaN	2.6	0
Producer	0	NaN	0	NaN	NaN	NaN	63.8	0	7.7	NaN

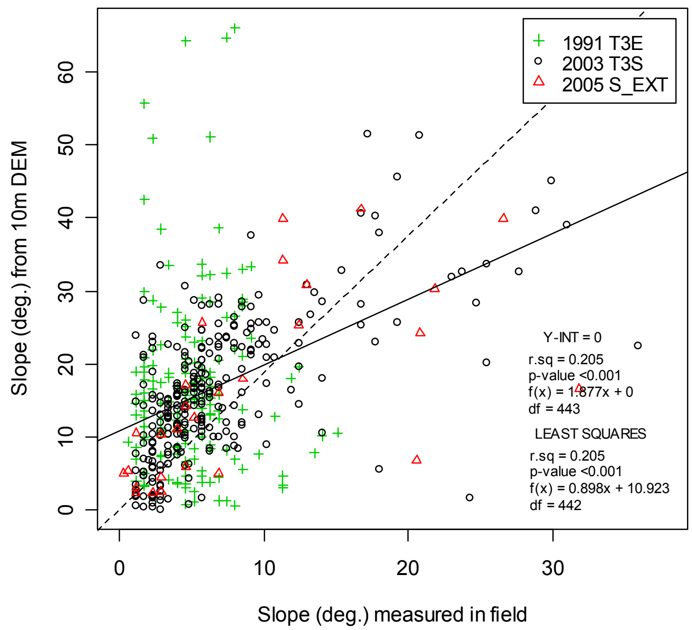
Kappa statistic = 8.

Table 7. Agreement between contractor and SCS/NRCS on clay content, a functional surrogate for soil texture.

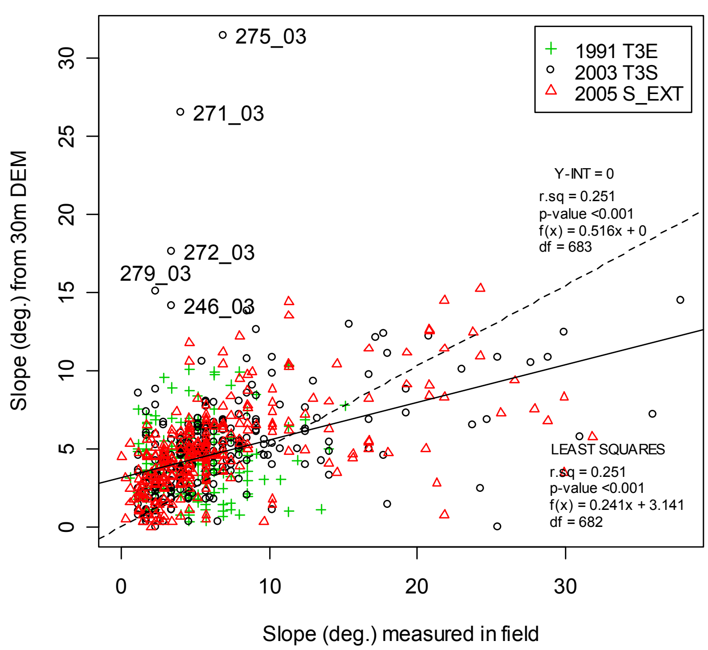
		Westech		
SCS/NRIS	(content)	High Clay (>50%)	Moderate Clay	Low Clay (<17%)
	High clay (>50%)	0	9	15
	Moderate clay (18-49%)	0	2	11
	Low clay (<17%)	0	51	158

		Westech	
SCS/NRCS		High Clay (>50%)	Low Clay (<35%)
	High Clay (>50%)	11	26
	Low Clay (<35%)	51	158

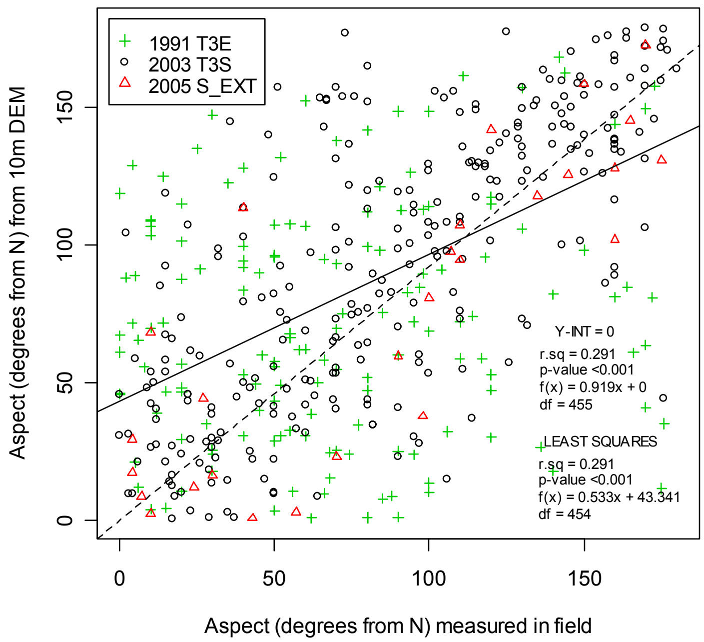
APPENDICES



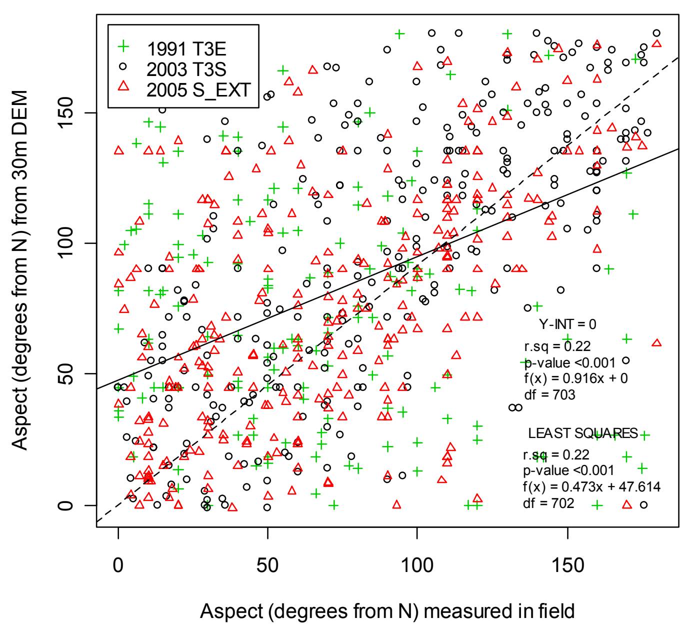
Appendix Figure 1a. Comparison of ground-truth slope and slope estimated from the 10m DEM, 1991-2003 and 2005 data.



Appendix Figure 1b. Comparison of ground-truth slope and slope estimated from the 30m DEM. 1991, 2003, and 2005 data included. Identified points were ignored in creation of lines.



Appendix Figure 2a. Comparison of ground-truth aspect and aspect estimated from the 10m DEM. 1991, 2003, and 2005 data included.



Appendix Figure. 2b. Comparison of ground-truth aspect and aspect estimated from the 30m DEM, 1991-2003, and 2005 data.

Chapter 5, VHA task 4.

ENVIRONMENTS OF ABSALOKA COMMUNITIES.

INTRODUCTION

We classified Absaloka vegetation data to identify vegetation types of the mine area, and by extension/ extrapolation, general vegetation types of the 15” rainfall belt on Ft Union formation of SE Montana. We described eight types including an old field type. Using a higher resolution classification several of the eight were found to contain sub-types. This more complex classification contained fifteen types.

We seek to correlate these vegetation types with landscape level environmental qualities. Such information will suggest environmental conditions needed to establish/support a given vegetation type. And, secondarily for our purposes, it will identify vegetation types which indicate a particular environmental condition dependably. Strong correlations will indicate strong causal relationships, while weak correlations will indicate ‘factors’ with partial control or ‘not-factors’ correlated with controlling factors.

We pursue correlations at two levels. First, we determined, for each vegetation type, the central condition for presumptive factors, one at a time. This approach might be characterized as ‘testing single-factor ecology’. Second, where several factors might simultaneously control, one can correlate vegetation cover with several environmental qualities simultaneously, e.g. with logistic regressions or CART models. The second approach will be pursued in Chapter 6. A third approach is to integrate the factors by logical combination, e.g. by simulating/combining slope and aspect effects on radiation/heat by calculations based on their physical relationships, rather than mere correlation.

To test the capacity of a presumptive factor to distinguish types one can inspect associations/correlations demonstrated in contingency tables. We contracted to consider three factors - - slope, aspect, and soil texture. Thirteen presumptive factors were actually considered--often with data from two or more sources (mine and public, Tables 3-15). In each contingency table vegetation type is listed vertically and environmental states are listed horizontally. In the cells of these tables, the affinity of a vegetation type for the factor considered is stated with a mean (for continuous data) or a probability/proportion (for discontinuous data).

An alternate presentation would be more succinct, but less useful. The ‘total’ environment of a vegetation type could be described by listing, for that/each vegetation type, the ‘mean state’ with respect to every ‘factor’ considered. While the environment of the vegetation type would be summarily described, this presentation would give no indication of the predictive value of any factor for that type or the indicator value of that vegetation type for an environmental quality.

METHODS

Environmental data for the ‘thirteen’ presumptive factors were drawn from three primary sources. They were data gathered in three pre-mine ground surveys of the Absaloka mine (Westech 1991 Tract 3 East, 2003 Tract 3 South, and 2005 south extension baseline study areas), drawn from a 30m DEM of the area (USGS/NRIS), or drawn from publicly available environmental data (NRIS, USGS). These sources are reviewed in the GIS chapter (Table 1). For continuous data we stratified the data by vegetation type and expressed central tendency and spread by parametric and non-parametric measures. For each presumptive factor and vegetation type we calculated means and standard deviations along with medians and quartiles. The latter two may be preferred as less influenced by outliers and more indicative of normality.

For categorical data we stratified the data by vegetation type and determined the percentage of stands, within each type which fell into a particular category. The categorical data were mostly drawn from NRIS and when the characteristic of a point could not be determined it was recorded as ‘not available ‘NA’. NA points occurred when points fell outside the range of DEMs, the data were not recorded in the field, or when variables depended on other variables with missing data (e.g. radiation).

POSSIBLE FACTORS / RESULTS

The performance or distribution of vegetation (and its plant/animal components) is correlated with 'factors', natural phenomena which cause their behaviour. Two sources of data on factors likely to influence vegetation in SE Montana were correlated with vegetation samples: environmental records taken when pre-mine vegetation was sampled and environmental information for the same points drawn from independent field mapping by USGS, SCS/NRCS, and others.

To distinguish likely factors from phenomena 'randomly associated' with the distribution of vegetation we compare levels of 'presumptive factors' that may distinguish the environments of major vegetation types of SE Montana. Such information will identify 'true factors' with strong effects on vegetation quality, correlated/confounded pseudo-factors which never-the-less have high predictive value, and less strongly correlated 'factors' of either sort which may be combined through statistical models to have high predictive value.

Thus, in the following section, we use contingency tables to examine thirteen presumptive/possible factors. A parallel presentation is used for each factor. 1) Column one lists major communities of SE Montana in approximate order of increasing water demand. The vegetation types are reviewed in Table 1. The thirteen factors are summarized in Table 2. 2) Families of columns present data from various sources e.g. private company (PC) Absaloka/Westech information vs. public data (PD) information (e.g. NRIS, USGS). 3) Component columns compare the environments of the vegetation types. This information may be in the form of mean/median values/responses (e.g. Table 3) or percentages among multiple factor levels (e.g. Table 6)

Table 1. Vegetation types of the Absaloka area.

Formation	Vegetation type[1]	Varieties[2]
Grassland/ steppe	Agropyron smithii	Agsm 1, Agsm2
	Stipa comata	Stco 1, Stco 2
	Old field	Old field 1, Old field 2
Pine forest	Pinus/ Agropyron spicatum	
	Pinus/ Festuca idahoensis	Pipo 1, Pipo 2
Shrubland	Symphoricarpos	
	Prunus virginiana	Prvi 1, Priv 2, Prvi 3
Marsh	Spartina pectinata	Sppe 1, Sppe 2

[1]Pinus= P ponderosa, Symphoricarpos = S occidentalis ?
[2]Throughout the text plant names will be abbreviated with four letter codes, letters 1&2 representing the genus name and 3&4 representing the species epithet, Agropyron smithii= Agsm. Compare columns 3 and 4 above for other examples.

Table 2. Landscape factors studied. Landscape factors are manageable site qualities which affect proximal or determining environmental conditions. Landscape factors may affect more than one proximal factor and their relative import may vary among regions. In our semi-arid region most factors act primarily through effects on water availability.

	1^{o} control[1]	2^{o} control[1]	Table
Aspect	Water availability	Heat/ light	3
Slope	Water avail (evap, RO)	Heat/light	4
Radiation/Heat	Heat	Water avail	5
Topography	Water avail via substrate	Heat/light	6
Configuration.	Water availability		7
Texture	Water capture &dist	Nutrient SC[2]	8
Cobble content	Water distribution	Fire impact	9
Gravel content	Water distribution	Fire impact	10
Clay	Water SC[2]	Nutrient SC[2]	11
Permeability	Water capture & dis		12
WSC[2]	Water availability		13
Range site	Water availability		14
Soil name	Soil properties, info		15
Soil type.	SCS map legend, info		NOT INCLUDED

[1] Hypothetical primary and secondary controls.
[2] WSC= water storage capacity, NSC= nutrient storage capacity.

ASPECT

Different vegetation types often occupy different aspects. The aspect effect is attributed to higher radiation on south than north slopes. High radiation may act through warming or drying a site. The drying effect is most important in climates with a warm dry growing season, like ours. The warming effect is most important in cold environments of the arctic or alpine. Three data sets are available, one gathered in the field (PC), one drawn from an uncertain (PD) 10m DEM, and one drawn from a standard (PD) 30m DEM.

Consider the field data (Table3). 1) Grassland sites (Agsm, Stco, and Field) are the most south facing. Subsites in all three have different aspects. The environmental similarity between natural grasslands and old fields is surely due to the fact that fields were plowed from the richest natural grasslands. 2) *Ponderosa pine / Festuca idahoensis* sites tend to be north facing. 3) Average bottomland vegetation occupies intermediate aspects.

The aspect effect is more clearly demonstrated with point data than with coarser 10 and 30M DEMs. Thus measurements made at coarser scales, though in general agreement, are of less predictive value.

Table 3. Comparison of aspects (degrees from North) of major vegetation types of the Absaloka mine, SE Montana. Aspects were measured on the ground (Westech), on a suspect 10m DEM, and on a standard 30m DEM.

		Absaloka/Westech				10mDEM				30mDEM			
	N	Xbar±SE	M	Q1	Q3	Xbar±SE	M	Q1	Q3	Xbar±SE	M	Q1	Q3
1_AGSM	89	92.4 ± 4.9	94.5	56.8	126	99.3 ± 5.7	97.6	55.6	153.8	95.7 ± 5	96.3	62.5	122
1a_AGSM1	58	83.4 ± 5.7	85	50	113	71.4 ± 6.4	57.1	25.4	109.7	85.8 ± 5.8	91.1	55.3	116.6
1b_AGSM2	31	109 ± 8.5	110	72.5	149.5	133 ± 7	157.6	96.5	162.1	114.3 ± 8.7	113.2	76.7	167.8
2_STCO	137	96.4 ± 4.2	95	60	140	104.5 ± 4.3	117.2	64.4	143.5	93.4 ± 4.3	97.1	45	135
2a_STCO1	28	100.8 ± 10	111.5	59.2	148.5	101.5 ± 10.6	125.8	41.9	143.5	96.3 ± 10.9	102.9	36.8	143.7
2b_STCO2	109	95.3 ± 4.6	93	60	131.5	105.9 ± 4.5	109.6	80.1	143	92.7 ± 4.6	97.1	48.2	135
8_FIELD	59	85.9 ± 6.3	90	47.5	126	107.3 ± 6	123.2	59.4	137.6	89.2 ± 5.6	90	61	125.6
8a_FIELD1	3	117 ± 33.9	141	95.5	150.5	113.5 ± 29.2	134.6	95.2	142.4	119.2 ± 24.7	126.9	100	142.2
8b_FIELD2	56	84.2 ± 6.4	90	42.8	121.5	106.6 ± 6.2	121.2	62.8	137	87.6 ± 5.8	90	59.5	123.9
3_PIPO-AGSP	62	85.1 ± 6	80	53.2	115	95.2 ± 5.6	101.7	64.6	129.6	77.7 ± 5.8	74.8	45	111.6
4_PIPO-FEID	94	56.6 ± 4.5	49	22	81.5	60.5 ± 5	45.7	23.1	81.9	59.2 ± 4.6	47.2	23.4	80.4
4a_PIPO-FEID1	22	49.5 ± 7.6	40	19	80.2	35.3 ± 5	34.5	15	51.2	37.2 ± 7.6	33.1	11.6	44.2
4b_PIPO-FEID2	72	58.8 ± 5.4	49	24.5	81	71.5 ± 6.2	66.4	26.2	112.9	65.9 ± 5.4	54.3	26.3	100.2
6_SYOC	38	58.4 ± 7	45	27.2	102.5	68 ± 6.6	56.4	30.4	97.2	84.3 ± 8.6	90	34.7	132.3
5_PRVI	46	56.7 ± 6.1	39	26	93.8	92.6 ± 7.9	101.1	45.4	144.2	99.5 ± 7.2	101.6	61.6	143.4
5a_PRVI1	27	53 ± 8.4	37	22.5	84.5	88.8 ± 10.1	101.1	59.3	122.8	99.9 ± 9.1	94.8	63.4	137
5b_PRVI2	8	55.6 ± 17.6	33	17	102	82.1 ± 22.6	83.7	32.4	133.3	86.1 ± 16.9	67.5	55.5	101.2
5c_PRVI3	11	66.5 ± 8.7	76	43.5	89.5	101.8 ± 17	121.5	53.3	152.4	108.3 ± 17.2	140.2	81.7	146.3
7_SPPE	25	61.8 ± 10	51	18.5	79	86 ± 9.1	67.2	49.8	121.6	88.4 ± 11.2	90	36.9	135
7a_SPPE1	13	74.7 ± 16.6	74	20	115	83.6 ± 12	70.3	48.8	113.3	86.1 ± 16.8	90	36.9	135
7b_SPPE2	12	45 ± 8.1	45.5	18.2	71.2	88.3 ± 14.2	65.6	51.8	113.6	90.8 ± 15.5	90	62.1	135

Footnotes:
Vegetation types are named in Table 1.
Aspect data are described parametrically (x± SE) and non-parametrically (median & quartiles).
Shading highlights extreme aspects, i.e. light= southerly aspect and dark= northerly aspect.

SLOPE

Vegetation type often varies with slope. The effect may be attributed to variation in energy effects (e.g. warming and drying on steep southerly slopes) and runoff effects (e.g. high runoff from steep slopes).

Consider the most precise Westech field data (Table 4). At the Absaloka mine, slopes decline from pine to *Stipa* (and Field) to *Agropyron smithii*, to *Symphoricarpos occidentalis* on toes, to *Prunus* along draws, and Spartina in bottoms. The slopes of pine stands (shoulders) and *Spartina* (ponds) are consistent with their locations in the landscape. Slopes of old fields are between Stco and Agsm, as if they were plowed from both.

Data from the three measures are parallel (Table 4). As expected from the difference in pixel sizes the slope measured on the 30m DEM is less than that measured in the field. Contrary to the expected effect of pixel sizes, slopes measured from the suspect 10m DEM are not credible, i.e. greater than those measured in the field.

Table 4. Comparison of slopes (degrees) among major vegetation types of SE Montana. Slopes were measured on the ground, from a suspect 10m DEM, and from a 30m DEM.

		Absaloka/Westech				10mDEM				30mDEM			
	N	Xbar±SE	M	Q1	Q3	Xbar±SE	M	Q1	Q3	Xbar±SE	M	Q1	Q3
1_AGSM	89	4.5 ± 0.3	4	2.5	5.1	13 ± 0.7	11.8	8.5	17.3	4 ± 0.2	3.8	2.8	4.9
1a_AGSM1	58	4.8 ± 0.4	4.6	2.9	5.1	15.5 ± 0.8	16	11.5	18.5	4.2 ± 0.3	4.3	3	5.1
1b_AGSM2	31	4 ± 0.4	4	2.3	5.6	10 ± 1	9.2	6.9	11.7	3.5 ± 0.3	3.5	2.5	4.4
2_STCO	137	6.3 ± 0.3	5.7	4.6	7.4	16.9 ± 0.7	15.7	12	22.2	5 ± 0.2	4.9	3.6	6.1
2a_STCO1	28	6.4 ± 0.6	5.7	4.6	6.4	17.8 ± 1.7	14.6	12	22.2	5.6 ± 0.5	5.4	4.1	6.4
2b_STCO2	109	6.2 ± 0.4	5.7	4	8	16.4 ± 0.8	15.9	11	22.2	4.8 ± 0.2	4.7	3.6	5.7
8_FIELD	59	5 ± 0.4	4.6	3	6.1	13.9 ± 0.8	13.7	10.3	16.9	3.9 ± 0.2	4.1	2.7	5.3
8a_FIELD1	3	5.7 ± 0.7	5.7	5.1	6.3	14.4 ± 1.3	14.2	13.2	15.5	5.1 ± 0.4	4.9	4.7	5.4
8b_FIELD2	56	5 ± 0.5	4.1	2.9	6.1	13.9 ± 0.9	13.7	10.1	16.8	3.9 ± 0.2	3.9	2.5	5.3
3_PIPO-AGSP	62	14.7 ± 1.2	13.5	6.1	21.8	26.5 ± 1.6	25.3	17.1	32.5	7.1 ± 0.4	6.5	4.7	9.8
4_PIPO-FEID	94	9.9 ± 0.7	8.3	4.7	13	23.2 ± 1.1	22.9	16.6	28.5	6.7 ± 0.3	6.5	4.9	8
4a_PIPO-FEID1	22	8.8 ± 0.9	7.7	5.7	11.3	24.5 ± 2.1	23.4	19.8	28.8	6.5 ± 0.7	6.3	5.3	7.5
4b_PIPO-FEID2	72	10.2 ± 0.8	8.3	4.6	14.4	22.7 ± 1.2	22.9	15.8	28.4	6.8 ± 0.3	6.5	4.9	8.1
6_SYOC	38	4.5 ± 0.7	3.4	2.6	4.6	11 ± 1.3	8.8	6.1	12.1	3.1 ± 0.3	2.8	1.6	4.6
5_PRVI	46	3.4 ± 0.7	2.6	1.8	3.4	12 ± 1.6	9	4.3	17.3	3.5 ± 0.5	2.4	1.1	4.5
5a_PRVI1	27	3.9 ± 1.1	2.9	2.3	3.4	9.5 ± 1.3	8.8	6.3	12.9	2.9 ± 0.4	2.3	1.1	4.4
5b_PRVI2	8	2.1 ± 0.3	2.1	1.6	2.6	6.8 ± 2	4.9	3.9	7.8	1.6 ± 0.4	1.5	0.9	2
5c_PRVI3	11	2.8 ± 0.7	1.7	1.7	4.9	17.3 ± 4.4	14.5	5.5	26.7	6.5 ± 1.8	3.9	2.4	9.9
7_SPPE	25	2 ± 0.2	1.7	1.6	2.3	6.7 ± 1.5	3.5	1.8	10.2	2 ± 0.4	1.1	0.8	2.5
7a_SPPE1	13	1.8 ± 0.1	1.7	1.7	2.3	8.6 ± 2.1	5	2.3	15.1	2 ± 0.7	1.1	0.5	2.1
7b_SPPE2	12	2.2 ± 0.4	1.7	1.6	2.3	4.9 ± 2	2	1.3	5.3	2 ± 0.5	1.4	0.8	2.7

Footnotes.

Vegetation types are named in Table 1.

Shading emphasizes slope effects. Pines (shaded heavily) have steepest slopes, grasslands (shaded lightly) are intermediate, and slopes in bottoms (unshaded) are lowest.

Slopes calculated from the 10m DEM are not credible.

RADIATION

Differences in radiation load might cause differences in the temperature or, via evaporation, in the availability of water in different landscape segments, e.g. north vs. south slopes.

Radiation load can be calculated, from slope and aspect, thus integrating their energy effects. The products are 'radiation load' [with highest values in the south (McCune and Keon 2006)] and 'heat load' [with highest values in the south-west (McCune and Keon 2006)]. In multiple regressions that follow (Chapter 5) calculated radiation load, slope, and aspect are retained in the regressions because slope and aspect have non-energy effects (e.g. run-off, run-in, and substrate).

There is essentially no difference among vegetation types in estimates of either radiation load or heat load calculated from measures of slope and aspect (Table 5). Thus the slope and aspect effects observed in the preceding sections must be due to other physical effects (e.g. run-off, run-in, and substrate.

Table 5. Comparison of radiation and heat loads among major vegetation types of SE Montana. Radiation and heat loads were calculated from Absaloka-Westech slope aspect measures.

		RADIATION (MJ cm-2 yr-1)				HEAT_LOAD			
	N	Xbar±SE	M	Q1	Q3	Xbar±SE	M	Q1	Q3
1_AGSM	89	0.902 ± 0.003	0.902	0.891	0.918	0.904 ± 0.003	0.91	0.886	0.927
1a_AGSM1	58	0.896 ± 0.004	0.898	0.886	0.911	0.901 ± 0.004	0.908	0.881	0.927
1b_AGSM2	31	0.911 ± 0.004	0.911	0.901	0.929	0.909 ± 0.004	0.915	0.898	0.925
2_STCO	137	0.898 ± 0.003	0.9	0.877	0.928	0.903 ± 0.004	0.914	0.879	0.933
2a_STCO1	28	0.901 ± 0.008	0.912	0.878	0.934	0.898 ± 0.009	0.908	0.879	0.937
2b_STCO2	109	0.897 ± 0.004	0.9	0.877	0.923	0.904 ± 0.004	0.915	0.88	0.933
8_FIELD	59	0.895 ± 0.006	0.902	0.886	0.919	0.895 ± 0.005	0.899	0.88	0.923
8a_FIELD1	3	0.911 ± 0.024	0.927	0.895	0.935	0.904 ± 0.005	0.901	0.9	0.908
8b_FIELD2	56	0.894 ± 0.006	0.902	0.886	0.917	0.894 ± 0.005	0.898	0.879	0.926
3_PIPO-AGSP	62	0.852 ± 0.012	0.883	0.793	0.91	0.859 ± 0.016	0.897	0.825	0.942
4_PIPO-FEID	94	0.844 ± 0.008	0.854	0.821	0.893	0.847 ± 0.009	0.866	0.818	0.9
4a_PIPO-FEID1	22	0.844 ± 0.011	0.854	0.83	0.868	0.841 ± 0.014	0.85	0.806	0.874
4b_PIPO-FEID2	72	0.845 ± 0.01	0.852	0.82	0.895	0.848 ± 0.011	0.872	0.827	0.905
5_PRVI	46	0.886 ± 0.008	0.893	0.882	0.907	0.896 ± 0.006	0.902	0.889	0.913
5a_PRVI1	27	0.881 ± 0.013	0.89	0.882	0.906	0.892 ± 0.009	0.902	0.887	0.906
5b_PRVI2	8	0.899 ± 0.005	0.897	0.889	0.91	0.904 ± 0.006	0.901	0.893	0.915
5c_PRVI3	11	0.889 ± 0.006	0.893	0.881	0.904	0.904 ± 0.003	0.908	0.899	0.912
6_SYOC	39	0.877 ± 0.007	0.884	0.871	0.909	0.88 ± 0.009	0.89	0.873	0.907
7_SPPE	25	0.9 ± 0.002	0.9	0.892	0.906	0.905 ± 0.002	0.905	0.897	0.913
7a_SPPE1	13	0.904 ± 0.003	0.903	0.893	0.912	0.909 ± 0.003	0.912	0.899	0.917
7b_SPPE2	12	0.896 ± 0.002	0.897	0.888	0.904	0.901 ± 0.003	0.901	0.893	0.91

Footnotes

Vegetation types are listed in Table --.

Radiation and heat loads experienced by a vegetation type are expressed as average and median.

TOPOGRAPHIC POSITION

Environments of vegetation types often differ in topographic position. Position may influence vegetation through its relation to slope (energy/runoff), substrate (rock on ridges and slopes vs. clay on toes and riparian deposits in bottoms), or fire probability. We have two data sources, positions estimated by Westech in the field and positions estimated from a 10m DEM which seems to overestimate slopes.

Consider the field measures (Table 6). Grasslands and forests occupy slopes. And *Symphoricarpos*, *Prunus*, and *Spartina* occupy bottoms. In contrast estimates made from the 10m DEM place most vegetation on slopes, only hinting at the field-obvious location of the bottomland types. While the trends are parallel, we put more trust the stronger PC field data.

In our environment, the bottomland effect may be due to increase in effective water availability (due to run-in and reduced evapo-transpiration) and/or to reduction of fire probability (because fire is inhibited by steep walled draws/gullies).

Table 6. Comparison of topographic position of major vegetation types of SE Montana. Field measures were by Westech and remote measures were made by using the Zimmerman method (Zimmerman 2006) on a 10m DEM which probably overestimates slope.

		AbsWestech (simplified)					10m DEM/ Zimmerman				
	N	Ridge	Slope	Toe Slope	Valley Bottom	NA's	Ridge	Slope	Toe Slope	Valley Bottom	NA's
1_AGSM	89	2.2	55	5.6	7.9	29	0	27	0	0	73
1a_AGSM1	58	3.4	55	5.2	10.3	26	0	22.4	0	0	77.6
1b_AGSM2	31	0	55	6.5	3.2	36	0	35.5	0	0	64.5
2_STCO	137	12	77	2.9	0	7.3	0.7	46.7	0.7	0	51.8
2a_STCO1	28	7.1	82	7.1	0	3.6	3.6	67.9	3.6	0	25
2b_STCO2	109	14	76	1.8	0	8.3	0	41.3	0	0	58.7
8_FIELD	59	5.1	73	1.7	3.4	17	0	52.5	0	0	47.5
8a_FIELD1	3	0	67	0	0	33	0	100	0	0	0
8b_FIELD2	56	5.4	73	1.8	3.6	16	0	50	0	0	50
3_PIPO-AGSP	62	6.5	77	1.6	4.8	9.7	4.8	11.3	0	0	83.9
4_PIPO-FEID	94	9.6	63	3.2	16	8.5	3.2	34	3.2	1.1	58.5
4a_PIPO-FEID1	22	9.1	77	4.5	4.5	4.5	4.5	63.6	0	0	31.8
4b_PIPO-FEID2	72	9.7	58	2.8	19.4	9.7	2.8	25	4.2	1.4	66.7
6_SYOC	38	0	10	0	61.5	28	0	15.4	10.3	0	74.4
5_PRVI	46	0	0	4.3	91.3	4.3	0	19.6	15.2	2.2	63
5a_PRVI1	27	0	0	3.7	88.9	7.4	0	18.5	11.1	0	70.4
5b_PRVI2	8	0	0	0	100	0	0	12.5	0	0	87.5
5c_PRVI3	11	0	0	9.1	90.9	0	0	27.3	36.4	9.1	27.3
7_SPPE	25	0	0	0	96	4	0	20	24	8	48
7a_SPPE1	13	0	0	0	100	0	0	7.7	46.2	15.4	30.8
7b_SPPE2	12	0	0	0	91.7	8.3	0	33.3	0	0	66.7

Footnotes.
Vegetation types are listed in Table 1.
The distribution of each vegetation type among positions is indicated by the proportion of cases (%) allocated to each column.
Modal values are lightly shaded and near-modal qualities are darkly shaded.
The high % of NAs is due to the fact that 2005 data was not contained in the 10m DEM.

CONFIGURATION

Concave sites tend to capture runoff and blowing snow. Convex sites tend to lose both. And water reaching straight sites may remain there. Position was reported by Westech's ground crews; SCS/NRCS maps omit it, perhaps because the SCS scale is too coarse.

Grassland sites are straight to concave (Table 7). Concavity is emphasized in old fields suggesting that farmers chose to plow moister concave grasslands for crops. Pine forest can occupy convex and concave sites, rather than straight ones. That is, it appears below shoulders (concave) and on tops (convex). *Symphoricarpos, Prunus*, and *Spartina* clearly occupy convex run-in sites.

Table 7 . Comparison of configuration preferences of major vegetation types of the Absaloka mine, SE Montana. The data is presented as the percentage of sites of a vegetation type in each configuration category.

	N		Concave	Convex	Straight	Undulating	NA's
1_AGSM	89		39.3	4.5	46	7.9	2.2
1a_AGSM1	58		43.1	3.4	45	5.2	3.4
1b_AGSM2	31		32.3	6.5	48	12.9	0
2_STCO	137		29.9	23	30	16.8	0
2a_STCO1	28		50	11	25	14.3	0
2b_STCO2	109		24.8	27	31	17.4	0
8_FIELD	59		22	22	42	13.6	0
8a_FIELD1	3		66.7	0	0	33.3	0
8b_FIELD2	56		19.6	23	45	12.5	0
3_PIPO-AGSP	62		21	29	8.1	41.9	0
4_PIPO-FEID	94		43.6	26	17	12.8	1.1
4a_PIPO-FEID1	22		31.8	27	27	13.6	0
4b_PIPO-FEID2	72		47.2	25	14	12.5	1.4
6_SYOC	38		79.5	0	10	10.3	0
5_PRVI	46		89.1	0	2.2	8.7	0
5a_PRVI1	27		88.9	0	0	11.1	0
5b_PRVI2	8		75	0	13	12.5	0
5c_PRVI3	11		100	0	0	0	0
7_SPPE	25		100	0	0	0	0
7a_SPPE1	13		100	0	0	0	0
7b_SPPE2	12		100	0	0	0	0

Footnotes.

Vegetation types are listed in Table 1

Modal configuration preferences are lightly shaded to facilitate comparison of habitats preferences. Near modal cases are shaded darkly.

TEXTURE

Soil texture is determined by the distribution of particle sizes (sand/silt/clay) in a soil and affects the availability of oxygen, water, and nutrients in the soil. Columns in Table 8 are ordered by clay content (cf. Table 11) to demonstrate differences in clay content among vegetation types. Increasing clay will increase run-off of water, water holding capacity, and nutrient holding capacity and reduce soil oxygen, thus likely affecting the vegetation supported.

SCS/NRCS data show that the modal texture of most vegetation types is 10-16%, i.e. loams and sandy loams. Textures of *Prunus* vegetation can be either 10-16% or > 50%. Textures under *Spartina* vegetation are usually > 30%. Westech textures are different (i.e. differently calibrated), but show the same pattern.

Table 8. Soil textures under 7/15 vegetation types are compared using Absaloka/Westech and SCS/NRCS data. The data is presented as the percentage of sites of a vegetation type in each textural category. Textural classes were estimated from the textural triangle and ordered by clay contents specified in it.

			AbsWestech										SCS/NRCS					
% clay	N		45 CIL	34 SiCIL	34 SaCIL	16 L	14 SiL	10 SaL	7 LSa	5 Sa	NA's		70 Cl	50 SiCl	34 SiCIL	16 L	10 SaL	NA's
1_AGSM	89		3.4	9	3.4	0	34	49	0	0	1.1		5.6	0	2.2	34	12	46.1
1a_AGSM1	58		0	12	1.7	0	35	50	0	0	1.7		0	0	0	38	10	51.7
1b_AGSM2	31		9.7	3.2	6.5	0	32	48	0	0	0		16	0	6.5	26	16	35.5
2_STCO	137		1.5	2.2	5.8	0.7	9.5	77	2.9	0.7	0		0	0	1.5	10	43	45.3
2a_STCO1	28		0	0	3.6	3.6	25	68	0	0	0		0	0	3.6	0	43	53.6
2b_STCO2	109		1.8	2.8	6.4	0	5.5	79	3.7	0.9	0		0	0	0.9	13	43	43.1
8_FIELD	59		1.7	29	10	0	8.5	48	3.4	0	0		1.7	0	5.1	25	53	15.3
8a_FIELD1	3		0	0	0	0	0	100	0	0	0		0	0	0	0	100	0
8b_FIELD2	56		1.8	30	11	0	8.9	45	3.6	0	0		1.8	0	5.4	27	50	16.1
3_PIPO-AGSP	62		8.1	8.1	11	0	6.5	65	0	0	1.6		1.6	0	1.6	4.8	3.2	88.7
4_PIPO-FEID	94		0	1.1	0	6.4	36	52	2.1	2.1	0		0	0	1.1	1.1	16	81.9
4a_PIPO-FEID1	22		0	0	0	23	36	41	0	0	0		0	0	0	0	27	72.7
4b_PIPO-FEID2	72		0	1.4	0	1.4	36	56	2.8	2.8	0		0	0	1.4	1.4	13	84.7
6_SYOC	38		0	21	2.6	0	41	36	0	0	0		0	0	5.1	10	10	74.4
5_PRVI	46		4.3	15	0	0	35	33	0	0	13		11	6.5	0	35	15	32.6
5a_PRVI1	27		3.7	15	0	0	26	41	0	0	15		15	0	0	41	15	29.6
5b_PRVI2	8		13	0	0	0	38	25	0	0	25		0	0	0	50	38	12.5
5c_PRVI3	11		0	27	0	0	55	18	0	0	0		9.1	27	0	9.1	0	54.5
7_SPPE	25		0	20	0	0	44	0	0	0	36		20	16	12	16	4	32
7a_SPPE1	13		0	15	0	0	15	0	0	0	69		0	15	7.7	15	7.7	53.8
7b_SPPE2	12		0	25	0	0	75	0	0	0	0		42	17	16.7	17	0	8.3

Footnotes. Vegetation types are identified in Table 1. Modal textures for the vegetation types are shaded to facilitate comparison.

SURFACE COBBLE.

Vegetation type is expected to vary with surface rock. Cobbles are expected to favor deep rooted herbs, shrubs and trees over grasses. They act both by displacing water from surface horizons and minimizing fire damage. The ‘cobble effect’ is distinct from the ‘outcropping sedimentary rock effect’ associated with thin breaks and thin hills (see ‘range sites’, Table 14).

According to both data sets, the environments of most vegetation types are essentially cobble free (Table 9). Stco 1 may be an exception, having more cobbles- - in the eyes of SCS/NRCS teams, but not Westech._Prvi3, at streamsides, has more cobbles in the eyes of SCS/NRCS, but not according to Westech. The methods used vary slightly, with Westech vegetation/environment measurements being more tightly paired while SCS/NRCS examined a thicker soil layer more expertly/quantitatively.

Table 9. Comparison of cobble (> 3” rocks in soil) content of soils under major vegetation types of SE Montana. Cobble contents are expressed as % of sites with cobbles “C”and % without cobbles “NC”. Field data (Westech) and public data (SCS/NRCS) are presented separately.

		AbsWestech			SCS/NRCS		
	N	C	NC	NA's	C	NC	NA's
1_AGSM	89	0	98.9	1.1	7.9	46.1	46.1
1a_AGSM1	58	0	98.3	1.7	12.1	36.2	51.7
1b_AGSM2	31	0	100	0	0	64.5	35.5
2_STCO	137	2.9	97.1	0	2.2	52.6	45.3
2a_STCO1	28	10.7	89.3	0	49.5	7.3	43.1
2b_STCO2	109	0.9	99.1	0	2.8	54.1	43.1
8_FIELD	59	1.7	98.3	0	0	84.7	15.3
8a_FIELD1	3	0	100	0	0	100	0
8b_FIELD2	56	1.8	98.2	0	0	83.9	16.1
3_PIPO-AGSP	62	3.2	96.8	0	0	11.3	88.7
4_PIPO-FEID	94	0	100	0	0	18.1	81.9
4a_PIPO-FEID1	22	0	100	0	0	27.3	72.7
4b_PIPO-FEID2	72	0	100	0	0	15.3	84.7
6_SYOC	38	0	100	0	0	25.6	74.4
5_PRVI	46	0	100	0	6.5	60.9	32.6
5a_PRVI1	27	0	100	0	0	70.4	29.6
5b_PRVI2	8	0	100	0	0	87.5	12.5
5c_PRVI3	11	0	100	0	27.3	18.2	54.5
7_SPPE	25	0	100	0	16	52	32
7a_SPPE1	13	0	100	0	15.4	30.8	53.8
7b_SPPE2	12	0	100	0	16.7	75	8.3

Footnotes.

Vegetation types are named in Table 1.

Shading emphasizes the environmental quality modal for each vegetation type.

The high number of NA’s in the SCS/NRCS data is due to compositing of SCS/NRCS soil types with different cobble contents.

SURFACE GRAVEL

Surface gravel is expected to favor deep rooted forbs, shrubs, and trees over grasses. This is due to the displacement of water from surface horizons and minimizing fire damage to woody plants.

NRCS reports both gravelly and no-gravel sites in all vegetation types; thus gravel seems not to limit either alone or in concert with other presumptive factors (Table 10). Surface observations by Westech show far less gravel than did SCS/NRCS. While most sites were non-gravelly, gravel was present under some Stco1 and P pine/Agsp communities. Sites with gravel also have relatively high cobble contents (Table 9). This is consistent with the liklihood that cobbles and gravel may have been deposited together in ancient streambeds. The methods used vary slightly, with Westech vegetation/ environment observations being more tightly paired and SCS/NRCS examining a thicker soil layer more expertly/quantitatively.

Table 10 . Comparison of gravel contents of surface soils under major vegetation types of the Absaloka mine, SE Montana. The data is presented as percentage of sites of a vegetation type with gravel (G) and without gravel (NG).

			AbsWestech				SCS/NRCS		
	N		G	NG	NA's		G	NG	NA's
1_AGSM	89		0	98.9	1.1		34.8	19.1	46.1
1a_AGSM1	58		0	98.3	1.7		36.2	12.1	51.7
1b_AGSM2	31		0	100	0		32.3	32.3	35.5
2_STCO	137		3.6	96.4	0		48.9	5.8	45.3
2a_STCO1	28		10.7	89.3	0		46.4	0	53.6
2b_STCO2	109		1.8	98.2	0		49.5	7.3	43.1
8_FIELD	59		1.7	98.3	0		69.5	15.3	15.3
8a_FIELD1	3		0	100	0		100	0	0
8b_FIELD2	56		1.8	98.2	0		67.9	16.1	16.1
3_PIPO-AGSP	62		19.4	80.6	0		4.8	6.5	88.7
4_PIPO-FEID	94		4.3	95.7	0		17	1.1	81.9
4a_PIPO-FEID1	22		0	100	0		27.3	0	72.7
4b_PIPO-FEID2	72		5.6	94.4	0		13.9	1.4	84.7
6_SYOC	38		0	100	0		17.9	7.7	74.4
5_PRVI	46		0	100	0		26.1	41.3	32.6
5a_PRVI1	27		0	100	0		22.2	48.1	29.6
5b_PRVI2	8		0	100	0		37.5	50	12.5
5c_PRVI3	11		0	100	0		27.3	18.2	54.5
7_SPPE	25		0	100	0		32	36	32
7a_SPPE1	13		0	100	0		30.8	15.4	53.8
7b_SPPE2	12		0	100	0		33.3	58.3	8.3

Footnotes.

Vegetation types are named in Table 1

Shading indicates the environmental quality modal for each vegetation type.

The high number of NA's in the SCS/NRCS data are due to compositing of SCS/NRCS soil types which with different gravel contents.

SURFACE CLAY

Clay content is negatively associated with high sand. High sand favors most vegetation of arid environments by absorbing rainfall (minimizing runoff) and transmitting water below the heated surface. On the other hand, high clay (low sand) might favor hydric plants by sealing the 'ponds' they occupy in arid environments.

SCS/NRCS data show 10-16% clay in most soils (Table 11). The relatively high clay content of Agsmith and Prunus sites was probably delivered by run-in water. The still higher clay content underlying Spartina vegetation may have been similarly delivered and surely seals local basins to promote the flooding required by/associated with the species. While Westech estimates of clay contents at sites can be either higher or lower than SCS/NRCS estimates, their estimations are generally parallel.

Table 11. Comparison of clay contents (%) of surface soils under major vegetation types of the Absaloka mine, SE Montana. The data is presented as percentage of sites of a vegetation type in each clay content category.

		AbsWestsech									SCS/NRCS					
	N	5	8	10	12	16	28	32	34	NA's	10	16	34	50	70	NA's
1_AGSM	89	0	0	49.4	33.7	0	3.4	9	3.4	1.1	12.4	33.7	2.2	0	5.6	46.1
1a_AGSM1	58	0	0	50	34.5	0	1.7	12.1	0	1.7	10.3	37.9	0	0	0	51.7
1b_AGSM2	31	0	0	48.4	32.3	0	6.5	3.2	9.7	0	16.1	25.8	6.5	16.1	0	35.5
2_STCO	137	5	8	10	12	16	28	32	34	0	43.1	10.2	1.5	0	0	45.3
2a_STCO1	28	0	0	67.9	25	3.6	3.6	0	0	0	42.9	0	3.6	0	0	53.6
2b_STCO2	109	0.9	3.7	78.9	5.5	0	6.4	2.8	1.8	0	43.1	12.8	0.9	0	0	43.1
8_FIELD	59	0	3.4	47.5	8.5	0	10.2	28.8	1.7	0	52.5	25.4	5.1	0	1.7	15.3
8a_FIELD1	3	0	0	100	0	0	0	0	0	0	100	0	0	0	0	0
8b_FIELD2	56	0	3.6	44.6	8.9	0	10.7	30.4	1.8	0	50	26.8	5.4	0	1.8	16.1
3_PIPO-AGSP	62	0	0	64.5	6.5	0	11.3	8.1	8.1	1.6	3.2	4.8	1.6	0	1.6	88.7
4_PIPO-FEID	94	2.1	2.1	52.1	36.2	6.4	0	1.1	0	0	16	1.1	1.1	0	0	81.9
4a_PIPO-FEID1	22	0	0	40.9	36.4	22.7	0	0	0	0	27.3	0	0	0	0	72.7
4b_PIPO-FEID2	72	2.8	2.8	55.6	36.1	1.4	0	1.4	0	0	12.5	1.4	1.4	0	0	84.7
6_SYOC	38	0	0	35.9	41	0	2.6	20.5	0	0	10.3	10.3	5.1	0	0	74.4
5_PRVI	46	0	0	32.6	34.8	0	0	15.2	4.3	13	15.2	34.8	6.5	0	10.9	32.6
5a_PRVI1	27	0	0	40.7	25.9	0	0	14.8	3.7	14.8	14.8	40.7	0	0	14.8	29.6
5b_PRVI2	8	0	0	25	37.5	0	0	0	12.5	25	37.5	50	0	0	0	12.5
5c_PRVI3	11	0	0	18.2	54.5	0	0	27.3	0	0	0	9.1	0	27.3	9.1	54.5
7_SPPE	25	0	0	0	44	0	0	20	0	36	4	16	12	16	20	32
7a_SPPE1	13	0	0	0	15.4	0	0	15.4	0	69.2	7.7	15.4	7.7	15.4	0	53.8
7b_SPPE2	12	0	0	0	75	0	0	25	0	0	0	16.7	16.7	16.7	41.7	8.3

Footnotes.

Vegetation types are named in Table 1

Clay contents of both the SCS/NRCS and Westech data were estimated as mid-points in textural classes.

Modal clay contents are shaded lightly to facilitate comparison among vegetation types. Near modal points are shaded heavily.

PERMEABILITY

Soils with highly permeable surfaces accept rainwater falling on them, and depending on the permeability of deeper layers, may drain it below the reach of grasses and even deep rooted forbs, shrubs, and trees. Differences in deep drainage should be reflected in soil water storage capacity (Table 13)

Most soils are permeable (0.6-2 inches per hour, Table 12). Those under grassland, old fields, pines and *Symphoricarpos* are especially permeable, due to sandy soils (reciprocal of clay, Table 11). The low runoff-low evaporation of permeable soils yields quick local drainage which probably raises productivity over less sandy soils. *Prunus* 1& 3 sometimes grow on soils with low permeability. And both *Spartina* types grow on impermeable soils. One can probably engineer permeability to favor one vegetation type over another.

Table 12. Comparison of the permeabilities of soils associated with major vegetation types of the Absaloka mine, SE Montana. The data is presented as the percentage of sites of a vegetation type occupying each soil permeability category.

	N		<0.06"	0.06-0.1"	0.2-0.5"	0.6-2.0"	2.0-6.0"	NA's
1_AGSM	89		5.6	3.4	7.9	70.8	12.4	0
1a_AGSM1	58		0	1.7	6.9	81	10.3	0
1b_AGSM2	31		16.1	6.5	9.7	51.6	16.1	0
2_STCO	137		0	1.5	0	52.6	43.8	2.2
2a_STCO1	28		0	0	0	57.1	42.9	0
2b_STCO2	109		0	1.8	0	51.4	44	2.8
8_FIELD	59		1.7	10.2	1.7	33.9	52.5	0
8a_FIELD1	3		0	0	0	0	100	0
8b_FIELD2	56		1.8	10.7	1.8	35.7	50	0
3_PIPO-AGSP	62		1.6	0	4.8	90.3	3.2	0
4_PIPO-FEID	94		0	0	3.2	80.9	16	0
4a_PIPO-FEID1	22		0	0	0	72.7	27.3	0
4b_PIPO-FEID2	72		0	0	4.2	83.3	12.5	0
6_SYOC	39		0	2.6	7.7	79.5	10.3	0
5_PRVI	46		17.4	4.3	2.2	60.9	15.2	0
5a_PRVI1	27		14.8	3.7	3.7	63	14.8	0
5b_PRVI2	8		0	0	0	62.5	37.5	0
5c_PRVI3	11		36.4	9.1	0	54.5	0	0
7_SPPE	25		36	4	12	44	4	0
7a_SPPE1	13		15.4	0	7.7	69.2	7.7	0
7b_SPPE2	12		58.3	8.3	16.7	16.7	0	0

Footnotes.
Vegetation types are listed in Table 1
Modal configuration preferences are shaded to facilitate their comparison.
One can probably engineer permeability to favor one vegetation type over another.

WATER STORAGE CAPACITY.

Plant available rainwater is absorbed by and reserved in the soil and used gradually. Water stored in surface layers tends to favor diffuse rooted grasses while that stored at depth favors deep rooted plants like forbs, shrubs, and trees. We have four data sets representing increasingly thick layers (0-25, 0-50, 0-100, and 0-150 cm), all estimated by SCS/NRCS from horizon thickness, clay content, and organic matter content.

Water storage capacities are remarkably similar among our vegetation types (Table 13). Stco, Pine and Prunus sites have slightly greater 0-25cm water storage capacities than other types. In thicker layers, only Stco and *Prunus* (ie not pine) have relatively high water storage capacities. It is doubtful that significant amounts of water are drawn from soils deeper than 1.5m. Sub-types of Stco, Field, Pipo-Agsp, Pipo-Feid, and Prunus have different water storage capacities.

That the effects of this hypothetically important factor are so weak can probably be attributed to the semi-arid climate of SE Montana. Water storage capacity is of little use to any vegetation type if it is not filled in the winter/spring. And if it were exercised, the greater storage at depth under grassland should favor tree growth, i.e. in the absence of other factors (e.g. fire), increased rainfall might be expected to support tree invasion of grassland.

Table 13. Comparison of soil storage capacities among major vegetation types of SE Montana. Estimates were made for horizons of increasing thickness, 0-25, 0-50, 0-100, and 0-150 cm. Estimates were all made by SCS/NRCS using horizon thickness, stone content, and clay/organic matter contents?

		AWS 25cm				AWS 50cm				AWS 100cm				AWS 150cm			
	N	Xbar±SE	M	Q1	Q3	Xbar±SE	M	Q1	Q3	Xbar±SE	M	Q1	Q3	Xbar±SE	M	Q1	Q3
1_AGSM	89	3.78 ± 0.05	3.65	3.38	4.22	7 ± 0.08	6.63	6.49	7.7	11.19 ± 0.29	9.75	9.75	12.74	13.63 ± 0.61	9.75	9.75	16.53
1a_AGSM1	58	3.77 ± 0.05	3.76	3.38	4.22	6.97 ± 0.1	6.63	6.63	7.26	11.19 ± 0.36	9.75	9.75	12.74	13.7 ± 0.76	9.75	9.75	17.93
1b_AGSM2	31	3.78 ± 0.08	3.54	3.38	4.26	7.04 ± 0.14	6.63	6.4	7.71	11.19 ± 0.51	9.75	9.48	12.74	13.5 ± 1.04	9.75	9.53	16.53
2_STCO	137	3.85 ± 0.04	3.95	3.38	4.26	7.12 ± 0.07	6.74	6.63	7.71	11.46 ± 0.27	10.27	9.75	12.74	14.11 ± 0.55	11.61	9.75	16.53
2a_STCO1	28	3.79 ± 0.08	3.64	3.38	4.24	7.06 ± 0.14	6.63	6.63	7.7	11.19 ± 0.53	9.75	9.75	12.74	13.37 ± 1.11	9.75	9.75	16.53
2b_STCO2	109	3.87 ± 0.04	4.18	3.38	4.26	7.14 ± 0.09	6.9	6.44	7.71	11.54 ± 0.31	10.27	9.75	12.74	14.34 ± 0.63	11.61	9.75	17.23
8_FIELD	59	3.82 ± 0.06	4.13	3.38	4.25	6.99 ± 0.11	6.63	6.17	7.71	10.91 ± 0.39	9.75	8.64	12.74	12.98 ± 0.78	9.75	8.84	14.77
8a_FIELD1	3	3.76 ± 0.27	3.67	3.38	4.15	7.15 ± 0.51	6.89	6.63	7.57	11.79 ± 2.01	10.01	9.75	13.97	14.71 ± 4.29	10.68	9.75	19.93
8b_FIELD2	56	3.83 ± 0.06	4.13	3.38	4.25	6.97 ± 0.12	6.63	6.17	7.71	10.84 ± 0.4	9.75	8.64	12.74	12.85 ± 0.79	9.75	8.84	14.77
3_PIPO-AGSP	62	3.78 ± 0.06	3.54	3.38	4.26	6.75 ± 0.1	6.63	6.29	7.16	10.21 ± 0.35	9.75	8.69	10.27	11.83 ± 0.69	9.75	8.86	11.61
4_PIPO-FEID	94	3.92 ± 0.04	4.22	3.38	4.26	6.63 ± 0.08	6.63	6	6.9	9.94 ± 0.31	9.75	7.19	10.9	11.79 ± 0.6	9.75	7.19	15.4
4a_PIPO-FEID1	22	3.82 ± 0.09	3.9	3.38	4.25	6.88 ± 0.17	6.63	6.33	7.1	10.97 ± 0.65	9.75	8.96	12.43	13.54 ± 1.34	9.75	9.08	17.93
4b_PIPO-FEID2	72	3.95 ± 0.05	4.26	3.38	4.26	6.53 ± 0.09	6.4	6	6.63	9.52 ± 0.34	9.75	7.19	10.27	11.09 ± 0.65	9.75	7.19	11.61
6_SYOC	39	3.74 ± 0.07	3.54	3.38	4.26	6.85 ± 0.12	6.63	6.29	7.16	10.55 ± 0.46	9.75	8.69	10.43	12.29 ± 0.93	9.75	8.86	12.56
5_PRVI	46	3.93 ± 0.06	4.24	3.53	4.26	6.69 ± 0.15	6.63	6	7.16	9.99 ± 0.52	9.75	7.19	10.27	11.73 ± 0.96	9.75	7.19	11.61
5a_PRVI1	27	3.8 ± 0.08	3.54	3.38	4.26	6.63 ± 0.18	6.63	6.29	6.89	9.87 ± 0.61	9.75	8.69	10.27	11.28 ± 1.1	9.75	8.86	11.61
5b_PRVI2	8	4.04 ± 0.12	4.26	3.75	4.26	7.08 ± 0.38	7	6.22	7.74	11.28 ± 1.4	10.71	8.31	13.36	14.27 ± 2.64	12.7	8.44	17.95
5c_PRVI3	11	4.2 ± 0.08	4.26	4.26	4.26	6.57 ± 0.34	6	6	6.31	9.35 ± 1.28	7.19	7.19	8.47	10.99 ± 2.37	7.19	7.19	8.47
7_SPPE	25	3.8 ± 0.08	3.54	3.38	4.26	6.72 ± 0.12	6.63	6.4	7.16	10.1 ± 0.48	9.75	9.75	10.27	11.59 ± 0.96	9.75	9.75	11.61
7a_SPPE1	13	3.77 ± 0.12	3.54	3.38	4.26	6.66 ± 0.16	6.63	6.29	6.63	9.77 ± 0.62	9.75	8.69	9.75	10.75 ± 1.2	9.75	8.86	9.75
7b_SPPE2	12	3.84 ± 0.13	3.87	3.38	4.26	6.79 ± 0.18	6.63	6.4	7.16	10.46 ± 0.74	10.01	9.75	10.9	12.5 ± 1.52	10.68	9.75	15.4

Footnotes:

Vegetation types are listed in Table 1

Differences in water storage capacities are slight. Shading highlights vegetation types with relatively high (light) or low (dark) water storage.

RANGE SITE

The range site we report (SCS 1985) is subjectively assigned according to soil depth, soil texture, and the vegetation occupying it. It is the best single indicator of present vegetation. Its high indicator value may be due to the circularity of reasoning used in its application.

Ag smith occupies tight (clayey or silty, cf Table 14) soils, Stipa and old fields occupy sandier (sandy or silty, Table 14) soils, pine occupies rocky soils of thin hills and thin breaks. One pine type, snowberry and two Prunus types occupy occasionally flooded (overflow) sites. Prunus occupies bottomland-hardwood forest sites sometimes occupied by Acer, Oak, and cottonwoods. And Spartina vegetation types occupies subirrigated sites.

Table 14. Comparison of 'range site' designation of major vegetation types of the Absaloka mine, SE Montana. The data is presented as the percentage of sites of a vegetation type occupying each range site category.

	N		Sb	BHF	Ov	TB	TH	Sa	Si	Cl	NA's
1_AGSM	89		0	0	12	0	2.2	7.9	56	20	1.1
1a_AGSM1	58		0	0	17	0	3.4	8.6	53	16	1.7
1b_AGSM2	31		0	0	3.2	0	0	6.5	61	29	0
2_STCO	137		0	0	0	0	7.3	49.6	33	7.3	2.9
2a_STCO1	28		0	0	0	0	10.7	46.4	36	7.1	0
2b_STCO2	109		0	0	0	0	6.4	50.5	32	7.3	3.7
8_FIELD	59		0	1.7	0	0	1.7	50.8	31	15	0
8a_FIELD1	3		0	0	0	0	0	100	0	0	0
8b_FIELD2	56		0	1.8	0	0	1.8	48.2	32	16	0
3_PIPO-AGSP	62		0	0	0	9.7	29	6.5	34	3.2	17.7
4_PIPO-FEID	94		0	0	21	0	27.7	22.3	21	2.1	5.3
4a_PIPO-FEID1	22		0	0	9.1	0	45.5	31.8	14	0	0
4b_PIPO-FEID2	72		0	0	25	0	22.2	19.4	24	2.8	6.9
6_SYOC	38		2.6	5.1	85	0	2.6	2.6	2.6	0	0
5_PRVI	46		0	37	63	0	0	0	0	0	0
5a_PRVI1	27		0	7.4	93	0	0	0	0	0	0
5b_PRVI2	8		0	50	50	0	0	0	0	0	0
5c_PRVI3	11		0	100	0	0	0	0	0	0	0
7_SPPE	25		88	8	4	0	0	0	0	0	0
7a_SPPE1	13		92	7.7	0	0	0	0	0	0	0
7b_SPPE2	12		83	8.3	8.3	0	0	0	0	0	0

Footnotes

Vegetation types are named in Table

Range sites are, roughly in order of effective water availability, bottom hardwood forest (BHF), overland flow (ov), subirrigated (Sb), thin breaks (TB, rocky), thin hilly (TH, rocky), sandy (Sa), silty (SI), and clayey (Cl).

SOIL NAME

Precipitation and energy availabilities influence the suitability of a site for different vegetation types. In our region, the influence is often due to effects on water availability. Substrate also influences water availability, sometimes discriminating between plant forms, eg grass vs deep rooted forbs, shrubs, and trees. The 'soil type' integrates a complex of soil qualities and, for this reason, a type (name) is expected to be correlated with particular vegetation types.

Certain soil types support particular vegetation types (Table 15). McRae, Nelson-Alice, Thedalund, Midway and Ascalon, for example, support grasslands. Midway and Chugter support shrubland. Kyle supports Spartina. Thurlow and Thedalund support pine. And several types (Thedalund, Talag, Hydro, Nelson, and Haverson can support various vegetation types according to other the presence/absence of other factors.

Table 15. Soil types underlying major vegetation types of the Absaloka mine, SE Montana. The data is presented as the percentage of sites of a vegetation type occupying each soil type category (SCS/NRCS).

	N	MCRAE	NELSON-ALICE	THEDALUND-ROCK OUTCROP	MIDWAY	ASCALON	THURLOW	THURLOW-MIDWAY	THEDALUND-FT COLLINS	THEDALUND-CUSHMAN	FT COLLINS	MIDWAY-THEDALUND	THEDALUND-MIDWAY	NELSON	THEDALUND-WIBAUX	KIM	TALAG	HYDRO	HAVERSON	NUNN	NUNN-MIDWAY	CHUGTER COMPLEX	KYLE	WAGES LOAM	NA's
1_AGSM	89	7.9	.	.	.	1.1	2.2	5.6	1.1	1.1	15	19	7.9	11	11	3.4	5.6	3.4	4.5	.	.	.	.	.	0
1a_AGSM1	58	12	.	.	.	1.7	.	6.9	1.7	1.7	14	17	6.9	8.6	17	5.2	.	1.7	5.2	.	.	.	.	.	0
1b_AGSM2	31	.	.	.	.	.	6.5	3.2	.	.	16	23	9.7	16	.	.	16	6.5	3.2	.	.	.	.	.	0
2_STCO	137	2.2	0.7	0.7	1.5	.	.	.	1.5	1.5	2.2	12	17	44	11	2.9	.	1.5	1.5	.	.	.	.	.	0.7
2a_STCO1	28	.	.	.	3.6	.	.	.	.	.	.	21	14	43	18	.	.	.	.	.	.	.	.	.	0
2b_STCO2	109	2.8	0.9	0.9	0.9	.	.	.	1.8	1.8	2.8	9.2	17	44	9.2	3.7	.	1.8	1.8	.	.	.	.	.	0.9
8_FIELD	59	.	.	.	3.4	5.1	1.7	.	.	1.7	14	1.7	8.5	48	3.4	1.7	1.7	10	.	.	.	.	.	.	.
8a_FIELD1	3	.	.	.	.	.	.	.	.	.	.	.	.	100	.	.	.	.	.	.	.	.	.	.	.
8b_FIELD2	56	.	.	.	3.6	5.4	1.8	.	.	1.8	14	1.8	8.9	45	3.6	1.8	1.8	11	.	.	.	.	.	.	.
3_PIPO-AGSP	62	.	.	.	.	.	.	3.2	4.8	1.6	.	24	16	3.2	39	3.2	1.6	.	1.6	1.6	.	.	.	.	.
4_PIPO-FEID	94	.	.	.	.	.	.	2.1	3.2	.	.	29	14	16	34	1.1	.	.	.	1.1	.	.	.	.	.
4a_PIPO-FEID1	22	.	.	.	.	.	.	.	4.5	.	.	14	9.1	27	46	.	.	.	.	.	.	.	.	.	.
4b_PIPO-FEID2	72	.	.	.	.	.	.	2.8	2.8	.	.	33	15	13	31	1.4	.	.	.	1.4	.	.	.	.	.
6_SYOC	38	.	.	.	.	.	.	.	.	2.6	2.6	18	33	10	18	2.6	.	2.6	2.6	5.1	2.6	.	.	.	.
5_PRVI	46	.	.	.	.	.	.	.	.	.	4.3	4.3	2.2	15	22	8.7	11	4.3	17	.	2.2	2.2	6.5	.	.
5a_PRVI1	27	.	.	.	.	.	.	.	.	.	7.4	3.7	3.7	15	15	11	15	3.7	19	.	3.7	3.7	.	.	.
5b_PRVI2	8	.	.	.	.	.	.	.	.	.	.	13	.	38	.	13	.	.	38	.	.	.	.	.	.
5c_PRVI3	11	.	.	.	.	.	.	.	.	.	.	.	.	.	55	.	9.1	9.1	.	.	.	.	27	.	.
7_SPPE	25	.	.	.	.	.	.	.	.	.	.	.	.	4	32	8	20	4	4	12	.	.	16	.	.
7a_SPPE1	13	.	.	.	.	.	.	.	.	.	.	.	.	7.7	54	15	.	.	.	7.7	.	.	15	.	.
7b_SPPE2	12	.	.	.	.	.	.	.	.	.	.	.	.	.	8.3	.	42	8.3	8.3	17	.	.	17	.	.

Footnotes

Vegetation types are named in Table 1

Soil types are named, described, and evaluated in Meshnick et al 1977.

Modal soil types for each vegetation type are shaded. Common soils support more vegetation types than rarer ones.

Figure 16. Summary of vegetation environment (habitat) associations. Communities are listed as in Tables 1 and 3-15. And the information in tables 3-15 is categorized and shaded to link vegetation types with common environmental conditions.

	Topo	Slope	Aspect	Radiation	HL	R site	Soil name	Texture	Clay	Cobble	Gravel	Perm	Config
1_AGSM	S	M	S			S	G	C	N	N	G	P	SV
1a_AGSM1	S	M	S			S	G	C	N	N	G	P	SV
1b_AGSM2	S	M	S			S	G	CF	N	N	GN	P	SV
2_STCO	S	M	S			S	G	C	N	N	G	P	SX
2a_STCO1	S	M	S			S	G	C	N	CN	G	P	SVX
2b_STCO2	S	M	S			S	G	C	N	N	G	P	SVX
8_FIELD	S	M	S			S	G	C	N	N	G	P	S
8a_FIELD1	S	M	S			S	G	C	N	N	G	P	V
8b_FIELD2	S	M	S			S	G	C	N	N	G	P	S
3_PIPO-AGSP	S	H	M			R	M	C	N	N	G	P	
4_PIPO-FEID	S	H	N			R	M	C	N	N	G	P	VX
4a_PIPO-FEID1	S	H	N			R	M	C	N	N	G	P	VX
4b_PIPO-FEID2	S	H	N			R	M	C	N	N	G	P	VX
6_SYOC	B	L	N			B	M	CF	N	N	G	P	V
5_PRVI	B	L	N			B	M	CF	N	N	GN	PI	V
5a_PRVI1	B	L	N			B	M	CF	N	N	GN	PI	V
5b_PRVI2	B	L	N			B	M	CF	N	N	GN	P	V
5c_PRVI3	B	L	M			B	M	CF	C	CN	GN	PI	V
7_SPPE	B	L	M			W	S	CF	CN	N	G	PI	V
7a_SPPE1	B	L	M			W	S	CF	CN	N	G	PI	V
7b_SPPE2	B	L	M			W	S	_	CN	N	GN	PI	V

Footnotes:
Communities as in Table 1.
Differential shading distinguished distinct environmental conditions.

DISCUSSION AND CONCLUSIONS.

FACTORS. We have correlated vegetation type with presumptive factors (Tables 3-15) and summarized this information in Table 16. The tables can be read to explore the relationship of environment to formations physiognomic types), principle types, and sub-types/varieties.

When a presumptive factor varies among formations (i.e. physiognomic types), vegetation types, or vegetation varieties, it is believed to be a factor and engineering with it should improve establishment of vegetation types. On the other hand, engineering with a presumptive factor which varies little among vegetation types is likely to be fruitless. While the invariant presumptive factor may influence vegetation in a broader geographic scale, it has little influence in our region (SE Montana/Absaloka mine). At the formation level surprising examples of 'non-factors' are radiation level, heat load, soil gravel and cobble and soil water storage capacity (Tables 16 and 5, 9, 10, 13).

ENVIRONMENT AND PHYSIOGNOMIC TYPES. Major vegetation types (physiognomic types) tend to occupy different landscape segments (Table 16 and 3, 4, 6). Grasslands occupy uplands (S) with moderate slopes, and southerly aspects. Pines occupy uplands with steep slopes and northerly aspects. Riparian shrublands (snowberry and *Prunus)* occupy bottoms with low slope and northerly aspects. And wet-lands tend to occupy bottoms with low slopes and with east-west aspects. Configurations are variable within all types, except those that occupy convex stream sides (Table 7).

Engineering with this information will be facilitated if underlying more proximal/ more physiologic factors can be identified. Thus we attempt to correlate them with controls of radiation and water.

1) These landscape segments are poorly differentiated by radiation and heat loads as calculated from slope and aspect (Table 5, McCune and Keon 2006). This suggests that site properties associated with slope and aspect other than radiation input are controlling.

2) Neither are individual soil properties well correlated with physiognomic types. Grasslands and pines are indistinguishable, but the soils of bottomlands are somewhat different. First, deviant textures (fine, Table 16 and 8), clay contents (clayey, Table 16 and 11), cobble contents (no cobble, Table 16 and 10), gravel (gravely, Table 16 and 10) are largely limited to bottomlands

and ‘marshes’. Second, one expects permeability (rain absorption) and water storage capacity (Table 16 and 13) to be controlling because they are controls of the limiting water factor. With respect to physiognomic types, our data does not validate either hypothesis.
3) What controls vegetation distribution if neither radiation nor soil qualities are well correlated with vegetation type? Subsoil properties, multi-factor soil qualities, run-off/run-in characteristics, wind exposure, and fire are possibilities.

While we have not discovered the factors underlying the landscape factor, we have discovered that vegetation is also predicted by related factors, that is, ‘range site’ and ‘soil type’. Both ‘range site’ and ‘soil type’ are complex ‘factors’. The good correlation with range site (Tables 16 and 14) may be due both to inclusion of additional information (e.g. overflow and ‘thin to rock- - thin breaks and thin hilly- - both engineerable) or a circularity of application (e.g. description of site by vegetation occupying it, such as bottomland hardwood forest). The strong correlation with soil types (Table 16 and 15) is unexpected because individual soil characteristics are poorer predictors. The improvement in prediction could be due to integration of soil qualities not individually controlling (e.g. texture), control by soil qualities other than those examined separately, or a circularity of application. Such circularity undoubtedly arises, to some degree, because soil mappers recognize soil/vegetation relations and use them to map soils from vegetation cover.

ENVIRONMENT AND VEGETATION TYPES. Vegetation of types within a physiognomic type may occupy different environments. With respect to topography, note that Agsm sites are less likely sloping than Stco sites (Table 16 and 4). With respect to aspect (Table 16 and 3), the Pine Agsp sites are more southerly than the Pine Feid sites. With regard to slope (Table 16 and 4), Pine-Agsp sites are shallower than Pine-Feid sites. With respect to permeability, Agsm sites are less permeable than Stco sites (Table 16 and 12).

Varieties of a vegetation type may occupy environmentally distinct sites. The fact that vegetation type varieties occupy different environments supports their separation. With respect to aspect (Table 16 and 3), Agsm , Stco , *Prunus ,* and *Spartina* varieties differ. With regard to configuration (Table 16 and 7), Stco and old field types are distinct. And with regard to cobble (Table 16 and 9), the Stco types differ.

ENGINEERING. A presumptive factor which varies between vegetation types may be causing the difference in the vegetation. If so, one can engineer a site for a particular vegetation type by choosing or emplace-ing the appropriate condition. Or, one can choose a vegetation type for a particular site by examination of its environmental qualities.

While identification of vegetation environment (habitat) associations (VHA) suggests specific management behaviour, conclusions drawn from identification are fallible because a correlated factor may or may not be causal. That is, a seemingly causal site quality might be correlated with a causal quality which is not emplaced when the presumptive factor is emplaced.

The cost of reclamation in dollars and time (decades to centuries!!) is large. Thus, ecologists and engineers will seek information on the physiologic underpinnings of complex factors for two reasons: 1) To minimize error. And 2) as a key to substituting a inexpensive solution for the more expensive ‘natural solution’. For example, when the good correlation of ‘range site’ with vegetation type suggests installation of surficial bedrock to establish pine forest, the engineer will call that very expensive and ask what properties of bedrock are critical and whether those properties might be installed in other ways.

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Appendix table 1. Data layers presented in the Absaloka geographic information system and their sources.

Character	Figure/Table	Source	Comments	Citation/address
SITE DATA				
Basemap	1	USGS	DOQ	http://nris.state.mt.us/
Man-made features	1	Abs/WESTECH	from CAD data	
Data points	2	Abs/WESTECH		
VEGETATION				
Vegetation types	t3	Abs/VHA task 1		
TOPOGRAPHY				
Topographic map	3	Abs/WESTECH	CAD topo lines	
Elevation 10m	4a	Derived, Fig 3		
Elevation 30m	4b	USGS		http://nris.state.mt.us/
Abs point aspect		Direct	Abs/WESTEC	Abs point survey
10m aspect	5a	Derived, Fig3	ArcInfo Interpolation	
30m aspect	5b	USGS		http://nris.state.mt.us/
Abs point slope		Direct	Abs/WESTEC	Abs point survey
10m slope	6a	Derived, Fig 3	ArcInfo interpolation	
30m slope	6b	USGS		http://nris.state.mt.us/
Slope position	6c	Derived, Fig 3		http://www.wsl.ch/staff/niklaus.zimmermann/progs.html
SOIL QUALITY/POTENTIAL				
Mine generated geol map.		Abs/Mont DEQ	Not available.	
NRCS soil units	7	NRCS	SSURGO Data	http://www.ncgc.nrcs.usda.gov/
Mine generated soil types		Abs/Mont DEQ	Not available	
Soil characteristics	t#	Abs/NRCS	SSURGO/Direct data	
Solum thickness	8	NRCS	SSURGO Data	http://www.ncgc.nrcs.usda.gov/
Soil % clay	9	NRCS	SSURGO Data	http://www.ncgc.nrcs.usda.gov/
Abs point texture		Abs/WESTECH	Not available, not comparable.	
Soil water storage				
0-25cm	10a	'Available soil water'		
0-50cm	10b	NRCS	SSURGO Data	http://www.ncgc.nrcs.usda.gov/
0-100cm	10c			
0-150cm	10d			
Range site	11	'Precipitation x water storage'		
		NRCS	SSURGO Data	http://www.ncgc.nrcs.usda.gov/
SITE POTENTIAL (yield)				
Range yield		NRCS	SSURGO Data	http://www.ncgc.nrcs.usda.gov/
Wet yr	12a			
Ave yr	12b			
Dry yr	12c			
Alfalfa yield		NRCS	SSURGO Data	http://www.ncgc.nrcs.usda.gov/
Ave yr	13a			
Irrigated	13b			

Chapter 6, VHA task 5.

IDENTIFYING TARGET VEGETATION FOR INSTALLATION ON MICROSITES- - VHA FOR RECLAMATION

INTRODUCTION

Reclamation ecologists (miners to foresters) seek to install, on surfaces they manage/create, vegetation meeting their goals with respect to productivity, forage quality, aesthetics, preservation of rare species or providing food/cover habitat for game. Installation may be conducted by planting or management with forces such as fire or grazing.

The object of our project is to initiate development of objective methods for either 1) choosing vegetation appropriate for particular post-disturbance (e.g. mining or fire) surfaces or 2) engineering surfaces most likely to support particular vegetation types. Our approach is to correlate pre-mine (pre-disturbance) vegetation and environment to identify vegetation habitat associations (VHA) that are probably due to/caused by vegetation requirements for the correlated characteristics (or combinations of characteristics). When presumptive 'factors' are identified, the manager can plant each site with the vegetation type best matched to factor levels existing at the site. Alternatively, the VHA information can be used to guide preparation of sites with factor levels suitable for a particularly desirable vegetation type.

METHODS

Our project is based on the assumption that the environment correlates of (near-climax) vegetation distinguish sites occupied by one vegetation type from those occupied by another. Thus we have correlated vegetation presence and environmental qualities methods with two separate objectives. To find the best points/environments for placement/establishment of a specific vegetation type. And to find the best vegetation for a specific point/environment.

Vegetation types of the Absaloka mine area were identified (Chapter 1). In the permitting process species were listed with cover estimates at ~ 800 points. The data were ordinated and the continuum was partitioned with a classification program (McCune and Mefford 1999), and the classification was pruned at two near-optimal levels, ie at 8 and 14 types. The eight types are described in Chapter 1.

Environmental data were gathered at each point sampled for vegetation (Westech 1992, 2004, 2006). Some data were gathered in the (private company – PC) field (slope, aspect, position (= top, shoulder, slope, toe, bottom), topography (= convex, concave, straight). Radiation (southerliness, McCune and Keon 2002) and heat (souhwesterliness, McCune and Keon 2002) were calculated from slope, aspect, and latitude. And some data were taken from public sources (public data – PD) , ie NRIS (texture, soil type, and range type) and USGS DEMs (NRIS).

We used two methods, one graphical and one statistical, to describe the distribution of each vegetation type in relation to slope and aspect. Our graphical method consisted of plotting the coordinates of each sample point on a conical surface whose margin contained 360 degrees and whose peak represented 90 degrees. This approach allows one to study the range of community distribution in slope/aspect space, rather than the mean condition focused on in the following regression method.

To choose the best slope/aspect environment for each vegetation type, we regressed each vegetation type against slope, aspect, and derivative interaction, radiation, and heat terms with logistic generalized linear regression models. 1) Environmental variable selection for the logistic regressions was made by using forward and backward stepwise regressions. The Aikike Information Criterion (AIC) was used as a measure of model quality. The pool of variables consisted of slope, aspect, radiation, and heatload, one interaction term (slope*aspect), and quadratic terms for each variable: ($slope^2$, $aspect^2$, $radiation^2$, and $heatload^2$). Regression models were created in R, using “MASS” (Ripley 2006), and default R-packages. 2) Logistic GLMs do not have the same properties as ordinary least squares regressions since, because dependent variable responses are binary (presence/absence), predicted responses from the model probabilities are logit-transformed. Thus, with GLMs, one uses the D^2 statistic 1-(residual deviance/null deviance), which is analogous to the R^2 statistic, to measure model performance. In addition, each term in every model was tested with the Analysis of Deviance test with the Chi-squared test distribution.

To determine the vegetation type most likely to succeed on each environment/point of a graded surface we used classification and regression tree analysis (CART, Breiman et al 1984). One set of CART models for the 8 and 15 type classifications were based on slope, aspect and their derivatives gathered in the field (Westech 1992, 2004, 2006.). Additional models based on field slope/aspect data along with other field (e.g. position and configuration) and public data (e.g. soil type, range site as interpreted by Westech) were created for both 8 and 15 class classifications. A second set of models was based on slope aspect data taken from the 30m DEM alone or with other field (position and configuration) and public (soil type, range site, etc, as interpreted by Westech) was created for both 8 and 15 class classifications. The CART models were run using default parameters from the R-package "tree" (Ripley 2006).

RESULTS

GRAPHING COMMUNITY/TOPOGRAPHY RELATIONSHIPS. We have graphed the relationship of the presence/absence of communities with respect to slope and aspect. Figure 1 compares the distribution of Agropyron smithii 'toe slope communities' and Pinus ponderosa 'north slope communities'. Figure 2 compares the environmental distribution of two old field communities. Because their topographic preferences are so similar, one suspects that their habitats differ in soil qualities. While further analysis is beyond the scope of our pilot project, our graphical device lends itself to visual analysis, analyzes variance, will be useful in other contexts, and will be used to compare the topographic environments of other vegetation types.

SITING A COMMUNITY. Logistic regressions were used to identify combinations of site characteristics best correlated with (predicting) the presence/absence of a pre-mine vegetation type Assuming that the site characteristics studied control environmental quality (e.g. water, nutrient, heat, fire) we expect the community to establish well on post-disturbance sites with similar quality. Our expectation might fail if (in nature) the community is displaced from its favorite site by another community more competitive there.

Optimal logistic models for environmental placement of eight major communities and 15 nested communities- - based on field (point correct) vegetation and slope aspect data (Westech 1992,2004,2006)- - are presented in Tables 1 and 2. Similarly/in contrast, optimal models based on field vegetation and slope/aspect data derived from a 30m DEM are presented in Tables 3 and 4. Neither environmental data type/set correlated well with (predicted) vegetation presence/absence, as demonstrated by low D^2 in logistic regressions (Table 1, 3). While average D_2 statistics were slightly higher for logistic models based on point-correct field data (Westech), than on publicly available GIS data (D^2= 0.151 and 0.127 respectively) the differences were not statistically significant at $\alpha = 0.05$ (t = 1.27 p-value = 0.109, df = 20).

Significant regression coefficients in Table 1 suggest a strong association (control) of vegetation presence/absence by the corresponding landscape factor. 1) Significant slope and slope squared coefficients suggest slope control, with stronger inferential weight being given to the quadratic slope term. Thus Stipa and pine increase as slopes increase. 2) Significant aspect and aspect squared coefficients suggest aspect control with primary attention given to aspect squared. Negative aspect squared suggest that Agsm and Pipo avoid south slopes, while Stco prefers south slopes. 3) While we have no indication that slope/aspect interact multiplicatively, combining them to generate indices of radiation load (r and r^2) and heat load (h and h^2) shows the expected relationships. As one moves toward steeper south facing slope (high radiation, Mccune 1999) Prunus, Syoc, and Spartina tend to decrease. As one moves toward steeper south facing slopes (high radiation, McCune 1999) Prunus, Syoc and Spartina tend to decrease. As one moves toward southwest facing slopes (high heat, McCune 2002), Pipo-Feid and Syoc tend to decrease while some Stco, Pipo-Agsp, and Spartina I tend to increase. 4) Intercepts are generally low for zonal vegetation and higher for azonal Prunus, Syoc, and Spartina of draws and toe-slopes. The interpretation is not clear.

VEGETATING A SURFACE. CART models were used to identify the vegetation type best correlated with a particular combination of environmental qualities, i.e. to vegetate a surface with no consideration of/regard for community qualities. The models differed according to the vegetation types considered and the environmental data used.

CART models improve as they are given more environmental data. We demonstrate this with our primary seven vegetation types (omitting old fields) and our most precise environmental data (field data). Misclassification error rates decreased from correlations based on slope or aspect alone (62-67%) to slope/aspect& derivatives (57%), to S/A&D/&4 public variables (41%) to SA&D/&5 public variables (31%, Table 5).

CART models are best when vegetation data and environmental data are tightly linked, ie environmental data were measured in the field rather than from 30m DEMs. Paried field/DEM based values for seven vegetation types are slope alone 62 (field)-64 (DEM), aspect alone 67-66, slope/aspect&D, 57-62, and slope/aspect&D+4 public variables 41- X.

CART models are improved when ambiguous data are omitted. Each of the seven native vegetation types presumably occupy particular environments and representatives of each of these types presumably have very similar environments. In contrast, our eighth type (old field) occupies the multiple environments it was plowed from and thus includes greater vegetation and environmental variability. Thus, analysis of the field type (#8) with the native type members is expected to confuse the correlations, because environments of old fields correlate better with one or another native vegetation type than with other old field members. Paired error rate values contrasting seven (homogeneous) classes and eight classes, one of which is heterogeneous, and using precise slope/aspect field data are 57 vs 61%. Using less precise DEM data error rates are 57 vs 67%. When more environmental data is used (slope, aspect, radiation, heat load and range site) error rates for seven native classes vs seven native plus old field are 41vs 47%.

When vegetation tree pruning is near optimal, CART models perform better with fewer, rather than more classes. Comparisons of error rates between seven vs thirteen classes (old fields omitted) are 57 vs 66% when based on precise (field) slope aspect data (Westech) - - and 62 vs 70% when based on public DEM slope aspect data . When the comparison is based on more environmental data (ie SA + four) error rates are 41 vs 53%. Use of still more environmental data (SA+5) dropped the error rates still further, to 33-53%. The observed rise in error rate with increasing number of classes is logically/ mathematically necessary. This is because, with one environmental class no error is possible, but with seven (to thirteen) classes a community might be mis-assigned to any of the six (twelve) it doesn’t belong in.

DISCUSSION.

The method. We outline a four-step method: identify pre-disturbance vegetation types present at the site, describe the pre-disturbance environments of these vegetation types, correlate vegetation with the presumptive factors on a single or multifactorial basis, and choose vegetation for postdisturbance micro-sites on the basis of the vegetation/habitat association (VHA) model.

Vegetation types are identified with ordination and classification methods *(Chapter 1).* Ordinations relate stands sampled, one to another. Classifications objectively segment the continuum into types which can be planted/ managed for. Because classifications are heirarchial they identify groupings at several levels, of which some are more useful than others. If too few vegetation types are used, sub-types will require different environments, thereby confusing the assignment of particular vegetation types to specific field sites(=microenvironments). If too many types are used, the costs of planting/management will be too high.

Environments are described with measures of presumptive factors selected to be physiologically understandable, quantifiable, and ideally engineer-able *(Chapters 2& 4).* Insistence on physiological meaning selects for physiological or landscape factors, i.e. against site characteristics which are correlated with plant performance, but not controlling it. Measurability is required both to gather data used to determine the vegetation environment association (identifying the factors) from pre-mine samples. And to either characterize post-mine microsites for identification/choice of the best suited vegetation or to guide creation/engineering of surfaces/environments for particular vegetation types. Attention to engineerable factors (e.g. slope or soil type) is desirable because it allows the ecologist to create diversity or even to design sites for particular vegetation types.

Vegetation types are correlated with environmental qualities to determine presumptive factors. Factor-by-factor analysis may be suggestive, but rarely satisfying *(Chapter 4),* because the presence of a vegetation type is usually determined by more than one factor. Combination of two presumptive factors may improve correlation/prediction whether the combination is irrational (e.g. graphs) or rational (e.g. combining slope and aspect with physical calculations to generate predictors of energy or heat income). Given that all variables are accurately measured/

indexed, use of increasing numbers of true factors will improve the prediction of vegetation. One might imagine that too many presumptive factors might be included. This won't happen because non-factors are filtered out by their high variability in both GLM logistic and CART regressions.

Multiple regressions are best for determining qualities for a site being prepared for a particular community because they optimize use of all factors in evaluation of the information for the community considered. CART analysis is best for determining what community is most likely to fit a particular point in a reclamation landscape. While the CART analysis chooses the best fit, it does not tell us how much better the fit is than that of a competing vegetation type- - a type that might be nearly as fit, but more desirable for other reasons, such as productivity, quality, or aesthetics.

Achieving best results. CART models can generally be improved in four ways. 1) Prediction improves with increasing numbers of environmental qualities considered, e.g. misclassification error was reduced as predictors increased from slope or aspect, to slope/aspect& their derivatives (energy and heat), to slope/aspect/derivatives/range site, to slope/aspect/derivatives/range site/& soil qualities The increase might have four causes. 1) Inclusion of more characteristics may provide information on more physiological dimensions of the niche. Inclusion of more characteristics may improve the description of a physiological dimension e.g. water. Because inclusion of characteristics was ordered, the 'best predictors' may have been saved till last. That this is the case is suggested by the fact that range site and soil type are primary (first choice) predictors for CART models that include them. Why are range site and soil type such good predictors of vegetation type? Probably because they are determined by examination of the vegetation present at the point considered, i.e. by inappropriate 'circular definition/measurement'. 2) Prediction improves with quality of the environmental data, e.g., when slope/aspect data were considered, PC field data outperformed public DEMs because the environmental qualities more tightly paired to the vegetation predicted. 3) Elimination of ambiguity improves model prediction. For example, prediction of vegetation is confused when the environment considered might be occupied by either a native type or an old field plowed from it. 4) Error in prediction of vegetation type increases with an increasing number of vegetation classes considered. For example, there is greater possibility for error when two sister types must be distinguished than when they are pooled. Technical note: The possibility for error is doubled if equal numbers are in the pool, but not if the numbers are unequal. Neither will error rates double if, in division, the members of a type flow down different arms of the CART heirarchy.

Regarding logistic models, we expect/hypothesize the same results. Correlations/predictions will improve/strengthen with increasing environmental information [While poor p-factors are eliminated in multiple regressions, the best are retained for improved prediction.], decreasing number of vegetation classes [Perhaps not true if envt of a broad vegetational class is heterogeneous.], improvement of environmental data, and reduced ambiguity of vegetation data. We did not test these hypotheses.

As applied the CART and logistic models instruct us in different ways. Our CART studies show us the power, perhaps deceivingly, of range site and soil type measures not included in the logistic regressions. On the other hand, the logistic regressions show us the relative strength of the factors.

Applications. We expect strong correlation/association between vegetation type and underlying environment, because we believe that climax vegetation is determined by underlying environment. Thus we will interpret strong correlations as indicators of presumptive factors and use them in siting vegetation in reclamation of disturbed sites.

This approach is relevant to re-vegetation after mining, The application may be less useful than imagined, because other factors (eg soils) may differ between pre- and post-mine surfaces. On the other hand, to the extent that soil properties are engineer-able, they may be managed to improve site quality for particular/desirable vegetation types.

The VHA method may guide post-disturbance reclamation, as well or better, in non-mine contexts. It may be increasingly useful from post-farming to post-grazing to post-fire reclamation. Post-farming sites have little soil modification. Post-grazing sites have little soil modification and a propagule bank, but perhaps including weedy as well as native species. And post-fire range or forest sites may have little soil modification, a good native seed bank, and few established weeds.

Results of VHA identification by the CART approach lend themselves to mapping of potential vegetation. If post-disturbance surface environmental characteristics are mapped, pre-mine VHA relations provide a basis for predicting the most likely vegetation type for each point--and thus provide a basis for mapping seeding units and potential vegetation. This map does not weigh differences in vegetation quality which might be considered if establishment probabilities (not measured) of two vegetation types were similar.

The results of VHA identification by logistic regression can be used to locate/map all the sites where a particular vegetation type is likely to grow well, even if it might be slightly out-competed by another type. Comparison/ overlaying of single type logistic maps and CART maps might be used to modify CART recommendations where alternate plantings yield more desirable vegetation with similar establishment probabilities. If the favored type and the competitor were almost evenly matched, replacement of a slightly 'wrong' type would likely be very slow. [Such differential establishment possibilities is being examined in the proposed Spring Creek project.]

As noted above, analysis by logistic regression can also serve as a basis for designing sites for an especially desirable vegetation type. Site design might include engineering with particular combinations of landscape factors such as slope, aspect, and soil type.

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Table 1. Topographic factors predicting (influencing) the presence of eight vegetation types and their varieties. Coefficients of logistic regessions indicate the strength and direction of factors derived from slope aspect **Westech data.**

			COEFFICIENTS									
	AIC	D^2	Slope	Aspect	Slp*Asp	$Slope^2$	$Aspect^2$	Rad	HeatL	Rad^2	$HeatL^2$	Intercept
1_AGSM	446.9	0.07829	-0.15690	0.02465	--	--	-0.00009	--	--	--	--	-1.965
1a_AGSM1	355.5	0.02796	-0.10140	--	--	--	--	--	--	--	--	-1.532
1b_AGSM2	213.6	0.12068	-0.24314	0.01597	--	--	--	--	--	--	--	-3.052
2_STCO	553.3	0.08928	0.36456	0.00884	--	-0.01906	--	--	--	--	--	-2.963
2a_STCO1	214	0.05984	0.35380	--	--	-0.01896	0.00005	--	--	--	--	-4.508
2b_STCO2	501.9	0.07668	0.34993	0.00500	--	-0.01736	--	--	5.255	--	--	-7.655
3_PIPO-AGSP	297	0.22752	0.20390	--	--	--	-0.00004	--	6.221	--	--	-9.080
4_PIPO-FEID	409.3	0.16840	0.41138	--	--	--	-0.01650	--	--	--	--	-0.012
4a_PIPO-FEID1	159.3	0.18410	0.67243	--	--	-0.03050	-0.00009	--	-9.512	--	--	3.010
4b_PIPO-FEID2	362.7	0.12605	0.31677	-0.01362	--	-0.00804	--	--	--	--	--	-2.655
5_PRVI	231.3	0.19054	-0.81431	--	--	0.01697	--	-37.988	--	--	11.923	24.459
5a_PRVI1	180	0.14601	-0.56370	--	--	--	--	-234.565	--	125.257	--	108.680
5b_PRVI2	71.88	0.18165	-0.77320	--	--	--	--	--	--	--	--	-1.582
5c_PRVI3	55.28	0.09346	-0.44410	--	--	--	--	--	--	--	--	-2.874
6_SYOC	248.4	0.08587	-0.35150	--	--	--	--	-14.820	-11.868	--	--	22.726
7_SPPE	118.7	0.40416	7.22000	--	--	-2.15600	--	--	--	--	--	-6.857
7a_SPPE1	85.12	0.36804	7.31900	--	--	-2.16300	--	--	55.020	--	--	-57.549
7b_SPPE2	72.26	0.35205	6.06700	--	--	-2.00700	--	-73.254	--	--	--	59.488
8_FIELD	365.7	0.02782	-0.09174	0.00418	--	--	--	--	--	--	--	-1.879
8a_FIELD1	37.39	0.15194	5.80420	--	--	-0.48590	--	--	--	--	--	-21.105
8b_FIELD2	353.3	0.02243	-0.08719	--	--	--	--	--	--	--	--	-1.623

Vegetation types are Agropyron smithii (Agsm), Stipa comata (Stco), Pinus ponderosa – Festuca idahoensis (Pipo-Feid), Prunus virginiana (Prvi), Symphoricarpos occidentalis (Syoc), Spartina pectinata (Sppe) and old field (Field).

D^2 and AIC index the fit of the regressions, see text.

Table 2. Statistical significance of coefficients in logistic equations predicting the presence of eight vegetation types and their varieties from topographic factors. Underlying data from **Westec** and the predictive equations are presented in Table 1.

	P-Values								
	Slope	Aspect	Slope*Aspect	Slope^2	Aspect^2	Radiation	Heatload	Radiation^2	Heatload^2
1_AGSM	0.0000022	0.00053	--	--	0.09000	--	--	--	--
1a_AGSM1	0.00148	--	--	--	--	--	--	--	--
1b_AGSM2	0.00100	0.00005	--	--	--	--	--	--	--
2_STCO	0.20000	0.00003	--	4.419E-09	--	--	--	--	--
2a_STCO1	0.63800	--	--	0.00500	0.02400	--	--	--	--
2b_STCO2	0.28000	0.00059	--	0.0000005	--	--	0.10000	--	--
3_PIPO-AGSP	1.072E-18	--	--	--	0.12000	--	0.03000	--	--
4_PIPO-FEID	0.0000048	1.548E-08	--	1.004E-07	--	--	--	--	--
4a_PIPO-FEID1	0.18100	--	--	0.00007	0.00025	--	0.11300	--	--
4b_PIPO-FEID2	0.00002	0.00001	--	0.00021	--	--	--	--	--
5_PRVI	0.0000003	--	--	0.00014	--	0.00500	--	--	0.05200
5a_PRVI1	0.00100	--	--	--	--	0.00400	--	0.00100	--
5b_PRVI2	0.00010	--	--	--	--	--	--	--	--
5c_PRVI3	0.02100	--	--	--	--	--	--	--	--
6_SYOC	0.00300	--	--	--	--	0.00100	0.15000	--	--
7_SPPE	2.543E-14	--	--	0.00002	--	--	--	--	--
7a_SPPE1	0.00000002	--	--	0.00200	--	--	0.05700	--	--
7b_SPPE2	0.00000077	--	--	0.00400	--	0.13900	--	--	--
8_FIELD	0.00442	0.14000	--	--	--	--	--	--	--
8a_FIELD1	0.71800	--	--	0.01900	--	--	--	--	--
8b_FIELD2	0.00463	--	--	--	--	--	--	--	--

Vegetation types are Agropyron smithii (Agsm), Stipa comata (Stco), Pinus ponderosa – Festuca idahoensis (Pipo-Feid), Prunus virginiana (Prvi), Symphoricarpos occidentalis (Syoc), Spartina pectinata (Sppe) and old field (Field).

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Table 3. Topographic factors predicting (influencing) the presence of eight vegetation types and their varieties. Coefficients of logistic regressions indicate the strength and direction of factors derived from slope aspect **30m DEM data.**

			COEFFICIENTS									
	AIC	D^2	Slope	Aspect	Slp*Asp	$Slope^2$	$Aspect^2$	Rad	HeatL	Rad^2	$HeatL^2$	Intercept
1_AGSM	465.5	0.06464	0.53849	--	--	-0.06642	--	177.396	--	-115.089	--	-70.462
1a_AGSM1	366.3	0.02790	0.42743	--	--	-0.05312	--	--	--	--	--	-2.705
1b_AGSM2	215.3	0.13091	1.0556	--	--	-0.1725	--	--	--	14.499	--	-11.859
2_STCO	586.3	0.06006	0.71545	--	--	-0.05657	--	7.71328	--	--	--	-8.558
2a_STCO1	219.5	0.04430	0.63695	--	--	-0.04152	--	--	--	5.35088	--	-7.753
2b_STCO2	525.9	0.04951	0.69275	--	--	-0.05909	--	6.28669	--	--	--	-7.637
3_PIPO-AGSP	353.2	0.10377	0.26010	--	--	--	-0.00003	--	--	--	--	-3.255
4_PIPO-FEID	416.1	0.19662	0.42328	-0.01482	0.00208	-0.02573	--	--	--	-10.532	--	2.753
4a_PIPO-FEID1	158.1	0.17654	0.19556	-0.02773	--	--	--	--	--	--	--	-2.632
4b_PIPO-FEID2	363.1	0.14951	0.57729	--	--	-0.02464	--	--	--	-8.76513	--	2.888
5_PRVI	282.4	0.13871	-0.59527	--	--	0.04183	--	376.395	--	-242.496	--	-146.560
5a_PRVI1	193.2	0.14048	-0.18210	--	--	--	--	1249.9260	--	-821.5247	--	-476.979
5b_PRVI2	68.9	0.27124	--	0.01411	--	-0.34058	--	--	-103.177	--	--	90.224
5c_PRVI3	104	0.10975	-0.35987	--	--	0.03024	--	9.26168	--	--	--	-10.171
6_SYOC	265.2	0.07227	-0.33110	--	--	--	--	--	--	--	--	-1.2812
7_SPPE	168.5	0.20124	-0.97732	--	--	0.04434	--	--	--	--	--	-0.574
7a_SPPE1	107.5	0.17532	-0.98153	--	--	0.04699	--	--	--	--	--	-1.326
7b_SPPE2	101.3	0.15815	-0.6616	--	--	--	--	--	--	--	--	-1.7257
8_FIELD	359.3	0.06818	0.62680	--	--	-0.08011	-0.000069	20.039	--	--	--	-17.340
8a_FIELD1	37.19	0.27017	16.33500	--	--	-1.59100	--	-784.543	--	541.931	--	236.770
8b_FIELD2	348.1	0.06603	0.564800	--	--	-0.07488	-0.00007	10.988	--	--	--	-10.686

Vegetation types are Agropyron smithii (Agsm), Stipa comata (Stco), Pinus ponderosa – Festuca idahoensis (Pipo-Feid), Prunus virginiana (Prvi), Symphoricarpos occidentalis (Syoc), Spartina pectinata (Sppe) and old field (Field).

D^2 and AIC index the fit of the regressions, see text.

Table 4. Statistical significance of coefficients in logistic equations predicting the presence of eight vegetation types and their varieties from topographic factors. Underlying data from our **30m DEM** and the predictive equations are presented in Table 3.

	P-Values								
	Slope	Aspect	Slope*Aspect	Slope^2	Aspect^2	Radiation	Heatload	Radiation^2	Heatload^2
1_AGSM	0.00116	--	--	0.00032	--	0.02	--	0.14	--
1a_AGSM1	0.08000	--	--	0.01000	--	--	--	--	--
1b_AGSM2	0.00400	--	--	0.00200	--	--	--	0.00033	--
2_STCO	0.52000	--	--	7.740E-07	--	5.014E-04	--	--	--
2a_STCO1	0.19400	--	--	0.04800	--	0.04000	--	--	--
2b_STCO2	0.9700	--	--	6.236E-06	--	0.01000	--	--	--
3_PIPO-AGSP	1.55E-09	--	--	--	0.05000	--		--	--
4_PIPO-FEID	7.763E-11	0.14000	0.09000	0.04000	--	--	--	6.257E-12	--
4a_PIPO-FEID1	0.01100	3.261E-07	--	--	--	--	--	--	--
4b_PIPO-FEID2	1.742E-08	--	--	0.02000	--	--	--	8.979E07	0.15000
5_PRVI	0.00047	--	--	8.37E-06	--	0.01000	--	0.03000	--
5a_PRVI1	0.00004	--	--	--	--	0.02000	--	0.00500	--
5b_PRVI2	--	0.13300	--	0.000027	--	--	0.0920	--	--
5c_PRVI3	0.0830	--	--	0.01100	--	0.12800	--	--	--
6_SYOC	0.0000065	--	--	--	--	--	--	--	--
7_SPPE	6.504E-10	--	--	0.09600	--	--	--	--	--
7a_SPPE1	0.0000154	--	--	0.08900	--	--	--	--	--
7b_SPPE2	0.0000192	--	--	--	--	--	--	--	--
8_FIELD	0.01000	--	--	0.00433	0.01000	0.06000	--	--	--
8a_FIELD1	0.86700	--	--	0.01700	--	0.13100	--	0.15300	--
8b_FIELD2	0.00418	--	--	0.01000	0.01000	0.12000	--	--	--

Vegetation types are Agropyron smithii (Agsm), Stipa comata (Stco), Pinus ponderosa – Festuca idahoensis (Pipo-Feid), Prunus virginiana (Prvi), Symphoricarpos occidentalis (Syoc), Spartina pectinata (Sppe) and old field (Field).

Table 5. Increasing quality and amount of environmental data reduces CART error while increasing number of vegetation classes increasing it. Data sources are listed vertically and while data source (quality) and vegetation classes are listed horizontally. Percent error is reported in the body of the table.

	Westech[1]					**30m DEM**[1]				
Veg type # [2]	3	7	8f	13	15f	**3**	**7**	**8f**	**13**	**15f .**
Factors[3]										
1Slope	-	**62%**	-	-	-	-	**64**	-	-	-
1Aspect	-	**67**	-	-	-	-	**66**	-	-	-
4SA&derive	-	**57**	61	66	70	-	**62**	67	70	74
6SA,d&RS	-	**41**	47	53	59	-	-	-	-	-
9SA,d&RS&ST	-	**33**	-	52	-	-	-	-	-	-

[1]Data quality declines from point samples (Westech) where vegetation and slope/aspect measurements were tightly coupled to 30m DEM measures where they are less tightly coupled.

[2] Error increases from few (3) to many (15) vegetation classes, because assignments must be more precise. Analyses marked with 'f ' include old field types.

[3] Data quantity increases from one factor (slope or aspect) to four factors (slope, aspect, radiation, and heat load - - should we count interaction and quadratics, I think not), to 'six' factors (slope/aspect/derivatives and RS.), to nine factors (slope/aspect/derivatives, RS, and soils)

Table 6. Summary of CART models used in Chapter 6, models. Most are also reported in Table 5.

Model	Misclass. Error rate (%)	Resid. mean deviance	Variables used by model	Classes predicted
Slope or Aspect only; 7 (no field) classes				
WESTECH 7 class (no field)	62.3	3.014	Slope	4/7
WESTECH 7 class (no field)	66.6	3.435	Aspect	2/7
30m DEM 7 class (no field)	64.4	3.174	Slope	3/7
30m DEM 7 class (no field)	65.5	3.415	Aspect	4/7
Slope and aspect only; 7 (no field) or 8 classes				
WESTECH 8 class	60.68	3.154	Slope, radiation, aspect	5/8
30m DEM 8 class	67.45	3.419	Slope, radiation	5/8
WESTECH 7 class (no field)	56.81	2.842	Slope, radiation	5/7
30m DEM 7 class (no field)	61.71	3.104	Slope, radiation, heat load	5/7
Slope and aspect only; 13 (no field) or 15 classes				
WESTECH 15 class	70.13	3.91	Slope, radiation	7/15
30m DEM 15 class	73.82	4.248	Slope, radiation, aspect	5/15
WESTECH 13 class (no field)	65.53	3.533	Slope, radiation, heat load	7/13
30m DEM 13 class (no field)	69.65	3.820	Slope, radiation, aspect, heat load	8/13
Additional variables used; 7 (no field) or 8 classes				
WESTECH 8 class	46.65	2.177	Range site, slope, radiation, aspect, heat load	7/8
WESTECH 7 class (no field)	41.01	1.894	Range site, slope, aspect, heat load	7/7
WESTECH 7 class (no field)*	33.15	1.789	Range site, slope, heat load, soil type, topography	7/7
Additional variables used; 13 (no field) or 15 classes				
WESTECH 15 class	59.02	2.96	Range site, slope, radiation, texture, heat load, configuration	8/15
WESTECH 13 class (no field)	53.09	2.678	Range site, slope, radiation, texture, heat load,	9/13
WESTECH 13 class (no field)*	51.69	2.488	Range site, soil type, aspect, heat load, clay, texture	12/13

*Soil type used as a variable

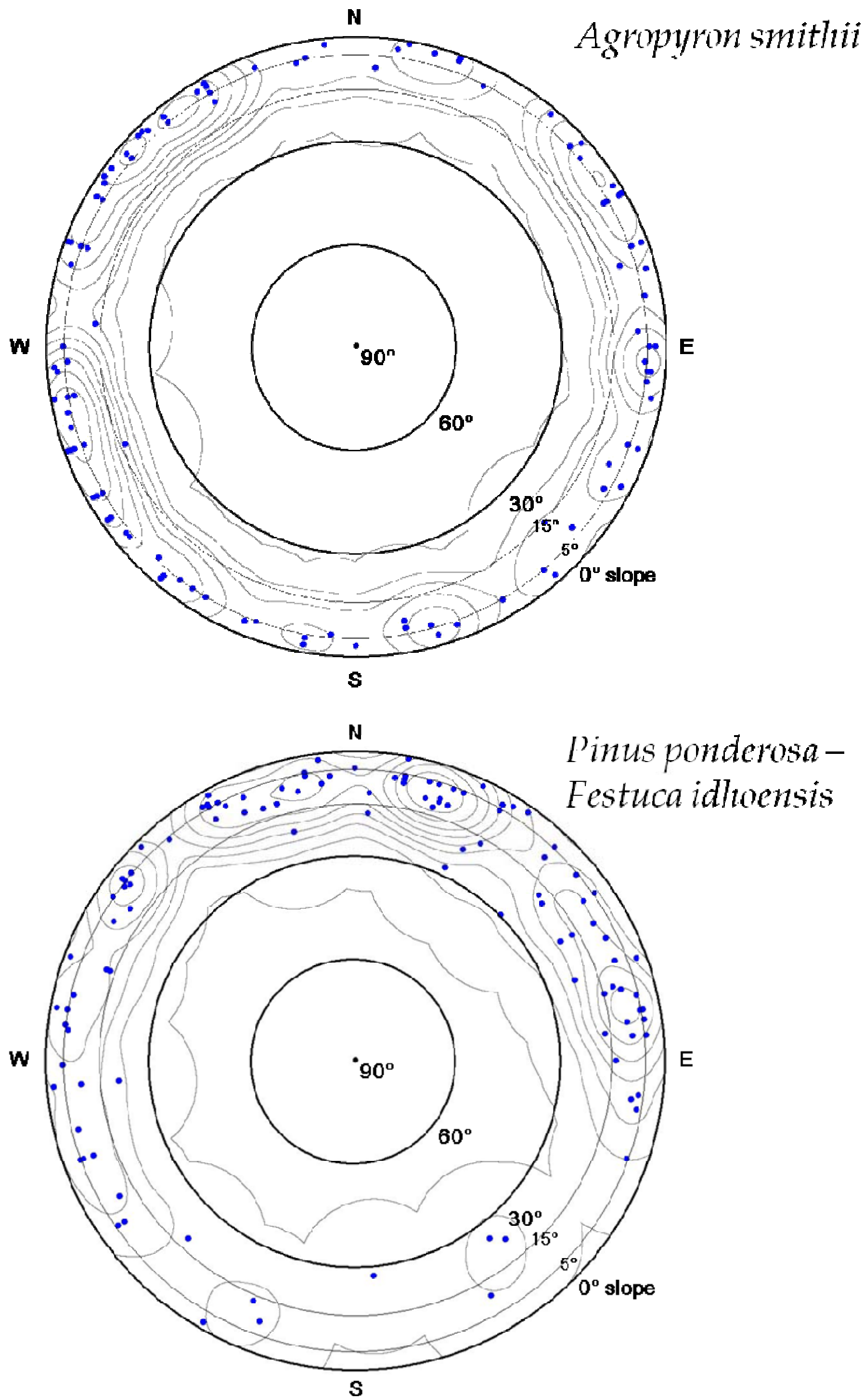

Figure 1. Distribution of two vegetation types (grassy Agropyron smithii and savanna Pinus ponderosa) in slope aspect space of SE Montana (Absaloka mine, Hardin MT). Aspects are displayed around the circumference of the figure. Slope increase (0- 90^{o}) from margin to center. Points represent individual stands. Do pines occupy steeper or more northerly slopes than Agsm?

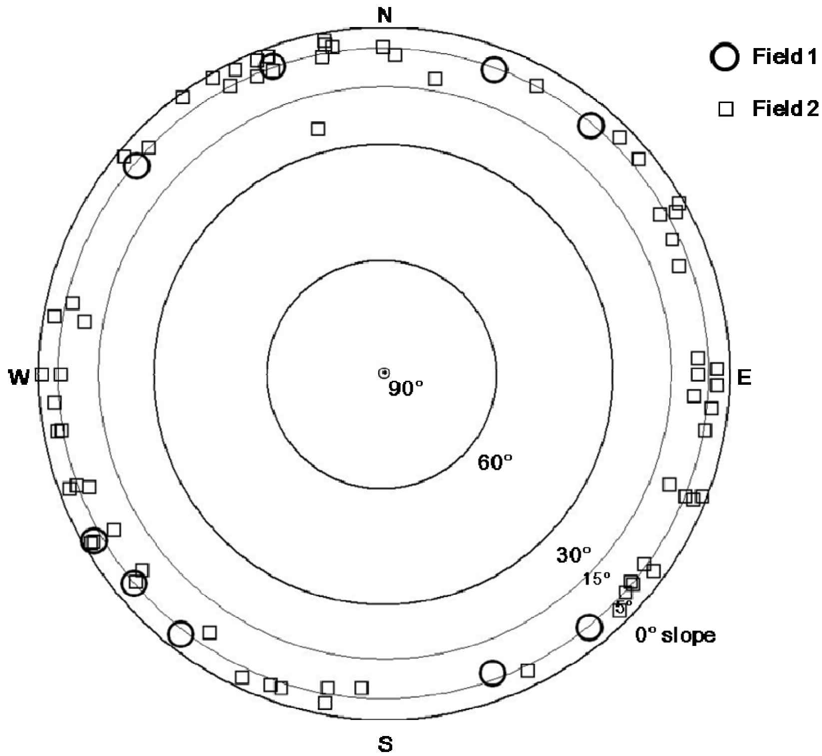

Figure 2. Distribution of two old field vegetation types (I and II) in slope aspect space of SE Montana (Absaloka mine, Hardin MT). Aspects are displayed around the circumference of the figure. Slope increase (0- 90°) from margin to center. Circles represent type 1 and squares represent type II. Fields were plowed from gentle slopes; is type II more concentrated in the east/west than type I?

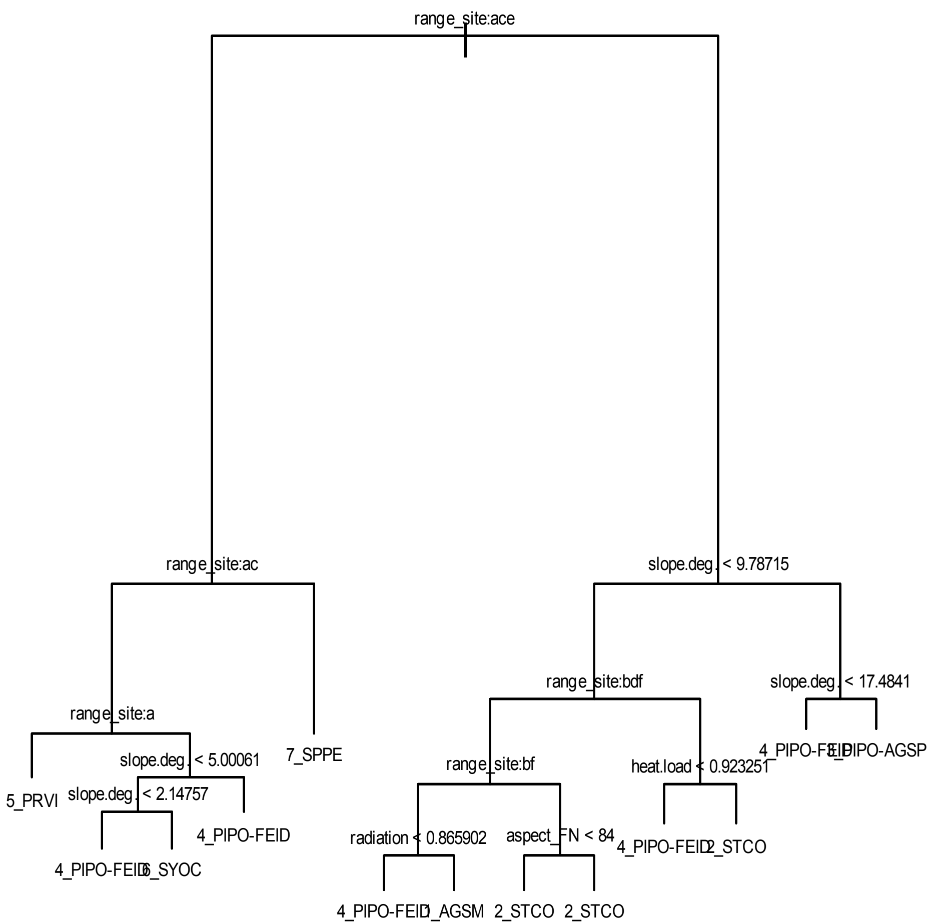

Figure 3. A CART tree representative of those summarized in Tables 5 and 6. 8 class CART tree using WESTECH slope, aspect, radiation, heatload, configuration, range site, texture, topography, and Westech clay. Old field(#8)is not predicted by the model.

```
Range site: a"BHF" b"Cl"  c"Ov"  d"Sa"  e"Sb"  f"Si"  g"TB"  h"TH"
Classification tree:
tree(formula = VHA_NAMES_ ~ slope.deg. + aspect_FN + radiation +
    heat.load + configuration + range_site + Texture + topography +
    Westech_Clay)
Variables actually used in tree construction:
[1] "range_site" "slope.deg." "radiation"  "aspect_FN"  "heat.load"
Number of terminal nodes:  13
Residual mean deviance:  2.177 = 816.6 / 375
Misclassification error rate: 0.4665 = 101 / 388
```

Table 7. Error Matrix for the 8 class CART tree presented in Figure 3. Error Matrix for 8 class CART tree using slope, aspect, radiation, heatload, configuration, range site, texture, topography, and Westech clay. Westech data used. 8_FIELD not predicted by model.

CART PREDICTION

VHA PREDICTION	1_AGSM	2_STCO	3_PIPO-AGSP	4_PIPO-FEID	5_PRVI	6_SYOC	7_SPPE	8_FIELD
1_AGSM	34	4	0	6	2	6	0	0
2_STCO	27	50	1	17	0	0	0	0
3_PIPO-AGSP	3	13	17	14	0	0	0	0
4_PIPO-FEID	5	17	9	52	1	2	0	0
5_PRVI	0	0	0	5	11	20	0	0
6_SYOC	0	1	0	5	2	25	1	0
7_SPPE	0	0	0	0	2	0	20	0
8_FIELD	9	20	1	1	1	0	0	0

Chapter 7
OVERALL SUMMARY AND CONCLUSIONS.

To re-vegetate a post-mine landscape with native vegetation one must identify target communities and establish them in suitable micro-environments. Our project explores these (two) operations at regional (Chapter 1) and local (Chapter 2-6) scales. While developing/testing of approaches was our primary goal, the project yielded facts relevant to managers in the region. The chapters are free-standing , each with its own introduction, conclusions and figure/table numbering system. Appendices reside with their chapters.

At the regional scale (Chapter 1, Table 6), we identify nine/twelve physiognomically distinct vegetation types including grassland, sage grassland, and pine savanna. We correlated them simultaneously with precipitation (13-17”/year), aspect (N-S facing), and landscape position (ridge, slope, slope-toe, and bottom). Vegetation responses were consistent with the hypothesis that vegetation in thissemi-arid region varies with water availability- - as driven by precipitation, evapotranspiration (aspect), and soil storage (topographic positions). Our review provides a basis for selection of vegetation for sites at both regional and microenvironment (aspect/position) levels. We expect to publish this chapter as an independent paper.

We undertook a more detailed pilot analysis of vegetation and its relation to its environment at the Absaloka mine (Chapters 2-6). Our analysis- - identification of target vegetation types and their environmental correlates/factors- - was based on its exceptionally large, varied, detailed, and internally consistent pre-mine data set (~800 sample sites). The analysis proceeded in five steps described below.

Qualitative (species list) and quantitative (cover) descriptions of vegetation based on point samples were ordinated and classified to identify eight vegetation types (15 varieties, Chapter 2, Task 1). The communities identified were consistent with our physiognomic types (Chapter 1), Westech subjective types, and our more regional types (Weaver and Aho 2006).

Environmental data for characterizing the sample points were sought (Chapter 3, Task 2, Table 1). The object was to contrast environments occupied by pre-mine vegetation types/ postmine targets as a base for identifying/creating microenvironments on which each type might be expected to establish. The first source was slope, aspect, and soil gathered at sites sampled (PC) during the vegetation inventory. We only contracted analysis for these. We gathered additional data from public data sets (e.g. NRIS & USGS) to determine whether their inclusion in descriptive models would improve our capacity to recognize habitat appropriate for particular vegetation types.

The incongruence of public data with PC ground truth largely disqualified its use, for our application (Chapter 4). Average slopes calculated from a 30 DEM were low (25% of ground truth), but while the average aspects were consistent the variances associated with both showed these data to be undependable. We attribute the deviance to averaging of environmental information when small sample units are combined into large sample units. Soil texture data drawn from the two data sources also correlated poorly. The deviance might be attributed either to error in sampling from coarse public data or to inexpert analysis by PC field technicians recording pre-mine environments. Analysis could be made more certain- - for both professional and technical analysts, if samplers incorporated simple/inexpensive quantitative and QA/QC methods. Our results should be published and the problem should be investigated further to develop/test the promise of public data.

Correlation between vegetation and environment suggests causal influence of environment on vegetation. We tested five methods. 1) Environments of the vegetation types were described, character-by-character, and contrasted. Several presumptive factors seemed influential (Chapter 4, Table 16), either due to direct causation likely transferable to the post-mine landscape (e.g. slope, aspect, and position) or to questionably transferable survey mechanics (e.g. soil type and range site).

2) Factor pairs may be profitably combined. Such combinations may be modeled physically or mathematically, as when one properly integrates radiation& heat delivery/ evapotranspiration from slope and aspect (chapter 4 & 5).

3) Two-factor scatter diagrams, despite their lack of physical basis, usefully compared communities. While western wheatgrass occupies toe slopes without regard to aspect, P pine is shown to prefer steeper north-facing slopes. And because distinct old field communities occupying Agropyron and Stipa environments are energetically similar, we must attribute environmental differences to edaphic factors.

4) Multifactor logistic regressions were used community-by-community to determine the environments best suited for planting a community desirable for its productivity, appearance or support of rare species. While single factors had highly significant effects, overall predictions were poor (D^2, similar to R^2 = 0.02-0.40). This may suggest that we haven't measured controlling factors,

that we haven't measured them well, or that our combination/modeling of factors inadequately expresses causal mechanisms.

5) Because all vegetation types are considered concurrently, multifactor CART regressions should assign vegetation types optimally to a varied surface. The match between vegetation assignments made from pre-mine environmental data and pre-mine vegetation improves as 'confusing' multi-environment communities (old fields) were removed, as the number of vegetation types was reduced as the number of environmental correlates/ factors increased. While the last sentence seems logically obvious, the measure may be misleading, because some of the data added (range site and soil type) may not be independent of the predicted vegetation type. Despite trends, the 30-70% error rate in predicting pre-mine vegetation from pre-mine environment is disappointing.

Integrating across the entire project we draw seven conclusions.

1) Precipitation level affects vegetation presence (Chapter 1).
2) Slope/aspect and derivative radiation, heat, and evaporative loads affect vegetation presence (Chapters 5&6).
3) It seems clear that soils are major determinants of habitat quality (Chapters 1, 5, and 6) and the omission of soils from many of our models may be responsible for their low predictive power. Soil effects are , however, especially hard to evaluate (Chapters 5& 6) both because of the unknown quality of both field and public data. And because we have no measures of belowground conditions.
4) If pre-mine vegetation were seral, between stage heterogeneity might 'confuse' correlations as it did between old field types. We doubt that this contributes significantly in our lightly populated region- - and to the extent that it might be, it was stratified against by samplers who excluded disturbed sites.
5) Land to be reclaimed will have a given mean precipitation, a variety of slopes and aspects and soils with questionable relationship to pre-mine soils. We have shown that macroenvironment (precipitation) and the slope/aspect aspect of microenvironment are insufficient for accurate prediction of pre-mine vegetation. While better understanding of soil effects should improve prediction of pre-mine vegetation, the introduction of newly created 'mine soils' will add, so far, unstudied soil effects.
6) The fruitful pursuit of the VHA concept may depend on more use of mechanistic (vs correlation) models and will certainly depend on more investigation of substrate effects.
7) The potential for investigation of soil effects is very exciting- - because it will provide reclamation ecologists, not only a tool for understanding the distribution of vegetation, but a tool for constructing soils that will support the vegetation they desire.