MONTANA STATE UNIVERSITY

# Site Location Using Geographic Information Systems

## A Case Study

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Geographic Information Systems (GIS) have been implemented in countless industries since their inception in the early 1980's. With GIS it is possible to organize, analyze, manipulate, synthesize and query spatial information to arrive at conclusions to difficult questions. GIS can be utilized to model our world and make predictions as to what is likely to occur. Soil formation is a difficult process to uncover but with GIS involved the sites for a thorough investigation into their origin can be located without ever setting foot in the field. GIS saves researchers valuable time and money by eliminating the field research necessary to begin a scientific study. This research paper analyzes the process of using GIS to solve the question, "What are the best sites to conduct a climosequencing soil study in the Bridger Mountain Range?" A thorough investigation on data compilation, data analysis, methods and theory within GIS and product output is contained within this analysis of GIS applied to site location processes.

Soil scientists have determined five major soil forming factors: climate, biota, topography, parent material and time. Within these five factors there are many variables and by picking them apart and trying to understand each variable alone it can be determined how and why a particular soil forms. (Brady, 2000) With the resulting knowledge, important land use decisions about each soil can be made. This knowledge is integral for wildlife management, urban development, conservation efforts, wildfire response teams and waste management practices. Because there are so many factors that go into the formation of each soil it is essential to study one factor at a time (Jenny, 1994). For his masters thesis, Montana State University graduate student John Sudgen, the direct client for this site location analysis, is conducting a climosequencing soil study in the Bridger Mountain Range to determine what effect elevation has on soil formation. The data that he derives from his study will contribute to base line data available for soil formation in the local area as well as to the information currently available on the effects of elevation on soil formation. GIS are heavily used in the soil sciences and are an immensely beneficial tool for cost and time savings as this research paper will show through an analysis of the site location process within ArcGIS™ 10.1 (ESRI, 2012).

Elevation is studied in a soil climosequence and to be accurately studied it must be the only variable of the soil formation process. A GIS is used in this regard to isolate the soil forming factor of interest, elevation, and all attempts were made to locate potential soil sampling sites with the remaining soil forming factors, within reason, kept constant. Subsequently, the sites located for this climosequencing soil study need to have the same slope, aspect, land cover, parent material, time of formation and general climate and differ only by 100 meters in elevation between each soil sampling site. As elevation is being studied it is of the foremost importance to determine a parent material of soil that reaches from valley to peak within the mountain range of study (Nettleton, 1986). With a review of the Bridger Mountain's geology sourced from the Montana Bureau of Mines and Geology, limestone was chosen as the parent material for this climosequencing soil study because it adequately meets the elevation requirements. Confined to spans of limestone, ArcGIS™ 10.1 was used to overlay many data sources and arrive at site locations that were as close to identical as possible yet separated by one hundred meters in elevation. The data sources that were used in this study include: Digital Elevation Model Data Sets, Montana 2011 Color NAIP Orthophotos in 30 by 30 meter resolution and National Land Cover Data Sets all sourced from the United States Geological Survey via nris.mt.gov. Geologic data came from Montana's Bureau of Mines and Geology and roads and Bozeman City limits data was sourced from the U.S. Census Bureau's Geography Division.

Montana State University has a strong and developing soil studies program with many field laboratory sites currently in use. The sites chosen in this study will likely be revisited many times by soil research teams at MSU as well as MSU students enrolled in soil classes. As such, accessibility to the soil study site is quite important. After the potential sites for study were determined, specific sites were selected based on their accessibility from roads and trails. Based on this analysis, final soil sampling sites were selected and teams will be sent to inspect them in the field. This research paper presents the step by step process of using a geographic information system, specifically ArcGIS™ 10.1, to locate the best sites for a climosequencing soil study in the Bridger Mountain Range.

With the issue being addressed defined and the audience identified the next step is to determine product output. For this project the product output is a series of maps in a large scale defining each soil sampling site with its specific latitude and longitude as well as a smaller scale map that shows all of the sites in relation to each other which are all included as appendices at the end of this paper. The methods used for data analysis in the site selection project will be thoroughly discussed in the bulk of this paper. Data compilation is a crucial step in answering a spatial question as the quality of the answer produced is directly tied to the quality of the data that is analyzed. Many data sets were analyzed for the site selection process including land-cover data, 30 by 30 meter land-sat images, slope, roads and trails, aspect and parent material geology. Of these various data sources the limiting input layer was the geology layer sourced from the Montana Bureau of Mines and Geology at a scale of 1:100,000. It should be noted that the scale itself is limiting but so is the meticulousness of the surveyor. The Bridger Mountain Range intersects four different quadrangles and each quad's geology was recorded by a different geologist. At the intersection of the quads, some of the geologic codes are more precise while in the next quad they are grouped together. All of the codes analyzed still correspond to limestone but some codes represent a grouping of limestone as well as other geologic bedrock variants.

Data acquisition can be an exhaustive process rent with search after search, trial and error and many transformations from one file format to another. Fortunately Montana, unlike many states, has a comprehensive, free of charge and very well maintained spatial data clearinghouse with spatial data for the Bridger Range readily available from websites like nris.mt.gov and bozeman.net. Once the source data were acquired and properly transformed into a usable file format they were brought into the ArcGIS™ 10.1 software package. The first data layer brought into this project was the Digital Elevation Model (DEM) for the Bozeman, Ringling, Livingston and Townsend quadrangles which were mosaicked into one seamless base layer as seen in figure 1-1. The DEM was used to create many layers for the site selection analysis such as a hillshade for reference as well as a contour, slope and aspect map of the area. However, creation of the slope and aspect maps alone is not adequate for this site selection process. The data was analyzed as to which slope and aspect are preferred for the study and then re-classed from their original values into an ordinal scale for use in a map algebra expression. The aspect data layer was re-classed from the degrees of each cardinal direction into an ordinal scale giving preference to Northeast, East and Southeast aspects as shown in table 1-1. Likewise, the slope layer was re-classed from the

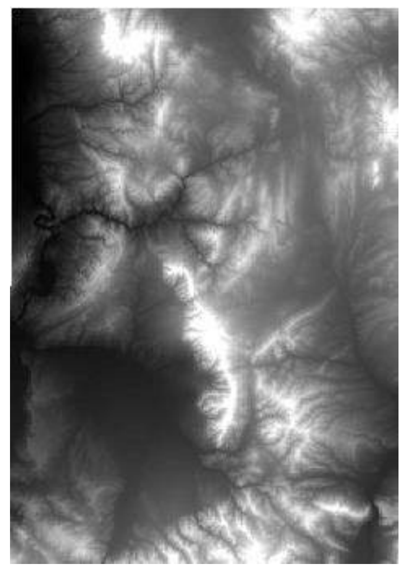

Figure 1-1. Mosaicked DEM.

| Direction | Degrees | Ordinal |
|---|---|---|
| North | 348.75-33.75 | 6 |
| Norhteast | 33.75-78.75 | 9 |
| East | 78.75-123.75 | 10 |
| Southeast | 123.75-168.75 | 9 |
| South | 168.75-213.75 | 6 |
| Southwest | 213.75-258.75 | 4 |
| West | 258.75-303.75 | 3 |
| Northwest | 303.75-348.75 | 4 |

Table 1-1. Re-class of Aspect.

| Slope | Ordinal |
|---|---|
| 0-5 | 10 |
| 5-10 | 9 |
| 10-15 | 8 |
| 15-20 | 7 |
| 20-25 | 6 |
| 25 and up | 1 |

Table 1-2. Re-class of Slope.

degrees of slope to show preference to slopes that are flatter for the site selection process, as shown in table 1-2.

| Quad | Value | Codes |
|---|---|---|
| Bozeman | MBMG_CODE | ^m, ^pi, ^pm,^Sr, Dj, Jme, MDt and Ml |
| Ringling | MBMG_CODE_1 | ^m, ^pi, ^s, Je, Jm, Jme, Mmc, Mm, Ml |
| Townsend | MLABEL | Mm, Ml, Mmu, _m, _pi, _pp, Dj, Je, Jm, and Jme |
| Livingston | MBMG_CODE_2 | &Mqa, ^gs, ^m, ^pi, Je, MDtm, Ml, Mm, Mmc, Mst, O^sp, PMpa |

**Table 2-1. Limestone Geology Codes.**

The next data source that was used in the site selection process is perhaps the most important; the geology layer. All soils are a composite of particles of sand, silt and clay (Brady, 2010). These particles are formed from the weathering of bedrock so it is of primary importance to select one bedrock parent material to be studied in order to isolate elevation as the single soil forming factor variable. In this study, limestone was chosen as the parent material and as such the geology data layers for the four quads of Bozeman, Ringling, Townsend and Livingston were added into the ArcGIS™ 10.1 software package and unioned to create one data layer. After this unioned geology layer was properly projected, all of the codes that reported limestone as a parent material were selected using a Structured Query Language (SQL) statement and a new layer representing only those codes was created and added to the project analysis. The codes corresponding to limestone parent material are shown in table 2-1 and were sourced from reports complied by the United States Geological Survey for each individual quadrangle.

All of the sites chosen for the climosequencing soil study are within the Bridger Mountain Range and as such they will all have the same effective climate, a necessary soil forming factor to be held constant for the elevation factor analysis. Additionally, because all of the potential sampling sites are confined to a single parent material within a single mountain range the time of soil development, another soil forming factor necessary to keep constant, can be considered equal. For the analysis to be complete, however, the sites selected for sampling must all have the same vegetation land cover. This is essential because the roots of trees and the roots of grasses effect soil formation quite differently (Brady, 2010). From the final selected soil sampling sites, pits will be dug that are deep enough to analyze all of the soil horizons. These pits are typically at least six feet deep and wide enough in diameter to accommodate several people. Considering that the selected soil sampling sites will be located in the back country near the top of the Bridger Mountain Range and that they must be hiked to and dug by hand, it is desirable to dig through shallower, thinner grass roots instead of deeper and larger tree roots. It is for these reasons that grassland, shrub-land and barren/rock land cover data was selected as the only land cover classes to analyze in the site selection process. Because no other land cover classes were to be considered, the three aforementioned land cover classes were selected by entering their codes into an SQL statement and a new layer representing only those classes was created and added into the site selection project in ArcGIS™ 10.1. This land cover data layer representing only the desired land cover classes was then intersected with the selected limestone data layer and again a new layer was created from the result of this intersection

With this last intersection the base layer data was limited to a specific range of acceptable areas for potential soil sampling sites which is represented by the bright green swath along the ridge of the Bridger Range as seen in figure 2-1; the north end of the Bozeman city limits are in pink at the bottom left corner of the map to serve as reference. At this point in the site selection process the re-classed aspect and re-classed slope data layers were added into the project by computing a map algebra expression. In this case both the slope and aspect are equally important so an average of their re-classed values was used to preferentially differentiate potential sampling site locations within the limestone/land cover base areas. The map algebra expression that was used is as follows: (re-classed slope value + re-classed aspect value)/2. From the averaged values that result, a new data layer was created within ArcGIS™ and then added to the project.

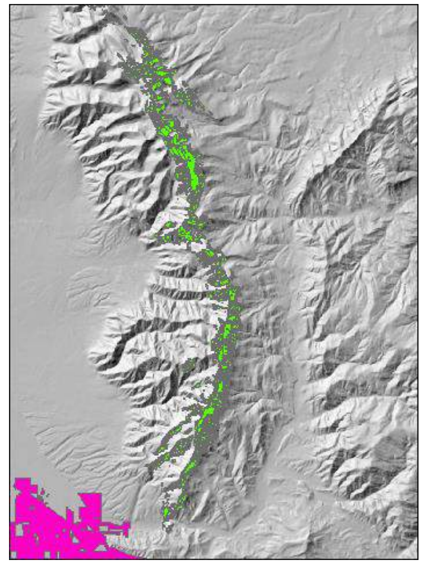

Figure 2-1. Land Class/Geology Intersect.

Another intersect was performed at this point in the site selection process to once again confine the new averaged value of slope and aspect to the limestone/land cover base areas previously selected. The results of this intersection now show the shaded values of the map algebra expression confined to the area already defined as being acceptable for site selection based on their parent material and land cover class as is shown in figure 3-1. This figure is zoomed in to a larger scale to allow easier viewing of the individual shaded polygons. As seen at this scale as well as along the entire region of the study zone there are very few potential soil sampling sites with a perfect average of ten (red) for slope and aspect combined within the limiting parent material and land cover class available in the Bridger Range and those areas with a value of ten that are available are too small to be considered accurate at a scale of 1:100,000. However, any map algebra value of six or above was considered in the analysis for this site selection process and there were many that met the distance requirement. At a scale of 1:100,000 the potential for horizontal ground error measurement is plus or minus 167 feet. As a result of this potential error, for an area to be considered in the site selection process it must be fully contained within an area representing a high value from the map algebra/limestone/land cover intersect that has a horizontal distance of well over 350 feet. As shown in figure 3-2, represented by the blue line with a ground measured distance of 112.3 meters or 368.4 feet, many of these areas are appropriate. A distance of 350 feet as a minimum was selected because if each edge of the potential area for a dig site has the full error value of 167 feet toward its center

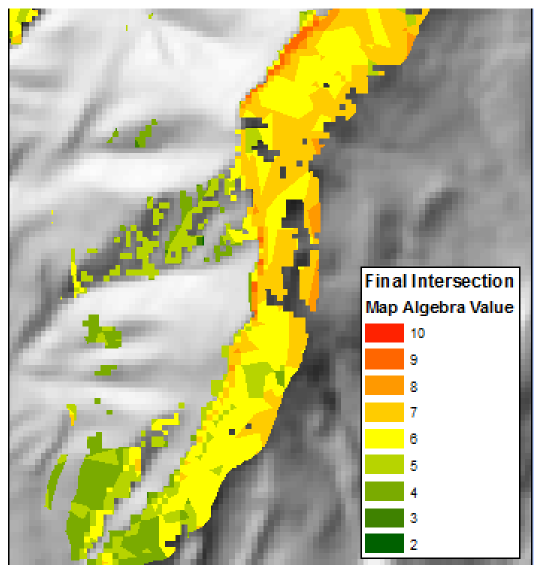


Figure 3-1. Map Algebra Results.

the total area that could be considered spatially accurate is 14 feet which is enough for a soil sampling site to be dug. With a distance of 368.4 feet and a map algebra value of six, the area shown by the blue line in figure 6-2 is more than adequate for a potential soil sampling site and is appropriate for further investigation in the field.

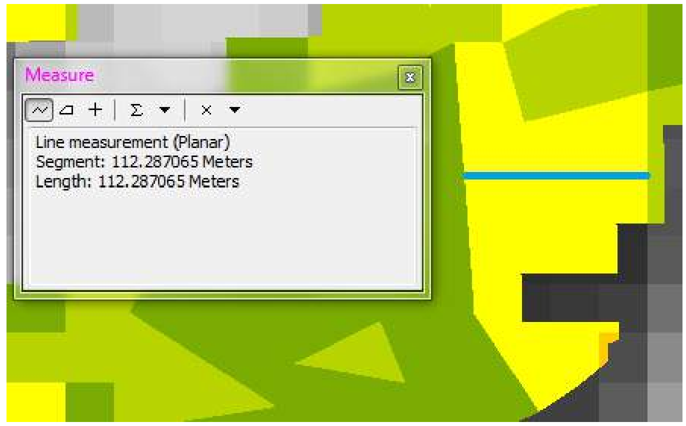


Figure 3-2. Measuring Distance for a Potential Sampling Site.

With all of the available data layers for soil forming factors added and properly analyzed within ArcGIS™ the final step of the site selection process was to manually choose sites that are within the selected area, have the highest possible value from the map algebra expression and are varied by 100 meters in elevation. This was accomplished by adding the contour line map created from the original DEM layer and symbolizing the contour lines at 100 meter intervals. Figure 4-1 shows an area of the Bridger Range at a scale of 1:20,000 in order to clearly present the contour lines at 100 meter intervals. With the contour lines overlaid on the potential areas for soil sampling, careful analysis, based on required distances, for site selection began. First an area was selected and measured to make sure it would clear the ground error tolerances. Next, a point, with a specific latitude and longitude, was placed within the selected area. This point was then buffered 167 feet on all sides to account for the potential ground error. Following the Bridger Mountain Range north from near the start of the 'M' trail off of Bridger Canyon Drive, this measuring, point placing and buffering process was continued as close to every 100 meters in elevation as the map algebra values would allow until the Bridger's height was exhausted. All of these points were cataloged into a table with the latitude and longitude of the buffered areas center recorded which can be seen in Appendix N.

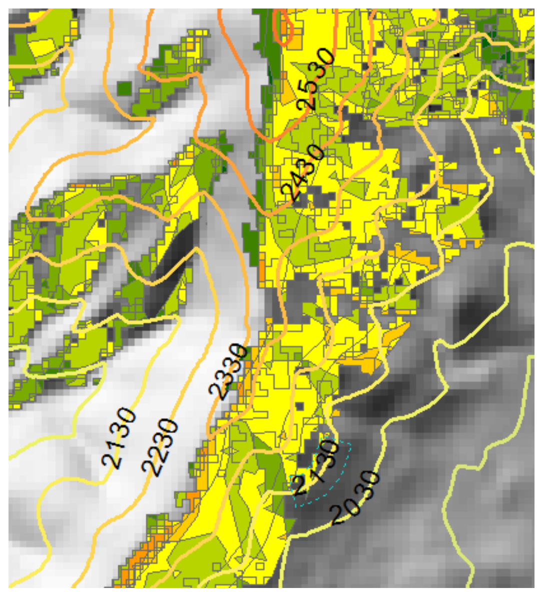


Figure 4-1. Contour Lines.

With a series of potential soil sampling sites now selected final product creation began. In order to create relevant maps for a field researcher, 30 by 30 meter land-sat aerial images were overlaid on the site selection analysis. Then the selected sites were brought to the surface of the aerial images along with the 100 meter interval contour lines. Each selected soil site was prepared within its own large scale map and its exact latitude and longitude included, for GPS navigation, as seen in appendix B through M. A small scale map of the entire study area was also created with all of the selected sites represented as seen in Appendix A. Due to its distance from the other sites, site twelve was purposefully left off of this map.

After applying a roads layer to the selected soil sampling site analysis it was evident that only Beasley Creek Road would be of practical use for accessing potential soil sampling sites seven through eleven. Beasley Creek Road should be taken to the end where the remainder of the distance to the dig sites must be hiked. The best way to access sites one through six is to hike the 'M' trail to the top and cross the ridge to the first site's location then follow the ridge to access the rest. Many of the sites are located along the eastern ridge of the Bridger Mountains so once the ridge is reached accessing them should be easier. An average weight for soil is thirteen pounds per gallon and there are typically at least four horizons that need to be sampled for a complete analysis of each site. Considering the size of the sampling pit that needs to be dug for proper analysis each site will take at least one day to complete. It is recommended that a team of no less than four be employed due to the length of the hike to each site as well as the weight of materials required for the dig and the weight of the soil samples to be hiked out.

The first time that the analysis methods described in this paper were applied to the site selection project the chosen preferred aspect was west. After implementation of the methods it was clear that the limestone that was westerly facing was heavily forested making the digging of a soil sampling pit extremely difficult. After a meeting with the client it was decided that an eastern aspect would suffice. Similarly, the original degrees of slope decided upon was less than 20 however, with the core of the limestone parent material being concentrated along the ridge it was necessary to expand the slope tolerances to slightly higher degrees. The site selection analysis methods were then redone according to the process laid out in this paper and a greater number of potential sites were located.

Utilizing real world data in a GIS application brings many challenges. There is the limiting factor of scale, the compounding factor of many different data sources all of which must be carefully considered in the site selection analysis as well as the difficulty of transforming and converting file formats into those appropriate for analysis within the project. Site location is a difficult process for any study primarily because the study site is of primary importance to any field based research. The client was pleased with the results and will be investigating the selected sites in the field. The client also happens to be a friend of mine and as such I will be joining him in his study as a GIS technician for his project so as to gain experience.

The benefits of GIS utilized for site location processes are many fold. By eliminating fuel costs for travel, the environment is benefited by greatly reducing carbon emissions. With GIS, one technician can complete the necessary site analysis within a time frame of days as compared to the weeks of field research or potential trial and error that site location used to require. Although site location within GIS is a difficult process, it is an incredibly cost effective alternative to real world examination of potential study sites.

**Data Dictionary**

Montana Digital Elevation Model Data – National Elevation Dataset. Montana: Montana State Library 2002. Available: nris.mt.gov (March 10th 2013).

Four data sets were used in total from this resource as follows:

d46111_d, d46110_c, d45111_b and d45110_a.

These quadrangle digital elevation model rasters were added to ArcGISTM 10.1 and mosaicked to create one seamless elevation raster encompassing the base study range; the Bridger Mountain Range. This mosaicked digital elevation model was used in the site location process by providing a base layer from which to create the necessary slope and aspect portions of the weighted overlay analysis. Additionally this data source was used to create a contour map with 100 Meter contours marked to perform the site selection analysis based on elevation.

Data Type: DEM format (USGS)

Data Source URL: http://nris.mt.gov/nsdi/nris/el10/dems2Old.asp

Data Coordinate System: NAD 1983 UTM Zone 12 coordinates

Data Scale: 1:60,000

Data Attributes: Elevation in Meters

GIS Digital Data Links. Montana: Montana Bureau of Mines and Geology 2001. Available: mbmg.mtech.edu (March 10th 2013).

Three quadrangle maps were used from this resource as follows:

Bozeman, Ringling and Livingston.

These quadrangle maps were added to ArcGIS™ 10.1 and combined with the Townsend quadrangle to create a geology base map encompassing the Bridger Mountain Range. From the combined geology map the Limestone bed rock formations were chosen in which to select the sites for the Climosequencing Study.

Data Type: Raster

Data Source URL: http://www.mbmg.mtech.edu/gis/gis-datalinks.asp

Data Coordinate System: NAD 1927 UTM Zone 12 coordinates

Data Scale: 1:100,000

Data Attributes: MBMG_CODE values corresponding to Limestone geology as follows:

| Quad | Attribute Used | Attribute Value |
|---|---|---|
| Bozeman | MBMG_CODE | ^m, ^pi, ^pm,^Sr, Dj, Jme, MDt and Ml |
| Ringling | MBMG_CODE | ^m, ^pi, ^s, Je, Jm, Jme, Mmc, Mm, Ml |
| Livingston | MBMG_CODE | &Mqa, ^gs, ^m, ^pi, Je, MDtm, Ml, Mm, Mmc, Mst, O^sp, PMpa |

Geologic Map of the Townsend 30' x 60' Quadrangle, Montana. U. S. A. : U. S. Geological Survey 2006.
Available: Montana Bureau of Mines and Geology (March 10th 2013).
This quadrangle map was added to ArcGIS™ 10.1 and combined with the Bozeman, Ringling and Livingston quadrangle maps to create a geology base map encompassing the Bridger Mountain Range. From the combined geology map the Limestone bed rock formations were chosen in which to select the sites for the climosequencing study.

Data Type: Shapefile

Data Source URL: http://www.mbmg.mtech.edu/gis/gis-datalinks.asp

Data Coordinate System: NAD 1927 UTM Zone 12 coordinates

Data Scale: 1:100,000

Data Attributes: MLABEL values corresponding to Limestone geology as follows:

| Quad | Attribute Used | Attribute Value |
|---|---|---|
| Townsend | MLABEL | Mm, Ml, Mmu, _m, _pi, _pp, Dj, Je, Jm, and Jme |

National Land Cover Data Set (NLCD) Shapefiles for Montana. Montana: Montana State Library 2000.
Available: nris.mt.gov (March 10th 2013).
Six quadrangle maps were used from this resource as follows:

lu177, lu178, lu179, lu204, lu205, and lu206.

These quadrangle land cover maps were added to ArcGIS™ 10.1 and combined to form one continuous map of land cover data. From the combined map the areas of shrub land, grass land and barren land were chosen, using a Structured Query Language statement, for the site selection analysis.

Data Type: Shapefile

Data Source URL: http://nris.mt.gov/nsdi/nris/nlcd/nlcdvector.asp

Data Coordinate System: State Plane Coordinate System 1983

Data Scale: 1:60,000

Data Attributes: LC_CODE values as follows:

| LC_CODE | Description |
|---|---|
| 31 | Bare Rock/Sand/Clay |
| 51 | Shrubland |
| 71 | Grasslands/Herbaceous |

Montana 2011 Color NAIP Orthophotos, 24-Kilometer Tiles. Montana: Montana State Library 2011. Available: nris.mt.gov (March 10th 2013).

20 aerial orthophotos were used from this source and mosaicked together to form one aerial photo covering the study area for use as a reference layer. The photos used are as follows:

2829, 2831, 2833, 2835, 2837, 3029, 3031, 3033, 3035, 3037, 3229, 3231, 3235, 3233, 3237, 3429, 3433, 3435, 3437, 3431.

Data Type: .sid photos

Data Source URL: http://apps.msl.mt.gov/Geographic_Information/Data/Aerial_Photos/naip_2011_default.aspx

Data Coordinate System: NAD 1983 HARN

Data Resolution: 1 Meter ground resolution.

Bozeman.SDE.city_limits_adjusted. Montana: City of Bozeman GIS Department 2004. Available: bozeman.net (March 10th 2013).

This layer was used as a reference layer to show the site locations in relationship to the city of Bozeman.

Data Type: Shapefile

Data Source URL: http://www.bozeman.net/Departments-%281%29/Public-Works/GIS/Download-Data/GIS-Data.aspx#.UVyzqbV-7o8

Data Coordinate System: NAD 1983 UTM Zone 12

Data Scale: 1:24,000

Data Attributes: Shape

Street.SDE.centerline. Montana: City of Bozeman GIS Department 2004. Available: bozeman.net (March 10th 2013).

This layer was used as a reference to identify the roadways near the sites selected for soil analysis. Additionally this layer was used for the Euclidian distance analysis.

Data Type: Shapefile

Data Source URL: http://www.bozeman.net/Departments-%281%29/Public-Works/GIS/Download-Data/GIS-Data.aspx#.UVyzqbV-7o8

Data Coordinate System: NAD 1983 UTM Zone 12

Data Scale: 1:24,000

Data Attributes: Roadways.

# Works Cited

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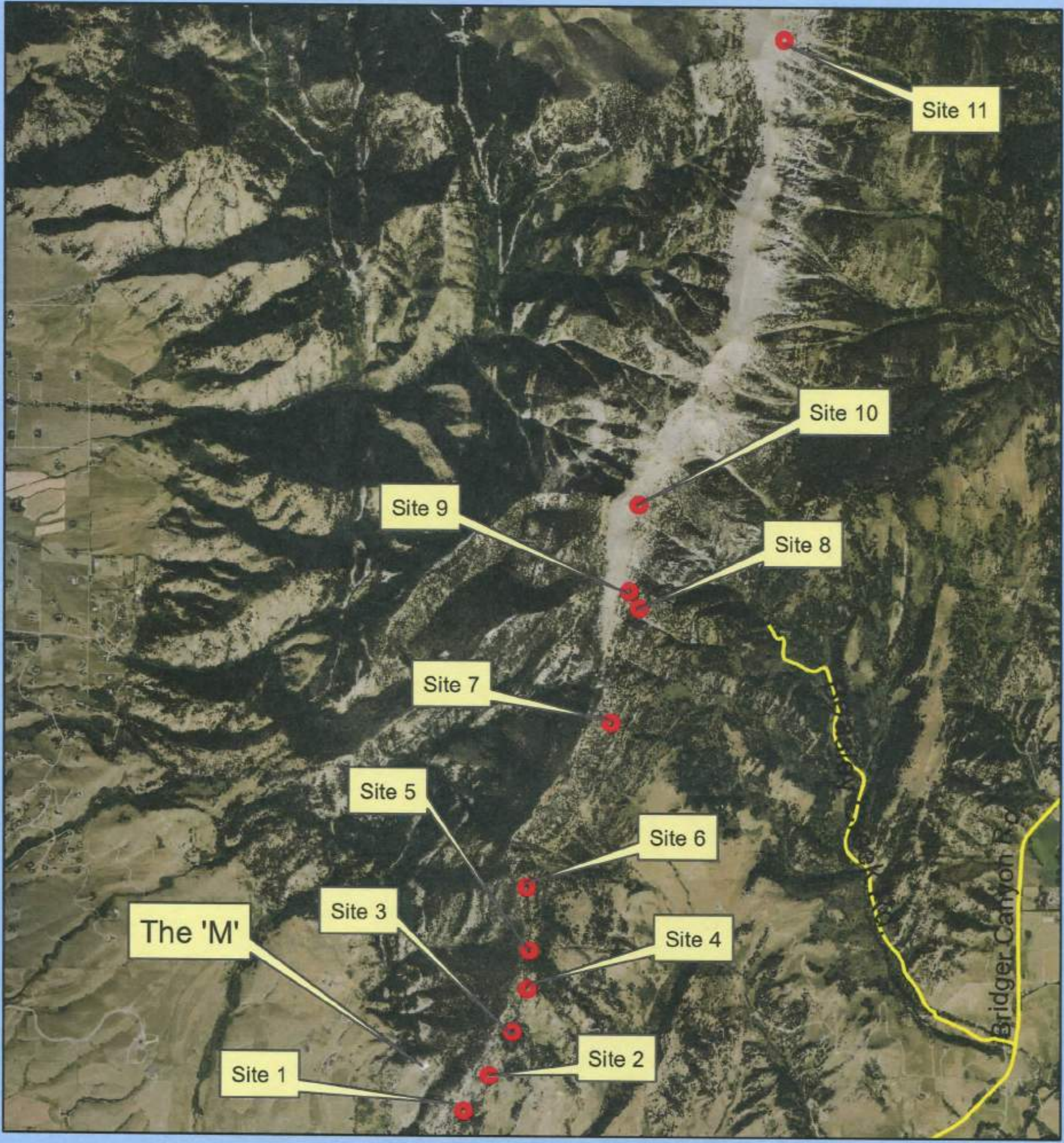
ESRI 2012. ArcGIS Desktop: Release 10.1. Redlands, CA: Environmental Systems Research Institute. Software Application.

Jenny, Hans. (1994) Factors of Soil Formation. A System of Quantitative Pedology. (New York: Dover Publications) Print.

Nettleton, W. D., et al. (1986). "Differentiation of Spodosols and Andepts in a Western Washington Soil Climosequence." Soil Sci. Soc. Am. J. **50**(4): 987-992.

## Appendix List

# Potential Soil Sampling Sites in the Bridger Range




N

Outlined in red are the potential areas for soil sampling sites to be dug based on the defining layers of limestone parent material and shrubland/grassland/barrenland cover combined with the highest value possible for preferred slope and aspect. Roads are in yellow.

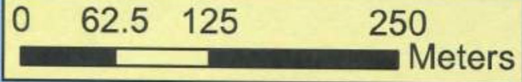
0 5001,000 2,000 3,000 4,000 Meters

Credits: Jhanek Szypulski, April 5th 2013, nris.mt.gov, bozeman.net, mbmg.mtech.edu, usgs.gov.

# Potential Soil Sampling Site 1



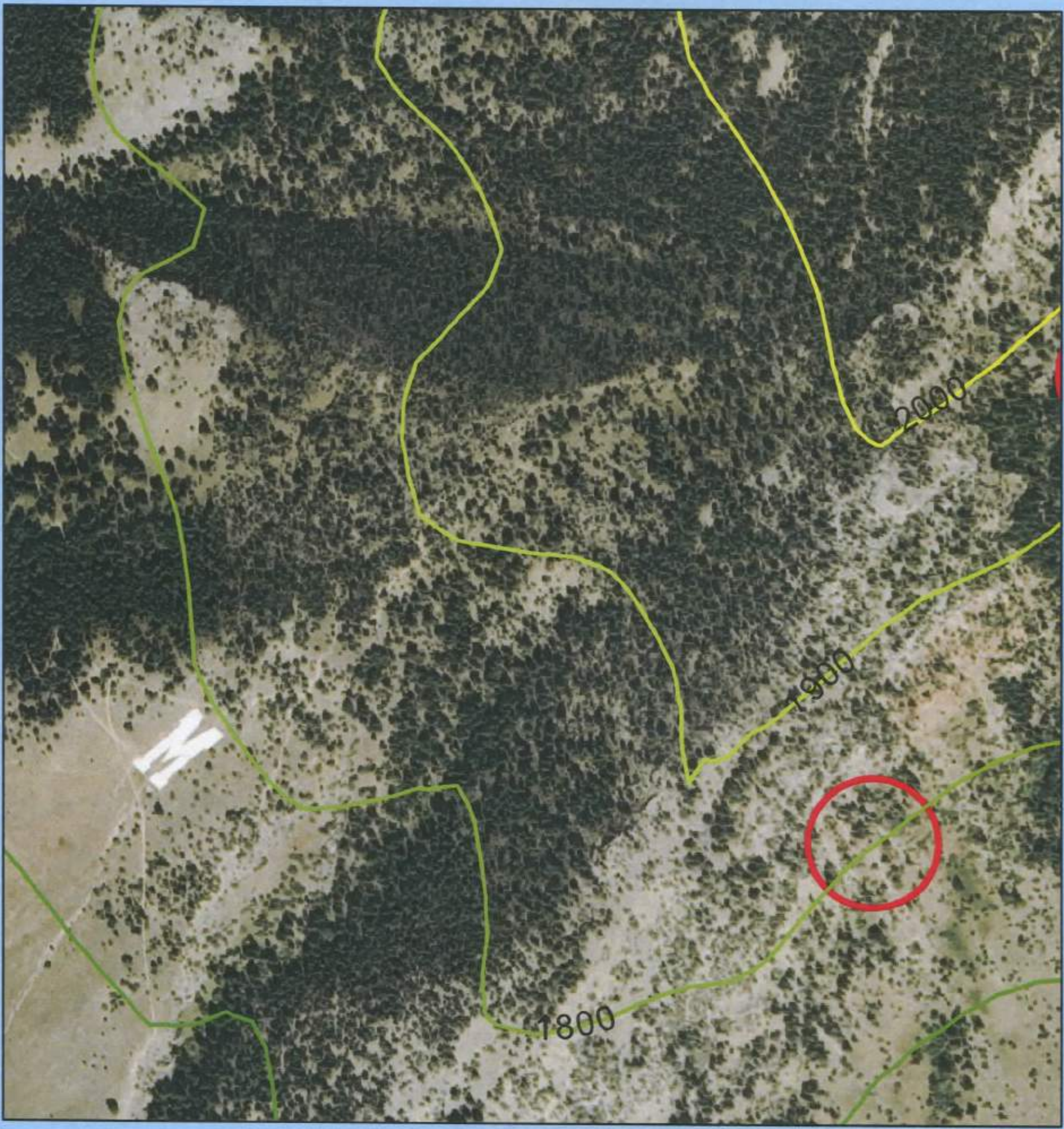
Latitude 45° 42' 40.090" N
Longitude 110° 58' 9.966" W




Outlined in red is the potential area for a soil sampling site to be dug based on the defining layers of limestone parent material and shrubland/grassland/barrenland cover combined with the highest value possible for preferred slope and aspect. Contours are in meters. Coordinates of the circles centroid are provided.

Credits: Jhanek Szypulski, April 5th 2013, nris.mt.gov, bozeman.net, mbmg.mtech.edu, usgs.gov.

# Potential Soil Sampling Site 2




N

Latitude 45° 42' 50.262" N
Longitude 110° 57' 59.877" W

0 62.5 125 250 Meters

Outlined in red is the potential area for a soil sampling site to be dug based on the defining layers of limestone parent material and shrubland/grassland/barrenland cover combined with the highest value possible for preferred slope and aspect. Contours are in meters. Coordinates of the circles centroid are provided.

Credits: Jhanek Szypulski, April 5th 2013, nris.mt.gov, bozeman.net, mbmg.mtech.edu, usgs.gov.

# Potential Soil Sampling Site 3


N

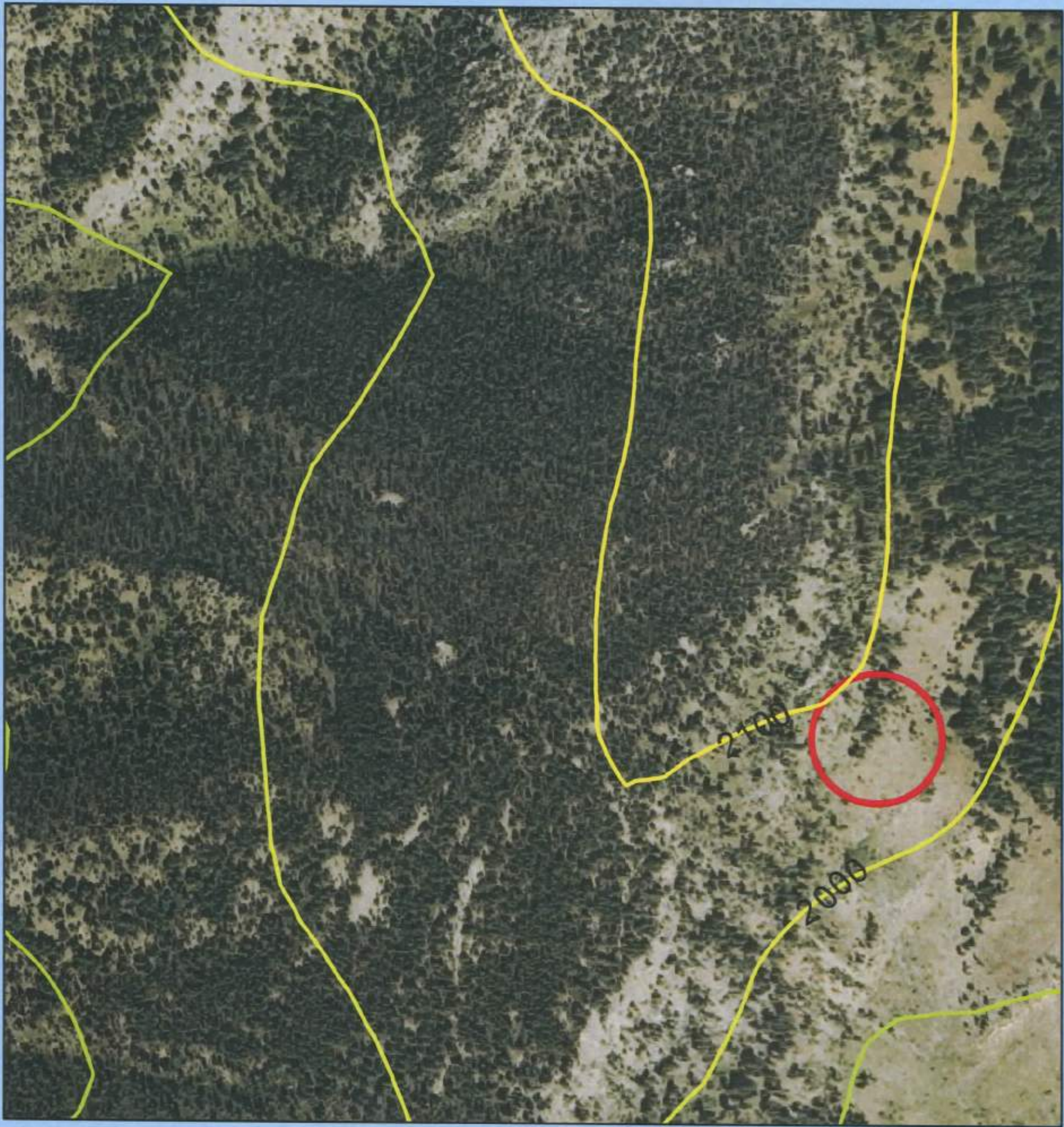
Latitude 45° 43' 1.827" N
Longitude 110° 57' 50.804" W

0 62.5 125 250
Meters

Outlined in red is the potential area for a soil sampling site to be dug based on the defining layers of limestone parent material and shrubland/grassland/barrenland cover combined with the highest value possible for preferred slope and aspect. Contours are in meters. Coordinates of the circles centroid are provided.

Credits: Jhanek Szypulski, April 5th 2013, nris.mt.gov, bozeman.net, mbmg.mtech.edu, usgs.gov.

# Potential Soil Sampling Site 4




N

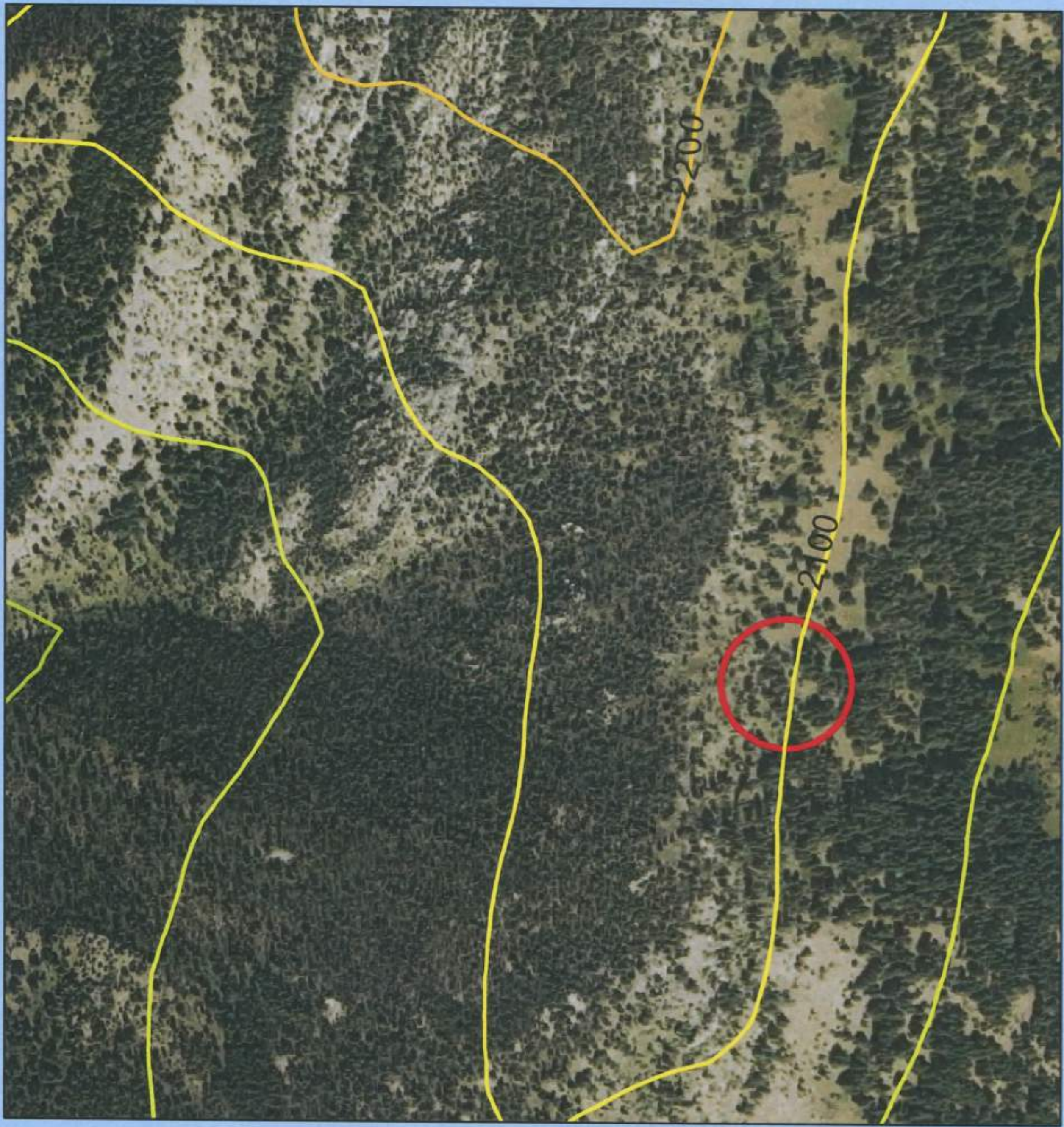
Latitude 45° 43' 13.717" N
Longitude 110° 57' 45.060" W

0 62.5 125 250
Meters

Outlined in red is the potential area for a soil sampling site to be dug based on the defining layers of limestone parent material and shrubland/grassland/barrenland cover combined with the highest value possible for preferred slope and aspect. Contours are in meters. Coordinates of the circles centroid are provided.

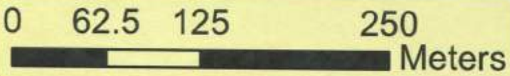
Credits: Jhanek Szypulski, April 5th 2013, nris.mt.gov, bozeman.net, mbmg.mtech.edu, usgs.gov.

# Potential Soil Sampling Site 5





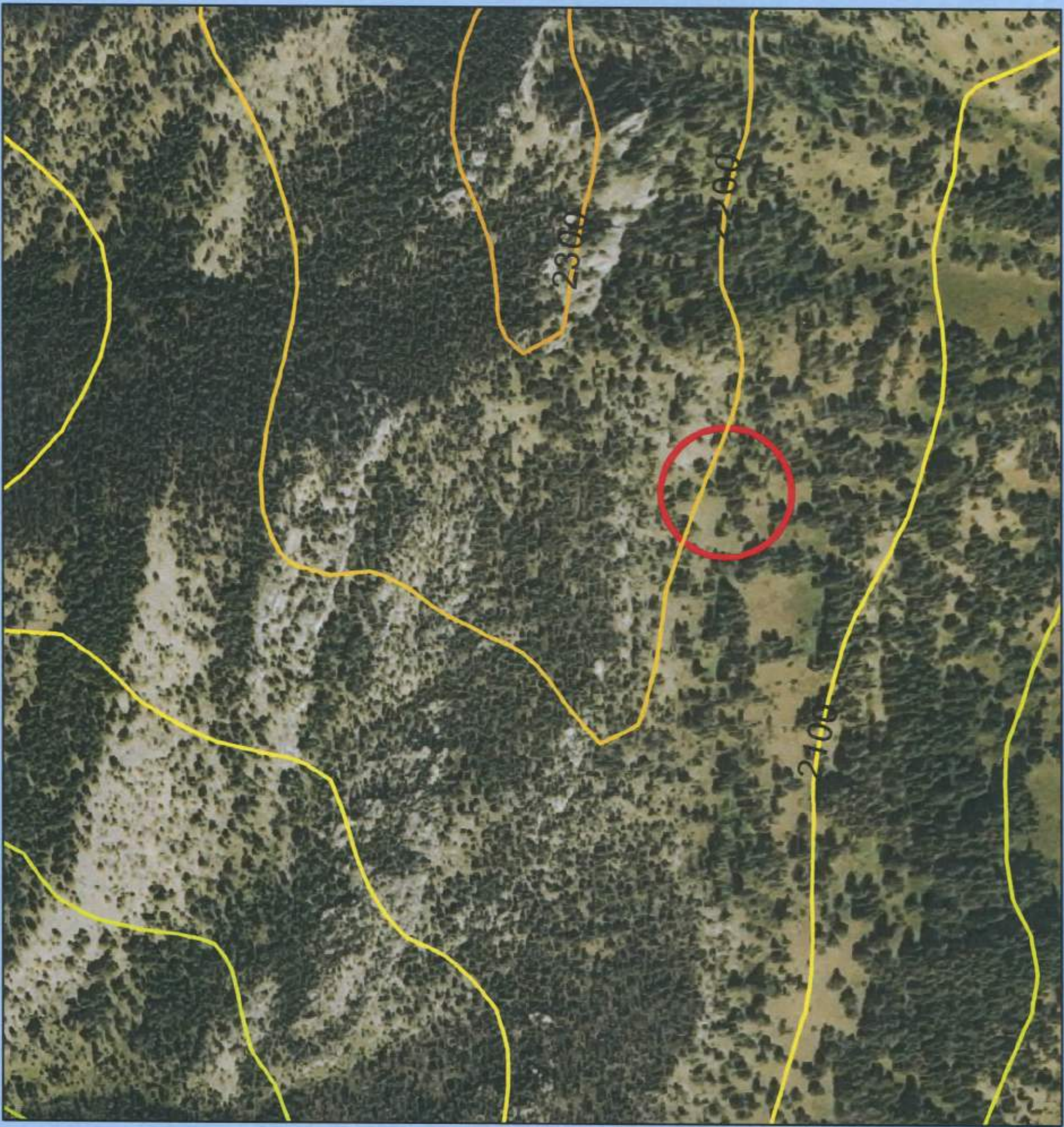
Latitude 45° 43' 24.280" N
Longitude 110° 57' 44.267" W




Outlined in red is the potential area for a soil sampling site to be dug based on the defining layers of limestone parent material and shrubland/grassland/barrenland cover combined with the highest value possible for preferred slope and aspect. Contours are in meters. Coordinates of the circles centroid are provided.

Credits: Jhanek Szypulski, April 5th 2013, nris.mt.gov, bozeman.net, mbmg.mtech.edu, usgs.gov.

# Potential Soil Sampling Site 6




N

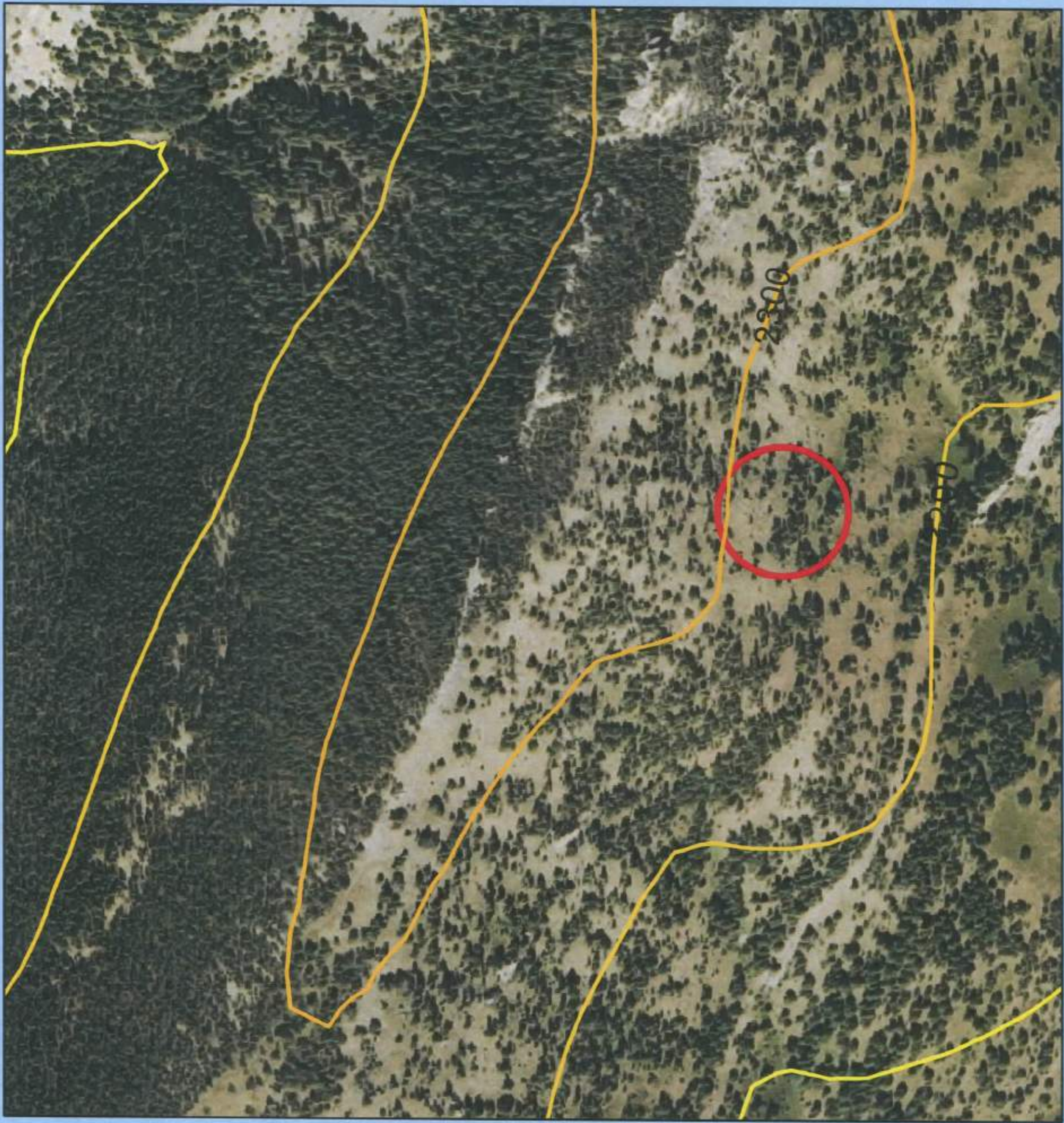
Latitude 45° 44' 26.870" N
Longitude 110° 57' 12.618" W

0 62.5 125 250
Meters

Outlined in red is the potential area for a soil sampling site to be dug based on the defining layers of limestone parent material and shrubland/grassland/barrenland cover combined with the highest value possible for preferred slope and aspect. Contours are in meters. Coordinates of the circles centroid are provided.

Credits: Jhanek Szypulski, April 5th 2013, nris.mt.gov, bozeman.net, mbmg.mtech.edu, usgs.gov.

# Potential Soil Sampling Site 7



N

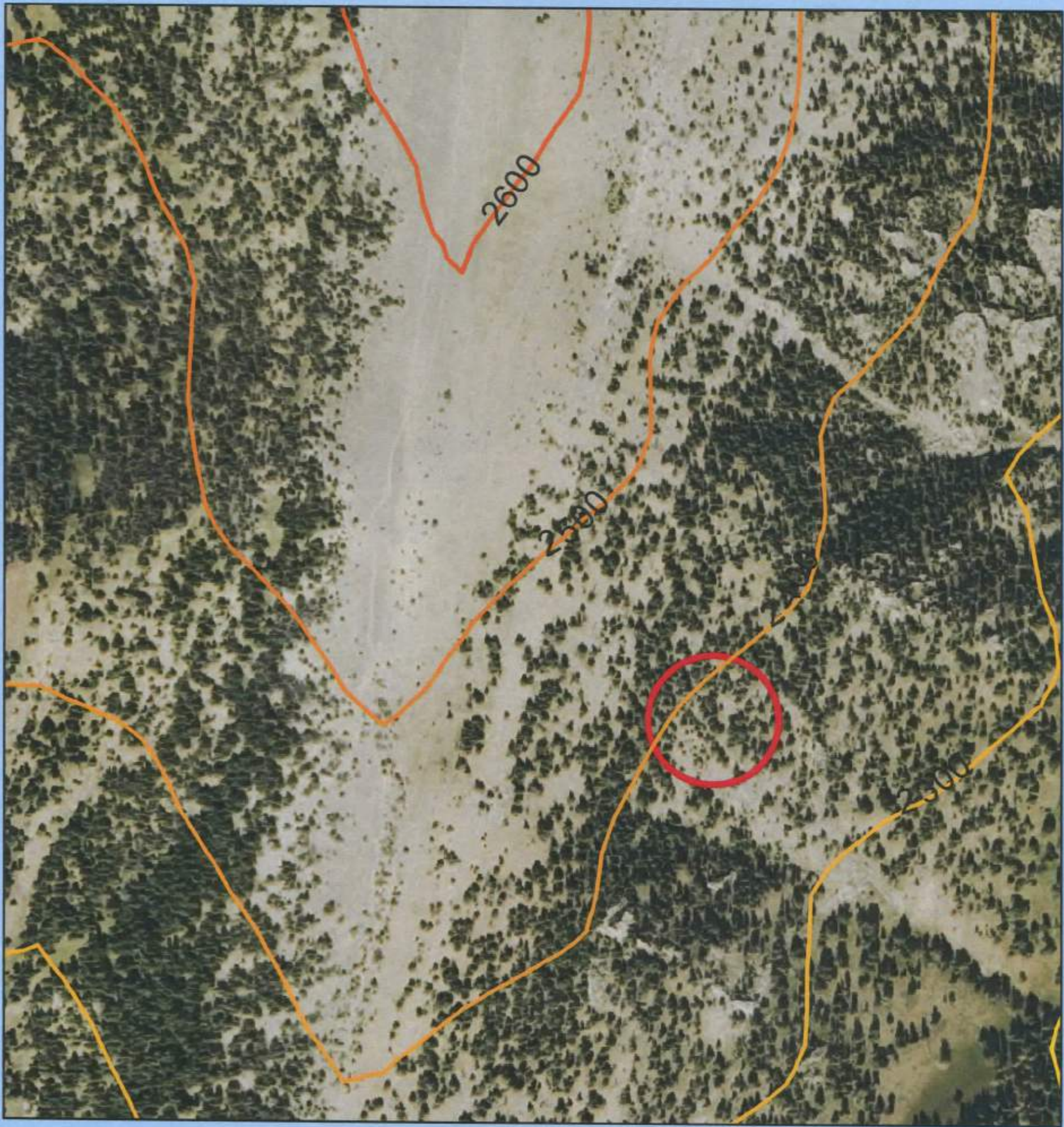
Latitude 45° 43' 41.616" N
Longitude 110° 57' 45.273" W

0 62.5 125 250
Meters

Outlined in red is the potential area for a soil sampling site to be dug based on the defining layers of limestone parent material and shrubland/grassland/barrenland cover combined with the highest value possible for preferred slope and aspect. Contours are in meters. Coordinates of the circles centroid are provided.

Credits: Jhanek Szypulski, April 5th 2013, nris.mt.gov, bozeman.net, mbmg.mtech.edu, usgs.gov.

# Potential Soil Sampling Site 8




N

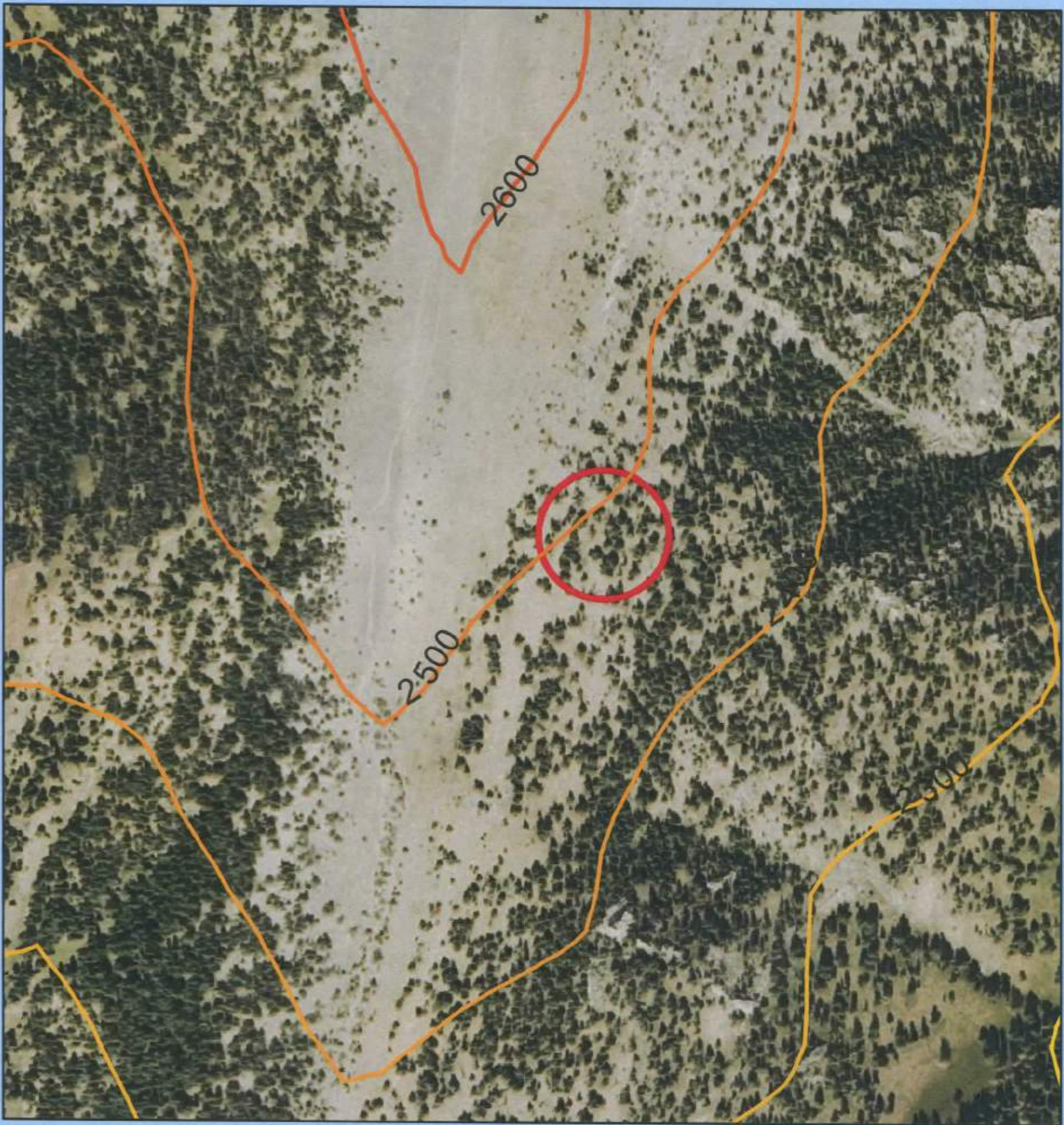
Latitude 45° 44' 58.394" N
Longitude 110° 57' 1.807" W

0 62.5 125 250
Meters

Outlined in red is the potential area for a soil sampling site to be dug based on the defining layers of limestone parent material and shrubland/grassland/barrenland cover combined with the highest value possible for preferred slope and aspect. Contours are in meters. Coordinates of the circles centroid are provided.

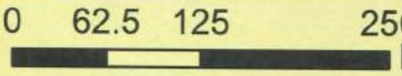
Credits: Jhanek Szypulski, April 5th 2013, nris.mt.gov, bozeman.net, mbmg.mtech.edu, usgs.gov.

# Potential Soil Sampling Site 9





Latitude 45° 45' 3.029" N
Longitude 110° 57' 5.598" W




Outlined in red is the potential area for a soil sampling site to be dug based on the defining layers of limestone parent material and shrubland/grassland/barrenland cover combined with the highest value possible for preferred slope and aspect. Contours are in meters. Coordinates of the circles centroid are provided.

Credits: Jhanek Szypulski, April 5th 2013, nris.mt.gov, bozeman.net, mbmg.mtech.edu, usgs.gov.

# Potential Soil Sampling Site 10


N

Latitude 45° 45' 26.973" N
Longitude 110° 57' 1.921" W

0 62.5 125 250 Meters

Outlined in red is the potential area for a soil sampling site to be dug based on the defining layers of limestone parent material and shrubland/grassland/barrenland cover combined with the highest value possible for preferred slope and aspect. Contours are in meters. Coordinates of the circles centroid are provided.

Credits: Jhanek Szypulski, April 5th 2013, nris.mt.gov, bozeman.net, mbmg.mtech.edu, usgs.gov.

# Potential Soil Sampling Site 11


N

Latitude 45° 47' 34.740" N
Longitude 110° 56' 5.390" W

0 62.5 125 250
Meters

Outlined in red is the potential area for a soil sampling site to be dug based on the defining layers of limestone parent material and shrubland/grassland/barrenland cover combined with the highest value possible for preferred slope and aspect. Contours are in meters. Coordinates of the circles centroid are provided.

Credits: Jhanek Szypulski, April 5th 2013, nris.mt.gov, bozeman.net, mbmg.mtech.edu, usgs.gov.

# Potential Soil Sampling Site 12


N

Latitude 45° 53' 23.753" N
Longitude 110° 57' 38.108" W

0 62.5 125 250 Meters

Outlined in red is the potential area for a soil sampling site to be dug based on the defining layers of limestone parent material and shrubland/grassland/barrenland cover combined with the highest value possible for preferred slope and aspect. Contours are in meters. Coordinates of the circles centroid are provided.

Credits: Jhanek Szypulski, April 5th 2013, nris.mt.gov, bozeman.net, mbmg.mtech.edu, usgs.gov.

| Sampling Site | Elevation in meters | Latitude | Longitude | Map Algebra Value |
|---|---|---|---|---|
| 1 | 1700 | 45° 42' 40.090" N | 110° 58' 9.966" W | 6 |
| 2 | 1800 | 45° 42' 50.262" N | 110° 57' 59.877" W | 6 |
| 3 | 1900 | 45° 43' 1.827" N | 110° 57' 50.804" W | 6 |
| 4 | 2000 | 45° 43' 13.717" N | 110° 57' 45.060" W | 6 |
| 5 | 2100 | 45° 43' 24.280" N | 110° 57' 44.267" W | 7 |
| 6 | 2200 | 45° 44' 26.870" N | 110° 57' 12.618" W | 7 |
| 7 | 2300 | 45° 43' 41.616" N | 110° 57' 45.273" W | 7 |
| 8 | 2400 | 45° 44' 58.394" N | 110° 57' 1.807" W | 7 |
| 9 | 2500 | 45° 45' 3.029" N | 110° 57' 5.598" W | 6 |
| 10 | 2600 | 45° 45' 26.973" N | 110° 57' 1.921" W | 8 |
| 11 | 2700 | 45° 47' 34.740" N | 110° 56' 5.390" W | 8 |
| 12 | 2800 | 45° 53' 23.753" N | 110° 57' 38.108" W | 7 |