TOPOGRAPHIC RECONSTRUCTION THROUGH GEOMORPHIC APPROACH FOR PRELIMINARY RECLAMATION: CABALLO MINE, WYOMING

by
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ABSTRACT

Mining is an important undertaking to support local and global economies. However, most mining operations unavoidably lead to substantial environmental damage. After the mining activity is complete, suitable reclamation policies are applied to post-mining areas. Whenever possible, reclamation activities are implemented while mining operations continue. The traditional approach to topographic reconstruction primarily consists of the grading and shaping of waste rock. Slopes and stream channels are constructed without much thought concerning their integration into functional drainage catchment areas as open, process response systems. Unfortunately, traditional reclamation can be costly and have unintended consequences on the environment. The objective of this study was to test the hypothesis that geomorphic reclamation is a more cost-effective approach and has less adverse impacts on the surrounding environment. To test the hypothesis, a geomorphic reclamation approach was applied on a small northern section of Caballo mining, Wyoming. Geomorphic reclamation is proposed as an alternative to the common traditional reclamation. A Digital Elevation Model was constructed and processed in ArcGIS software to investigate comparative characteristics among the study area (traditional reclamation landscape), a reference area for the reclamation, and the new reconstructed landscape (geomorphic approach). The overall goal is to generate a geomorphically reclaimed landscape that mimics the natural features of the surrounding area and estimate the cost that is associated with material volume. The number of drainage-catchment areas, average mean slope, and the number of drainage networks for the reference surrounding area is closely replicated in the reconstructed topography. After those adjustments, the reclamation surface became more reflective of the design. The difference in elevation created between the topography of the study area and the reconstructed landscape was manipulated to give a material volume difference of the topographies. The cost of reclamation was then estimated from the amount of material to be moved to achieve that topography. The geomorphic reclamation results indicate an efficient mining reclamation alternative to the traditional approach.

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CHAPTER ONE: INTRODUCTION

1.1 Motivation for Research

Mine reclamation is an important undertaking during mining. However, traditional reclamation (i.e. engineering approach) can be costly and have significant impacts on the environment (erosion, slope instability, etc.). Reclamation is the combined process by which adverse environmental effects of surface mining are minimized and mined lands are returned to a beneficial end use. End uses may be open space, wildlife habitat, agriculture, or residential and commercial development (Bangian et al. 2012). The traditional approach to topographic reconstruction primarily consists of the grading and shaping of waste rock. Slopes and stream channels are constructed without much thought concerning their integration into functional drainage catchment areas as open, process response systems (Haigh, 2000: Loch, 1997). This is done for the mass stability of the unconsolidated waste. Stability analyses for hillslope design commonly are based upon the equilibrium of forces and resistances along a two-dimensional cut through the hillslope, selected along the potential failure surface (Toy and Chasu, 2004). In general terms, hillslope stability increases as hillslope gradient decreases, hillslope height decreases, and pore-water pressures decrease.

Once mass stability is achieved, the next objective is erosion control. In general terms, erosion rates decrease as hillslope steepness decreases and as hillslope length decreases (Whisenant, 2005). A relatively new reclamation technique called Geomorphic reclamation is a landscape reconstruction technique that attempts to recreate the original surface forms surrounding a mined area, thereby mimicking the natural drainage patterns of a natural landscape (Toy and Chuse. 2004; Toy and Black, 2001). Reclaimed landforms designed using the geomorphic approach create functional watershed systems similar to those that develop naturally given the local climate, soils and vegetation. Instead of the uniform, planar terraces that are typical of traditional reclaimed landforms, geomorphic landforms provide a complex, varied surface with ridges and valleys that create many small drainage paths. Small, tributary drainages converge into channels that take a natural-looking meandering course and have the same wide, shallow shape that is typical of stable natural channels. A primary goal of geomorphic design is to produce landforms that do not require ongoing maintenance to prevent erosion, and a finished site that is in a stable hydrologic equilibrium, is visually appealing and promotes a self-sustaining ecosystem (Martín-Duque et al., 2010; Toy and Chuse. 2004) . Although Geomorphic reclamation appears to be appealing, limited comparative tests have been conducted in terms of cost and environmental impacts.

1.2 Problem Statement

This study aims to address the following research questions:

1) How much topographic change through geomorphic reclamation will be achieved that favors a reduction in erosion? The scope of this work covers the investigation of potential erosion failure spots in the case study area and recommends a reclamation method to reconstruct the disturbed land. Irrespective of the cause of failures, the goal of the topographic reconstruction is to create steady-state landscapes and prevent future soil erosion. The new geomorphic design will establish steady-state, morphologic characteristics of hillslopes and stream channels that are similar to the surrounding undisturbed natural landscape. Hence, this study will demonstrate the advantages of geomorphic reclamation on environmental impacts over traditional reclamation.

2) How much earth material will be moved to achieve the topographic design and what the estimated cost to move the earth material is? Generally, the main cost of reclamation is returning the pit and waste piles to near-original contours. The cost of the material to be moved to attain approximate original contours in the disturbed area is the bulk of the total reclamation costs. Final grading costs for land-forming and drainage are usually only 10 to 20% of the total cost of reclamation. Thus, the upfront cost will be calculated by the amount of material moved to attain the proposed landscape. From previous geomorphic reclamation work in San Juan and Navajo mine, engineering costs were slightly higher for the geomorphic method (personal communication with field expert of the mines), including dozer equipment and operator hours. However, less costs for rework due to erosion and lesser bonding fees due to faster bonding release will be cost advantages with the geomorphic method. Goodwill acquired with the community and environmental regulatory agencies is also a cost advantage, although difficult to quantify. Therefore, while the engineering and material movement cost would be expected to be higher using the geomorphic method, the overall cost could be less than that of the traditional method.

1.3 Thesis Objective

Reclaimed land is doomed to erosion at any time if it is not handled appropriately. This research evaluates a previous mining site that is likely to be subjected to erosion due to high precipitation and proposes a geomorphic reclamation design to minimize erosion. This study requires mapping and evaluating different geomorphological factors to identify the zones with high run offs. In this research average mean slope, the number of drainage networks and average catchment area are the site characteristic factors to evaluate and reconstruct the study area. The potential erosion sites are then topographically reconstructed using the geomorphic reclamation approach. This study aims to demonstrate that a geomorphic approach for reclamation can be designed from a Digital Elevation Model (DEM) and result in a steady-state landscape. The study also provides an insight into a preliminary cost estimation of a topographic design through a geomorphic approach.

1.4 Research Hypothesis

This study is designed to test the hypothesis that topographic reconstruction through geomorphic reclamation reduces the potential for soil erosion and overall reclamation costs compared to the traditional reclamation method. Further the following sub hypotheses will be tested: Sub-hypothesis 1- The small hillslopes in geomorphic reclaimed area would form various watersheds which allow the water from high rain events to flow in different directions. Whereas, in the traditionally reclaimed area, high rain events would blow out resulting in severe downslope erosion.

Sub-hypothesis 2- The geomorphic approach is initially more expensive because of the higher volume of material to be moved and higher engineering cost. However, there should be long-term savings because the landscapes will require less monitoring and maintenance than landscapes designed by the standard engineering approach.

1.5 Thesis Organization

This thesis is organized into 7 chapters: Chapter one provides a brief introduction to this research, identifies the hypotheses, main objectives, and research questions central to this project. Chapter two summarizes the literature review by giving an overview of mine reclamation, common methods of mine reclamation, introduction to geomorphic reclamation, goals of geomorphic reclamation method and a general overview of the reclamation tasks. Chapter three describes the case study area, defines the characteristics of a mine site, and provides critical background information and engineering characteristics of the area. Chapter four delivers the methodology of the experiment conducted. It describes details of the methods used to perform this research. Chapter five presents the findings of this study. Chapter six discusses an analysis of the results, highlights the contributions of this research, and concludes by presenting a summary of the key findings and makes recommendations for future research.

CHAPTER TWO: LITERATURE REVIEW

2.1 Overview of Mining Reclamation

Generally, the mining industry is contemplated to be one of the harmful production sectors in terms of global warming and environmental pollution. Open-pit mining is more popular than underground mining methods because production activities are carried out on the surface. The topographic and ecological environment is the most impacted by the consequence of opencast mining, particularly in coal mining. Soils' chemical and physical properties are also affected by the main activities of mining such as stripping, excavation, transportation, and dumping (Feng, 2019). Mining operations and post-operation processes can be a source of significant damage to the environment. Surface mining is most known for moving large volumes of earth materials, therefore creating a high likelihood of erosion-induced dissection and mass instability in drainage catchment area surfaces. Large amounts of sediment are produced, transported off-site, and deposited in streams, lakes, and reservoirs. On-site and off-site environmental degradation occurs rapidly, and collectively may affect areas many times the size of initial land disturbance (Hooke, 1994). Examples of environmental problems associated with surface mining include (Sengupta 1993):

- Land damage: Abolition of agricultural lands, deforestation, pit formation on the land, destruction of roads, and other infrastructure leading to socio-economic and cultural problems.
- Environmental damage: natural landscapes and habitats destruction, health problems caused by pollution, water, and wind erosion in post-mining areas.
- Soil texture damage: soil loss, landslides, geological problems, ground collapse, strata structure destruction of the lower soil, Saltiness, and pH change
- Water Contamination: mine water drainage causes contamination of surface water; excavated material poured into lakes, seas, and oceans also causes pollution, air pollution and noise pollution are also caused because of equipment operation and blasting.

- Fauna damage: the complete destruction of natural fauna and fishing areas as a result of sea pollution.

- Flora damage: complete destruction of natural flora, plant shriveling as a result of dust accumulation.

In recent decades, different countries have issued different mandatory environment protection regulations to control and treat the environmental impact of mining activities (Bangian et al. 2012). Several aspects were addressed by these regulations:

(i) Controlling and preventing the spread of the pollution generated by mining,

(ii) Monitoring and preventing the increase in the rate of pollution generated,

(iii) Treatment of the generated contamination,

(iv) Recognizing the type and rate of contamination generated.

Moreover, several additional regulations have also been issued to restore, reclaim, and rehabilitate the land in mined areas (Bangian et al. 2012). While mining processes continue to destroy vegetation, ecosystem and natural topographic landscapes, reclamation processes are conducted to return the mines land to its original state by restoring the natural properties of the land through a series of reclamation methods (Bugosh, 2019). Reclamation is defined as the restoration of a fertile and pleasing landscape, either for the economic return from agriculture and forestry or for the sake of recreation (Knabe, 1964). Mine reclamation ranges from the restoration of productive ecosystems to the creation of industrial and municipal resources that meet a variety of goals. It offers landowners the opportunity to restore drastically disturbed lands to beneficial uses. Careful management of the landscape resources on mined land can improve the quality of the environment both onsite and offsite (Carlson, 2010).

Although the process of mine reclamation usually occurs after mining is completed, the preparation and planning of mine reclamation activities occur prior to a mine being permitted or started. Modern mine reclamation minimizes and mitigates the environmental effects of mining.

Nowadays, mine reclamation is a regular part of modern mining practices. (Slingerland et al., 2018). Reclamation consists of processes in which adverse environmental effects of surface mining are minimized and mined lands are returned to beneficial end use. Some components of reclamation include practices that control erosion and sedimentation, stabilize slopes, and avoid and repair impacts to wildlife habitat. The general reclamation process consists of the following sequential steps (Toy and Daniels, 2000): site characterization, reclamation planning and engineering, material management, topographic reconstruction, replacement of topsoil or soil substitute, surface manipulation, the addition of soil amendments, revegetation, irrigation, if needed, and site monitoring and maintenance. Topographic reconstruction is an essential part of high-quality reclamation because the resulting landscapes are the foundations for all other reclamation practices, and the surfaces for future land use. Other reclamation goals, such as sustained agricultural production or wildlife habitat, are impossible without geomorphicaly stable landscapes. End uses may be open space, wildlife habitat, agriculture, or residential and commercial development.

2.2 Common Practical Approaches to Mine Reclamation

2.2.1 Forestry Reclamation Approach

Forestry reclamation is the planting of productive hardwood trees on mined lands and abandoned mine lands. The main goal of this reclamation method is planting more high-value hardwood trees on mined lands to increase the survival and growth rates of planted trees, and to accelerate the natural process of succession and reestablish forest habitat (Angel and Burger, 2009). During mining operations, all highly acidic or toxic material and all highly alkaline materials with extreme soluble salts should be covered with four to six feet of a suitable rooting medium that will support trees (Angel and Burger, 2009)**.** For this type of reclamation, growth media with low to moderate levels of soluble salts, equilibrium pH of 5.0 to 7.0, low pyritic sulfur content, and textures conducive to proper drainage are preferred (Burger et al., 2005).

The first step is to create a suitable rooting medium for good tree growth that is no less than four feet deep and includes topsoil, weathered sandstone (Angel, 2008). The second step is to loosely grade the topsoil or topsoil substitutes established in step one to create a noncompacted soil growth medium. In steep slope mining areas, the majority of the backfill is placed and compacted as usual, but the final four to six feet of growth medium should be dumped and lightly graded to achieve the required final grade. This technique helps reduce erosion, restore the hydrologic balance, provide enhanced water infiltration and allows trees to achieve good root penetration (Angel and Burger, 2009). Reduced compaction rates create a significant positive change in superior tree survival and growth rates (Graves et al., 2000). It is important to use less competitive ground covers that are compatible with growing trees. The core task of forestry reclamation is to plant two kinds of trees: early succession species tress is preferred for wildlife and soil stability, while valuable crop trees are favored for commercial uses. Using proper tree-planting techniques is substantial on forestry reclamation (Angel and Burger, 2009).

2.2.2 Traditional Reclamation Approach

The traditional approach to topographic reconstruction primarily consists of the grading and shaping of waste rock. The landform design includes terraced landforms, benches, and graded waste banks consisting of irregular short constant-gradient out slopes and (Loch, 1997). Channels are required to follow a smooth, concave-upward stream-course, gentle, without abrupt changes in gradient. The principal objective of this method is mass stability. The construction of slopes and watercourse channels primarily favor mass stability. The integration of the landscape to a functional drainage system is less concerning in this reclamation method (Toy and Black, 2001).

Stability analyses for hillslope design are based upon the study of the equilibrium of forces and resistances along a two-dimensional cut through the hillslope of the selected potential failure surface (Toy and Chasu, 2004). In general terms, as hillslope gradient decreases, hillslope stability increases, hillslope height decreases, and pore-water pressures decrease. In the traditional reclamation method, once mass stability is achieved, the next objective is erosion control. Erosion rates decrease as hillslope steepness decreases, and as hillslope length decreases (OSMRE, 2016). Mining reclamation is anticipated to minimize both on-site and off-site impacts. In spite of the significant development of reclamation techniques during the last decades, numerous failures have occurred. Engineering methods of reclamation, with gradient terraces of down drains, are not able to guarantee long-term landform stability (Haigh, 2000). Without maintenance, the reclaimed landforms submit to water erosion (Loch, 1997).

Soil erosion is one of the significant barriers to the success of restoration practices (Whisenant, 2005). It affects vegetation growth through different mechanisms: direct plant removal, the removal of seeds and nutrients from the topsoil, and the loss of water resources through surface runoff (Pimentel et al., 1995; Moreno-de las Heras et al., 2008). Erosion problems also arise because benches exceed the storage capacity (Sawatsky et al., 2000). On traditionally reclaimed lands, drainage catchment areas often are too large for the number and size of the channels excavated (Toy and Black, 2001). Intense rainstorms may result in gullying. Linear slopes are also unstable, due to lack of appropriate drainage density. Hillslopes on reclaimed lands, especially in surface-mine areas, often form long embankments with convex or straight profiles. A study of 57 reclaimed mines in North America illustrated that deficiency in the number of drainage network design was a common reason for failure of mine reclamation landscapes (Toy and Daniels, 2000, McKenna and Dawson, 1997). While the traditional reclamation method is common, the above-mentioned studies illustrate that there is still a challenge that needs to be addressed to prevent erosion. This study is designed to show that the geomorphic method to reclamation is a better approach to prevent erosion and acquire long term stability.

2.3 Geomorphic Reclamation

The search for the best possible land reclamation methods associated with land transformed and degraded by earth movements is one of the main challenges of the mining industry. Human activities, particularly mining activities have cumulative profound effect on global change (Osterkamp and Morton, 1996). Geomorphology, the science which deals with the shape of earth's landforms and the surface processes (Toy and Daniels, 2000; Godfrey and Cleaves, 1991), offers a useful context both for an understanding of the soil properties and environmental effects of surface mining to sedimentation processes (Wilkinson and McElroy, 2007). Proper landform design in mining reclamation can be accomplished, leaving the disturbed land to natural processes (Schumm and Rea, 1995; Toy and Black, 2000; Toy and Chuse, 2005). While effective control of erosion and sedimentation in reclaimed mining areas and their surroundings is mainly dependent on integrated management of mining wastes, water, topography, surface soil cover and vegetation, in previous studies topographic reconstruction has not received the same attention as the other factors (Nicolau, 2003). Earth movement is the most expensive part of reclamation, however topographic landform reconstruction remains the major phase of the process (Brenner, 1985; Zipper et al., 1989; Environment Australia, 1998). An appropriate landform design in mining reclamation can be effective in ecological and economic terms ((Toy and Daniels, 2000; Sawatsky, 1998). The landforms that traditionally result from reclaimed mining cuts and waste dumps nearly always have a geometric topography, graded slopes, benches, and terraced appearance. They are usually combined with elements to redirect and slow runoff, rock-filled gabions, erosion control blankets, concrete linings, drainpipes (Nicolau 2002, 2003; Bugosh, 2006a). Traditional approach of uniform slopes and terracing in mining reclamation results in an immature topography that does not present in nature (Sawatsky, 2000).

Geomorphic reclamation is a landscape reform technique that attempts to restore the original surface forms surrounding a mined area, by mimicking the natural drainage patterns of a natural landscape (J. Toy, Willow R. Chuse 2004; Toy and Daniels, 2000). The geomorphic approach creates functional watershed systems like those that develop naturally given the soil, vegetation and climate that characterize the natural project area. It provides a complex, varied surface with ridges and valleys that create many small drainage paths unlike traditional reclaimed landforms that generate uniform, planar terraces. Small streams converge into larger water channels that take a natural-looking winding course and have the same wide, shallow shape that is typical of stable natural channels. The aim of the fluvial geomorphic reclamation is to achieve long-term stability against erosion, increased biodiversity and reduced maintenance as compared to mines reclaimed using traditional reclamation methods.

In geomorphic method of reclamation, a dynamic balance between areas of natural and areas where sediments are deposited prevents the entire stream channel from experiencing large-scale degradation. Fauna and flora are also enhanced in the restored stream (Martín-Duque et al., 2010). A primary goal of geomorphic design is to create landforms that do not require on-going maintenance to prevent erosion, produce a finished site that is visually appealing and promotes a self-sustaining ecosystem. Therefore, the aim of any surface mining reclamation should be to design a reclaimed landform into the shape that the natural geomorphic processes would tend to occur under existing environmental conditions (Bugosh, 2004, 2007).

2.3.1 Geomorphic Goals for Land Reclamation

Geomorphic reclamation is based on the scientific principle that slope and fluvial processes mostly operate for an extended time within drainage catchment areas of natural geomorphic processes (Zapico and Martín Duque, 2018). From a geomorphic perspective, the goal of topographic reconstruction is a steady-state landscape that has a sustainable natural geomorphic process. The final landscapes consist of drainage catchment areas that function as open process-response systems with efficient flow of water and sediment, no environmental degradation, geomorphic processes operating at low rates and sustaining productive post-reclamation land uses (J. Toy, R. Chuse. 2004). Unfortunately, it is not always possible to construct landscapes in a perfect steady-state, given the fact that many types of external disturbances constantly destroy geologic structures (Martín-Duque et al., 2010). Vegetation and root networks develop over several years. Strata structures and soil consolidation regenerate over decades. However, landscapes that approximate steady-state configurations have less modification by geomorphic processes after reclamation than landscapes that are not near to steady configurations. If a reclaimed landscape is similar to a surrounding steady state, the prospect for reclamation success increases, and the demand for post-reclamation site maintenance decreases (Toy and Chuse,2004). Hence, the main goal of a geomorphic reclamation is the reconstruction of mined landscapes that approach a steady state configuration.

Geomorphic reclamation methods create a significant difference compared to the traditional (engineering) method of reclamation (Duque et al., 2010). One of the main advantages of geomorphic approach is that it creates long-term stability (mainly against water erosion) and dynamic equilibrium between landform and processes compared to the traditional reclamation method. Traditional reclamation has short-term stability (mainly for mass movements), and failure under water erosion over the long term. Geomorphic reclamation also provides a landscape with a natural appearance (blending in with the surrounding), and a landscape designed to support functional and self-sustained ecosystems that replicate the natural ones, thereby creating options for sequential use. In terms of landscape maintenance after reclamation, Geomorphic reclamation reduces or eliminates any maintenance and is thus less costly than conventional reclamation, in both the short and long term. The principal goal of designing slopes and landforms based on natural ones is that they are more functional and are more visually attractive and cost effective (Schor and Gray, 2007). During any type of reclamation, abundant attention should be given to hydrology, geomorphology, and visual compatibility with the surroundings in order to ensure long-term stability (Hancock, 2003).

2.3.2 The Geomorphic Reclamation Method Development

Since the main goal of Geomorphic reclamation method is to create a landscape that resembles the surrounding areas, the first step is to find a surrounding landscape in which to base the planning and design of entire drainage catchment areas (Toy and Chase, 2004, Riley, 1995). The four most important drainage-catchment area characteristics to consider in planning and design exercises are average weighted mean slope, drainage-catchment area, drainage network pattern and drainage-catchment area relief (Toy and Chase, 2004). The average weighted mean slope assigns weights that determine in advance the relative importance of each contour slope. A weighted average is most often computed to equalize the frequency of the slope values. The average slope determines the steepness of the hillsides which influence the rate of runoffs. The drainage-catchment area is the surface that collects precipitation, generates runoff, and produces sediment yield from erosion processes. As the catchment area increases, the total stream length, sediment leaving the catchment area (sediment discharge), runoff, and stream discharge also increase. As the drainage catchment area increases, sediment yield and the sediment delivery ratio (sediment yield/total erosion) decrease, which results in relatively less erosion (Toy and Chuse, 2004; Ritte, 2002). The spatial arrangement of stream channels in a drainage catchment area is referred to as a drainage network. The drainage network is largely determined by the geology of the drainage catchment area. Dendritic drainage patterns develop in the absence of geologic controls, with channels appearing in plain view much like the veins on a leaf. For reclaimed land, a dendritic channel pattern is appropriate for the drainage catchment areas because mining processes destroy geologic structures and homogenize lithologies (Toy and Chuse, 2004; Ritter, 2002). Drainage catchment area relief is the change in elevation between the drainage divide and the mouth of the catchment area. It is largely determined by the geomorphic history, mining operations, and regional geology. As relief increases, runoff, erosion, and sediment yield (sediment discharge per unit area) also increase (Toy and Chuse, 2004).

The geometric relations cited above confirm that drainage catchment areas develop and function as open, process-response systems. For this reason, drainage catchment areas are regarded by geomorphologists as fundamental landscape units (Toy and Chuse, 2004; Chorley, 1971). The design of steady state drainage catchment areas begins by locating the main channel through the area to be reclaimed. The position of this channel is determined by the topography of adjacent, undisturbed areas, and the overall topography of the disturbed land. Drainage networks for the reclaimed areas are then designed (Martín-Duque et al., 2010; Toy and Chuse, 2004).

Digital elevation modeling software can be used to integrate geomorphic principles into topographic reconstruction during the planning and design stages of reclamation (Toy and Chuse, 2004). The first step is geomorphic analyses of the pre-disturbance or undisturbed surrounding area landscape to determine essential drainage-catchment area characteristics. These characteristics then provide targets for topographic reconstruction. The assumption in geomorphic reclamation is that the adjusted topographic characteristics of the reclaimed landscape will sustain natural geomorphic processes and steady-state conditions. The digital elevation model can be manipulated with the software until the selected geomorphic characteristic values are approximately similar to those values for the surrounding or pre disturbance area. The drainage network, the weighted mean slope of the catchment areas, and the average catchment area should be about the same as the selected reference area. After the overall drainage network is determined, hillslopes and stream channels are finally designed according to standard practices (Toy and Chase, 2004; Toy and Black, 2001).

CHAPTER THREE: DESCRIPTION OF THE CASE STUDY AREA

3.1 Caballo Mine

Wyoming is the most prolific coal-producing state in the United States. Annually, Wyoming's coal mines account for almost 40 percent of U.S. coal production (Wyoming State Geological Survey, 2019). Wyoming's large surface coal mines are also the most efficient in the nation, with an average recovery factor of 92 percent (DOE-EIA, 2015). This is the highest productivity in the nation and more than double the productivity of the next top coal-producing state. Between 1865 and January 1, 2020, more than 12.2 billion short tons of coal had been mined in Wyoming, most of it in the last 20 years (Wyoming Mining Association, 2020). As of 2021, sixteen coal mines are in operation in Wyoming, located in three counties: Campbell, Lincoln, and Sweetwater. While fifteen of the mines extract coal through surface mining techniques, one mine operates underground in Sweetwater County. Eleven out of the sixteen mines in Wyoming are in one county, Campbell County. The study area of this project, Caballo mine, is one of the eleven mines which exists in Campbell county. Therefore, the drive for this research is that these numerous surface mines, located in a relatively small region, call for attentive and effective reclamation plans. While the different coal mining companies in the area have different reclamation approaches, this research aims to demonstrate that geomorphic reclamation is the most effective.

The Caballo Mine is a surface coal mine, operated by Caballo Coal Company, a subsidiary of Peabody Energy. Peabody Energy is the world's largest private-sector coal company and global leader in sustainable mining and clean coal solutions. The company serves metallurgical and thermal coal customers in more than 25 Countries on six continents (Wyoming Mining Association, 2020). Caballo mine opened in 1978 and still actively produces coal at an average of 12.6 million short tons per annum (Global Energy, 2020). Caballo is well known for its high safety standards. The mine employees 247 men and women. The Surface Mine Emergency Team (SMET) contributes to their safety standards. Some employees participate in the SMET program, and SMET members work their regular shifts alongside other members of their crew and respond to any emergency on the mine site. In 1995, Caballo Mine worked 564,000 employee hours (476 days) without a single lost time accident. Caballo Mine works two twelve- hour shifts, twenty- four hours a day, 365 days a year (Peabody Environmental Policy, 2020). Caballo mine is known for is wildlife protections. Some of the wildlife found on the mine property include deer, antelope, eagles, rabbits, and coyotes. Equipment operators always must watch for the animals on the haul roads because at Caballo, animals have the right of way (Mining Data Solution, 2018).

According to the office of Surface Mining Reclamation and Enforcement (OSMRE), almost 50% of all land in Wyoming disturbed by coal mining has been reclaimed or is in the process of being reclaimed. The remaining land consists of active mine sites, facilities, and stockpiles (Wyoming mining association, 2020). Surface coal mines in Wyoming follow strict laws and work closely with the Environmental Protection Agency (EPA), Wyoming Department of Environmental Quality (WDEQ), Office of Surface Mining (OSM), and Bureau of Land Management (BLM). It is governed by the Surface Mining Control and Reclamation Act (SMCRA), which was passed in 1977. The law's main purpose is to establish how surface coal mines must reclaim the ground that is removed during mining (OSMRE, 2018). According to the reclamation regulations, the reclaimed area should be able to sustain vegetation and wildlife as it was before mining. One outcome of this research is a landscape that doesn't favor erosion, and consequently creates a favorable land for vegetation and ecosystem.

3.2 Study Area

The study area for this paper is a small, mined land in the northern part of Caballo mine (Fig. 1). Although Caballo mine has several sections, this specific site was selected because it is assumed that it has no active mining activities and believed to be already traditionally reclaimed land. This assumption was made based on an observation of the area from satellite imagery over several years. The area is believed to have coal mining activities from 2003 up to 2014. Generally, Caballo mine uses truck, shovel, and dozer push method of surface mining, therefore this specific area is also assumed to have been mined similarly. The area is characterized by highwalls and benches created during the mining activities. Seasonally, this area is also characterized by long and cold winters with snow fall, and short dry summers. The Spring and Fall seasons are usually wet (Weather Atlas, 2021). The intention of this study is to develop a topographic design of this mined land through geomorphic approach that will show a steady drainage system. The other objective is to estimate cost of reclamation from the new landscape design. The total area of the study site is 10 km^2 or 3.86

mi^2 with a perimeter of 16 km or 9.94 mi.

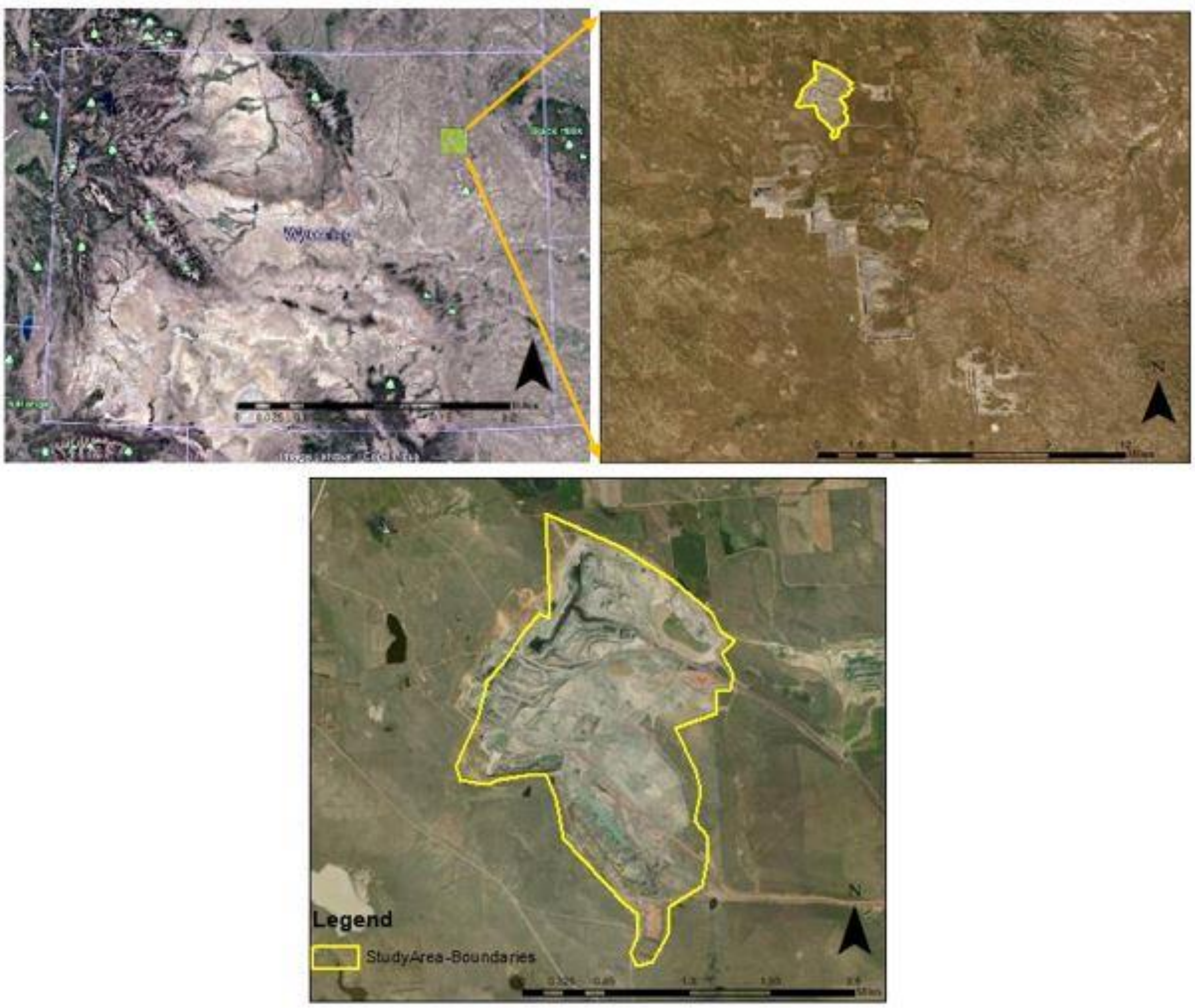


Figure 3.1: Satellite images of Wyoming State, location of Caballo Mine and study area

3.3 Reference Area

From previous studies and practices mentioned in chapter two, undisturbed surrounding area is required in a geomorphic reclamation approach to have a definite reference while planning and designing a reclamation landscape (Toy and Chuse; Toy and Black, 2001). The reference area for this study is selected based upon characteristics that were considered in previous geomorphic projects, where a steady area with gentle slope, multiple drainage channels and large catchment area is generally preferred for reference area. Therefore, for this study the above-mentioned characteristics were considered to select the reference area. The area selected is located 12 km to the west and 6 km south of study area (Fig. 3. 2). The area is characterized by multiple drainage networks which makes it suitable for reclamation purposes. No mining or human activities were conducted in this area, characterized by an ordinary landscape shaped by natural geomorphologic processes.

The purpose of this reference area is to evaluate the above-mentioned characteristics (slope, number of drainage catchment areas and number of drainage networks), and to use them as a reference for a landscape design for reclamation. As discussed in the proceeding chapters and for an accurate assessment, the shape, size, area, and perimeter of the reference area should be the same as the study area. Thus, a site with a total area of 10 km^2 or 3.86 mi^2 and a perimeter of 16 km or 9.94 mi is clipped from DEM (Digital Elevation Module) as a reference area (Figure 3.2).

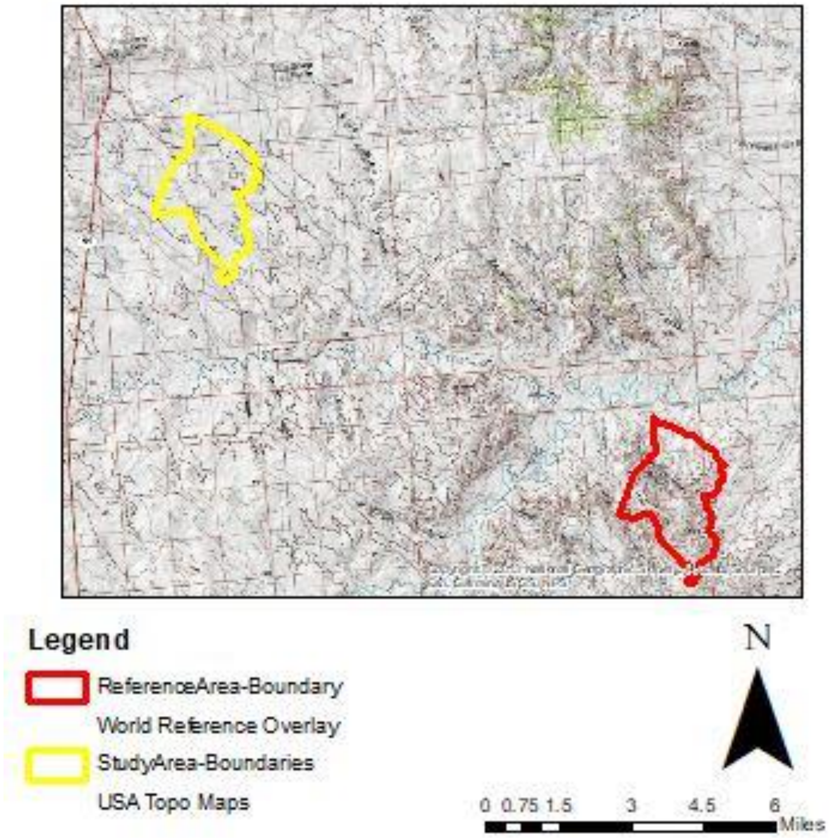


Figure 3.2: Locations of Study area (yellow boundary) relative to Reference area (red boundary). The reference area selected is located 12 km to the west and 6 km south of the study area.

CHAPTER FOUR: METHODOLOGY

4.1 Overview of Methodology

In this research, Digital Elevation Models (DEMs) are used to compute and evaluate the comparison characteristics of the study area and reference area. The evaluation of these characteristics then provides a target to construct a new topographic module for reclamation. Although the scope of this research is only focused on preliminary topographic design, DEM processing software (in this case, ArcGIS) offers the opportunity to integrate detailed geomorphic principles into topographic reconstruction during the planning and design stages of reclamation (Toy and Chuse, 2004). Caballo mine is selected for this purpose of reclamation design because topographic maps, Satellite imagery, and a digital elevation model were easily accessible for this site. Satellite imagery was taken from Google Earth Pro, as shown in Figure 1. A DEM was extracted from United States Geological Survey (USGS) website with a 1 arc-second (approximately 30 m) resolution. The elevations in this Digital Elevation Model (DEM) represent the topography of bare-earth surface. These data serve as the elevation layer of the site and provide foundational elevation information for further evaluation of the area and mapping applications.

The first step to construct a reclamation topography is geomorphic analyses of the surrounding area (which will be used as a reference area for reclamation). The landscape should be a combination of different features to determine essential characteristics for reclamation. These characteristics provide targets for topographic reconstruction (Toy and Chuse, 2004). The assumption is that the essential characteristics will be used to adjust the mined landscape to approximate the surrounding area. In this study, average slope, number of drainage catchment areas and number of drainage networks were selected to evaluate the site characteristics. After a reference area is selected, the evaluation factors are processed from the DEM. The same evaluation factors are also processed for the site to be reclaimed. The average slope of the reference area provides insights on how significant the mining activities were in creating steepness to the area, which creates the potential for runoff (Mu et al., 2015). The evaluation also gives an average value of slope for the topographic reconstruction. The numbers of drainage catchment areas of the study area and reference area were also measured from DEM in ArcGIS to provide an understanding of to what extent mining activities have influenced the watershed area. The third characteristic of the areas for evaluation is the number of drainage networks. A drainage network system is the critical focus of geomorphic reclamation because it has a significant effect on local vegetation and the ecosystem after reclamation (Whisenant, 2005). The numbers of drainage networks of the study area and reference area were also computed from DEM in ArcGIS software.

The next step is to design a reclaimed topography of the mined site. Although various programs could be used, ArcGIS was selected because the software is commonly used, and it gives a wide range of evaluation tools. In previous studies, a digital elevation model was manipulated with ArcGIS until the values for selected geomorphic characteristics were similar to those values for the reference landscape (Toy and Chase 2004), In this case, however, a different approach was introduced. Elevation points of the study area and reference area were digitized in ArcMap. These points contain the x, y coordinates and z (elevation value) of a certain point at each site. Since the shape, area and perimeter of the study and reference area are the same, the elevation points were digitized in such a manner that they represent the same position in both sites, as shown in Figure 10. Thus, each point at both sites represents the same position and ID number but different elevation value. The idea behind digitizing the same points in both sites is to transfer the elevation of points at the reference area to the area to be reclaimed. When the new elevation points are transferred to the mined area, the mined land now has a new set of elevation points that can be reconstructed to a new DEM. The reconstructed DEM can then be evaluated to calculate the average slope, number of drainage catchment areas and number of drainage networks in the new landscape. The new DEM also gives an overview of what the landscape design would look like.

The last step is to calculate the volume of the earth material that would be moved to achieve the reclaimed landscape. ArcMap tools were used to compare the mined landscape and the newly designed geomorphic landscape. The amount of earth material that should be cut and fill for the reconstruction is calculated from the difference of the DEMs. The volume of the material moved is then used to estimate the cost of the reconstruction of the topography.

4.2 DEM Preparation of Study Area and Reference Area

A Digital Elevation Model (DEM) is a rectangular grid with a specialized database that represents the relief of a surface between points of known elevation, which can be used as input to quantify the characteristics of a land surface. A DEM is usually formed by interpolating known elevation data from sources such as ground surveys and photogrammetric data capture. In GIS, it is also known as a raster representation of a continuous surface. GIS software uses digital elevation models for 3D surface visualization, generating contours, and performing many other geological analyses.

For this research, a 2018 DEM of a 1 arc-second (approximately 30 m) resolution was downloaded from the USGS website. It covers the entire Campbell county, in which the study area is located. Since the focus of the research is on a relatively small, mined area of the Caballo Mine, the DEM for that specific study area was clipped in ArcMap. To capture the right boundary of the study area, a border line was digitized on Google Earth Pro and then transformed to ArcMap, as shown in Figure 4.1. The study area covers an area of $10km^2$ and a perimeter of 16km. The reference area was also clipped from the original DEM with the same shape, area, and perimeter as the study area. The selection of this reference area was based on the reasons mentioned in chapter three. As stated above, the characteristics of the reference area were to be used as check point for the construction of the reclamation landscape. Figure 4.1 shows the clipped DEM for the study and reference area.

A **B**

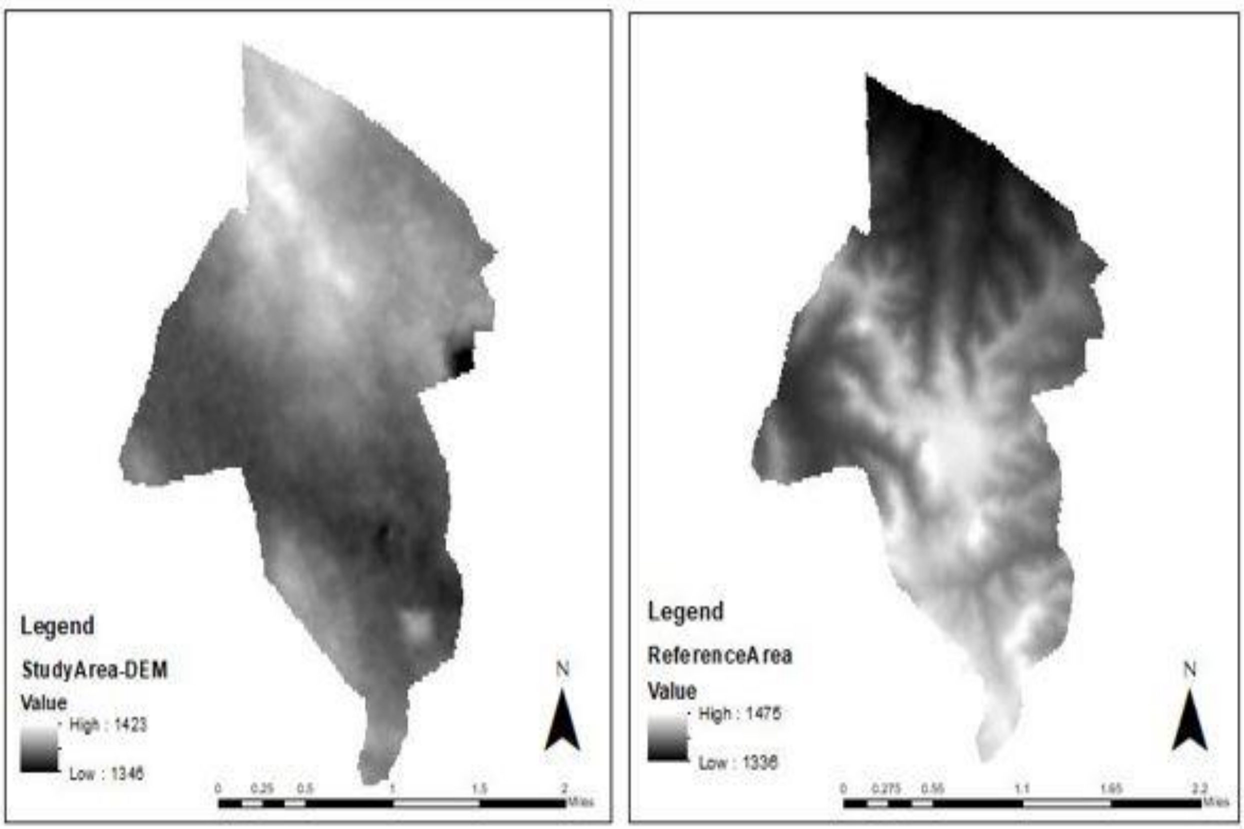


Figure 4.1: Clipped DEM of the study area (A) and reference area (B). The Same shape and area of DEM as the study area is clipped for reference area for consistency in comparison. A visual difference in the structure of topography can be recognized between the DEM

4.3 Analysis of Study Area

4.3.1 Slope Analysis

In general, the steeper and longer a slope is, the faster water runs off of it, and the greater potential there is for erosion. With the increase in slope, the soil infiltration rate will decrease, which can increase the runoff amount (Yu et al., 2015). While many other factors come into play in determining the cause for erosion, in this research the steepness of the study area will be considered as one of the factors for assessment.

Although there are multiple softwares that can be used to compute the average slope of an area from a DEM, for consistency and accuracy of the results ArcMap is selected for all data processing of this research. Slope (Spatial Analyst) tool identifies the slope (gradient or steepness) from each cell of a raster in ArcMap. The slope tool was run for the study area to produce a map that shows the slope allocations of the area (Fig. 4.2). The unit of measure is degrees, which ranges from 0 to 90. The value of interest is the average mean slope of the study area, which is computed automatically from the slope map in ArcMap. For this area, the minimum and maximum degree are 0 and 20 degrees, respectively. And the average mean slope is 4.16 degrees. The observation from the slope map is that the slope distribution of the area is very uneven. Areas of higher slope degree are almost invisible on the map, and there is a wide range of low grounds which is believed to be formed by mining activities. The majority of the area seems to be from 0 to 5 degrees and the high grounds seem to be located on specific edges of the site.

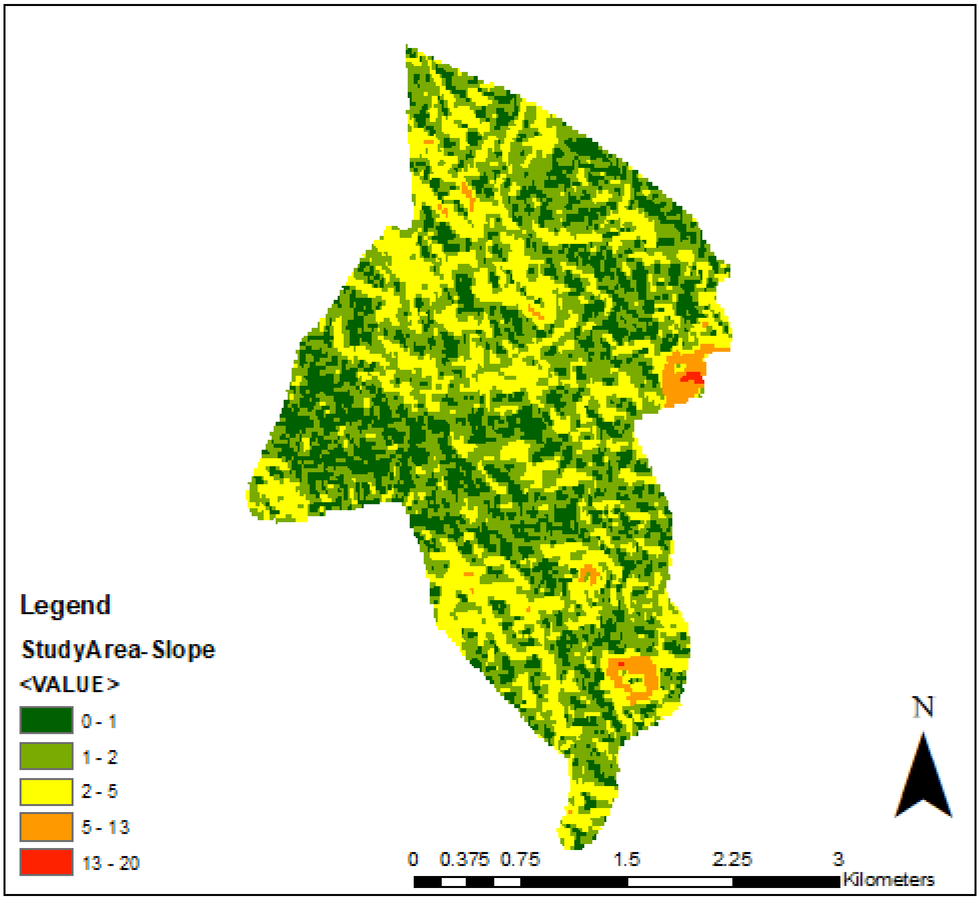


Figure 4.2: Computed Slope map of the study area (traditional reclamation landscape). Slope range from 0 to 20 degrees with an average mean slope of 1.8 degrees.

4.3.2 Watershed Area Analysis

As stated in Chapter two, the drainage-catchment area is a catchment area for all the precipitation that falls in that specific area which generates runoff and yields sediment. The size of a watershed area influences total stream length, amount of sediment yield, speed of runoffs, stream discharge etc. (Ritter et al., 2002). Drainage catchment area for the reclaimed areas is designed to feed multiple drainage patterns and sufficient drainage densities to accommodate the anticipated water and sediment discharge (Toy and Black, 2001). As mentioned in the literature review, the importance of increasing the number of watershed catchment areas in geomorphic reclamation is to provide different flow directions for runoffs. The higher the number of catchment areas, the higher possibility of runoffs flowing to different directions, which consequently reduces the speed of the water flow (Ritter et al., 2002).

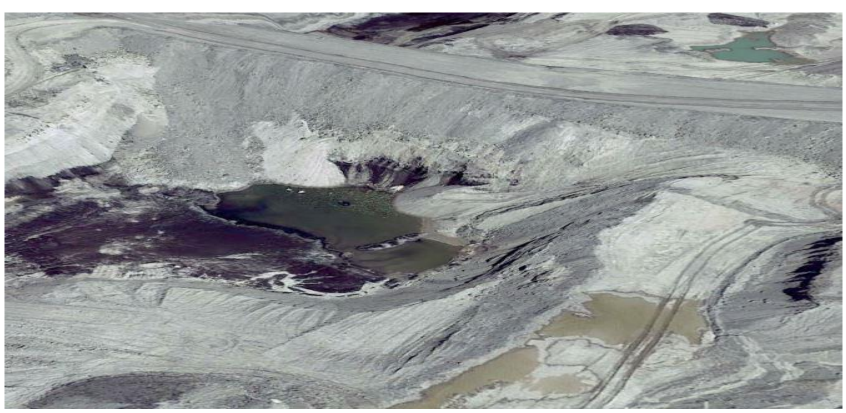
The study area is characterized by high walls and benches. As shown in Figure 4.3, the natural topography is completely distracted by mining activities. The natural watershed catchment areas of the study area are altered to human made benches. ArcGIS hydrology tools can compute and extract watershed Bains from DEM. However, they are limited to only assess naturally made drainage catchment areas. ArcMap tools cannot distinguish natural catchment areas from a disturbed area. For that reason and observation of satellite images, it is assumed that there is no natural-like catchment area in the traditional landscape of the study area.

Figure 4.3: Images A, B and C show some parts of the study area. Image A and B illustrate the benches made as a result of mining activities. Image C shows an example of a high wall located on the western part of the study area.

A

B

C



As previously stated, the goal of geomorphic reclamation is to create catchment areas that look like the natural catchment area of the surrounding. The generation of numerous drainage catchment areas for the topographic reconstruction will make sediment yields and the sediment delivery ratios (sediment yield/total erosion) decrease, which result in less erosion (Toy and Chuse, 2004: Ritte, 2002).

4.3.3 Drainage Network Analysis

Drainage systems, also known as river systems, are the geomorphic patterns formed by the streams, rivers, and lakes in a particular drainage catchment area. While, they are mainly governed by the topography of the land, several other factors also influence the drainage pattern of a landscape. Local geologic factors determine the characteristics of a particular drainage pattern and its network of stream channels and tributaries (Hutson, et al., 2017). Drainage patterns are classified based on their form and texture, and their shape or pattern develops in response to the local topography and subsurface geology (Bugosha and Eppb, 2019). Geomorphologically, drainage channels develop where surface runoff is enhanced, and where earth materials provide the least resistance to erosion (Walker, 2013). Fewer drainage channels will develop where the surface is flat, and the soil infiltration is high because the water will soak into the surface. The fewer number of channels, the coarser will be the drainage pattern (Hutson and Thoman, 2017).

For the geomorphic reclamation approach, the design of steady-state drainage catchment areas begins by locating the main channel through the reclaimed area. The position of this channel is determined by the topography of adjacent, undisturbed areas and the overall, post-reclamation topography of the disturbed land (Toy and Chuse, 2004). One of the tasks in this research is to map the drainage networks in the study area and compare the differences in the number of drainage networks with the reference area. The final goal is to mimic the drainage network of the reference area on top of the study area, which will give an overview of the main channels for detailed further design.

Drainage networks of the study area are mapped out from a catchment area map. The flow direction of the raster cells is used to identify the catchment area, but also to compute the flow accumulation of the runoff flowing in the same direction. The flow direction map was run under a flow accumulation tool which creates a raster of accumulated flow into each cell of the

DEM. The result of the flow accumulation tool is a raster of accumulated cells that flow into the same downslope cell. At this stage, the raster cells of the DEM that flow to the same downslope area are categorized. The study area shows a range of 0 to 6075 cells that flow into different downslope raster cells of the DEM. A raster calculator is then used to sketch out the drainage patterns in raster format. The study area has a flow accumulation range of 0 to 6075. The raster calculator is then executed to sketch out the streams of cells that catch a flow of 500 or greater raster cells. Flow accumulation > 500 cells are calculated in the raster calculator. The 500-flow accumulation value was selected to include even small drainage networks that contribute to the larger streams. Less than 500 flow accumulation cells are assumed not to have a significant effect on the main streams. To have a definite number of stream networks the drainage raster map is then changed to polylines. The final drainage network map shows the position, structure, and number of drainage networks in the study area, (Figure 4.4). While hydrology tools in ArcMap are used to detect natural drainage networks, this experiment was done on a site which was disturbed by mining activities to detect drainage channels that are formed naturally in new topography.

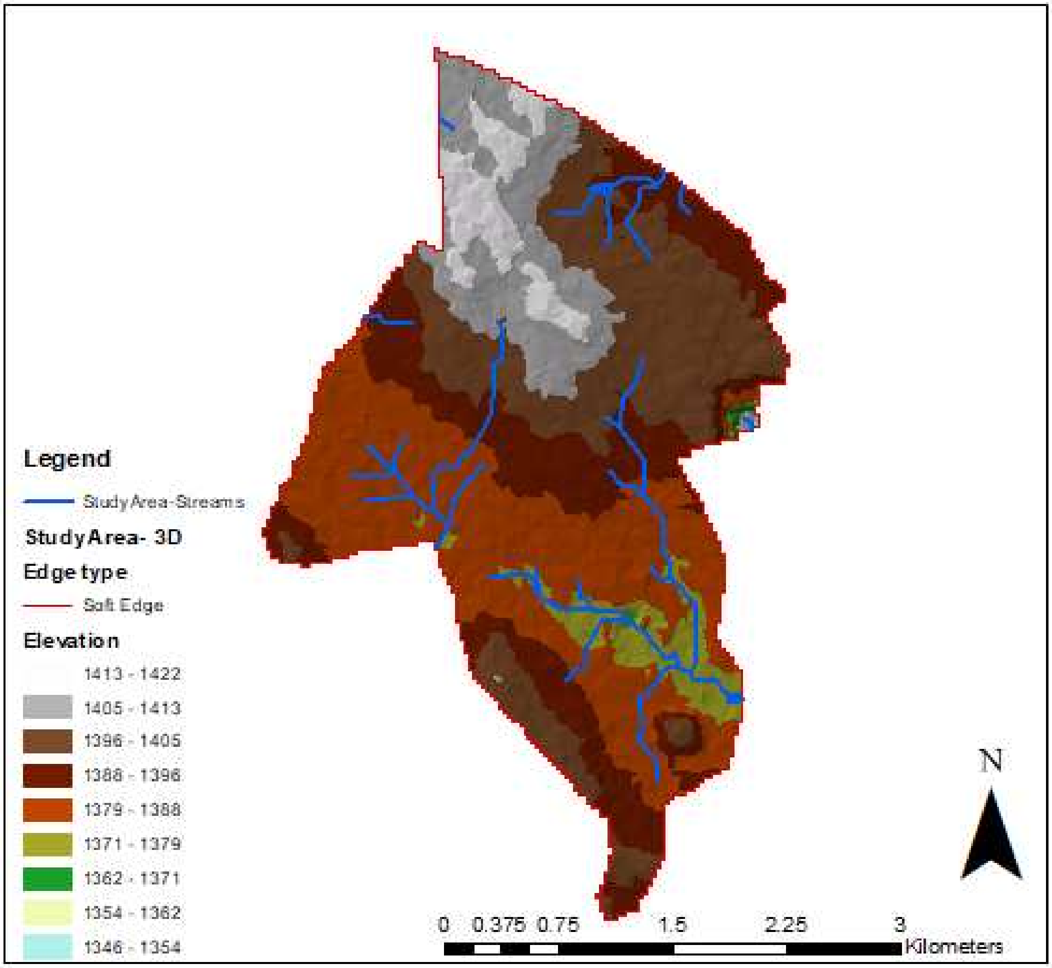


Figure 4.4: Drainage network map of study area (traditional landscape). Shows the position, structure, and number of drainage networks (80 Small- and large-scale channels) in the study area.

The analysis shows that the study area has 80 small and large-scale drainage networks. These number of networks will later be compared with the drainage system of the surrounding reference area to see how much the mining activities have influenced the drainage network systems and to define a target number for the topographic reconstruction.

4.4 Analysis of Reference Area

4.4.1 Slope Analysis

The purpose of creating a slope map of the reference area is to examine the slope distribution of the undisturbed land, and to compute an average mean slope. The assumption in geomorphic reclamation is that the average slope of the reclamation site should approximate the average mean slope of the surrounding reference area (Toy and Chuse, 2004). In addition to the average slope angle, the distribution and gentleness of the topography of the reclamation site should be similar to the reference area. Some steep hill slopes on one side of an area, and a flat ground on another side can give an average mean slope that is similar to an evenly distributed high, low, and middle ground. Thus, the slope map of the reference area is expected to show not only the average mean slope but the distribution of the high and low grounds.

After a DEM of the reference area is clipped from the original USGS DEM, it is uploaded to ArcMap software to extract a slope map and to compute the average mean slope. As mentioned above, the Slope spatial analyst tool detects the slope gradient or steepness from each cell of a raster in ArcMap. The reference area DEM was run under the Slope tool to produce a map that shows the slope distributions of the area (Figure 4.5).

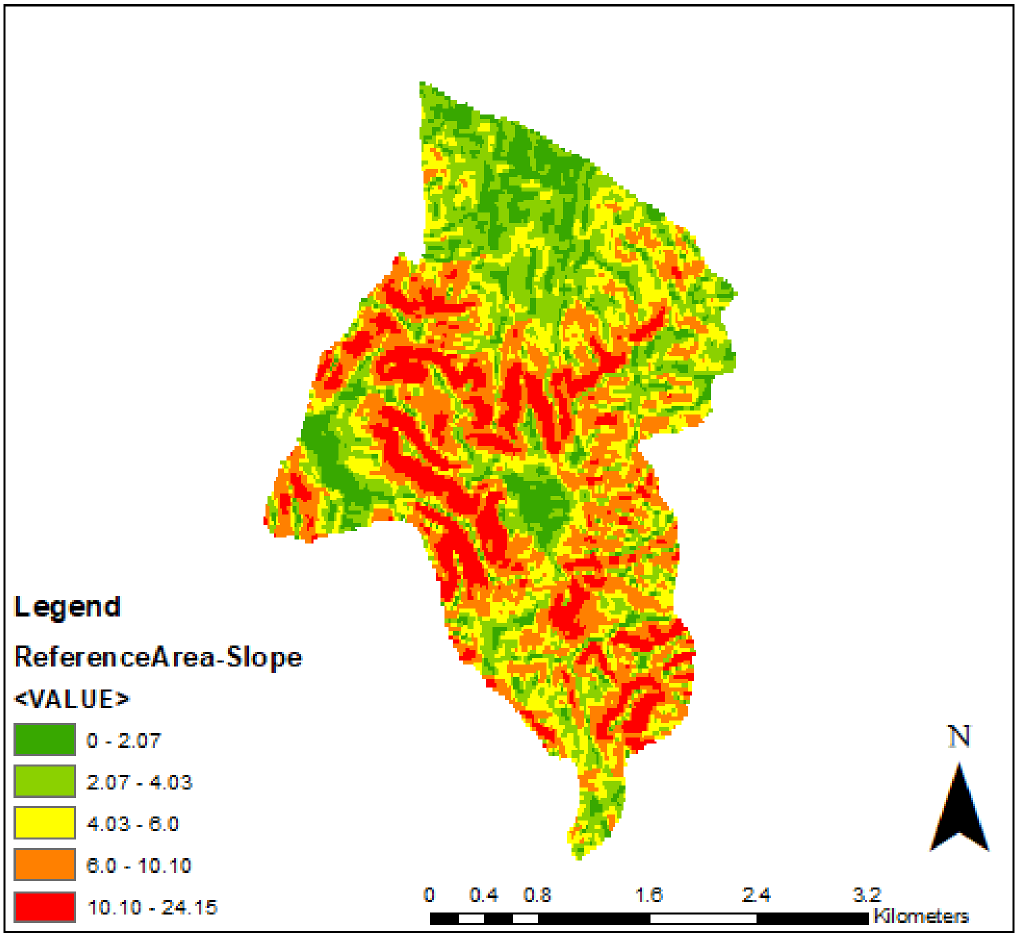


Figure 4.5: Computed Slope map of Reference area (Surrounding area). Slope range from 0 to 24 degrees with an average mean slope of 6.05 degrees.

Degrees are the unit measurement of the map, which range from 0 to 90. The average mean slope is then automatically calculated from the slope map. For the reference area, the minimum and maximum slope angles are 0 and 24.15 degrees respectively, and the average mean slope is 6.05 degrees. The slope map of the reference area shows that the slope distribution of the area is even. High and low ground areas seem to be distributed evenly throughout the site. The average mean slope of the reference area is a target value for topographic construction.

4.4.2 Watershed Area Analysis

In geomorphic reclamation, significant attention is given to increase the number of watershed catchment areas because the larger the watershed area the slower the runoff speed (Toy and Black, 2001). For natural geomorphic processes, catchment area areas are preferred to be hillslope shapes which are low in gradient, short in length, and concave in profile (Toy and Chuse. 2004; Ritte, 2002). In this study, the primary purpose of the watershed area analysis is to investigate the changes in mining activities caused to the site. To examine the alteration, the number of watershed catchment areas of the study site calculated above is compared to the total number of catchment areas of the reference site. The difference in the number of catchment areas between the mined and reference area will give an understanding of how significantly the mining activities affected the catchment area.

The DEM of the reference site was run through multiple tools to determine the total catchment area. Initially, the original DEM was computed under the Fill tool to remove small imperfections in the data and to fill sinks in the raster surface. When a new filled DEM is created, it then runs under another tool called flow direction. As stated above, the Flow direction tool is used in ArcMap to analyze flow direction from each cell to its steepest downslope neighbor. The new flow direction DEM contains a categorized cell unit that flows in the same direction. The Catchment area tool was then run to map out the categorized areas that catch precipitation and flow in the same direction (Figure 4.6).

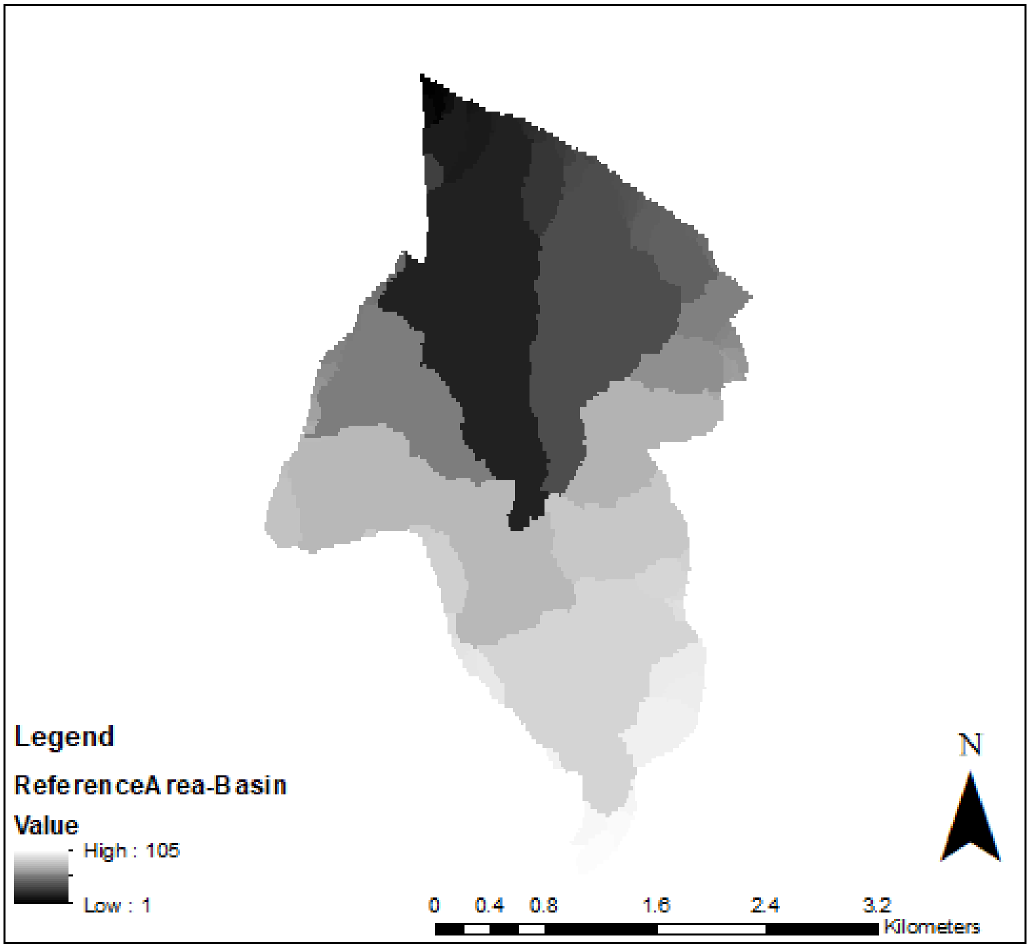


Figure 4.6: Catchment area map of the Reference Area (surrounding area). 105 small scale and large scales of the watershed catchment area.

The shaded polygons indicate the catchment area which flows in the same direction. The total number of the watershed catchment area of the reference area is 105. While the number of drainage catchment areas of the reference area is much fewer than the study area, it remains the target for the topographic reclamation because it is a naturally developed catchment areas (Toy and Black, 2001; Chorley, 1971).

4.4.3 Drainage Network Analysis

A dendritic drainage pattern is the most favored for geomorphic reclamation because it natural branches out in different directions (Haigh, 2000). A study done in 57 reclaimed mines in North America showed that deficient drainage design was a common reason for erosion in reclamation sites (Zapicoa et al., 2018; McKenna and Dawson, 1997). Failure in selecting a reference area with an appropriate drainage system can consequently cause the failure of the drainage design of the reclaimed land (Yavuz and Altay, 2014). As mentioned in Chapter Three, the reference area is mainly selected for its diverse drainage system. It has naturally branched water channels, which is expected to give diverse flow direction when mimicked for topographic reclamation.

A watershed map was used to generate a drainage network map of the reference area. Flow direction raster, which was previously used to generate the catchment area map was also used to compute the flow accumulation of the area. The Flow accumulation tool was used to process the flow direction raster, which was created earlier for the catchment area analysis. The result from flow accumulation tool is a raster of accumulated cells that flow into the same downslope cell. The new flow accumulation DEM contains categorized raster cells that flow to the same downslope area. The map displays a range of raster cells that accumulate flow from 0 to 2638 raster cells. A raster calculator is then used to sketch out the drainage patterns in raster format. Since the very small drainage networks are not significant for this study, only the large networks were mapped. To show a reasonable comparison between the study area and the reference area, the same sorting number was used for the raster calculator. Flow accumulation > 500 is calculated in the raster calculator to create a network of streams that accumulate flow from 500 or greater raster cells. To have a definite number of stream networks the raster drainage network is then changed to polylines. The same as the study area drainage map, the final drainage network map of the reference area also shows the position, structure, and number of drainage networks, as shown in Figure 9. The total number of small and large-scale drainage networks of the reference area was found to be 149 channels. The main objective of this research task is to mimic these drainage networks on the reclamation site.

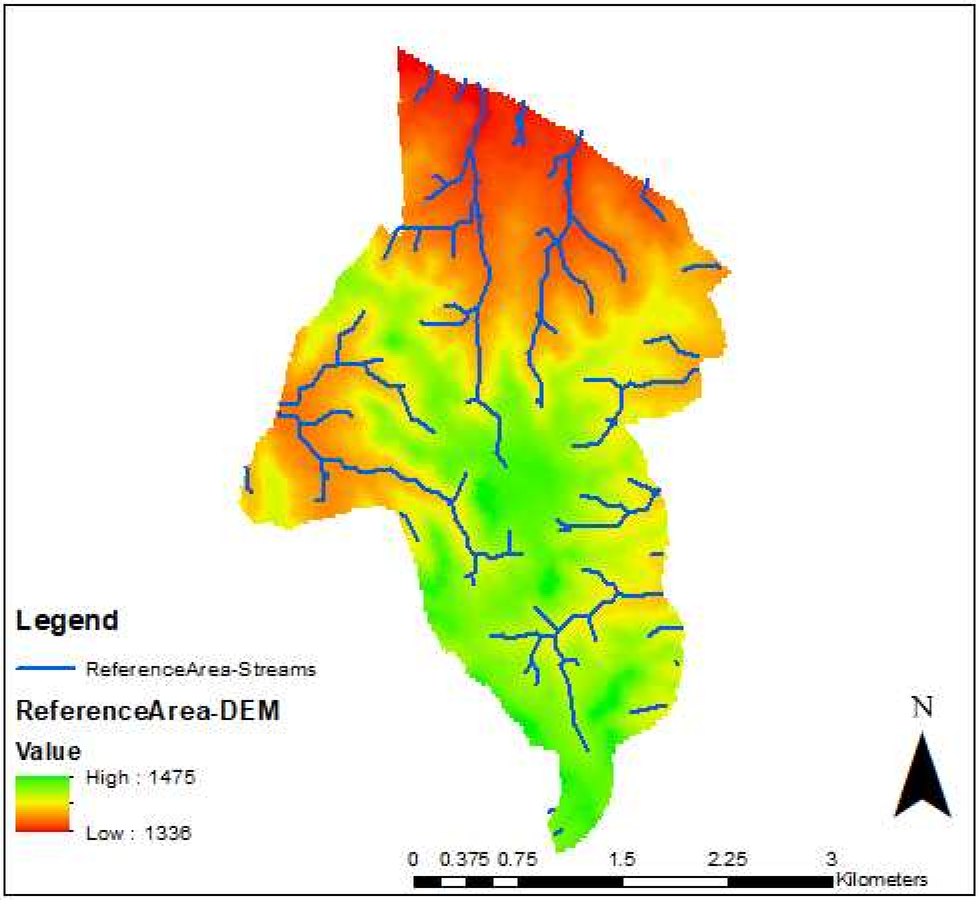


Figure 4.7: Drainage network map of the Reference area (Surrounding). Shows the position, structure, and number of drainage networks (149 Small- and large-scale channels) in the reference area.

4.5 Preliminary Reclamation Design

4.5.1 Digitization of Elevation Points of Reference Area

From previous studies, such as (Zapico et al., 2018: Martín-Duque et al., 2009: Toy and Chuse, 2004) on geomorphic reclamation, several methods were developed for landscape design. In some studies, a contour map of the mining site extracted from DEM was manipulated in Carlson software in order to approximate the characteristics of the surrounding area (Toy and Chuse 2004). According to information gathered from an expert (John Grubb, personal communication) in geomorphic reclamation from Navajo, San Juan, and La Plata mines, primarily an undisturbed reference area was selected for each area to be reclaimed. Then the design of the fluvial geomorphic landscape, the meandering streams and associated landforms were modeled by various software. The design was transferred to on-board dozer computers. GPS systems on the dozer and operator skills were utilized to bring the reclaimed area to the desired landforms and fluvial characteristics. Irrespective of the method, the common approach of geomorphic reclamation is that the area to be reclaimed must mimic the surrounding landscape (Zapico et al., 2018).

In this demonstration, a different method of mimicking the surrounding area was selected. The reference area was originally clipped as the same shape, size, area, and perimeter as the area to be reclaimed (i.e Study Area). The purpose of having the same structure and size of both the study and reference areas is to digitize points in the reference area, which will then be transformed into the study area. These digitized points occupy the same position in the study area as they do in the reference area, as shown in Figure 4.8. These digitized points are known as "features" in ArcMap. Each point is digitized manually on the reference area, and after all points are selected, they are saved as one feature class in ArcMap. To avoid confusion on the procedures, this feature class was named "digitized reference area elevation points." A data management tool called "copy feature" was used to make a copy of the digitized elevation points. The copied feature class was then named "digitized study area-elevation points." The "digitized study area-elevation points" feature class was then dragged and carefully overlayed on the study area. Since the overlay is manual, attention must be given to placing the points on the exact spot as it was in the reference area. Though the digitized points are on different sites, corresponding points of the study and reference area lay in the same position and have the same database ID number. The purpose of having the same digitized points on the reference and study area is that the elevation value of each point in the reference area will be transferred to the study area, which will then give the study area new elevation points.

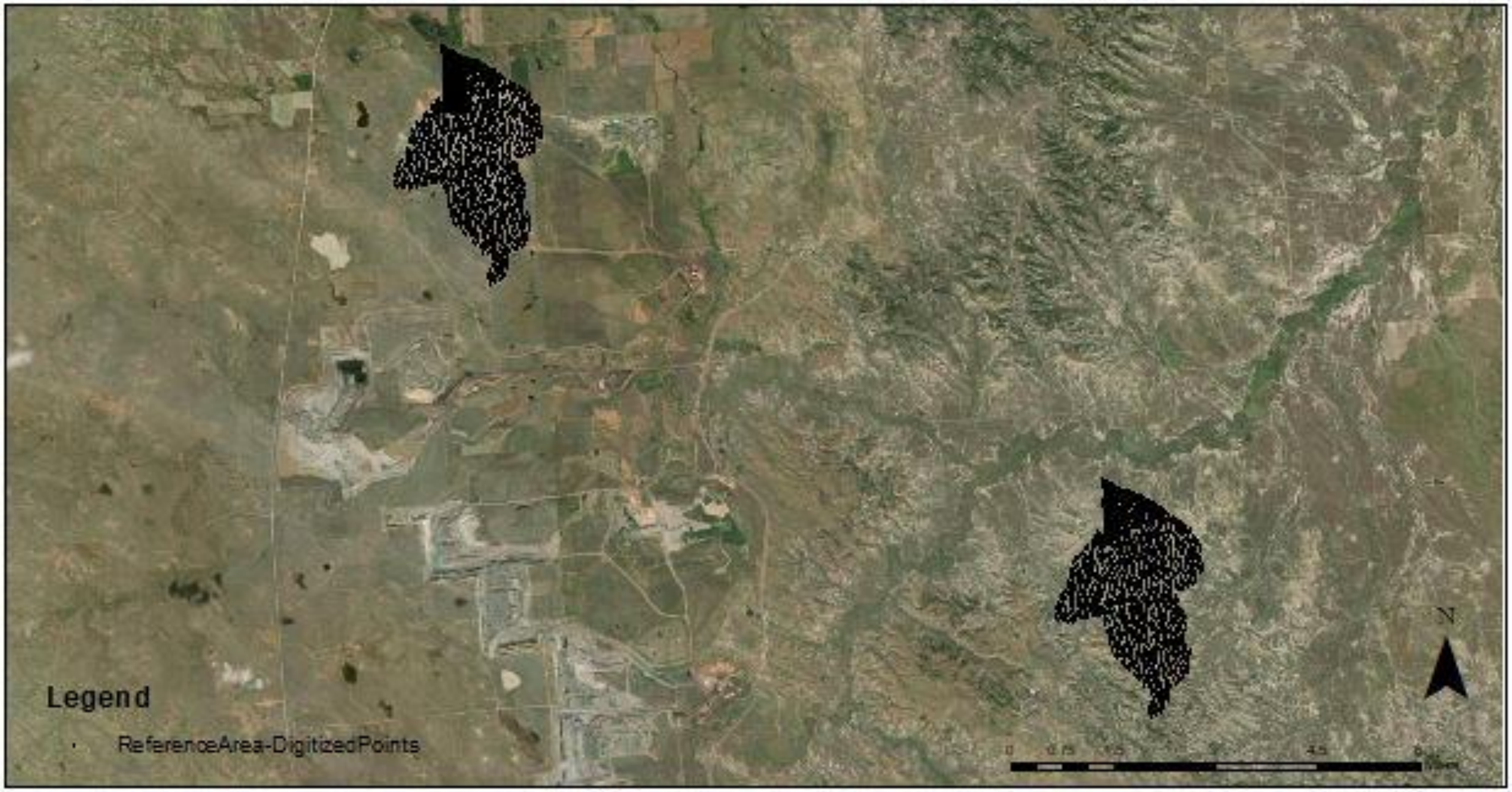


Figure 4.8: Digitization of elevation points on the reference and study areas. Corresponding digitized points in both sites have the same position and ArcMap ID number.

4.5.2 Generating New Digital Elevation Module for Study Area

A DEM is an elevation model. DEMs are usually generated from remote sensing data sets collected either from an aircraft (airplane, helicopter, drone) or spacecraft (satellite or Space Shuttle). It can also be generated either through direct measurement of point coordinates or extraction of x, y, z values from other data sets. For this demonstration, the latter one is selected.

When digitized elevation points were transferred from the reference area to the study area in the previous step, they were not projected. This implies that the points did not have x, y, and z coordinates. Both the digitized features on the study and reference area needed to be projected to the same planar region as the study and reference area. In this case, all geological maps were projected to WGS_1984_UTM_Zone_12N projection. Both digitized feature classes of the study and reference area were projected to the same zone by using the "Define Projection" tool in ArcMap. By projecting the digitized points, a coordinate system is assigned to each point on both sites. The corresponding points, with a same ID number, now have different coordinate systems. The next step is to calculate the elevation (z coordinate) of the reference site. Elevation value for each digitized point is calculated by the "Add Surface Information" tool in ArcMap. This tool runs the x and y coordinate of each point and extracts the z value from the DEM of the reference area. The reference site now has definite x and y coordinates and defined elevation values. The digitized feature class of reference and study areas both have attribute tables that contain ID numbers of the points and the x & y coordinates. After calculating the elevation, z coordinates for reference area, its attribute table now includes z values of each point. The purpose of calculating elevation values of the point in the reference area is to transfer the z (elevation) value to each corresponding point in the study area. While the digitized points in the study area have their own x and y coordinates, new elevation points are assigned by joining the attribute tables of both the study and reference areas' feature classes.

The new feature class of the study area now has an attribute table, which contains x, y and z (elevation) data. These data sets can describe the topographic feature of an area. As mentioned above, a DEM can be generated from topographic features. In this case, a "topo to raster" tool in ArcMap was used to create a new DEM for the study area from the new topographic feature created above. The newly generated DEM of the study area has an elevation range of 1336 to 1475 meters (Figure 4.9).

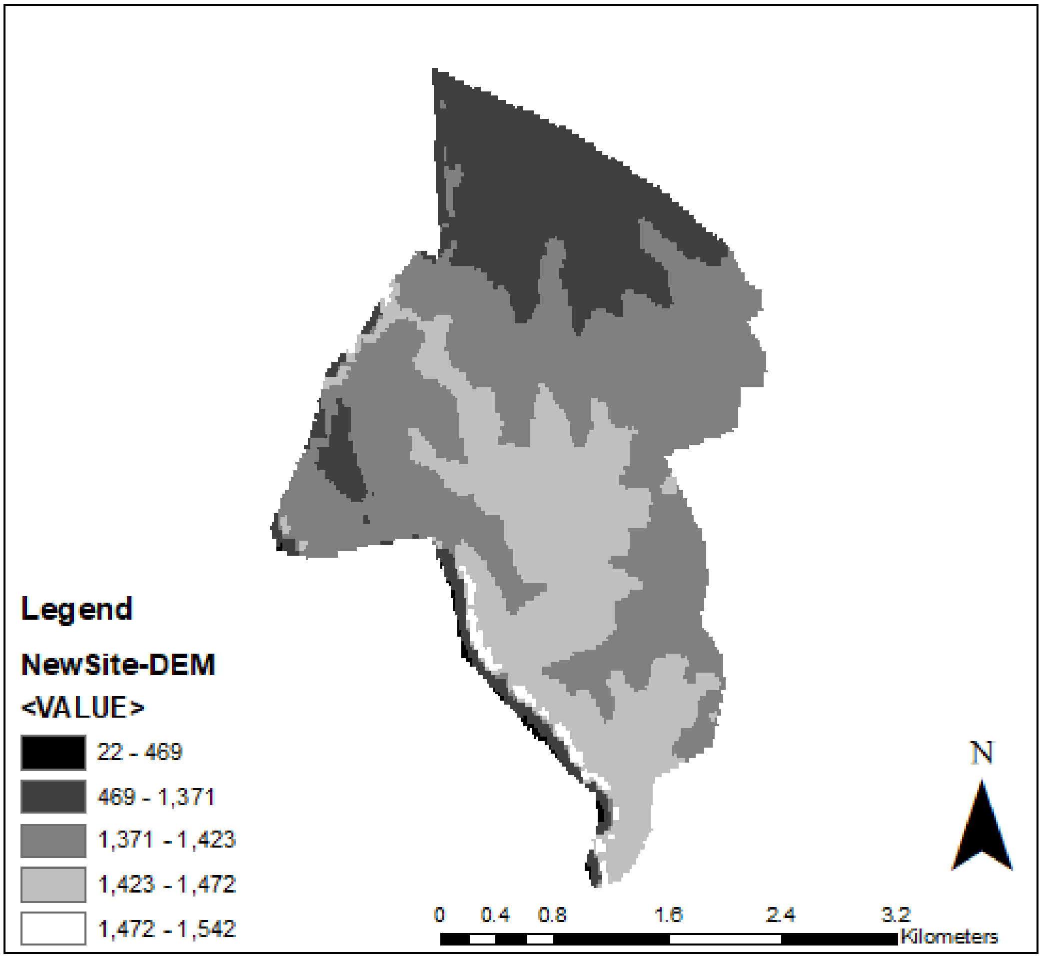


Figure 4.9: Constructed DEM of Geomorphic Reclamation Site

4.5.3 Topographic 3D Module of Reclamation Landscape

Three-dimensional (3D) models are often used to display proposed designs for different purposes. They do not only depict the physical features of a design, but they can also show relationships among the physical features of the surface. 3D modeling is especially useful when developing a preliminary study because it gives a perspective of the project and can be used as the foundation for further detailed studies. Particularly in this research, the purpose of the 3D modeling is to give a visual prospect of the reclaimed area and show how significant changes were created for the topography of the study area through the geomorphic reclamation approach.

After a DEM was generated for the reclamation site, it was transformed to triangular irregular networks (TIN) by a "Raster to TIN" tool in ArcMap. A TIN is vector-based digital geographic data that represents a surface morphology. It displays the physical features of a topography in a 3D module, (Figs 4.10 and 4.11). In preparation of the drainage network system of the new landscape, several analysis tools were used. The same procedures used to generate drainage network system of the study and reference area were also conducted for this task. The Fill tool was primarily used to remove small imperfections in the DEM and to fill sinks in the raster surface. Then the Flow direction tool was used to analyze the flow direction of the raster cells from each cell to its steepest downslope neighbor. Flow accumulation is then calculated to create raster of accumulated flow into each cell. The new topographic site has a range of 0 to 8255 flow accumulation cells that accumulate flow and drain into different downslope cell, which is much higher than the study and reference area. A raster calculator is then used to sketch out the drainage patterns. The same equation used for the study and reference area was used to maintain consistency of the results. Flow accumulation > 500 cells are calculated in the raster calculator to create streamlines raster cells. To have a definite number of stream polylines, the raster calculated map is then changed to polylines. These polylines represent the drainage network system of the reclamation land. Figures 12 and 13 show 3D surface module of the study area and the new reclamation landscape that illustrates the difference in visual appearance of the watershed hills and the drainage network systems of both topographies.

(A)

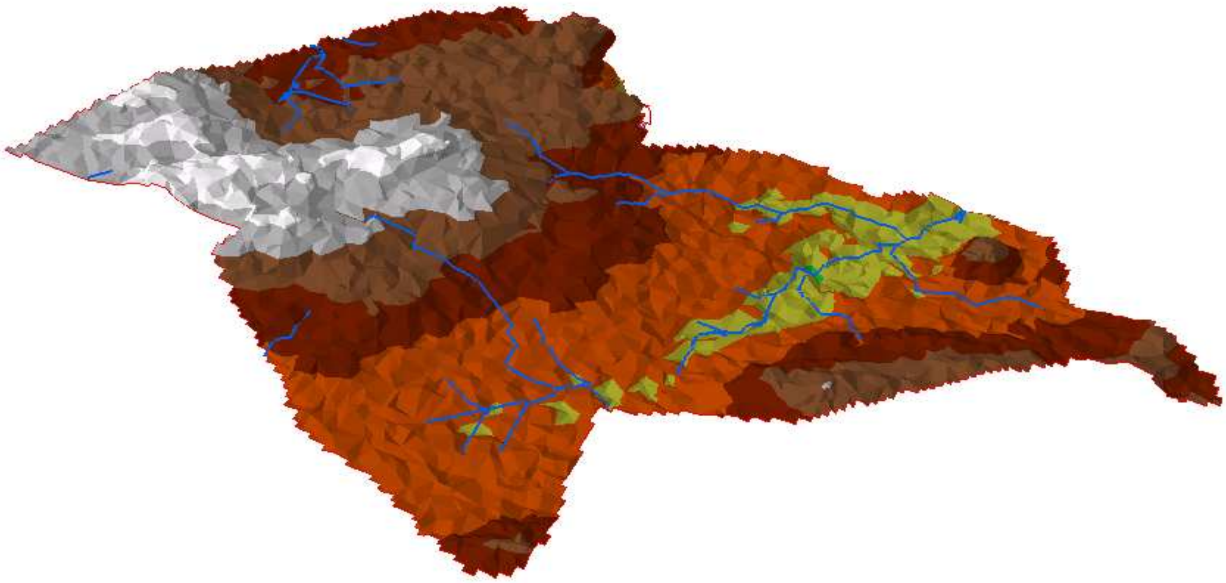


Figure 4.10: 3D Module of Study Area (Traditional Landscape)

(B)

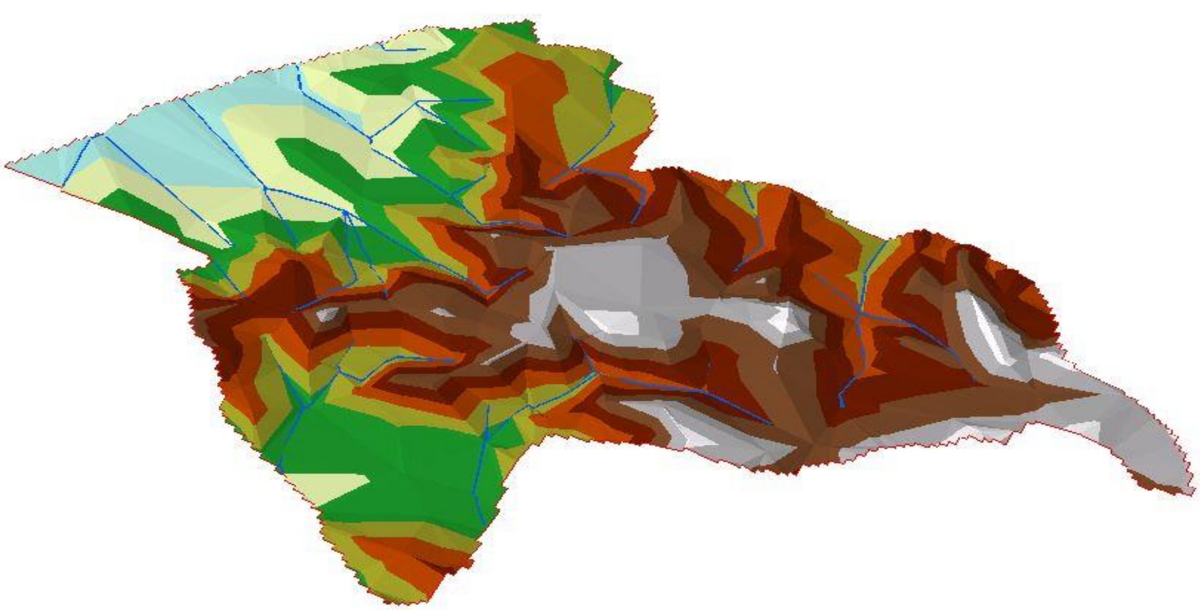


Figure 4.11: 3D Module of Reconstructed Geomorphic landscape

4.6 Volume Calculation of Earth Material

In this study, costs associated with the two reclamation approaches are estimated based on the amount of material to be moved to achieve the desired landscape. ArcMap software can compare the landscape surface of the study area to the reclamation surface generated above and calculate the amount of material that must be moved to achieve this landscape. While the actual topography reconstruction cost depends on multiple factors (de Werk et al., 2016), in this research, cost estimation is only based on the amount of material that must be moved.

To calculate the volume of the material to be moved for reclamation, the original DEM of the study area and the new DEM generated for reclamation were run using the "Cut and fill" tool. This tool calculates the volume change between two surfaces. It is typically used for cutting and fill operations. The map in Figure 4.12 shows the places where the majority of the cutting and fill should occur.

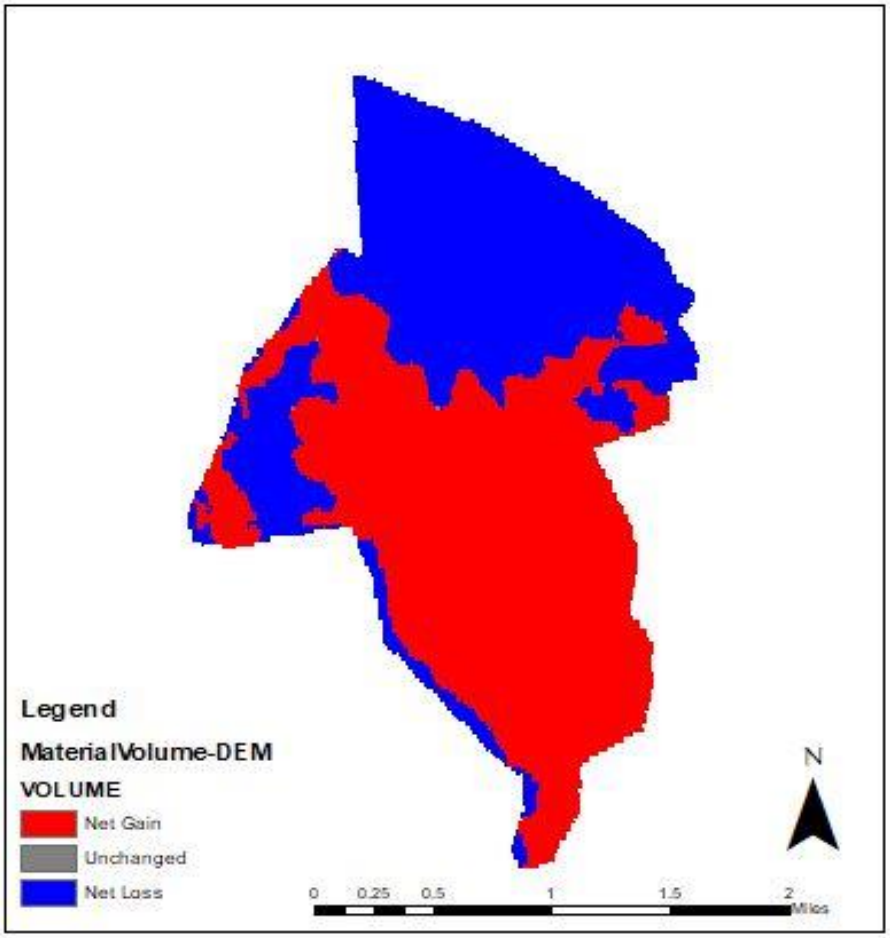


Figure 4.12: Cut and fill map (Blue area shows the cutting zone, red area shows filling zone). Cut volume = 163,157.56 ton: Fill volume = 642,184 ton

According to the cut and fill map generated, Table 4.1 shows the total volume of earth material to be cut and moved is 163,158 tons, and the total volume of filling material is 642,185 tons. If it is assumed the material moved from the cut would be filled, the total amount of material to be moved would be the difference between the volume of the cut and fill material, which in this case would be 479,027 tons.

Table 4.1: Volume of earth material displaced for reclamation.

Volume of Material Moved (tons)	
Cut	-163,157.56
Fill	642,184.92
Total tons	805,342.48
Fill-Cut (Expected volume to be moved)	479,027.36

CHAPTER FIVE: RESULTS

5.1 Topographic Reconstruction Results

The purpose of designing a topographic landscape in this study was to show a visual appearance of the study area after geomorphic reclamation, and to evaluate its characteristics before and after reclamation. For geomorphic reclamation approach, a surrounding undisturbed area was selected for reference for the construction. The selected reference area was within the same surrounding as the mine site and is located 12 km to the west and 6 km south of study area (Figure 2). The reference area is characterized by stable landforms naturally developed on geologic materials, and its geomorphic stability was determined by the absence of landform changes observed over the years from satellite images. On the contrary, the study area has long high walls and benches formed as a result of mining activities. The goal of this particular research task was to answer the research question, how much topographic change through geomorphic reclamation will be achieved that favors reduction in erosion? To answer the research question, the first task was to construct a reclamation landscape for the study area that mimics the reference area and evaluate the significant characteristic changes. Four evaluating characteristics were considered for comparison: average mean slope, number of watershed catchment areas, number of drainage networks and Melton Ruggedness Number (MRN).

The new DEM generated for reclamation and described in detail in Chapter 4, was processed for generating the slope, catchment area, and drainage network maps of the reclamation area by the same procedures mentioned above.

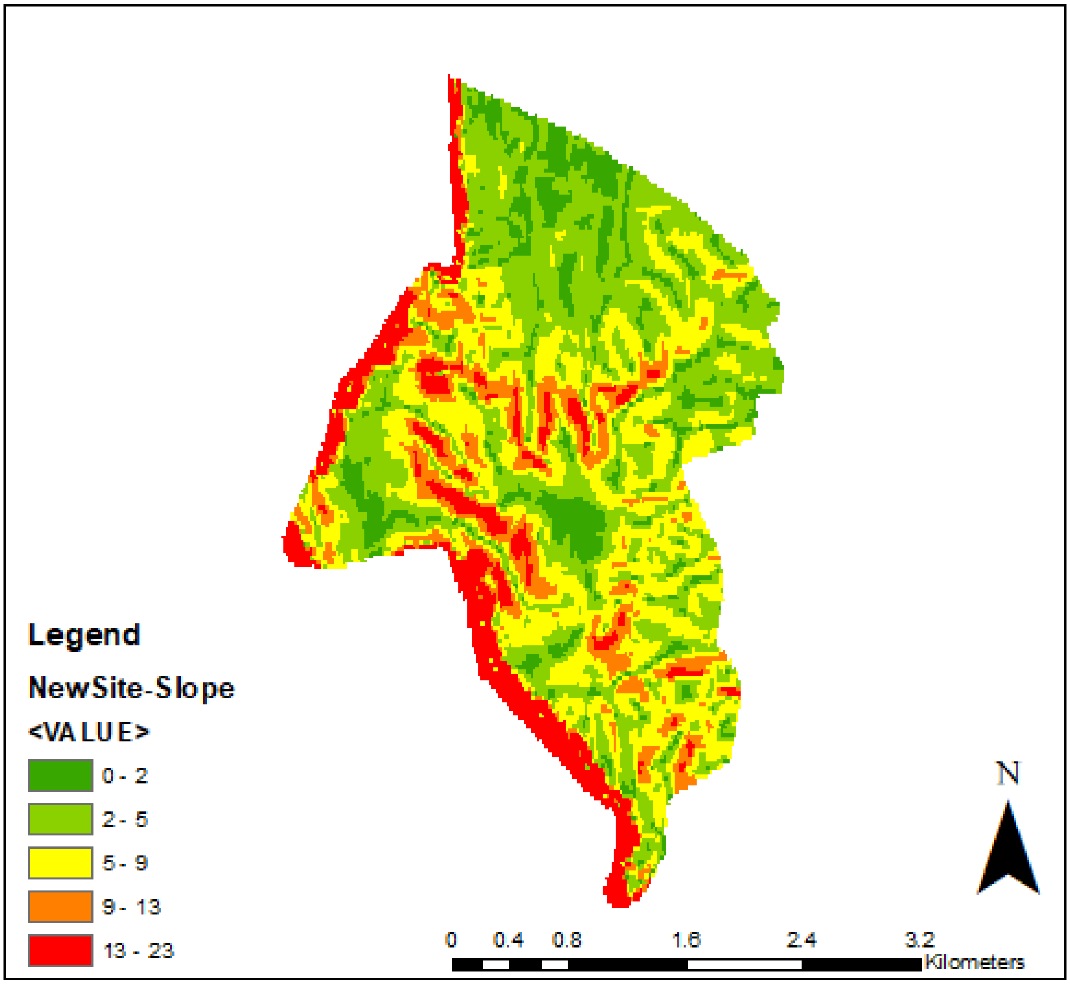


Figure 5.1: Computed Slope map of Geomorphic landscape (Reclamation area). Slope range from 0 to 23.5 degrees with an average mean slope of 9.11 degrees.

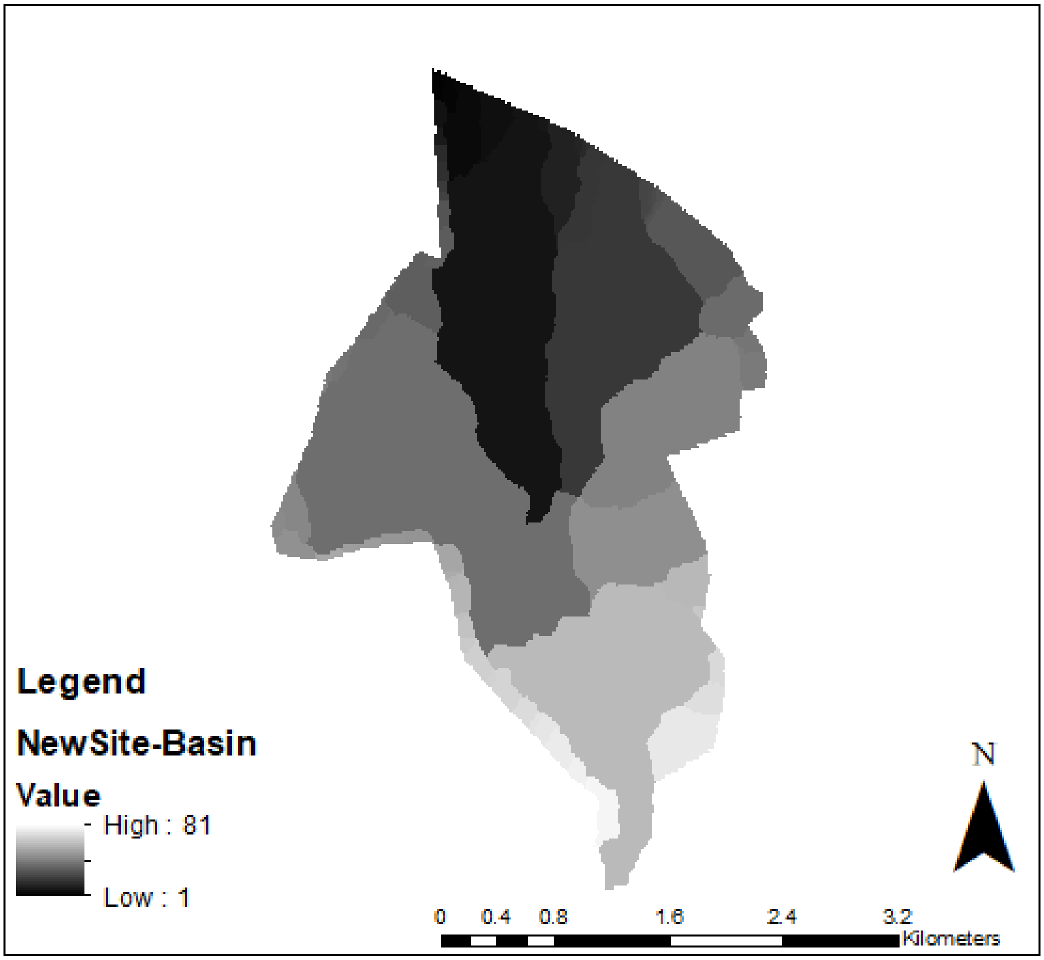


Figure 5.2: Catchment area map of the Geomorphic (Reclamation area). 81 small scale and large scales of watershed catchment area.

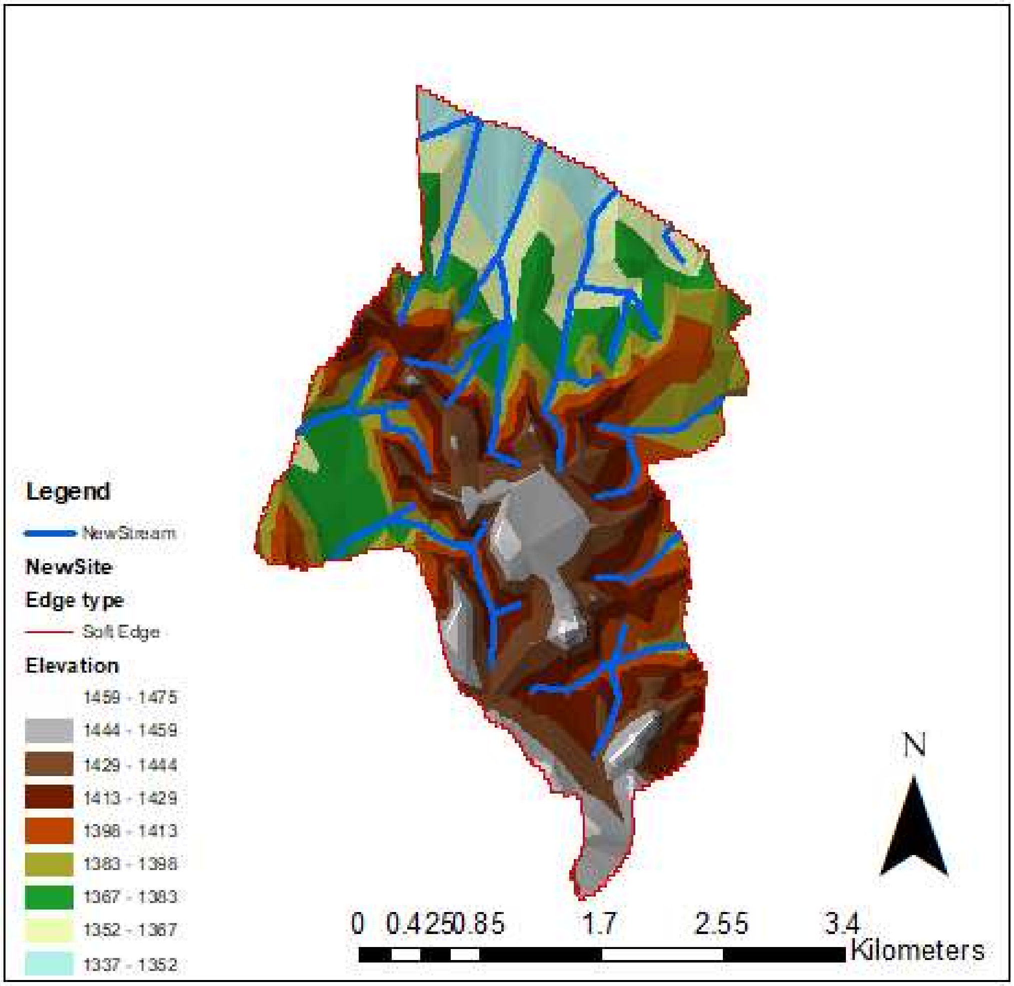


Figure 5.3: Drainage network map of Geomorphic landscape (Reclamation). Shows the position, structure, and number of drainage networks (189 Small- and large-scale channels) in the reconstructed landscape.

From the above maps, the average mean slope, number of watershed catchment areas and number of drainage networks of the new topography were computed. Meltons Ruggedness Number (MRN) was also computed to determine the differences in elevation of the catchment area relative to its area. Table 5.1 shows the alteration of topographic characteristics of the study area, reference area and the constructed reclamation landscape.

Table 5.1: Comparison of site characteristics of study area, reference area and reclamation area

Comparison Factors	Study Area	Reclamation Site	Reference Area
Average Mean Slope (Degrees)	1.8	9.11	6.05
Number of Catchment areas (Count)	No natural Catchment areas	81	105
Number of Drainage Network (Count)	80	189	149
Meltons Ruggedness Number (MRN)	6.35	7.44	7.64

As shown in Table 5.1, the average mean slope of the study area would be changed from 1.8 degrees to 9.11 for reclamation, which is closer to the average slope of the surrounding reference area. Increase in the number of catchment areas favor geomorphic process by creating a variety of surfaces for water flow (Haigh, 2000), in this study the number of watershed catchment areas almost approximate the reference area. The new topographic design generated 81 watershed catchment areas, which is almost similar to the number of catchment areas of the reference area (105). From the geomorphic reclamation approach, this is a good result for the number of catchment areas because as the number of drainage catchment area areas increase, sediment yield and the sediment delivery ratio (sediment yield/total erosion) decrease, which results in relatively less erosion (Zapico and Martín Duque, 2018: Toy and Chuse, 2004; Ritte, 2002). Regarding the number of drainage networks, the study area currently has 80 small and larger scale drainage channels. The target for reclamation from the reference area was 149 drainage streams; however, the new topographic design shows 189 streams. Not only does the new topographic design approximate the reference area, it also would produce more drainage systems. The increase in drainage systems would decrease runoff and could also be a better environment for vegetation and the ecosystem in general (Toy and Chuse 2004; Toy and Daniels, 2000). MRN is also calculated to evaluate the elevation of catchment area to the total site area. Since there is a little difference in slope on the traditional, geomorphic and reference landscape, the MRN also did not show a significant difference from the original traditional landscape, although it is closer to the natural reference site.

5.2 Cost Estimation of Material Handling

Open pit mining operations require complex systems including drilling, blasting, dewatering, materials handling, and primary crushing to be established. Selecting the best mining technology is at the core of mine design, production, and reclamation (Xiaohua et al., 2013). The factors that affect the selection of a haulage system in a mining operation are listed as follows (Rahmanpour et al., 2014): mine size and production rate, selective mining requirements, mining face length (or length of working benches), pit geometry (periodic pits and final pit geometry), climate and weather conditions, depth of the deposit and pit, topography of the pit surroundings, land disturbance, haul road grade and condition, reliability, availability, projected mine life, labor costs, useful life of equipment, haulage distance, in-pit crusher relocation and installation time, support and availability of spare parts, capital costs, the net-to-tare ratio of the trucks (the ratio of the load of the trucks to the empty truck weight), material size, material moisture, operational cost, density and swell factor, ground condition, flexibility of the system, safety, dumping level, dump configuration (side hill, valley fill, or heaped), type of production, noise exposure regulations, gas emission, dust emission, and management requirement.

Material haulage from one place to another is one of the major costs of mining operations and generally accounts for up to 60% of the total operating costs (Lieberwirth 1994). Cost analysis of material haulage depends on the purpose of the operation and is therefore affected by a wide range of factors listed above (Xiaohua et al. 2013). One of the most frequently used haulage methods throughout the world is truck and shovel system (TS) (de Werk et al., 2016). Caballo mine is also one of the mining companies that use truck and shovel system for its mining activities. For this reason, it was assumed that the mine would also use truck and shovel system for reclamation purposes.

This research cost analysis adopts the methodology described by de Werk et al. (2016). In their approach, the authors report that the average unit haulage cost of the truck and shovel method ranges between $12.246/ton and $18.930/ton. Based on that assumption, for geomorphic reclamation approach of 10 km^2 study area of this project, the total weight of materials to be handled (479,027 tons) would cost between $5,866,170 and $9,067,988 as calculated below:

Material to be handled [1] = 479,027.36 ton

Cost of haulage per ton (Marco de Werk et al., 2016) = $12.246/ton (minimum) [2] - $18.930/ton (maximum) [3]

*Minimum cost estimation = [1] * [2] = [479,027.36 tons] * [$12.246/ton] = 5,866,169.7$*

*Maximum cost estimation = [1] * [3] = [479,027.36 tons] * [$18.930/ton] = 9,067,987.92$*

The cost of reclamation estimated above is predicted to be lower than the actual cost because there are other main factors that contribute to cost in actual ground reclamation (de Werk, et al., 2017). In most mines, a limited budget is allocated for reclamation (Farber and Grinner, 2000). The main priorities are issues posing health and safety risks (first priorities) and those posing environmental problems are second priorities (Mishra et al., 2012). For the environmental problems, the main focus and budget is given to water management and treatment. The budget required to manage impacted water after a mine has been closed can have a significant effect on the overall reclamation costs (Espinoza and Morris, 2017). Other factors that also contribute to reclamation costs are the reconstruction of housing, aquatic life, vegetation, infrastructure, human labor, and facilities (Mishra et al., 2012). However, this research estimation is solely on the amount of material haulage and provides an approximation of cost per material handling in a given unit area for geomorphic reclamation.

5.3 Cost Comparison: Traditional and Geomorphic Reclamation

At a minimum, all mine reclamation plans should include an engineering design and process for minimizing pollution potential in the long term (Goldemund et al., 2008). A simple traditional reclamation plan may include the placement of a 60 cm thick soil cap. This soil cap minimizes contamination of contact rainwater runoff and reduce generation of AMD (Acid Mine Drainage). The uppermost 15 cm of the cap is typically topsoil; a minimum thickness necessary to allow permanent establishment of vegetation (Espinoza and Morris, 2017). Based on the hypothetical cost estimation of coal-mined lands by (Espinoza and Morris, 2017), soil cap design would require 2.4 mcm of traditional soils (i.e., 1.8 mcm of general fill and 0.6 mcm of topsoil). At $12/m3 for topsoil and $3/m3 for general fill, closure would cost $12.6 million just in placement of the soil cover for 4000 hectares land this estimation is without the inclusion of other reclamation costs such as regrading of side slopes, water management and treatment, and general site restoration. According to that estimation 10 km^2 (study area) soil cover would cost $3.15 million.

This paper examines potential costs for geomorphic mine reclamation, which is important for establishing correct accruals and to avoid understating future liabilities. A hypothetical example taken from the mining literature (Espinoza and Morris, 2017) is used as a comparison for the previous estimated geomorphic reclamation cost of this project. As expected, a traditional reclamation method is lower in capital cost ($3.15 million / 10 km^2) because the main task is to put topsoil back without much topographic reconstruction (Sommer and Sohngen, 2007). Whereas in geomorphic reclamation, the main focus is creating natural-like catchment areas and drainage networks (Toy and Chuse, 2004; Ritte, 2002), which cause higher capital costs ($5,866,169.7 to $9,067,987.92).

CHAPTER SIX: DISCUSSION AND CONCLUSIONS

6.1 Discussion

The geomorphic reclamation approach carried out in this research was selected because it is a better alternative to the widely used traditional (engineering) reclamation system (Martín-Duque et al., 2010; Toy and Chuse, 2004). Based on that hypothesis, the aim of this research was to design a landscape of a mine site through geomorphic reclamation approach from DEM data and test it. A subobjective for this research was to estimate the cost of reclamation based on the new topography design. Given that cost estimation in preliminary stages of reclamation can be complicated and expensive (Marco de Werk et al.,2016), this research is timely because it provides practical procedures to estimate cost by comparing the mined site to the new topography design.

The interpretation of results can be categorized in two outcomes: (1) Development of a reclamation topography from DEM and (2) cost estimation to achieve such reconstruction.

1. The reconstruction of topography outcome supports the hypothesis that a geomorphic reclamation method can be designed for a mined area from a DEM and can provide an insight about the resulting landscape. The goal is to show a preliminary design of a geomorphic reclamation that can give a perspective to what the average slope, shape, flow direction, number of catchment areas and drainage streams would look like after reclamation. The results of the comparison between the characteristics of the study area and those of the new topography highlight the significance of geomorphic reclamation. Based on previous practices, the increase in number of drainage networks and catchment area is believed to produce a favorable environment for vegetation and wildlife animals (Angel and Burger, 2009: Whisenant, 2005). Suitable drainage system produces distinctive vegetation patterns because the drainage ditches will not be subjected to bank erosion, sedimentation, and soil subsidence (Pal, 2017). Narrow and small-scale streams are effective in draining and function as small-scale topographic depressions. Flora species are distributed in association with soil moisture conditions induced by topographic variation at both small (i.e., ditches) and larger (i.e., site-wide) spatial scales. Hence the vegetation system and the wildlife that feed upon them are dependent on the drainage system of the landscape (Oltean, 2018; Pal 2017). The results of this study show that the new reclamation site has a greater number of drainage streams than the original study area, and an average mean slope that approximates

the reference area. The new topography characteristics can further be processed for further detailed design of the topography. The position of the streams can help to navigate the mainstream of the surrounding area, when constructing the streams on the ground. The position and shapes of watersheds are clearly mapped which contribute to further design of hillslopes on the ground. Future studies can take advantage of the initial results from this study to build more detailed topographic designs for environmental impact.

2. The second outcome of this study was an estimation of reclamation costs from the reconstructed topographic map. Cost estimation is significant because it is the principal factor for reclamation decision by mining companies (Marco de Werk et al., 2017). The method of reclamation to use mainly depends on the cost of the reclamation method. The primary goal of mining companies is to make profit with a minimum cost and reclamation can be expensive for mining industries (Toy and Chuse, 2004). Different methods of cost estimation are applicable nowadays. Some of the previously used cost analysis methods are (Espinoza and Rojo, 2017; Espinoza, 2017): Net Present Value (NPV) analysis reproduces the cash flow analysis of reclamation originally developed for investment purposes; Modern Asset Pricing (MAP) analysis is an alternative approach to valuing reclamation opportunities that takes advantage the availability of futures to account for risk; Decoupled Net Present Value (DNPV) analysis is a risk-averse method, asses the risk associated with reclamation cost. It always reduces the value of a reclamation investment proposition independent of the source of risk. These methods are detailed cost analysis methods, however in this study, a simple preliminary method of estimating cost was demonstrated. In this demonstration, the cost of the material handling was the only factor considered for cost estimation. The difference in elevation between the study area and the new topography shows places where there is a need to cut and fill the ground levels. Through that concept, the volume of the earth material was calculated. Cost was then estimated to range from $5,866,170 to $9,067,988, which is anticipated to be lower than the actual cost because there would be other additional costs of reclamation. According to (Toy and Chuse, 2004), initial costs associated with geomorphic reclamation method tend to be higher during the first stage of reclamation. A hypothetical example taken from (Espinoza and Morris, 2017) mining literature is used to compare with the previous estimated geomorphic reclamation cost of this project. For a

given area of 10 km^2, a traditional reclamation method is lower in capital cost (\$3.15 million / 10 km^2) of material handling than geomorphic reclamation, which range from \$5,866,169.7 to \$9,067,987.92 for material handling.

Other aspects of reclamation activity are also important in cost estimation. Some of the other main factors of reclamation are restoration of surface topography (dry and wet land), natural and cultural patterns, camouflage of reclamation landscape, revegetation, infrastructure, mass stability, air pollution, water treatment and water supply (USGS, 2000). However, the limitation of this research is that it considers only amount of material handling for cost estimation because it has more weight on the total cost (Marco de Werk, et al., 2016 :Lieberwirth 1994). Although the geomorphic reclamation approach has initially higher capital costs compared to other reclamation methods, cost savings in the long term would be expected, in addition to regulatory benefits. The goodwill achieved with the community and environmental regulatory agencies is also a cost advantage, although difficult to quantify.

6.2 Conclusions

The foundation for all future surfaces land use practices after mining rely on topographic reconstruction because it is a critical part of the reclamation process. The goal of topographic reconstruction is the creation of steady-state landscapes. Other reclamation goals can be effective because of a steady landscape (Toy and Chuse, 2004). A complete preliminary design of geomorphic reclamation (ArcGIS method) was carried out for the northern mined section of Caballo mine. A suitable and stable reference area was found nearby, from which the corresponding characteristic values were computed to make a new topographic DEM using ArcMap software. Following the generation of DEM for the reclamation site, comparisons of the characteristics of the two sites was carried out. The Average mean slope: 9 degrees, Number of drainage catchment areas: 81, Number of drainage networks:120 -189, MRN: 7.4 of the new reclamation topography appear to approximate the surrounding reference area of average mean slope: 6 degrees, Number of drainage catchment areas: 105, Number of drainage networks:149, MRN: 7.6, which is a primary goal of geomorphic reclamation approach. The contribution of this thesis is that the process of designing preliminary geomorphic reclamation, from finding suitable stable reference landforms to the design of reclamation site, is significant because: (i) there are not many examples of preliminary geomorphic-based reclamation (ii) To the Author's knowledge and literature search, DEM has not been used as the primary database for geomorphic reclamation design, and (iii) practical examples of preliminary cost estimation for geomorphic reclamation are extremely rare.

The characteristic values obtained from the new topography were as expected. These values can be considered reliable and representative for this reclamation method at this site because: (i) the average mean slope resembles the average slope of the reference area (ii) not only does the number of drainage catchment areas area approximate the number of catchment areas in the reference area, but the catchment areas also have similar profiles (iii) the number of drainage network surpasses the number of drainage of the reference area, which was proven beneficial in previous studies (Zapico et al., 2018). Although the described geomorphic reclamation is applied as a preliminary assessment tool on a reclamation project, it is concluded, from its results, that it constitutes a new, real approach for designing geomorphic mining reclamation.

6.3 Recommendations

The DEM manipulation approach used for geomorphic reclamation can be used as reliable preliminary reclamation design. Further detailed topographic design can be developed from the results of this method. Additional research is needed to establish a more conclusive evaluation of the site characteristics obtained from this geomorphic reclamation, to evaluate the credibility of the methods used, and to evaluate accuracy of the results reported herein by using a different approach to topographic design.

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APPENDIX A
SUPPLEMENTARY DATA FOR CHAPTER 3

Table A1: Boundary Table

Boundaries	FID	Id	Area (Km^2)	Perimeter (km)
Study Area	0	0	10	16
Reference Area	0	0	10	16

APPENDIX B

SUPPLEMENTARY DATA FOR CHAPTER 4

Table B1: List of Raster Elevation Cells of Study Area Slope Map

Rowid	VALUE	COUNT	AREA	MIN	MAX	RANGE	MEAN	STD	SUM
1	1347	3	2.31481E-07	1.718636751	3.623494148	1.904857397	2.399907112	0.86706438	7.199721336
2	1348	1	7.71605E-08	4.838617325	4.838617325	0	4.838617325	0	4.838617325
3	1349	1	7.71605E-08	7.861470222	7.861470222	0	7.861470222	0	7.861470222
4	1350	2	1.54321E-07	5.652274609	7.455642223	1.803367615	6.553958416	0.901683807	13.10791683
5	1351	1	7.71605E-08	7.901516914	7.901516914	0	7.901516914	0	7.901516914
6	1352	1	7.71605E-08	6.669693947	6.669693947	0	6.669693947	0	6.669693947
7	1353	1	7.71605E-08	7.760402203	7.760402203	0	7.760402203	0	7.760402203
8	1354	1	7.71605E-08	7.685398579	7.685398579	0	7.685398579	0	7.685398579
9	1355	2	1.54321E-07	14.17235565	17.76005173	3.587696075	15.96620369	1.793848038	31.93240738
10	1356	2	1.54321E-07	11.02115154	16.48736954	5.466217995	13.75426054	2.733108997	27.50852108
11	1358	2	1.54321E-07	11.3420763	12.89297485	1.550898552	12.11752558	0.775449276	24.23505116
12	1359	1	7.71605E-08	9.927913666	9.927913666	0	9.927913666	0	9.927913666

Table B1
Continued

13	1361	1	7.71605E-08	11.81838322	11.81838322	0	11.81838322	0	11.81838322
14	1363	1	7.71605E-08	11.73614407	11.73614407	0	11.73614407	0	11.73614407
15	1364	2	1.54321E-07	9.75932312	11.62231255	1.862989426	10.69081783	0.931494713	21.38163567
16	1365	1	7.71605E-08	12.37701893	12.37701893	0	12.37701893	0	12.37701893
17	1366	1	7.71605E-08	10.15479279	10.15479279	0	10.15479279	0	10.15479279
18	1367	3	2.31481E-07	9.395763397	19.84114647	10.44538307	16.09450785	4.747820802	48.28352356
19	1368	2	1.54321E-07	1.313744903	5.450723171	4.136978269	3.382234037	2.068489134	6.764468074
20	1369	6	4.62963E-07	1.642019272	20.0634594	18.42144012	11.11498133	7.02049681	66.689888
21	1370	6	4.62963E-07	2.500146151	17.67177963	15.17163348	6.873688499	5.082973217	41.24213099
22	1371	2	1.54321E-07	5.332045078	9.177010536	3.844965458	7.254527807	1.922482729	14.50905561
23	1372	6	4.62963E-07	1.038674831	9.390222549	8.351547718	4.52398026	3.044331416	27.14388156
24	1373	17	1.31173E-06	0	16.03211594	16.03211594	2.965213628	3.61453968	50.40863168
25	1374	54	4.16667E-06	0	11.0351162	11.0351162	2.324961816	2.358458213	125.547938
26	1375	60	4.62963E-06	0.328490198	11.45875263	11.13026243	2.447242262	2.015252539	146.8345357
27	1376	94	7.25309E-06	0.328490198	14.16183472	13.83334452	2.118182177	1.782190526	199.1091246

Table B1
Continued

28	1377	137	1.0571E-05	0	12.0292244	12.0292244	1.899479767	1.269573397	260.2287281
29	1378	244	1.88272E-05	0	14.32909012	14.32909012	1.727296694	1.585595458	421.4603934
30	1379	321	2.47685E-05	0	14.89722252	14.89722252	1.725618415	1.414148672	553.9235112
31	1380	463	3.57253E-05	0	13.67496204	13.67496204	1.44692129	1.162015701	669.9245571
32	1381	527	4.06636E-05	0	11.45875263	11.45875263	1.547618975	1.088205769	815.5951998
33	1382	691	5.33179E-05	0	11.04906178	11.04906178	1.362144265	1.078697108	941.2416873
34	1383	781	6.02623E-05	0	10.65098953	10.65098953	1.295550419	0.913271091	1011.824877
35	1384	605	4.66821E-05	0	10.27626038	10.27626038	1.447036912	1.117704655	875.4573317
36	1385	460	3.54938E-05	0	11.77517891	11.77517891	1.624375778	1.246340848	747.2128577
37	1386	354	2.73148E-05	0	12.47889709	12.47889709	1.86456048	1.368423177	660.0544099
38	1387	297	2.29167E-05	0	11.78815842	11.78815842	1.992325623	1.21779688	591.72071
39	1388	287	2.21451E-05	0.328490198	10.53911686	10.21062666	2.188604219	1.436061044	628.129411
40	1389	288	2.22222E-05	0	9.891299248	9.891299248	2.123671154	1.318490584	611.6172925
41	1390	345	2.66204E-05	0	10.90872192	10.90872192	1.859164002	1.369045182	641.4115806
42	1391	325	2.50772E-05	0	14.32909012	14.32909012	2.032382728	1.712134769	660.5243865

Table B1
Continued

43	1392	375	2.89352E-05	0	12.14531422	12.14531422	1.8714376	1.442386052	701.7891001
44	1393	440	3.39506E-05	0	10.20052719	10.20052719	1.79666626	1.245621649	790.5331545
45	1394	439	3.38735E-05	0	10.15479279	10.15479279	1.886322813	1.341787525	828.0957147
46	1395	434	3.34877E-05	0	10.36136436	10.36136436	1.880164583	1.484442899	815.991429
47	1396	399	3.0787E-05	0	9.125731468	9.125731468	2.011545704	1.194896405	802.606736
48	1397	442	3.41049E-05	0	7.848073006	7.848073006	1.832627464	1.12485264	810.0213393
49	1398	481	3.71142E-05	0	6.94959116	6.94959116	1.780349549	1.124961147	856.3481329
50	1399	502	3.87346E-05	0	7.166818142	7.166818142	1.746896008	1.038088901	876.9417961
51	1400	471	3.63426E-05	0	7.070299625	7.070299625	1.827378313	0.997390146	860.6951852
52	1401	483	3.72685E-05	0	6.93434906	6.93434906	1.750223544	0.994641219	845.3579718
53	1402	359	2.77006E-05	0	4.600716591	4.600716591	1.788320978	0.880946909	642.007231
54	1403	278	2.14506E-05	0	4.926170349	4.926170349	1.748290595	0.891084754	486.0247855
55	1404	208	1.60494E-05	0	3.935723543	3.935723543	1.895313303	0.763648058	394.2251671
56	1405	199	1.53549E-05	0	4.147892952	4.147892952	1.654562448	0.880487846	329.2579272
57	1406	182	1.40432E-05	0	3.962874174	3.962874174	1.748887324	0.800370127	318.297493

Table B1
Continued

58	1407	185	1.42747E-05	0	4.147892952	4.147892952	1.812948778	0.756989643	335.395524
59	1408	192	1.48148E-05	0	4.838617325	4.838617325	1.837551875	0.85881521	352.8099599
60	1409	213	1.64352E-05	0	5.595448017	5.595448017	1.840447447	0.887163781	392.0153062
61	1410	220	1.69753E-05	0	4.635463238	4.635463238	1.855052783	0.934659777	408.1116122
62	1411	202	1.55864E-05	0	5.604959965	5.604959965	2.16761493	0.972418646	437.8582158
63	1412	236	1.82099E-05	0	6.581706524	6.581706524	1.852151819	1.013155535	437.1078293
64	1413	208	1.60494E-05	0	5.855801105	5.855801105	2.124049804	1.00651732	441.8023592
65	1414	199	1.53549E-05	0	6.573647022	6.573647022	1.987132094	1.260150781	395.4392868
66	1415	123	9.49074E-06	0	5.332045078	5.332045078	2.304878843	1.174644858	283.5000976
67	1416	74	5.70988E-06	0	5.489698887	5.489698887	2.640279411	1.273151694	195.3806764
68	1417	63	4.86111E-06	0.464550197	5.604959965	5.140409768	3.021672668	1.242140897	190.3653781
69	1418	45	3.47222E-06	0.464550197	5.421302795	4.956752598	2.309668159	1.107701632	103.9350672
70	1419	44	3.39506E-06	0	5.421302795	5.421302795	2.629962939	1.30745632	115.7183693
71	1420	42	3.24074E-06	0.734494209	4.771877766	4.037383556	2.128669056	0.871581327	89.40410036
72	1421	36	2.77778E-06	0	3.346183062	3.346183062	1.49913257	0.856863553	53.96877253

Table B1 Continued

73	1422	18	1.38889E-06	0	3.839165211	3.839165211	1.544023262	1.025153155	27.79241872
74	1423	1	7.71605E-08	1.642019272	1.642019272	0	1.642019272	0	1.642019272

Table B2: Table of Study Area Drainage Network

Table B2: Table of Study Area Drainage Network						
FID	acrid	grid code	from node	to node	area	Length
0	1	1	1	2	128	129
1	2	1	4	5	22	22
2	3	1	5	6	22	22
3	4	1	6	7	22	22
4	5	1	7	8	22	22
5	6	1	8	9	44	45
6	7	1	9	10	22	22
7	8	1	10	11	289	290
8	9	1	11	12	22	22
9	10	1	3	12	116	116
10	11	1	5	13	31	31
11	12	1	13	14	22	22
12	13	1	6	14	31	31
13	14	1	14	15	22	22
14	15	1	7	15	31	31
15	16	1	15	16	22	22
16	17	1	8	16	31	31
17	18	1	9	17	31	31

Table B2
Continued

18	19	1	17	10	53	53
19	20	1	11	18	31	31
20	21	1	18	12	53	53
21	22	1	16	20	38	38
22	23	1	17	20	38	38
23	24	1	21	13	330	331
24	25	1	19	22	207	207
25	26	1	20	23	332	333
26	27	1	24	18	628	629
27	28	1	25	26	343	343
28	29	1	29	32	135	136
29	30	1	28	32	479	480
30	31	1	33	34	116	116
31	32	1	31	35	242	242
32	33	1	35	36	22	22
33	34	1	30	36	240	240
34	35	1	38	39	267	267
35	36	1	35	39	31	31
36	37	1	39	40	22	22
37	38	1	36	40	31	31
38	39	1	42	43	311	312
39	40	1	40	43	200	201
40	41	1	43	44	173	173
41	42	1	27	44	1483	1487
42	43	1	41	45	329	330
43	44	1	32	45	509	510
44	45	1	44	46	114	114
45	46	1	46	47	22	22
46	47	1	47	37	455	456

Table B2
Continued

47	48	1	46	48	31	31
48	49	1	48	47	53	53
49	50	1	48	49	162	163
50	51	1	51	53	343	343
51	52	1	53	54	22	22
52	53	1	50	54	93	93
53	54	1	53	56	31	31
54	55	1	56	57	22	22
55	56	1	54	57	31	31
56	57	1	52	58	181	181
57	58	1	45	58	602	603
58	59	1	56	59	53	53
59	60	1	57	59	31	31
60	61	1	59	60	401	402
61	62	1	55	60	233	234
62	63	1	60	61	275	276
63	64	1	61	62	541	543
64	65	1	63	61	650	651
65	66	1	62	64	73	74
66	67	1	58	64	689	690
67	68	1	64	65	351	352
68	69	1	65	66	22	22
69	70	1	66	67	22	22
70	71	1	68	69	22	22
71	72	1	65	69	31	31
72	73	1	69	70	22	22
73	74	1	66	70	31	31
74	75	1	70	71	22	22
75	76	1	67	71	31	31

Table B2 Continued

76	77	1	71	72	22	22
77	78	1	67	72	53	53
78	79	1	72	73	22	22
79	80	1	74	62	976	978

Table B3: List of Raster Elevation Cells of Reference Area Slope Map

Rowid	VALUE	COUNT	AREA	MIN	MAX	RANGE	MEAN	STD	SUM
1	1354	4	3143.972283	1.083696723	2.196475267	1.112778544	1.466817081	0.442994824	5.867268324
2	1355	12	9431.916848	1.021732569	3.679234266	2.657501698	2.051199605	0.748617691	24.61439526
3	1356	19	14933.86834	0.361270517	4.112097263	3.750826746	1.79570663	1.106748022	34.11842597
4	1357	33	25937.77133	0.80778265	7.080040455	6.272257805	2.683107311	1.500998471	88.54254127
5	1358	32	25151.77826	1.302372336	6.28408289	4.981710553	3.209225602	1.210132638	102.6952193
6	1359	23	18077.84063	1.14230144	7.406351566	6.264050126	3.73410851	1.891329153	85.88449574
7	1360	26	20435.81984	0.361270517	8.096418381	7.735147864	3.69957347	1.59168387	96.18891022
8	1361	49	38513.66046	0.361270517	7.685205936	7.323935419	2.838474283	1.937577803	139.0852399

Table B3
Continued

10	1363	58	45587.5981	0.361270517	10.08178234	9.720511824	3.665287015	2.172428125	212.5866469
11	1364	58	45587.5981	1.302372336	8.464285851	7.161913514	3.836863242	1.566739289	222.5380681
12	1365	47	36941.67432	1.841515541	10.73491669	8.893401146	4.715164971	2.091429651	221.6127536
13	1366	66	51875.54267	0.361270517	10.73491669	10.37364617	3.940442561	2.249046077	260.069209
14	1367	64	50303.55652	1.021732569	10.36852455	9.346791983	4.530069033	2.022512317	289.9244181
15	1368	63	49517.56345	1.615244269	9.063264847	7.448020577	4.750515662	1.964024816	299.2824867
16	1369	80	62879.44565	0.510906935	12.78918743	12.2782805	4.612528226	2.448990537	369.0022581
17	1370	74	58163.48723	0.510906935	12.48935509	11.97844815	5.042793023	2.54581021	373.1666837
18	1371	74	58163.48723	1.302372336	12.71257782	11.41020548	5.537718054	2.769870025	409.791136
19	1372	76	59735.47337	0	13.40680504	13.40680504	5.600042194	3.073326407	425.6032068
20	1373	68	53447.52881	1.021732569	12.87001801	11.84828544	6.251485774	2.78655209	425.1010326
21	1374	92	72311.3625	0	12.02118111	12.02118111	5.398897508	2.82720896	496.6985707
22	1375	90	70739.37636	0	15.64262581	15.64262581	5.79104677	3.118477023	521.1942093
23	1376	80	62879.44565	1.841515541	15.15445805	13.3129425	6.127461278	2.628652881	490.1969023
24	1377	85	66809.41101	1.805778384	15.36044121	13.55466282	6.60327185	2.664775884	561.2781073

Table B3

Continued

25	1378	89	69953.38329	0.80778265	15.32569599	14.51791334	6.556891692	3.363635392	583.5633606
26	1379	105	82529.27242	0.510906935	14.8691721	14.35826516	6.000230452	3.19197009	630.0241975
27	1380	100	78599.30707	1.302372336	14.78876495	13.48639262	6.1041662	3.091999872	610.41662
28	1381	109	85673.2447	0.80778265	16.37970161	15.57191896	6.692729808	3.605812524	729.507549
29	1382	126	99035.12691	0.510906935	15.91511536	15.40420842	6.178477911	3.414363601	778.4882168
30	1383	118	92747.18234	0.361270517	16.5110302	16.14975968	6.203634723	3.548105261	732.0288973
31	1384	134	105323.0715	0.722512305	15.97143269	15.24892038	5.917016595	3.135206009	792.8802237
32	1385	97	76241.32786	0.722512305	15.64262581	14.9201135	7.134674161	3.730429691	692.0633937
33	1386	119	93533.17541	0.510906935	18.31561661	17.80470967	6.456229624	3.341576693	768.2913252
34	1387	122	95891.15462	2.196475267	18.83035278	16.63387752	7.64641462	3.285596039	932.8625836
35	1388	119	93533.17541	0.722512305	16.10946274	15.38695043	7.469520932	3.39055818	888.8729909
36	1389	126	99035.12691	0.722512305	18.41450882	17.69199651	7.271281769	4.072255032	916.1815029
37	1390	132	103751.0853	0.361270517	16.23265266	15.87138215	6.870429001	3.344099605	906.8966281
38	1391	119	93533.17541	0.361270517	14.83305264	14.47178212	6.660208288	3.123321123	792.5647863
39	1392	133	104537.0784	0.361270517	20.00009727	19.63882676	6.961173957	3.849843175	925.8361363

Table B3
Continued

40	1393	139	109253.0368	0.722512305	19.54556656	18.82305425	6.810176741	3.740516712	946.614567
41	1394	158	124186.9052	0.361270517	18.86919594	18.50792542	7.00024771	3.875021398	1106.039138
42	1395	156	122614.919	0.722512305	18.98510933	18.26259702	6.835308662	3.622881754	1066.308151
43	1396	166	130474.8497	1.489240766	19.16165352	17.67241275	6.986209381	3.217938758	1159.710757
44	1397	159	124972.8982	0.80778265	18.49129486	17.68351221	6.895261345	3.821570354	1096.346554
45	1398	172	135190.8082	1.489240766	19.69016647	18.20092571	6.603865311	3.591048004	1135.864833
46	1399	178	139906.7666	0.80778265	18.83035278	18.02257013	6.67051112	3.918064503	1187.350979
47	1400	220	172918.4756	0.361270517	21.07956314	20.71829262	5.899928979	3.808334091	1297.984375
48	1401	200	157198.6141	0.361270517	16.33683014	15.97555962	6.278478757	3.603392447	1255.695751
49	1402	208	163486.5587	0.510906935	20.04699898	19.53609204	6.118500525	3.811759098	1272.648109
50	1403	218	171346.4894	0.80778265	22.13583565	21.328053	6.004649424	3.879196088	1309.013574
51	1404	211	165844.5379	0.361270517	21.42802429	21.06675377	6.211335413	3.896090987	1310.591772
52	1405	225	176848.4409	0.510906935	19.90584755	19.39494061	5.972325305	3.470446197	1343.773194
53	1406	233	183136.3855	0.361270517	19.64495468	19.28368416	6.330248191	3.90496606	1474.947829
54	1407	248	194926.2						

Table B3

Continued

55	1408	282	221650.0459	0	22.10216522	22.10216522	5.711795396	3.831354119	1610.726302
56	1409	281	220864.0529	0.510906935	16.83903313	16.32812619	5.537870536	3.42994978	1556.141621
57	1410	272	213790.1152	0.361270517	20.86191177	20.50064126	5.513679324	3.3156661	1499.720776
58	1411	259	203572.2053	0.510906935	21.2025547	20.69164777	5.578506181	3.633870335	1444.833101
59	1412	280	220078.0598	0.80778265	17.38643456	16.57865191	6.161264971	3.557704492	1725.154192
60	1413	262	205930.1845	0	19.13530731	19.13530731	5.852952614	3.443359469	1533.473585
61	1414	256	201214.2261	0.425759196	15.63507938	15.20932019	5.661111163	3.242965709	1449.244458
62	1415	239	187852.3439	0.361270517	18.55547905	18.19420853	6.16146883	3.529246603	1472.59105
63	1416	246	193354.2954	0.361270517	18.98806953	18.62679902	5.589491851	3.314680062	1375.014995
64	1417	279	219292.0667	0.722512305	15.27922249	14.55671018	5.567424813	2.955408317	1553.311523
65	1418	282	221650.0459	0	17.18286324	17.18286324	5.294197248	3.245528614	1492.963624
66	1419	287	225580.0113	0.361270517	17.00692177	16.64565125	5.0814411	3.280144782	1458.373596
67	1420	323	253875.7618	0	15.26369381	15.26369381	4.907103193	3.024455238	1584.994331
68	1421	293	230295.9697	0	17.14246178	17.14246178	4.743649826	2.851619273	1389.889399
69	1422	281	220864.0529	0.510906935	18.87814522	18.36723828	4.822873607	2.993111608	1355.227484

Table B3
Continued

70	1423	310	243657.8519	0.722512305	15.93357277	15.21106046	4.611310828	2.66828108	1429.506357
71	1424	258	202786.2122	0.510906935	17.90026474	17.38935781	4.423478881	2.68311555	1141.257551
72	1425	287	225580.0113	0	17.12896729	17.12896729	4.400217765	2.58728334	1262.862499
73	1426	284	223222.0321	0	17.90026474	17.90026474	4.352408445	2.878048172	1236.083998
74	1427	299	235011.9281	0.361270517	17.81378365	17.45251313	3.974416442	2.589382624	1188.350516
75	1428	242	190210.3231	0	15.93357277	15.93357277	3.876298482	2.321649305	938.0642326
76	1429	197	154840.6349	0.361270517	14.39541531	14.03414479	4.693131808	2.679340305	924.5469662
77	1430	214	168202.5171	0	12.91257858	12.91257858	4.036353768	2.237146132	863.7797064
78	1431	170	133618.822	0.361270517	16.37970161	16.0184311	4.157175412	2.635620643	706.7198201
79	1432	126	99035.12691	0.510906935	18.11575317	17.60484624	4.829679055	2.791697753	608.5395609
80	1433	141	110825.023	0.510906935	18.02742004	17.51651311	4.787573901	2.843903607	675.04792
81	1434	126	99035.12691	0.80778265	16.46503448	15.65725183	5.115619588	2.636732841	644.5680681
82	1435	113	88817.21699	1.021732569	18.31561661	17.29388404	5.264297447	3.245148803	594.8656116
83	1436	141	110825.023	0.80778265	16.46149063	15.65370798	4.592252811	2.45361716	647.5076463
84	1437	116	91175.1962	0.722512305	15.8410244	15.11851209	4.495284445	3.145888886	521.4529956

Table B3
Continued

85	1438	118	92747.18234	0.80778265	13.91563702	13.10785437	4.351495888	2.808794324	513.4765148
86	1439	101	79385.30014	0.510906935	13.54614162	13.03523469	4.827849857	2.644084277	487.6128355
87	1440	69	54233.52188	1.489240766	13.91563702	12.42639625	5.384358864	2.382513114	371.5207616
88	1441	83	65237.42487	1.841515541	14.49493122	12.65341568	5.174815052	2.097596608	429.5096493
89	1442	79	62093.45258	0.722512305	14.13027191	13.40775961	4.99714322	2.387193172	394.7743143
90	1443	55	43229.61889	0.722512305	15.69157028	14.96905798	5.327514751	2.505909893	293.0133113
91	1444	80	62879.44565	0.510906935	13.78060913	13.2697022	5.182053596	2.596489566	414.5642877
92	1445	40	31439.72283	1.489240766	11.16615868	9.676917911	4.836554936	2.025053045	193.4621974
93	1446	70	55019.51495	1.489240766	15.5099287	14.02068794	5.249371787	2.718823258	367.4560251
94	1447	51	40085.64661	1.14230144	13.42487717	12.28257573	5.174694082	3.029405592	263.9093982
95	1448	37	29081.74362	0.80778265	12.56263828	11.75485563	3.93852576	2.4905948	145.7254531
96	1449	59	46373.59117	0.80778265	15.46029186	14.65250921	4.811965712	3.113944864	283.905977
97	1450	37	29081.74362	0.80778265	14.4452734	13.63749075	4.167258952	2.915650174	154.1885812
98	1451	36	28295.75054	1.53239584	12.45007133	10.9176755	5.18438477	2.632111391	186.6378517
99	1452	37	29081.74362	0.80778265	11.08250618	10.27472353	4.503097157	2.64398391	166.6145948

Table B3
Continued

100	1453	26	20435.81984	0.510906935	12.10527897	11.59437203	4.051715081	2.957190336	105.3445921
101	1454	23	18077.84063	1.021732569	11.64889717	10.6271646	5.39797857	3.046516255	124.1535071
102	1455	25	19649.82677	0.361270517	9.371016502	9.009745985	5.438948797	2.324765236	135.9737199
103	1456	26	20435.81984	0.510906935	8.866008759	8.355101824	3.939824116	2.616968286	102.435427
104	1457	34	26723.7644	0.361270517	8.965214729	8.603944212	4.014464181	2.134374388	136.4917822
105	1458	19	14933.86834	2.196475267	6.563789845	4.367314577	3.755620103	1.099673258	71.35678196
106	1459	16	12575.88913	2.042815685	6.718220711	4.675405025	4.042578533	1.197072378	64.68125653
107	1460	20	15719.86141	0.361270517	5.497693539	5.136423022	3.154341124	1.398703666	63.08682248
108	1461	17	13361.8822	0.510906935	3.423279285	2.912372351	1.881159555	0.907383645	31.97971243
109	1462	6	4715.958424	1.021732569	1.841515541	0.819782972	1.426415861	0.309956401	8.558495164

Table B4: Table of Reference Area Drainage Network

FID	acrid	grid code	from node	to node	Length
0	1	1	1	4	317
1	2	1	2	5	179
2	3	1	6	7	95
3	4	1	8	7	53
4	5	1	8	9	22
5	6	1	7	9	31
6	7	1	8	10	31
7	8	1	10	11	22
8	9	1	9	11	31
9	10	1	10	12	31
10	11	1	12	13	22
11	12	1	11	13	31
12	13	1	12	14	31
13	14	1	14	15	22
14	15	1	13	15	31
15	16	1	14	16	31
16	17	1	16	17	22
17	18	1	15	17	31
18	19	1	3	19	500
19	20	1	20	16	91
20	21	1	17	21	62
21	22	1	22	19	53
22	23	1	22	23	22
23	24	1	19	23	31
24	25	1	22	24	31
25	26	1	24	25	22
26	27	1	23	25	31
27	28	1	18	26	201
28	29	1	27	28	121
29	30	1	24	28	284
30	31	1	25	29	187
31	32	1	29	30	22
32	33	1	31	26	247
33	34	1	26	32	186
34	35	1	33	32	53
35	36	1	33	34	22
36	37	1	32	34	31
37	38	1	36	28	190
38	39	1	33	37	31
39	40	1	37	34	53

Table B4
Continued

40	41	1	29	38	126
41	42	1	39	40	22
42	43	1	37	40	31
43	44	1	38	41	131
44	45	1	41	42	22
45	46	1	40	43	155
46	47	1	44	45	245
47	48	1	38	45	312
48	49	1	35	46	367
49	50	1	44	48	165
50	51	1	47	49	188
51	52	1	49	50	22
52	53	1	43	50	214
53	54	1	51	44	398
54	55	1	45	52	218
55	56	1	53	54	290
56	57	1	43	55	636
57	58	1	41	58	692
58	59	1	57	59	176
59	60	1	59	58	94
60	61	1	61	49	540
61	62	1	60	59	391
62	63	1	62	61	53
63	64	1	62	63	22
64	65	1	61	63	31
65	66	1	50	64	602
66	67	1	62	65	31
67	68	1	65	66	22
68	69	1	63	66	31
69	70	1	66	67	129
70	71	1	69	56	468
71	72	1	69	70	201
72	73	1	70	68	137
73	74	1	71	72	443
74	75	1	70	73	310
75	76	1	73	74	45
76	77	1	77	69	566
77	78	1	58	79	657
78	79	1	75	80	294
79	80	1	80	76	602

Table B4
Continued

80	81	1	81	79	74
81	82	1	65	82	598
82	83	1	84	82	76
83	84	1	82	84	31
84	85	1	78	85	231
85	86	1	85	83	411
86	87	1	84	86	31
87	88	1	73	87	453
88	89	1	88	89	45
89	90	1	89	90	22
90	91	1	80	90	233
91	92	1	89	91	31
92	93	1	91	90	53
93	94	1	85	93	322
94	95	1	94	91	358
95	96	1	93	95	62
96	97	1	95	96	85
97	98	1	79	97	588
98	99	1	92	99	193
99	100	1	100	95	283
100	101	1	93	102	1034
101	102	1	102	103	22
102	103	1	98	103	228
103	104	1	102	104	53
104	105	1	103	104	31
105	106	1	101	106	201
106	107	1	106	107	22
107	108	1	107	108	22
108	109	1	106	110	31
109	110	1	110	107	53
110	111	1	105	112	394
111	112	1	112	110	252
112	113	1	111	114	91
113	114	1	114	115	22
114	115	1	109	116	252
115	116	1	117	118	67
116	117	1	114	118	31
117	118	1	118	115	53
118	119	1	115	112	465
119	120	1	104	119	405

Table B4
Continued

120	121	1	113	120	156
121	122	1	119	120	265
122	123	1	120	121	94
123	124	1	122	123	89
124	125	1	124	125	67
125	126	1	125	119	177
126	127	1	125	127	62
127	128	1	126	128	341
128	129	1	128	129	319
129	130	1	131	128	288
130	131	1	130	133	243
131	132	1	133	131	257
132	133	1	132	134	391
133	134	1	134	135	112
134	135	1	133	135	38
135	136	1	131	137	191
136	137	1	138	136	270
137	138	1	134	139	203
138	139	1	135	140	196
139	140	1	140	141	127
140	141	1	142	139	91
141	142	1	143	144	38
142	143	1	139	145	172
143	144	1	146	147	22
144	145	1	140	147	357
145	146	1	149	148	270
146	147	1	147	150	330
147	148	1	152	151	54
148	149	1	154	153	74

Table B5: Digitized Points of Topographic Reconstruction Area

FID	Id	X	Y	Z
0	0	-105	44	0
1	0	-105	44	0
2	0	-105	44	0
3	0	-105	44	0
4	0	-105	44	1344
5	0	-105	44	1352
6	0	-105	44	0
7	0	-105	44	1355
8	0	-105	44	0
9	0	-105	44	1354
10	0	-105	44	1351
11	0	-105	44	1351
12	0	-105	44	1357
13	0	-105	44	1350
14	0	-105	44	1352
15	0	-105	44	1352
16	0	-105	44	1353
17	0	-105	44	1352
18	0	-105	44	1355
19	0	-105	44	1350
20	0	-105	44	1348
21	0	-105	44	1347
22	0	-105	44	1346
23	0	-105	44	1345
24	0	-105	44	1344
25	0	-105	44	1344
26	0	-105	44	1343
27	0	-105	44	1341
28	0	-105	44	1341
29	0	-105	44	1342
30	0	-105	44	1346
31	0	-105	44	1346
32	0	-105	44	1348
33	0	-105	44	1346
34	0	-105	44	1343
35	0	-105	44	1346
36	0	-105	44	1345
37	0	-105	44	1348
38	0	-105	44	1347
39	0	-105	44	1351
40	0	-105	44	1345
41	0	-105	44	1341

Table B5
Continued

42	0	-105	44	1339
43	0	-105	44	1337
44	0	-105	44	0
45	0	-105	44	1340
46	0	-105	44	1342
47	0	-105	44	1341
48	0	-105	44	1344
49	0	-105	44	1342
50	0	-105	44	1341
51	0	-105	44	1338
52	0	-105	44	1337
53	0	-105	44	1339
54	0	-105	44	1339
55	0	-105	44	1341
56	0	-105	44	1345
57	0	-105	44	1343
58	0	-105	44	1342
59	0	-105	44	1340
60	0	-105	44	1340
61	0	-105	44	1338
62	0	-105	44	1340
63	0	-105	44	1341
64	0	-105	44	1341
65	0	-105	44	1343
66	0	-105	44	1345
67	0	-105	44	1344
68	0	-105	44	1342
69	0	-105	44	1345
70	0	-105	44	1345
71	0	-105	44	1342
72	0	-105	44	1342
73	0	-105	44	1344
74	0	-105	44	1345
75	0	-105	44	1345
76	0	-105	44	1349
77	0	-105	44	1350
78	0	-105	44	1345
79	0	-105	44	1344
80	0	-105	44	1343
81	0	-105	44	1345
82	0	-105	44	1345
83	0	-105	44	1346
84	0	-105	44	1348
85	0	-105	44	1350

Table B5
Continued

86	0	-105	44	1354
87	0	-105	44	1356
88	0	-105	44	1357
89	0	-105	44	0
90	0	-105	44	0
91	0	-105	44	0
92	0	-105	44	1354
93	0	-105	44	1354
94	0	-105	44	1354
95	0	-105	44	1351
96	0	-105	44	1346
97	0	-105	44	1346
98	0	-105	44	1341
99	0	-105	44	1346
100	0	-105	44	1348
101	0	-105	44	1351
102	0	-105	44	1356
103	0	-105	44	1363
104	0	-105	44	1364
105	0	-105	44	1372
106	0	-105	44	1375
107	0	-105	44	1367
108	0	-105	44	1363
109	0	-105	44	1354
110	0	-105	44	1365
111	0	-105	44	1369
112	0	-105	44	1364
113	0	-105	44	1362
114	0	-105	44	1359
115	0	-105	44	0
116	0	-105	44	0
117	0	-105	44	1364
118	0	-105	44	1370
119	0	-105	44	1366
120	0	-105	44	1359
121	0	-105	44	1361
122	0	-105	44	1357
123	0	-105	44	1356
124	0	-105	44	1351
125	0	-105	44	1359
126	0	-105	44	1356
127	0	-105	44	1351
128	0	-105	44	1350
129	0	-105	44	1349

Table B5
Continued

130	0	-105	44	1349
131	0	-105	44	1352
132	0	-105	44	1353
133	0	-105	44	1351
134	0	-105	44	1349
135	0	-105	44	1347
136	0	-105	44	1347
137	0	-105	44	1346
138	0	-105	44	1343
139	0	-105	44	1344
140	0	-105	44	1343
141	0	-105	44	1338
142	0	-105	44	1339
143	0	-105	44	1339
144	0	-105	44	1339
145	0	-105	44	1344
146	0	-105	44	1344
147	0	-105	44	1343
148	0	-105	44	1341
149	0	-105	44	1345
150	0	-105	44	1340
151	0	-105	44	1339
152	0	-105	44	1340
153	0	-105	44	1342
154	0	-105	44	1344
155	0	-105	44	1346
156	0	-105	44	1340
157	0	-105	44	1347
158	0	-105	44	1341
159	0	-105	44	1339
160	0	-105	44	1339
161	0	-105	44	1343
162	0	-105	44	1361
163	0	-105	44	1363
164	0	-105	44	1358
165	0	-105	44	1359
166	0	-105	44	1357
167	0	-105	44	1362
168	0	-105	44	1363
169	0	-105	44	1360
170	0	-105	44	1355
171	0	-105	44	1370
172	0	-105	44	1375
173	0	-105	44	1367

Table B5
Continued

174	0	-105	44	1368
175	0	-105	44	1375
176	0	-105	44	1376
177	0	-105	44	1376
178	0	-105	44	1374
179	0	-105	44	1375
180	0	-105	44	1362
181	0	-105	44	1364
182	0	-105	44	1359
183	0	-105	44	1351
184	0	-105	44	1347
185	0	-105	44	1342
186	0	-105	44	1346
187	0	-105	44	1345
188	0	-105	44	1347
189	0	-105	44	1342
190	0	-105	44	1342
191	0	-105	44	1345
192	0	-105	44	1345
193	0	-105	44	1341
194	0	-105	44	1340
195	0	-105	44	1345
196	0	-105	44	1340
197	0	-105	44	1340