

APPENDIX A

The Integration of Geomorphic Design into West

Virginia Surface Mine Reclamation

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1. Introduction

Concerns of detrimental environmental impacts originating from mountaintop surface mining and valley-fill construction are of constant debate, resulting in a plethora of lawsuits (e.g. Hasselman, 2002, Davis and Duffy, 2009) and scientific studies throughout Appalachia (e.g. Hartman et al., 2005; Pond et al., 2008; Ferrari et al., 2009). State and Federal regulations have been promulgated to control environmental impacts associated with mountaintop mining and valley-fill construction through the Surface Mining Control and Reclamation Act (SMCRA) and the Clean Water Act (CWA). West Virginia has primacy of the State's regulatory enforcement and thus must meet stringent regulatory standards for valley-fill construction.

These regulations have resulted in geotechnically stable designs of valley-fills with runoff management. However, major environmental concerns have resulted, specifically the loss of headwater stream length, increased flooding risk, and degraded water quality in communities downstream. The predicted headwater stream loss in West Virginia is approximately 3,200 km by 2012, thus impacting the ability of West Virginia to support high quality and unique aquatic species (USEPA, 2005). Studies have shown that streams located below valley-fills often have elevated conductivity levels, resulting from water contact with the overburden (Hartman et al., 2005; Pond et al., 2008). Additionally, changes in thermal regime, chemistry, and sedimentation are potential impacts for streams below valley-fills (USEPA, 2005). One promising innovative technique used to lessen these impacts involves fluvial geomorphic landform design that incorporates mature landform shapes into the designs. These landform designs add variability and aid in establishing a site with a long-term hydrologic balance.

1.1 Objectives and Purpose

The work discussed in this report incorporates landforming into the traditional valley-fill design process, thus providing an alternative to the conventional reclamation techniques. The objectives of this research were to:

- Use an Appalachian surface mine site to evaluate valley-fill design options.
- Perform a geomorphic landform design using Carlson® Natural Regrade® with GeoFluv™ and landforming principles.
- Compare the geomorphic landform design outputs with the conventional approximate original contour valley-fill design outputs.

An alternative reclamation design was created and evaluated to determine if an effective and implementable valley-fill could be designed using Carlson's Natural Regrade® software following the Geofluc™ method as applied to mountainous terrain in the central Appalachian region of West Virginia.

1.2 Traditional Valley-fill Design

Appalachian surface mines are reclaimed to approximate original contour according to the Surface Mining Control and Reclamation Act (SMCRA) of 1977. Overburden, the material that lies above the coal seam, is placed using unconsolidated end dumping methods. Loosely placing overburden by end dumping has the potential to create unsafe conditions, especially in mountainous terrain where the end dump piles have significant depth. The material that has been dumped has little to no compaction and therefore lacks guaranteed stability. Loose materials also have a higher potential for internal erosion known as piping or suffusion. Piping is the transport of water and soil particles through channels in a mass of soil. Piping in channels exists

as a result of void spaces in the soil (Martin-Duque et al. 2010). Subsurface particle transport in loosely laid materials can also result in areas with excess pore pressure which can threaten the stability of the structure as well as the safety of any operators working on or around the structure. Loose materials have high void ratios which in turn can lead to settlement, and ultimately a change in the geometry of the structure. This change in geometry can affect the stability of the slopes and cause unsafe conditions for operators.

Maintenance can also be an issue in traditional AOC construction techniques due to surface erosive forces. The created AOC landforms are not necessarily stable landforms. Frequently, they are not at equilibrium with erosive forces and surface particle transport, as erosion, can occur.

Traditional surface mine reclamation practices also cause many other concerns besides instability. Typical valley-fill designs include uniform slopes with terraces and down-drains that appear un-natural and not aesthetically pleasing. Also, these valley-fills have caused major environmental concerns, specifically the loss of headwater stream length, increased flooding risk, and degraded water quality in communities downstream (McQuaid, 2009). A profile view of a typical valley-fill is shown below in Figures 1.3.1.

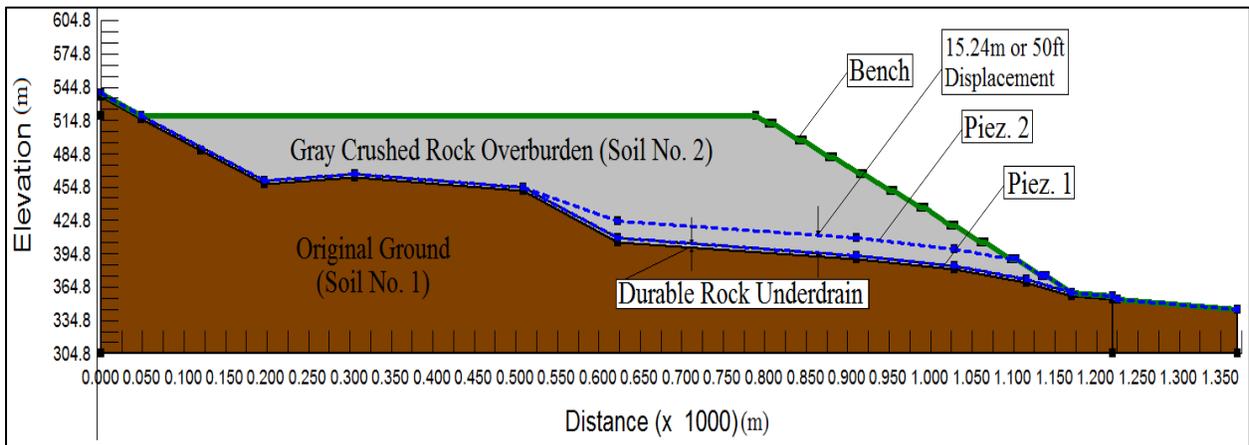


Figure 1.3.1: a) Traditional Valley-fill and b) Traditional Valley-fill Profile

1.3 Safety

Many safety issues involved with surface mining are thwarted by operator's own concern, care, and experience. However, it is imperative to consider that surface mining in West Virginia is particularly unique as a result of its rough and often exceedingly steep terrain. The condition of the terrain contributes to the difficulty of both mining and reclaiming mountaintop

removal mine sites. Many safety studies have been performed by the Mine Safety and Health Administration (MSHA), National Institute for Occupational Safety and Health (NIOSH) and other organizations in an attempt to improve technology and regulations, therefore making surface mining safer.

Mine safety issues involved with fluvial geomorphic reclamation design should be comparable to safety issues involved with AOC designs since the slope construction methods are similar. State and Federal regulations which control mine reclamation using the AOC approach have resulted in geotechnically stable designs of valley-fills constructed using waste rock overburden. However, when these valley-fills are constructed, there is a significant loss of headwater stream length as well as an associated increased flooding risk. Subsequently, it is necessary to consider operator safety, environmental concerns, and alternative design methods for surface mining.

Fluvial geomorphic landform design, when utilized as a valley-fill alternative, has promising potential to lessen the environmental impacts of surface mining and reduce the critical nature of mining accidents at these sites. The steep sloped natural terrain of Appalachia offers a variety of safety concerns, and therefore requires further investigation. Critical safety concerns involved with performing the construction of geomorphic landforms in mountaintop mine site reclamation were analyzed during this project.

2. Literature Review

Reclamation by approximate original contour design is the traditional method practiced in the central Appalachian region of the United States. These promulgated design requirements were needed to provide standards and controls. Prior to the Surface Mining Control and Reclamation Act (SMCRA), adopted into law in 1977, non-designed earth moving practices resulted in spoil materials being deposited into valleys, hillsides, and into ephemeral streams without consideration for erosion, geotechnical stability, seepage, and hydrology. Unfortunately, the end results included slope washes, loss of topsoil, and stream siltation. Figure 2.0.1 is an illustration of the AOC reclamation method with respect to the original contour of the mountain.

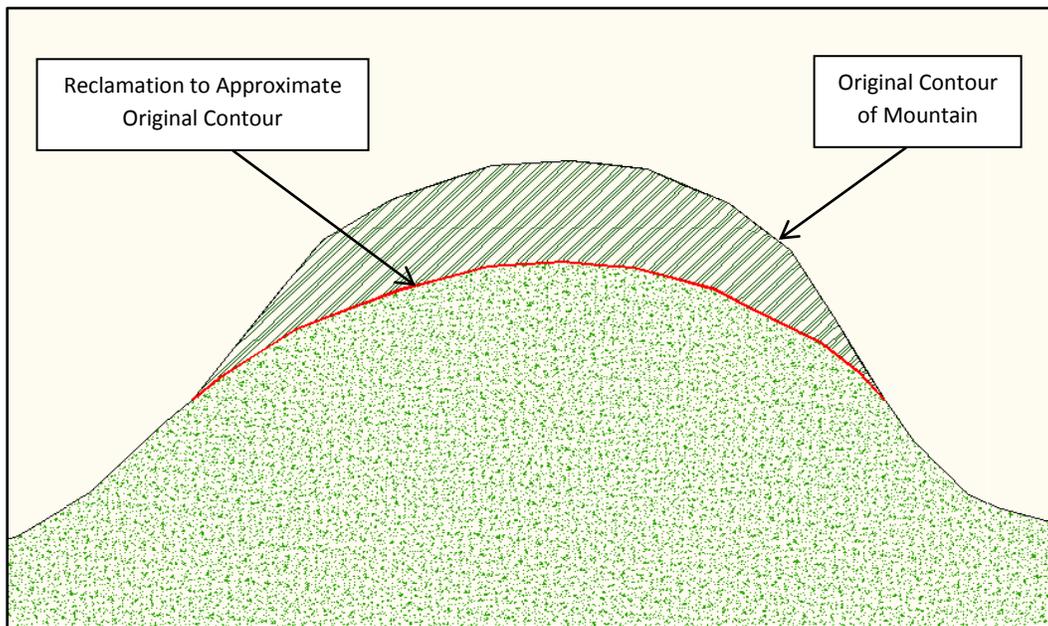


Figure 2.0.1: AOC Compared to Original Contour of Mountain

In West Virginia the Approximate Original Contour guidelines are promulgated by West Virginia Surface Mining Reclamation Regulations (WVSMRR), Code of State Regulations (CSR) §38 which require slope profile configurations constructed by the traditional backfilling technique. It is also required that grading of disturbed areas have a final profile which in effect

closely resembles the general surface configuration of the land prior to mining. The post mining slope design is intended to ensure slope stability, control drainage, complement the drainage pattern of the surrounding terrain, and prevent stream sedimentation. These requirements are comprehensive, covering the drainage pattern of the surrounding terrain, high walls, and spoil piles. Special circumstances and permit variances can be approved by regulatory agencies for specific areas that will not comply with AOC regulations. In addition, the West Virginia Department of Environmental Protection (WVDEP) and the US Environmental Protection Agency (EPA) implement the Clean Water Act of 1972 through the National Pollution Discharge and Elimination System (NPDES) in order to provide requirements for drainage and sediment control for the quality of the discharged runoff on the disturbed area.

The AOC requirements result in the typically profiled valley-fill slope shapes exhibiting uniform benches, planar slopes having unvarying contours with perimeter and/or center surface water ditches. To date, the AOC guidelines have provided help in the reduction in environmental degradation of mountain streams and an increase in the stability of slopes on the reclamation sites. In West Virginia the reclamation vegetation efforts using select grasses and hardwoods have proven somewhat effective in concealing the planar slope profiles and surface drainage structures. The effectiveness of post mine land use implemented by the mining industry has been successful to an extent and as tree canopy matures the slopes appear natural, to some degree. However, many public and industry individuals believe that this traditional, planar reclamation method can be improved to appear more natural and decrease the drawbacks associated with it. Figure 2.0.2 shows a newly constructed traditional valley-fill and a mature traditional valley-fill.



***Figure 2.0.2: a) Newly Constructed AOC Valley-fill and
b) Mature AOC Valley-fill***

The geotechnical safety benefits of the AOC valley-fill method requirements are not able to balance with the loss of streams and changes in watershed sizes that subsequently occur. These needs for a balanced surface mine reclamation method has opened the door for improvements. Under natural conditions, landforms develop a balance between erosive and

resistance forces, resulting in a system in equilibrium with low erosion rates. The fluvial geomorphic landform design approach attempts to design landforms in this steady-state condition, considering long-term climatic conditions, soil types, slopes, and vegetation types (Toy and Chuse, 2005; Bugosh, 2009). This design approach may provide the balance between valley-fill construction stability and surface hydrologic reclamation needs.

State and Federal regulations directing mine reclamation using the Approximate Original Contour approach have resulted in geotechnically stable designs of valley-fills constructed using waste rock overburden. Environmental concerns at mountaintop mining sites abound because of the loss of headwater stream length and increased flooding risk. One promising technique to lessen the impacts involves fluvial geomorphic landform design applied to the waste rock fill and slope profiles. These innovative geomorphic landforms designs are often created using Carlson's Natural Regrade[®] with GeoFluv[™] software.

Carlson[®] describes its Natural Regrade[®] software as a software that provides a natural, cost effective method to bring sustainability to disturbed lands, whether altered from mining or development (Carlson[®], 2011). Natural Regrade[®] utilizes the GeoFluv[™] method for landform design and minimizes material handling and surface erosion while creating sustainable landforms. It applies fluvial geomorphic principles to upland landform design and creates a landscape design that mimics the functions of the natural landscape that would have naturally evolved over time. The result is a stable hydrologic equilibrium that occurs naturally (Carlson[®], 2011).

The approach of GeoFluv[™] principles is to identify the type of drainage network, stream channels and valleys, which would form over a long time given the earth materials, relief, and climate of the site to achieve a stable landform, and to design and build that landform. The

resulting slopes and stream channels that are created are stable because they are in balance with these conditions. It is a reclamation alternative to the traditional designs with uniform slopes with terraces and down-drains. Rather than fight the natural forces that shape the land, GeoFluv™ helps create a landscape that harmonizes with these forces (Carlson®, 2011). Carlson lists the advantages of Natural Regrade® with GeoFluv™ as:

- Natural Regrade® software replaces lengthy and tedious manual calculations with fast, efficient design
- Natural Regrade® frees the user's creative design energies
- View topographic maps and three-dimensional images of the resulting landscape design
- One-button volumes and cut / fill material balance calculations for designs gives instant colored-coded feedback
- Rapid evaluation of many landscape design alternatives allows the user to select the optimum landscape design for bond alternatives, construction costs, changing mine plans, land use, etc.

Natural Regrade® with GeoFluv™ was created by Nicholas Bugosh and has received a Silver Award in the Services Category of Intermat's award series. Also, the U. S. Department of the Interior's Office of Surface Mining (OSM), Reclamation and Enforcement has identified Carlson® Natural Regrade® as a 'TIPS Core Software'. Figure 2.0.3 shows an example of a completed surface mine site that was reclaimed using geomorphic landforms design principles.



***Figure 2.0.3: a.) Surface Mining Site in Indiana Reclaimed using Natural Regrade®
b.) Surface Mining Site Reclaimed using Natural Regrade®***

3. Methods

3.1 Regulatory Drivers Affecting Geomorphic Landform Design

Challenges associated with implementing the geomorphic landform approach in the Central Appalachia Region extend beyond the complexity of designing and constructing mature landforms in steep terrain. Current, civil engineering based regulations for meeting Approximate Original Contour (AOC) and Surface Water Runoff Analysis (SWROA) do not readily support this nontraditional design approach, and perceived initial construction costs are greater than traditional designs (Michael et al., 2010). Also, without the undeniable evidence of the benefits of a geomorphic landform reclamation site in Central Appalachia compared to the traditional method, industry resistance from coal companies and regulators alike is inevitable. Therefore, the traditional AOC method and the new geomorphic design method must be compared to determine the benefits and disadvantages of each.

The geomorphic landform design procedure builds a drainage network using a reference landform approach. With this procedure, a reference watershed must be identified and characterized in order to begin. The information that is necessary to inform successful design (Toy and Chuse, 2005; Eckels and Bugosh, 2010) includes the main channel slope and landform profile shape, drainage density and area, and channel characteristics. Each of these design requirements is discussed in detail below.

Main channel slope especially represents the watershed slope. As the main channel slope increases, the stream power and erosion potential increase (Toy and Chuse, 2005). Longitudinal profile shapes of the landforms must also be considered as the concave shape differs among headwater and downstream locations. In mountainous terrain the nature of slope profiles develop into compound surface profiles. These profiles exhibit steep convex slopes at the head of the valley and progressively transition into a concave form gradually tapering to a uniform

profile. The development of natural stream design is effected by the fluvial influence stream cutting and surficial erosion and the rill to gully erosion all couple to effect. Valley-fills end up as unique landforms that exhibit geotechnical stability; however, they lack the ability, as currently regulated, to incorporate surface hydrologic features to enable stream replacement or development.

Drainage density is a measure of the average stream channel spacing and results from flow interactions with sediment and soil, vegetation, topography, and weather variables (Bugosh, 2004; Toy and Chuse, 2005). For a given reference landform, the drainage density describes the drainage network that can be supported without significant aggradation or erosion (Bugosh, 2004). The fluvial geomorphic design approach assumes a dendritic pattern, Natural channels vary in characteristics depending on its location in the watershed. Headwater streams are often steep ($>4\%$ slope), characterized as “A” channels as defined by the Rosgen classification system (Rosgen, 1996), and relatively straight (sinuosity = 1.0-1.2), and downstream channels have a lower gradient ($<4\%$ slope), C-channels, and increased sinuosity (>1.2 ; Rosgen, 1996).

The stream characteristics that must be considered when designing systems that will properly manage both flow and sediment discharge are bankfull width, width to depth ratio, sinuosity, meander belt width, A-channel reach length and sinuosity (Eckels and Bugosh, 2010). A-channel reach length is defined as the distance of one-half of a meander length in steep channels. Ridge to head of channel distance defines the length required to form concentrated flow, advising the channel head location in reference to the watershed boundary.

3.2 Training and Conferences

In order to have properly created the geomorphic landform valley-fill designs, I attended a training by Nicholas Bugosh (Natural Regrade[®] and Geofluv[™] creator) at West Virginia University, and also a training by TIPS (Technical Innovation and Professional Services) at the Office of Surface Mining in Pittsburgh, Pennsylvania. I have also been guided by my advisors as well as professionals that use Carlson's Natural Regrade[®] software in the industry.

During my graduate schooling and research, I attended the Society for Mining, Metallurgy, and Exploration Annual Meeting in Seattle, Washington, International Conference on Ground Control in Mining in Morgantown, West Virginia, and made a presentation about my research at the International Conference on Solid Waste Technology and Management in Philadelphia, Pennsylvania.

3.3 Step-by-Step Procedure and Method for Design

To create a valley-fill alternative, the topographic drawing containing the original contour lines was opened in Carlson's Natural Regrade[®] with AutoCAD. The mine property boundary was then established and drawn using a closed 2D polyline. The property was broken into watersheds in order to perform a proper balanced Natural Regrade[®] analysis. Each watershed was separated using a closed 2D polyline around its boundary.

The main watershed is chosen to do a Natural Regrade[®] design on first. The main channel is then drawn in the main watershed using a 2D polyline. The head elevation of the main channel must be greater than the base elevation and the main channel must extend outside of the watershed boundary on one end. Each of the channels, including the main channel must begin within the ridge to head-of-channel distance, which is a variable input in the settings. The default for the ridge to head-of-channel distance setting is 80 ft. We used this default setting in

order to create the Natural Regrade[®] design for the sample site due to a lack of on-site data because of current mining. After the main channel was drawn, the tributary channels were drawn in a dendritic pattern. Each tributary must begin within the ridge to head-of-channel distance of the boundary and must end very close to the main channel, but not connected to it. All of the channels drawn must satisfy the drainage density, which is a variable input in the settings. The drainage density is a very important part of a Natural Regrade[®] design. It is calculated by the valley length divided by the watershed area. The default setting for the drainage density is 100 ft/ac with a range of $\pm 20\%$. Therefore, the drainage density of each channel must range from 80-120 ft/ac.

Added tributary channels add to the drainage density of the main channel, which is also the case for channels that are added onto tributary channels. These channels affect the drainage density of the tributary channel they drain into and the main channel. Also, the channel length and location affect the drainage density. Therefore, if a channel has too high or too low of a drainage density, the channel can be moved, lengthened, shortened, or removed in order to achieve a drainage density within the selected range. More tributary channels will need to be added to the main channel closer to its mouth in order to satisfy the target drainage density, while less tributary channels will be needed at the head of the main channel to meet the drainage density requirement. The drainage density is incredibly important to the Natural Regrade[®] design because if the drainage density is too high or too low, erosion will occur until the correct drainage density is achieved.

There are numerous settings that can be customized by the user to match the site in which the geomorphic reclamation design is being created. Figure 3.3.1 shown below is a list of the global settings in Natural Regrade[®] along with their default values. All of these values can be

changed so that the design can blend in with the natural ridges and streams of the site and the area surrounding the site.

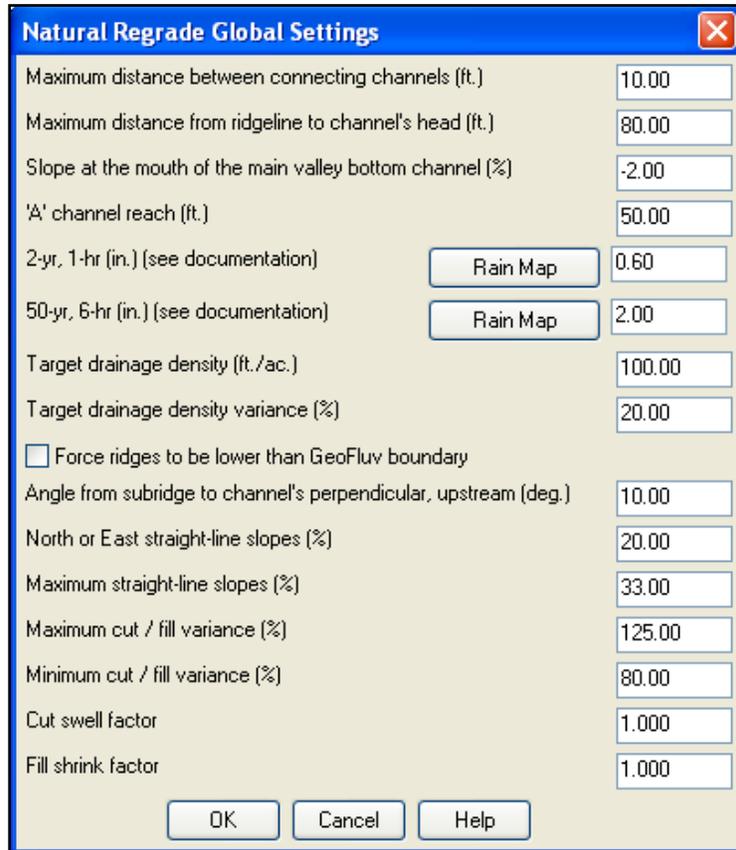


Figure 3.3.1: Natural Regrade[®] Global Settings and Default Values

Two of the global settings that were drastically changed for the sample site were that the 2 yr, 1 hr rainfall changed from 0.6 in to 1.41 in and the 50 yr, 6 hr rainfall changed from 2.0 in to 4.03 in. The default rainfall values are based on semi-arid regions of the United States where precipitation is lower as opposed to the higher precipitation region of the United States in which the sample site is located, based on type II storm and precipitation data.

Once the watershed boundary, main channel, and tributary channels have been drawn on the original topographic drawing, a Natural Regrade[®] design can be created. Once Natural

Regrade[®] is opened with AutoCAD, the “Design Natural Regrade” option is chosen under the Natural Regrade[®] tab. This opens the Carlson GeoFluv[™] box on the left side of the AutoCAD drawing. The first step is to click on the GeoFluv[™] boundary tab and then click the watershed boundary that was drawn previously. If all requirements were met, the program will state that the boundary has been accepted. If all of the requirements were not met, then it will not accept the boundary and it will state what error occurred or what needs to be fixed. Once the boundary is accepted, the select main channel tab is clicked. Then the main channel which was drawn previously is clicked. Next, the program asks if the user would like to choose the transition point of the main channel or if the user would like to have the program choose it. The transition point of a channel is where the stream changes from an A-channel to a sinusoidal channel. For the sample design, the program was allowed to choose the transition point of the main channel and the tributary channels. Once the main channel is selected, the valley length and the drainage density are calculated.

Next, the surface for elevations must be chosen by clicking on the surface for elevations tab. The program then asks if the user would like to choose an existing TIN file or create a new one by selecting the entities in the drawing. TIN files are used for storing triangulated irregular networks. Due to never making a TIN file of the sample site, all of the entities were chosen from the AutoCAD drawing with the original topography to make a new TIN file for the surface for elevations. Once the TIN file was created, the head and base elevations of the main channel were calculated and shown in the box under the select main channel tab.

Everything was completed in the setup tab, so the channels tab was clicked. Since the main channel had already been input into the program, all of the current channel settings and data for the main channel were displayed. The settings for the main channel that were displayed

include the upstream slope (%), maximum water velocity (ft/s), and width to depth ratio. There are other channel settings that could be changed in order for the user to customize the channels.

These channel settings are shown below in Figure 3.3.2.

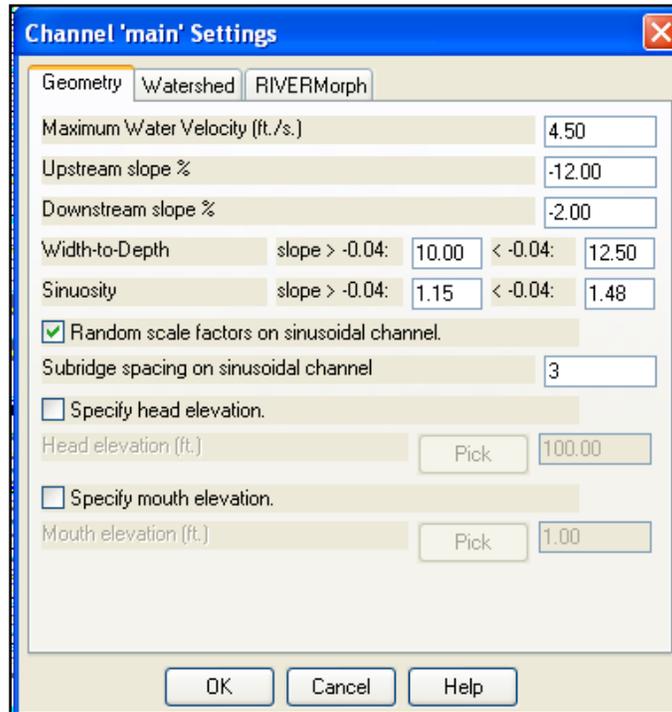


Figure 3.3.2: Channel Settings

All of the tributary channels had to be added individually into GeoFluv™. The add tab was clicked and then the channel was clicked. Just like the main channel, the program asked the user if the transition point would be chosen by the program or by the user. For the sample site, the program was allowed to choose the transition points on all of the channels. As each channel was added, the channel's data and drainage density was displayed in the box. The drainage density of the main channel as well as the channels that were previously added changed as more channels were added. After all of the channels were added, it was necessary to check to make sure all of the channels were within the target drainage density range. The arrow beside the

channel name was used to check each channel's drainage density. If the drainage density of one or more channels was not within the target drainage density, the drainage density would appear red as opposed to green and the channel would need to be altered until it was within the target drainage density range. The channels could be moved, shortened, lengthened, deleted, or another channel added to it in order to achieve the target drainage density.

The output tab was where the user could actually see the valley-fill design implemented. The user could click the preview tab to see where the ridges, in yellow, and the valleys, in light blue, would be located. If the location of the ridges and valleys were satisfactory, the user could close the preview and click the draw design surface tab so that the program would draw the design surface on the drawing. Once this tab was clicked, a new box appeared and many options were shown. These user options included the layers in which the channels and ridges would be located and whether to triangulate and contour the drawing. The draw design surface options are shown below in Figure 3.3.3 and the options that were used in the sample site design surface are chosen.

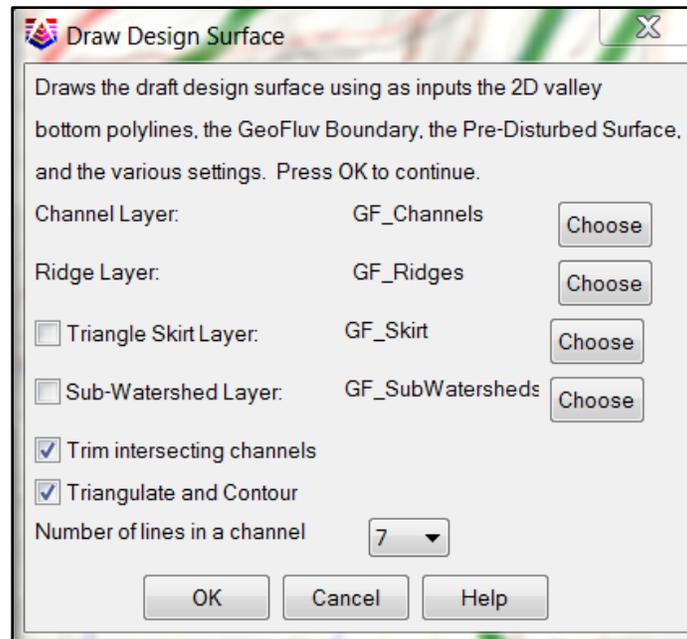


Figure 3.3.3: Draw Design Surface Options with Selected Options Used in Sample Site

Once the options were chosen, the OK tab was clicked. Next, the triangulate and contour from TIN box appeared automatically. This box contained three tabs of options that the user could customize the triangulation, contours, and labels of the drawing design surface. These options included writing the triangulation file of the design surface, the contour interval, and labeling the contours. Figure 3.3.4 shows the options that were under the triangulate tab and the options that were chosen for the sample site design surface.

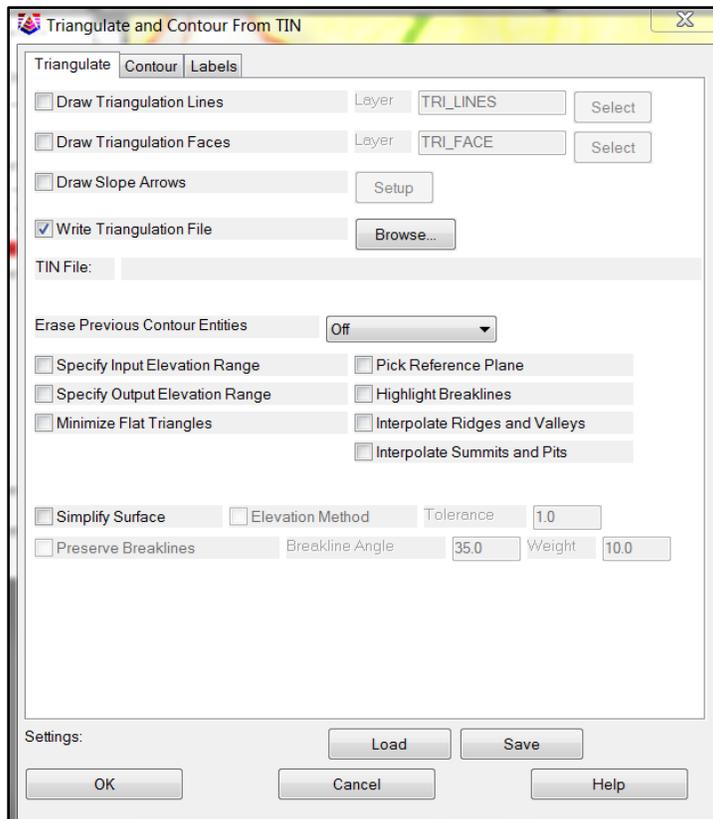


Figure 3.3.4: Triangulate Options with Selected Options Used in Sample Site

Figure 3.3.5 shows the contour options in the triangulate and contour from TIN box. It also shows the options that were selected with the sample site.

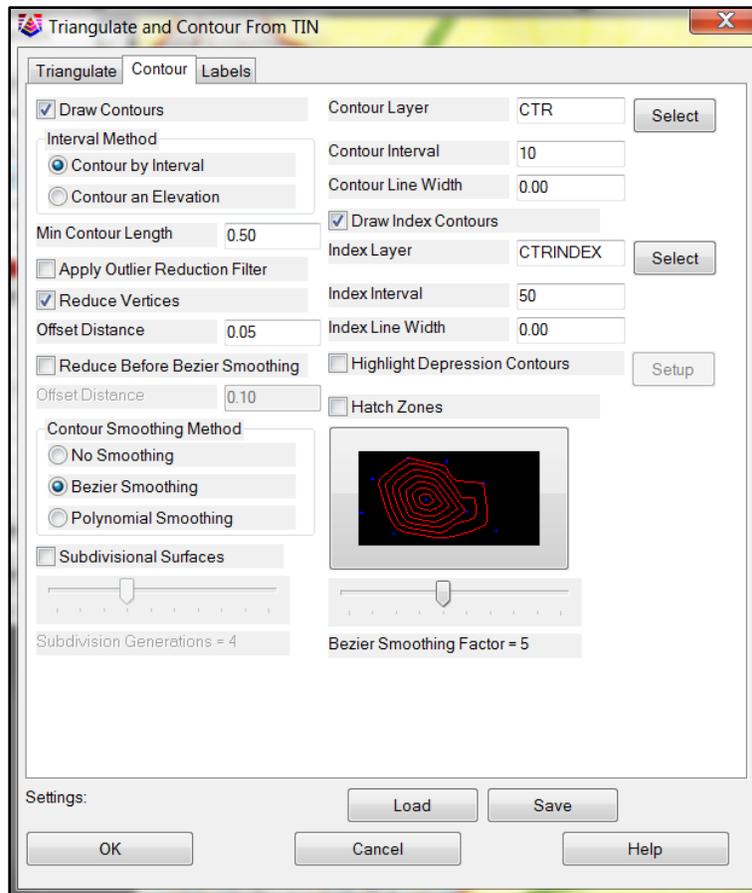


Figure 3.3.5: Contour Options with Selected Options Used with Sample Site

Figure 3.3.6 shows the label options that are available in the triangulate and contour from TIN box. The label options that were used in designing the sample site are also shown below in the figure.

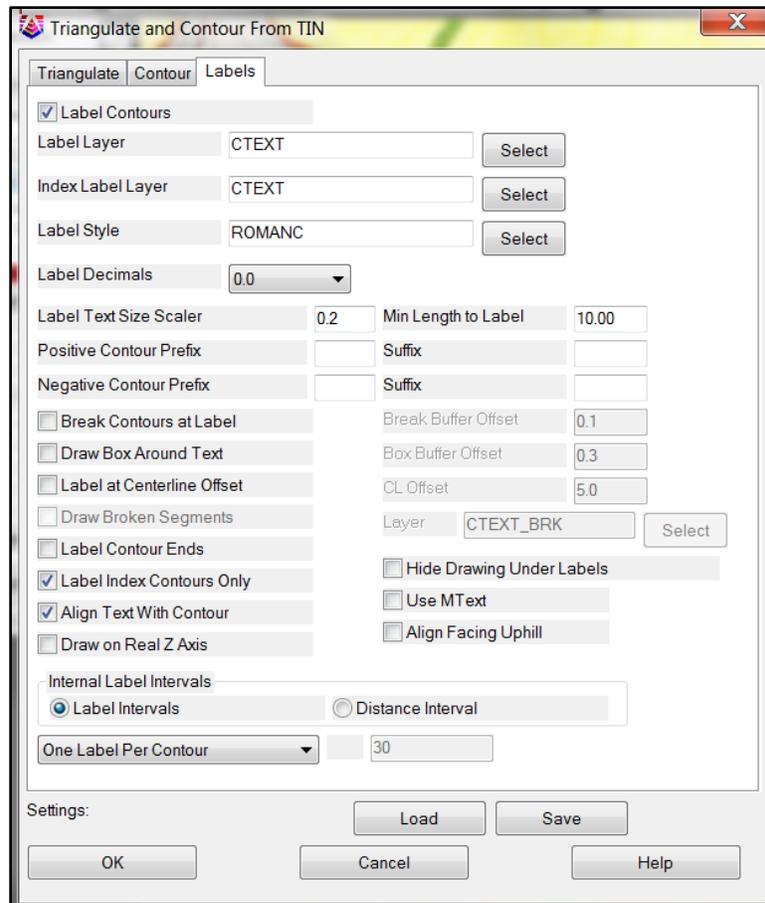


Figure 3.3.6: Label Options with Selected Options Used with Sample Site

After all of the options were chosen by the user, the OK tab was clicked and the program contoured the drawing according to the specifications of the user. Once Natural Regrade[®] created the contours on the drawing, the DWG tab and the Edit design surface in drawing options were automatically selected. Through the DWG tab, the user could view and edit the 3D surface that was just created. Figure 3.3.7 below shows all of the options of viewing and editing the drawing.

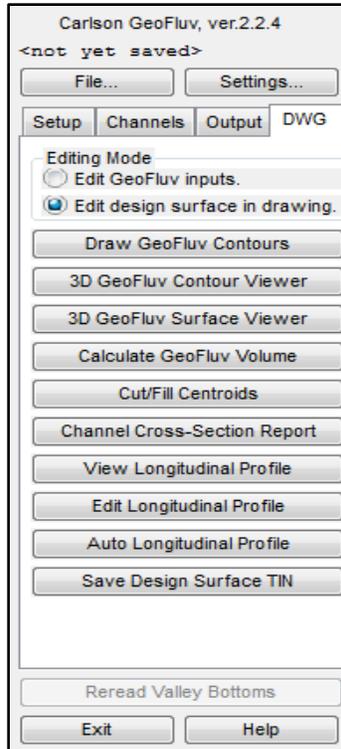


Figure 3.3.7: View and Edit Options for Created Drawing

3.4 Sample Site Description

In the first few months of the project, information was collected, including AutoCAD maps, soil samples, and site specific information. This was achieved by a visit to the sample surface mine in Southern West Virginia. We were taken on a tour of the pre-mined site, currently being mined, and reclaimed areas. Soil samples were taken on the site so that soil testing could be performed and AutoCAD maps of the property were collected in order to make a geomorphic reclamation design. Some pictures of the site visit are shown below in Figure 3.4.1.

a)



b)



Figure 3.4.1: Sample Surface Mine Site Visit at

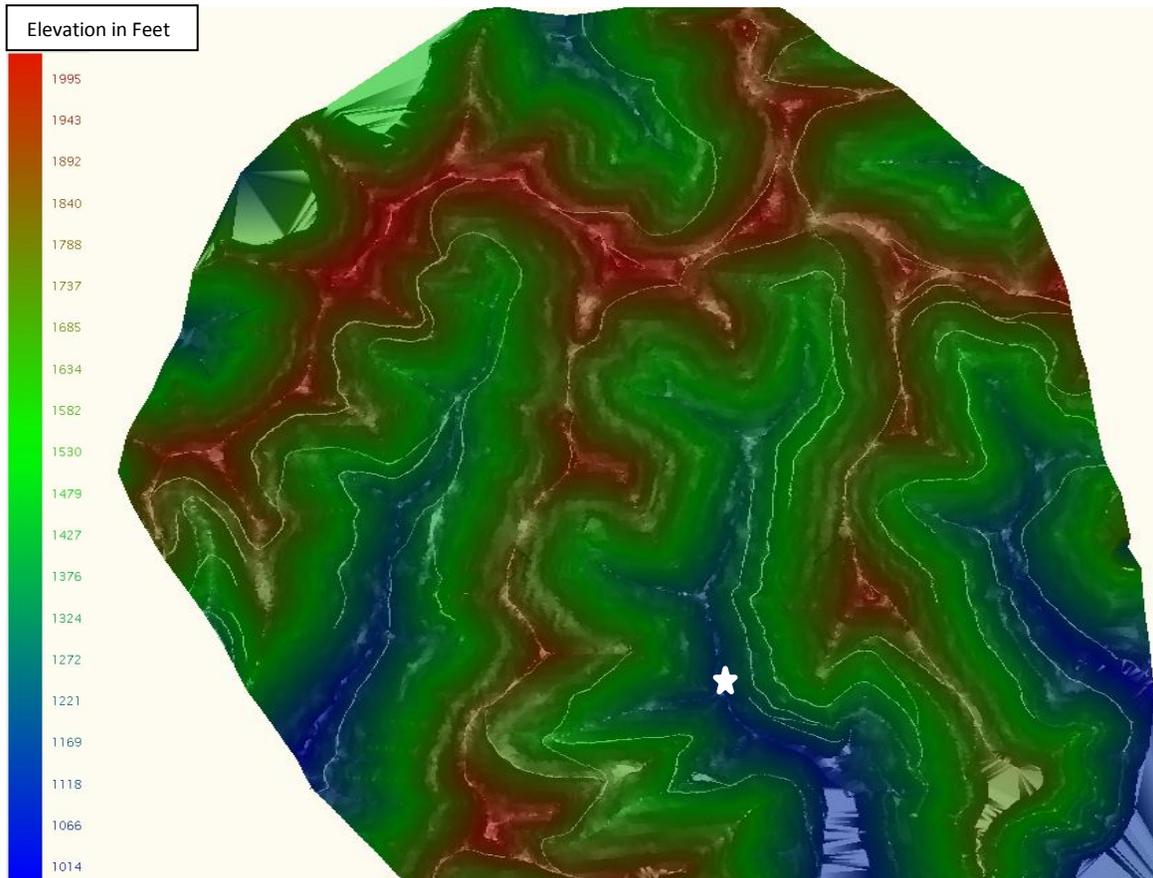
a) Area Currently Being Mined and b) Area Previously Reclaimed

Soil testing was performed at West Virginia University on the samples to obtain characteristics of the soils, such as soil classification, hydraulic conductivity, and moisture content which are specific to the sample site. This information was used in the strategic placement of the soil and rock, and was assessed in order to reduce the distance the material will be hauled. During the mining process, the overburden will be placed in areas where there are ridges in the geomorphic reclamation design so that it will not have to be moved twice, therefore lowering costs. Also, the placement of the soil was analyzed to reduce the amount of future leaching of selenium into groundwater and streams, a concern that has received recent emphasis in the mining industry.

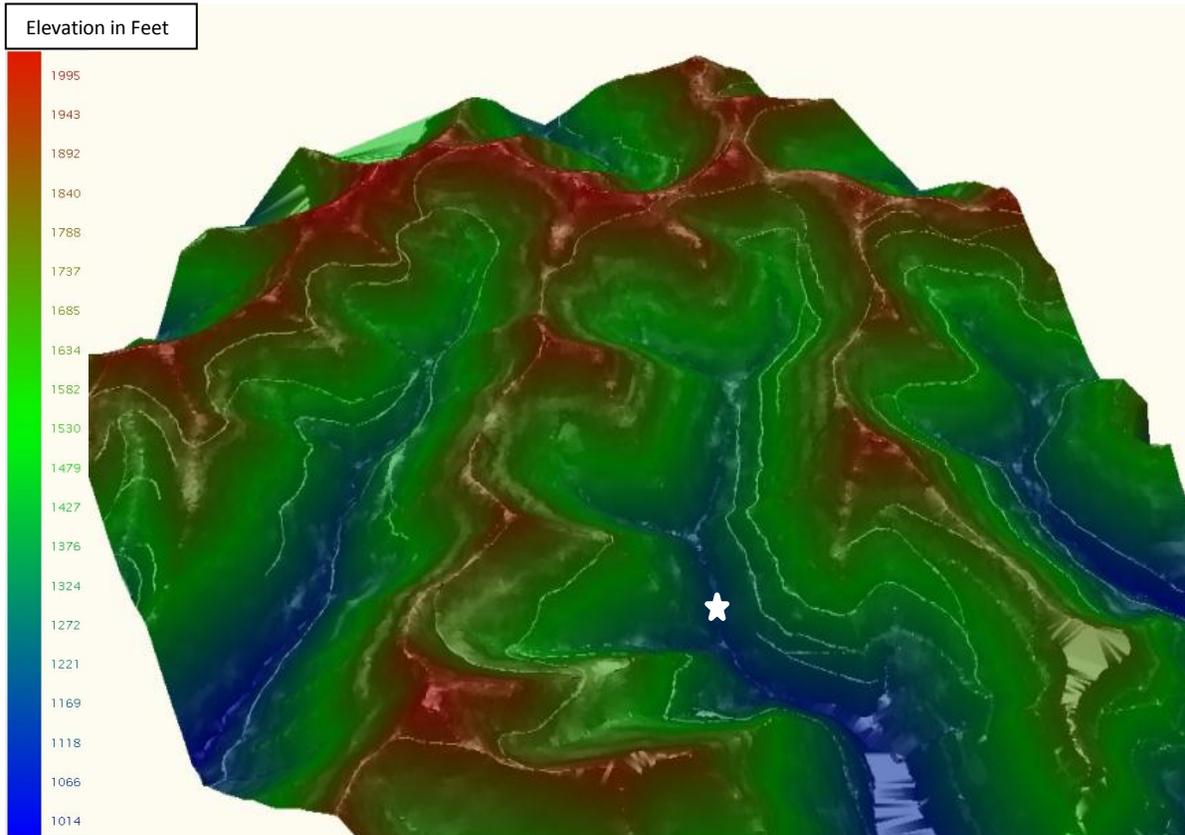
The design tool Carlson Natural Regrade[®] with GeoFluv[™] was used to apply the geomorphic landform design approach to a specific valley-fill study site that is located in the Southern West Virginia coalfield region. The area is characterized by a system of steep-sloped ridges and valleys which is shown in Figure 3.4.2.

The study site is a mountaintop removal surface mine site located among steep, rugged terrain. Approximately 75 million cubic yards of overburden and coal will be removed during the mining process, thus leaving the site as shown in Figure 3.4.3.

a)

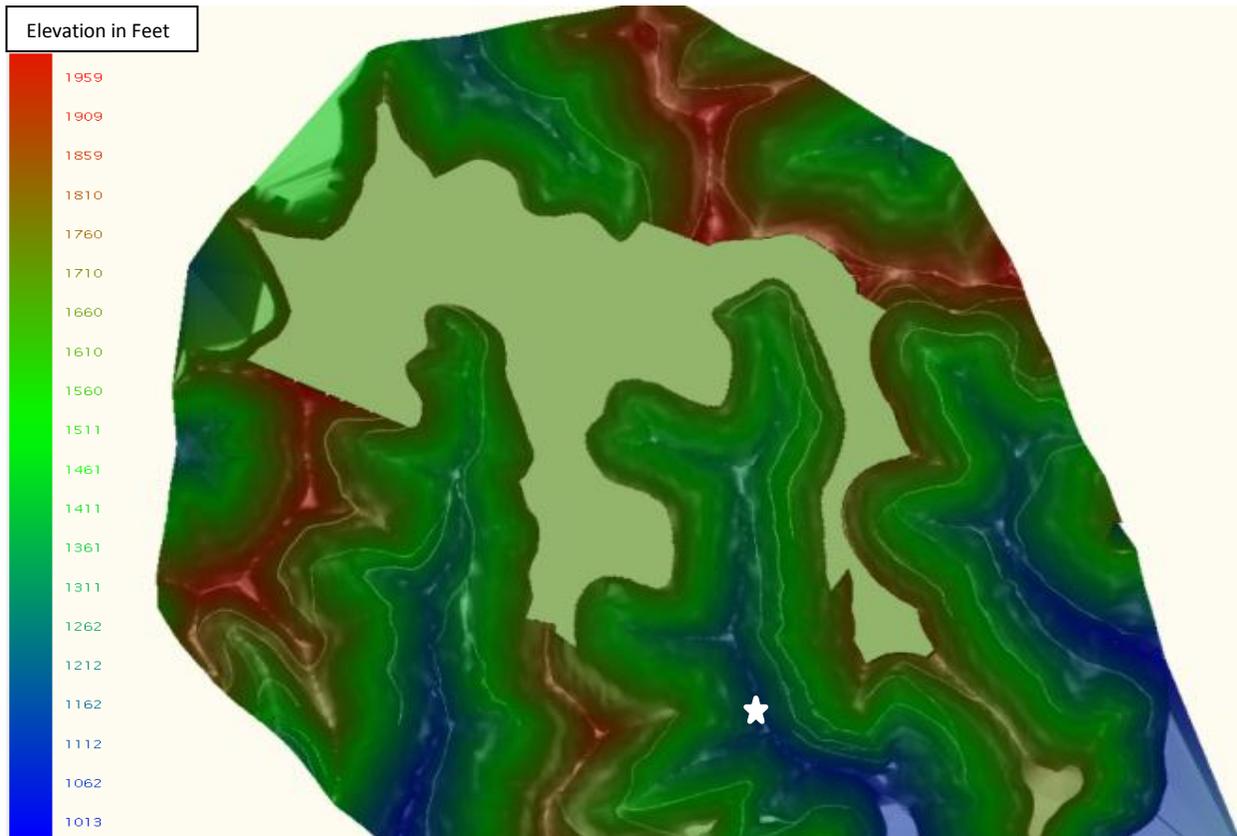


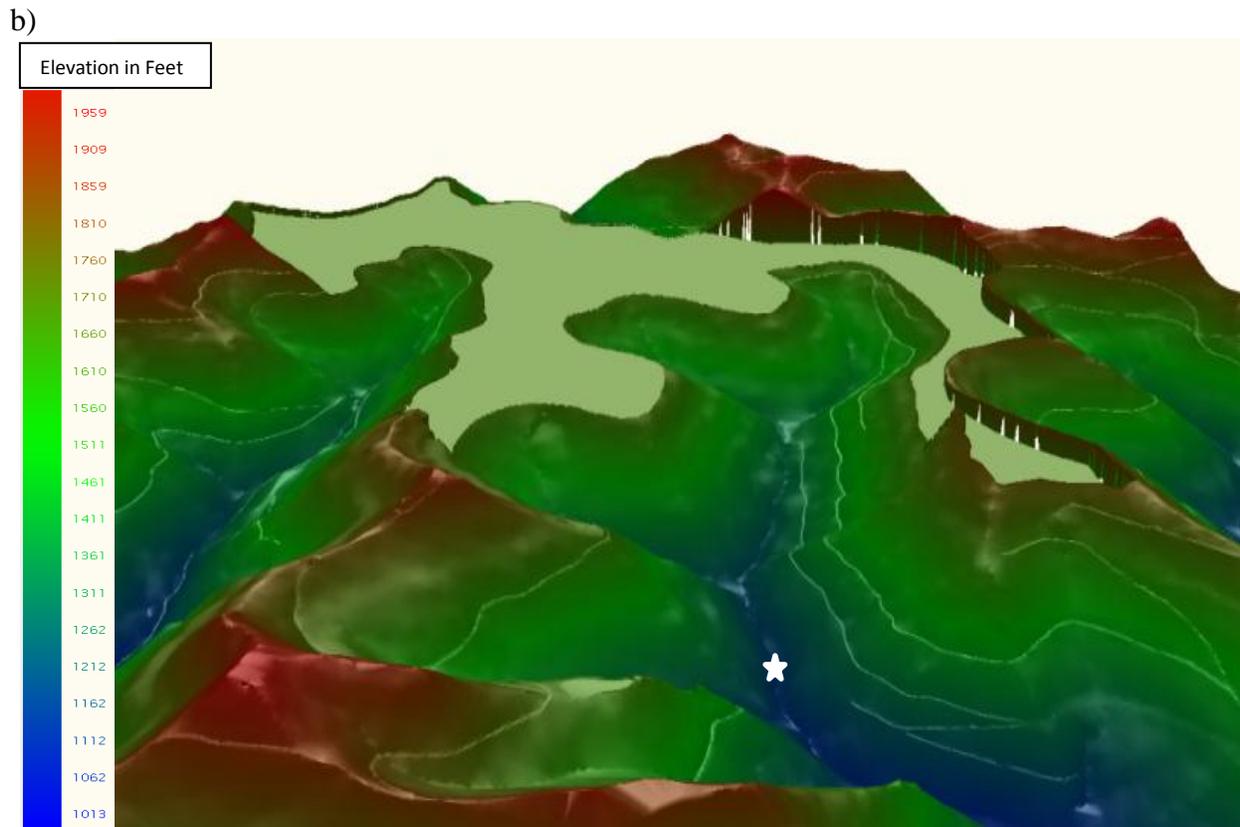
b)



*Figure 3.4.2: a) Original Plan View Drawing of Study Area and
b) Original Topographic Relief of Study Area*

a)





*Figure 3.4.3: a) Post-mined Plan View of Study Area and
b) Post-mined Topographic Relief of Study Area*

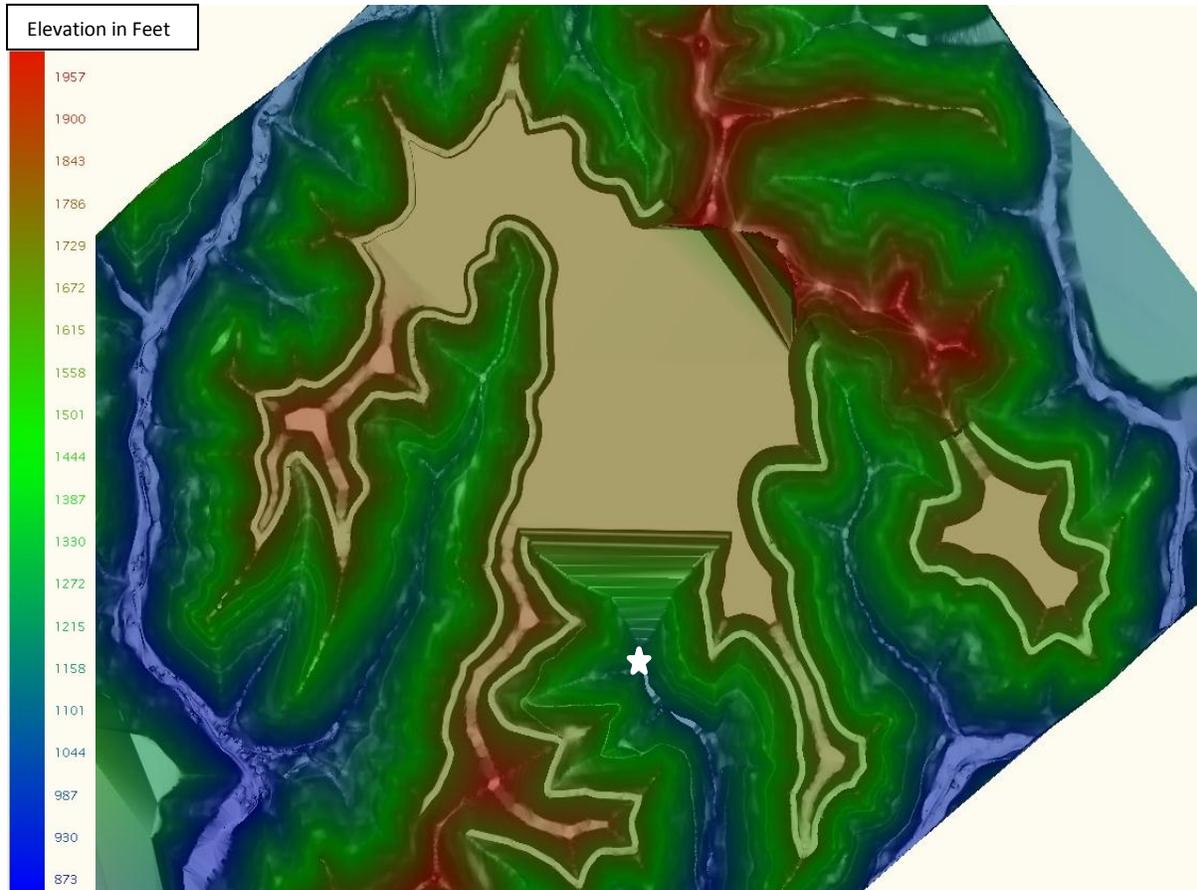
4. Data, Results, and Analysis

4.1 AOC Variance Valley-fill Design Analysis at Sample Site

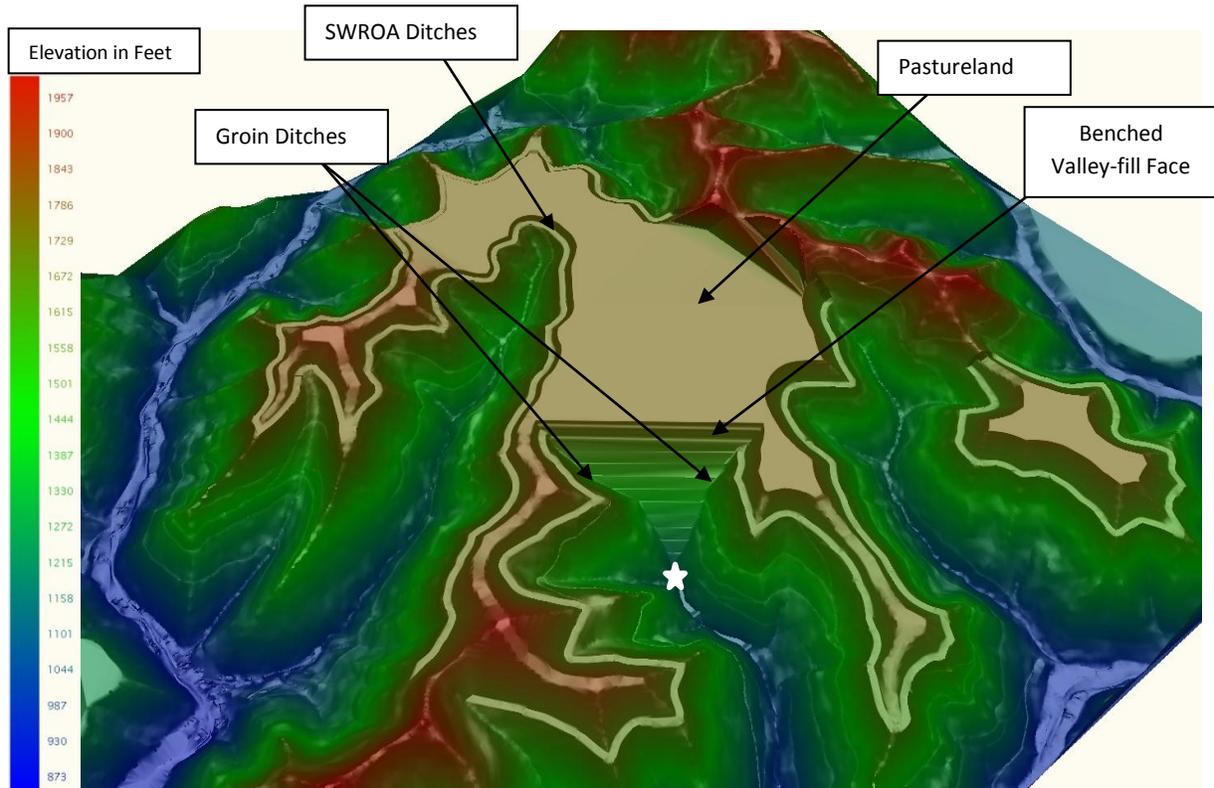
An AOC Variance valley-fill design was being implemented at the sample site in southern West Virginia. The area is characterized by a system of steep-sloped ridges and valleys as previously discussed. The post-mined land use of the area was determined to be pasture land and therefore an AOC variance was obtained in order to leave the land relatively flat at an elevation of approximately 1700 ft. The valley-fill covered approximately 340 ac and holds over

90 million cubic yards of fill material. Runoff from the property drained to Surface Water Runoff Analysis (SWROA) ditches that outlined the boundary and out National Pollution Discharge and Elimination System (NPDES) points into surrounding stream channels. Figure 4.1.1 shows the post-mined and reclaimed valley-fill at the site.

a)



b)



***Figure 4.1.1: a) Post-mined “Pastureland” Valley-fill Profile at Sample Site and
b) Labeled Features of Post-mined “Pastureland” Valley-fill at Sample Site***

The sample site valley-fill design contained numerous features that were typical for many AOC valley-fills designs. These include a traditional rock core underdrain that was formed from the natural segregation of the rock material as it was placed using end-dumping methods as well as a benched valley-fill face. The valley-fill would be highest in elevation along the top of the benched valley-fill area. The fill would then slope down one to two percent toward the north as well as to both sides. Therefore, all drainage would be directed away from the valley-fill face and into the pre-constructed SWROA ditches. This underdrain as well as a cross section of the

original topography and the valley-fill topography is shown below in Figures 4.1.2 and 4.1.3.

The face of the valley-fill, like many traditional fills, was constructed in benches as to provide stability to the structure. These benches were twenty feet wide and slope back at three to five percent. The benches are constructed every fifty feet in vertical elevation. The layout of the benched valley-fill face is shown below in Figures 4.1.3 and 4.1.4.

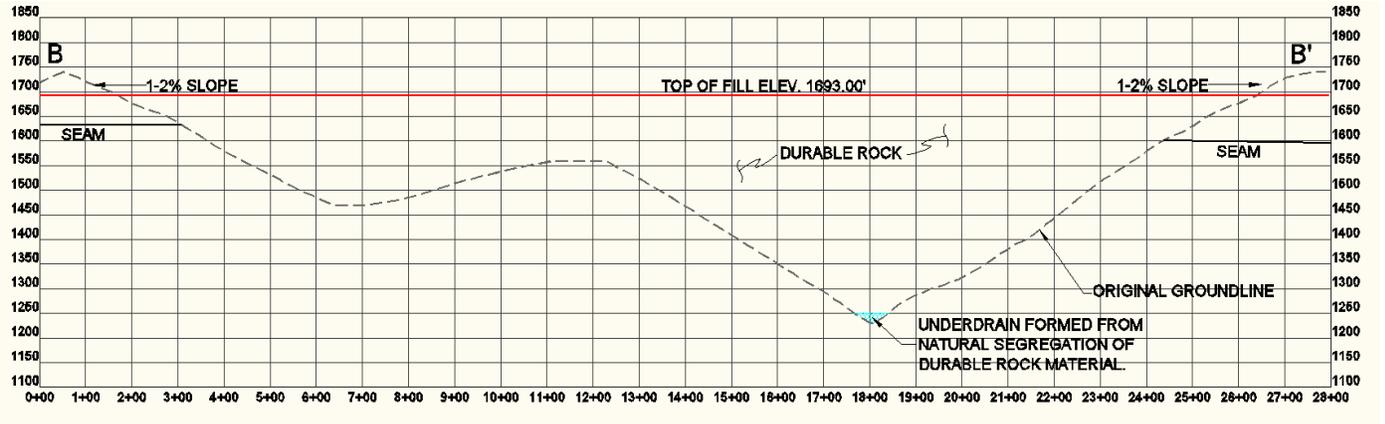


Figure 4.1.2: Sample Site Valley-fill Cross Section (East to West)

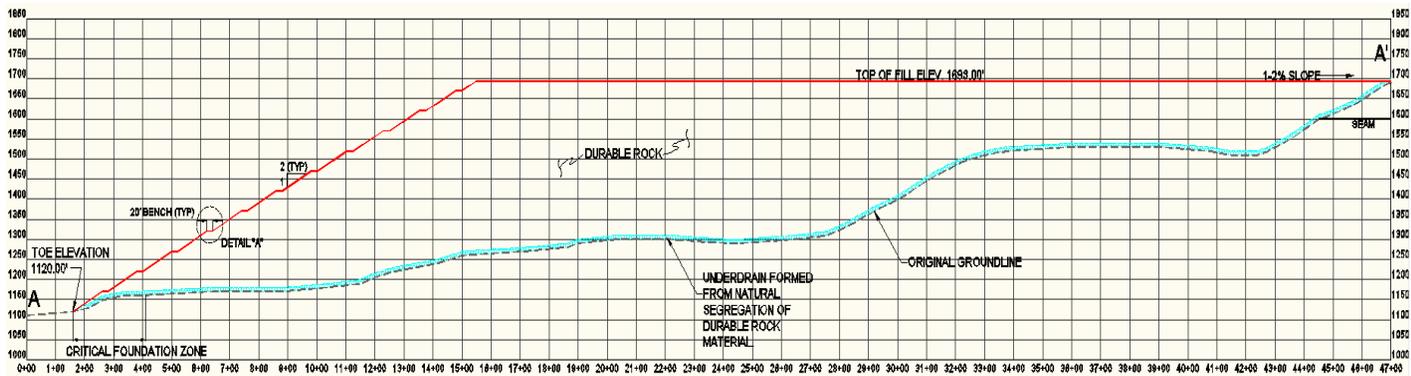


Figure 4.1.3: Sample Site Valley-fill Cross Section (South to North)

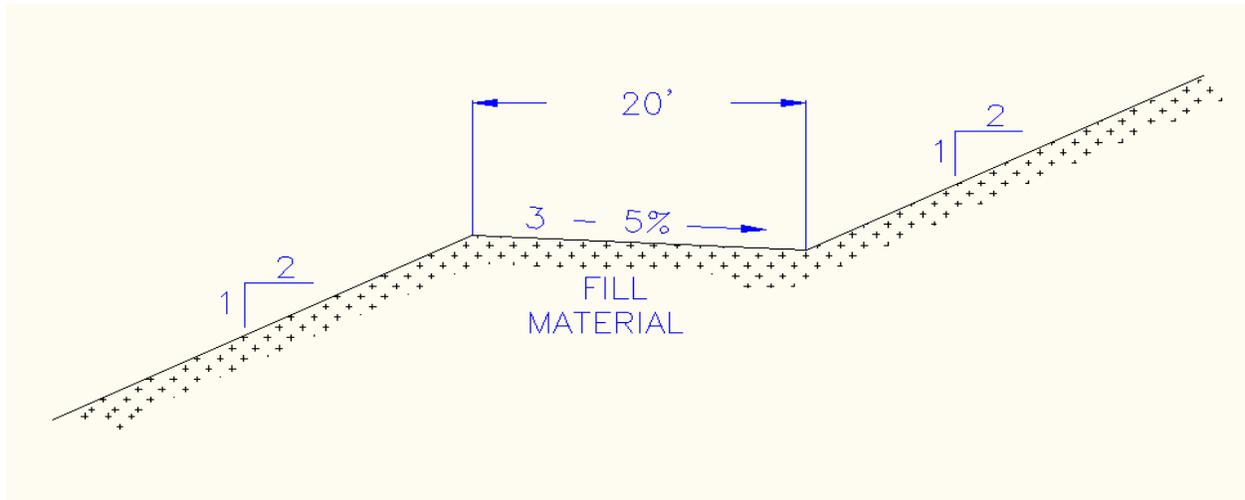


Figure 4.1.4: Sample Site Valley-fill Bench Specifications

4.2 Natural Regrade[®] with GeoFluv[™] Design

The sample site boundary was divided into subwatersheds, as identified in Figure 4.2.1, in order to perform a Natural Regrade[®] with GeoFluv[™] analysis over the entire disturbed surface mine area. Each subwatershed was designed to drain to existing NPDES permit points to maintain a hydrologic balance. There were a total of six subwatersheds, which ranged in size from just over 4 ac to 241 ac. The geomorphic design principles were then applied to each subwatershed, one at a time, to create balanced, stable landforms.

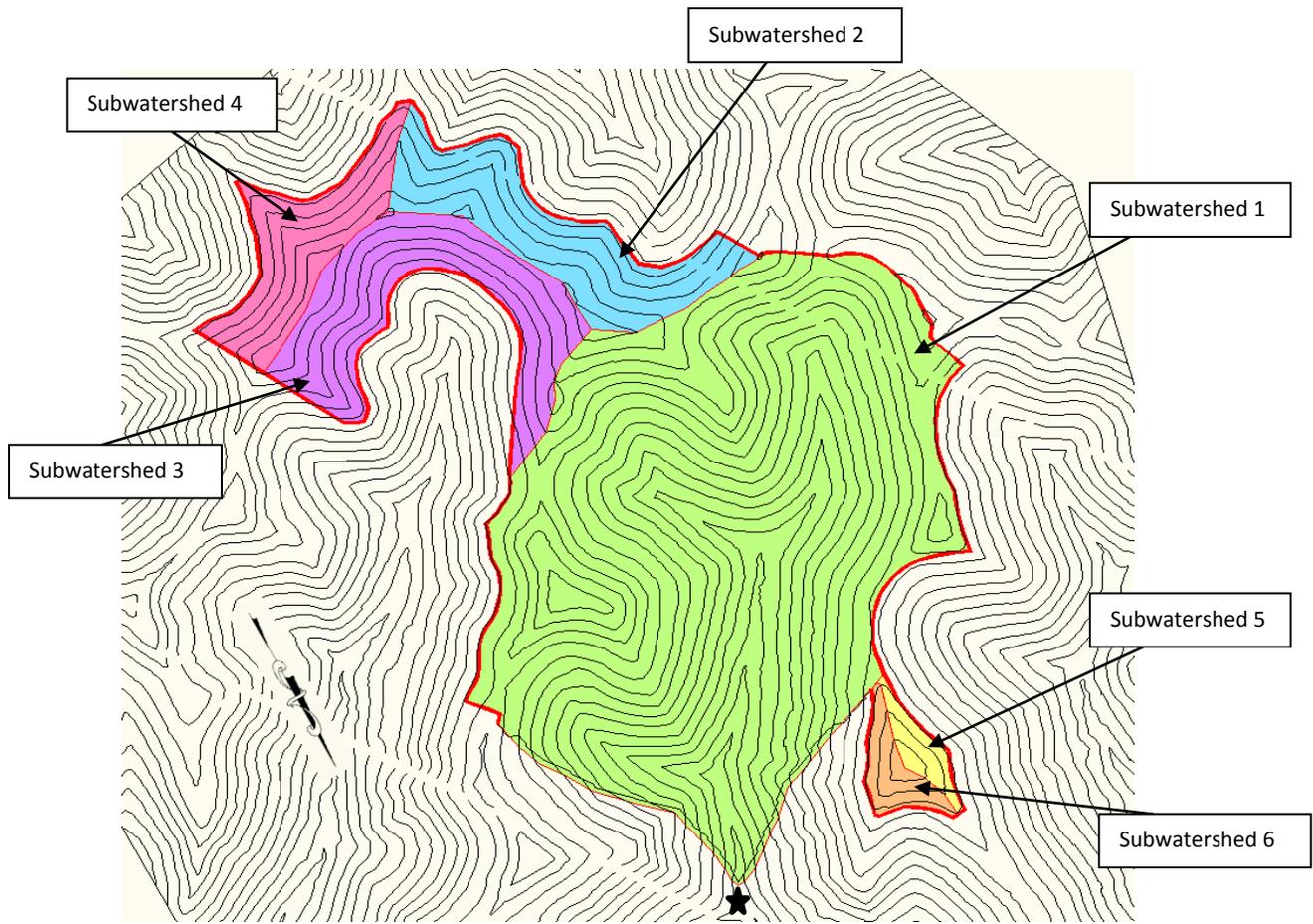


Figure 4.2.1: Subwatersheds Identified in the Valley-fill Study Site

The subwatershed highlighted in green, as shown below in Figure 4.2.2, was analyzed first because it was the largest subwatershed and was located in the center of the sample site property. The subwatershed covered approximately 241 ac and varied in elevation from 1150 ft to 1995 ft. It also contained over 8600 ft of original stream length. The original topography of the subwatershed 1 showed a valley running up the center of this property with ridges on the northern, eastern, and western sides. There were also three more subwatersheds located to the north-west side of the property and two more subwatersheds located at the south-east corner of the boundary. These subwatersheds were analyzed later in this section.

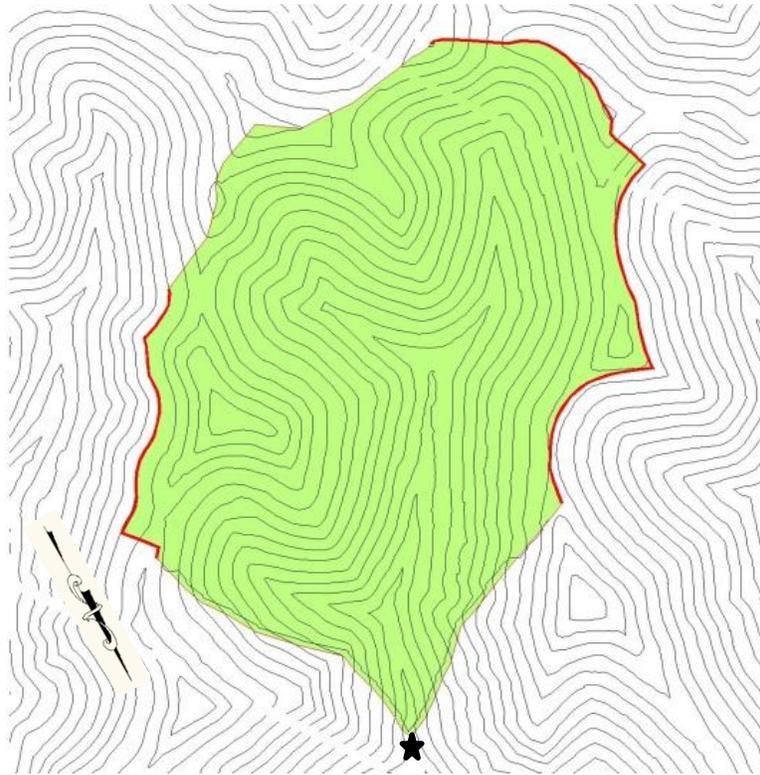


Figure 4.2.2: First and Largest Subwatershed Analyzed: “Subwatershed 1”

Figure 4.2.3, below, shows the stream channels created for the geomorphic design in the area associated with the subwatershed 1. The design was characterized by a main channel with twelve tributaries, forming a dendritic drainage pattern, which is typical for unconsolidated materials (Toy and Chuse, 2005; Eckels and Bugosh, 2010). The created channel pattern mimicked the original drainage pattern of the pre-mined site, but included many more channels. Therefore, the valley-fill created using Natural Regrade[®] had a greater amount of stream length within the same area compared to the original stream length (Table 6.0.1). More tributary channels were added to the main channel closer to its mouth in order to satisfy the target drainage density, while less tributary channels were added at the head of the main channel to meet the drainage density requirement.

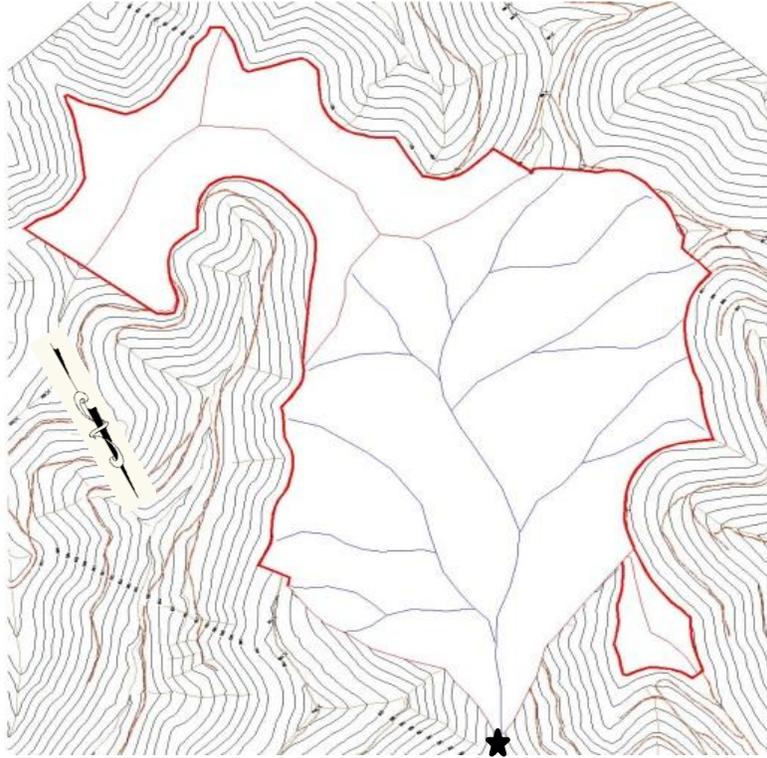


Figure 4.2.3: Subwatershed 1 and Streams Created in that Watershed

A close-up view of the created drainage channels within Subwatershed 1 is shown below in Figure 4.2.4. The main channel and the twelve tributary channels were labeled, according to their position with respect to the main channel. The channels ranged in length from 814 ft to almost 5,300 ft. The dendritic pattern of the channels matched the pattern of channels in watersheds surrounding the sample site property boundary. This was incredibly important due to one of the goals being to have the created valley-fill blend in with the surroundings.

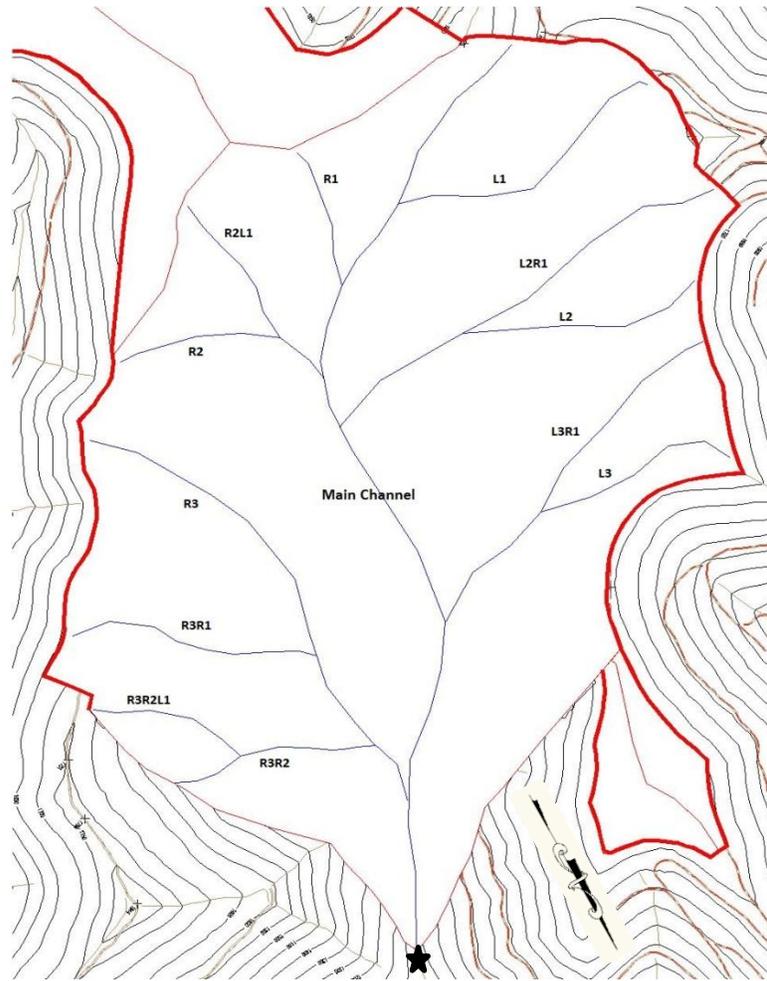


Figure 4.2.4: Subwatershed 1 with Labeled Created Streams

Geomorphic landform design principles using Natural Regrade[®] with GeoFluv[™] were applied to Subwatershed 1 after all of the channels were created and the drainage density was checked to be within the targeted area. The step-by-step method that was explained in the “Method: Step-by-Step Procedure and Method for Design” section was applied to this subwatershed, thus creating an aesthetically pleasing valley-fill that appeared natural with ridges and valleys. The geomorphic landform design also required fewer artificial elements and supported long-term stability due to the mature landforms that were created (Martin-Duque et al., 2009). This also led to reduced maintenance and cost because of decreased erosion of the

landforms. The created stream channels help control drainage on the property through the channelization of groundwater flow or precipitation.

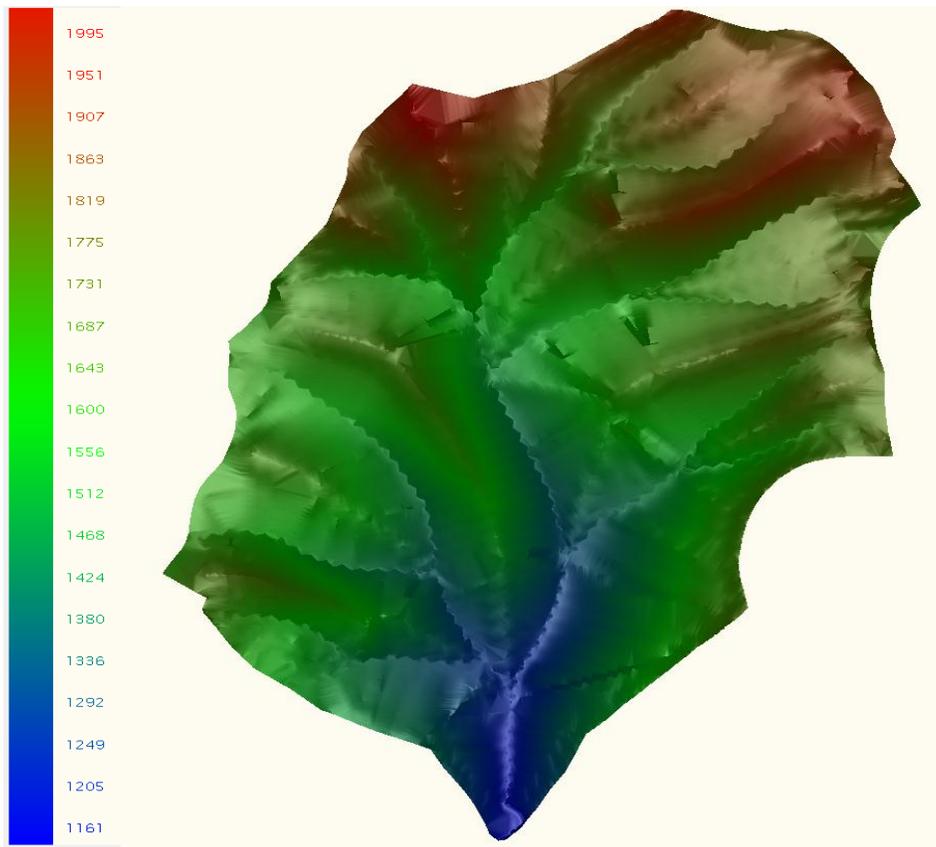


Figure 4.2.5: Completed Subwatershed 1 Geomorphic Valley-fill Design

There is a large amount of data that was obtained from the created geomorphic landform reclamation design. This wide range of data is shown in Tables 4.2.1 through 4.2.4. The watershed area that supplied each stream channel as well as the overall total watershed area, which is 241 ac for the subwatershed 1, was one of the important data that is obtained. The overall resulting drainage density for Subwatershed 1 was 90.62 ft/ac (Table 4.2.4), which lied within the target range of 80-120 ft/ac. Additionally, the drainage density of each channel was within the targeted range as to create a balanced design. The design included a total of 21,900 ft or over four miles of channel length, including type A and type C channels as defined by Rosgen

(1994). Also, this geomorphic valley-fill design allowed 1300 feet of original stream length to remain undisturbed compared to the traditional valley-fill design (Table 6.0.1). Additional design specifications are outlined in Tables 4.2.1-4.2.4.

Table 4.2.1: Channel Data for Subwatershed 1 Channels Main, R3, R3R2 and R3R2L1

Channel Data	main	R3	R3R2	R3R2L1
name				
watershed area (ac.)	241.14	63.95	17.25	6.89
add'l watershed area (ac.)	0.00	0.00	0.00	0.00
valley length (ft.)	5225.67	2622.37	1052.94	815.68
drainage density (ft./ac.)	90.62	90.22	108.33	118.44
head elevation (ft.)	1848.73	1668.39	1549.83	1693.06
base elevation (ft.)	1131.85	1238.35	1287.83	1458.08
relief (ft.)	716.89	430.04	261.99	234.98
head slope	-0.12	-0.15	-0.22	-0.26
base slope	-0.06	-0.12	-0.15	-0.22
slope range	-0.120 to -0.056	-0.149 to -0.120	-0.221 to -0.151	-0.258 to -0.222
bankfull width range (ft.)	0.36 to 18.93	0.45 to 8.75	0.35 to 4.54	0.17 to 2.87
bankfull depth range (ft.)	0.04 to 1.51	0.05 to 0.87	0.03 to 0.45	0.02 to 0.29
width to depth ratio, when slope < -0.04	12.50	12.50	12.50	12.50
width to depth ratio, when slope > -0.04	10.00	10.00	10.00	10.00
flood prone width range (ft.)	0.76 to 39.69	1.05 to 20.28	0.80 to 10.53	0.39 to 6.65
flood prone depth range (ft.)	0.08 to 4.50	0.12 to 2.32	0.09 to 1.20	0.04 to 0.76
entrenchment ratio	2.10 to 2.32	2.32	2.32	2.32
radius of curvature range (ft.)	1.37 to 58.99	n/a*	n/a*	n/a*
meander length range (ft.)	6.21 to 266.86	n/a*	n/a*	n/a*
meander belt width range (ft.)	2.92 to 125.60	n/a*	n/a*	n/a*
sinuosity (channel average)	1.15	1.14	1.15	1.15
meander width ratio	6.34	n/a*	n/a*	n/a*
maximum design velocity (ft./s.)	4.50	4.50	4.50	4.50
runoff coefficient	0.89	0.89	0.89	0.89
Shear stress, bankfull width (lbs/sq.ft.)	0.17 to 14.16	0.47 to 7.87	0.54 to 6.62	0.30 to 4.46
Shear stress, flood prone width (lbs/sq.ft.)	0.27 to 20.30	0.67 to 11.28	0.77 to 9.49	0.43 to 6.39
manual Qpk?	no	no	no	no
bankfull Qpk (cfs)	129.84	34.43	9.29	3.71
flood prone Qpk (cfs)	432.81	114.78	30.96	12.36

*GeoFluv(TM) approach is used for channels steeper than -0.04 in lieu of Williams (1986) approach.

Table 4.2.2: Channel Data for Subwatershed 1 Channels R3R1, L3, L3R1 and L2

Channel Data	R3R1	L3	L3R1	L2
name				
watershed area (ac.)	15.57	34.02	12.86	35.95
add'l watershed area (ac.)	0.00	0.00	0.00	0.00
valley length (ft.)	1278.59	1838.51	1234.84	2046.70
drainage density (ft./ac.)	82.11	90.35	96.03	98.67
head elevation (ft.)	1673.72	1768.39	1802.30	1811.93
base elevation (ft.)	1381.33	1369.81	1531.97	1529.90
relief (ft.)	292.38	398.58	270.33	282.04
head slope	-0.21	-0.19	-0.20	-0.12
base slope	-0.15	-0.13	-0.19	-0.12
slope range	-0.205 to -0.150	-0.193 to -0.126	-0.199 to -0.190	-0.120 to -0.120
bankfull width range (ft.)	0.52 to 4.32	0.42 to 6.38	0.47 to 3.92	0.25 to 6.56
bankfull depth range (ft.)	0.05 to 0.43	0.04 to 0.64	0.05 to 0.39	0.03 to 0.66
width to depth ratio, when slope < -0.04	12.50	12.50	12.50	12.50
width to depth ratio, when slope > -0.04	10.00	10.00	10.00	10.00
flood prone width range (ft.)	1.21 to 10.01	0.97 to 14.79	1.08 to 9.09	0.59 to 15.20
flood prone depth range (ft.)	0.14 to 1.14	0.11 to 1.69	0.12 to 1.04	0.07 to 1.74
entrenchment ratio	2.32	2.32	2.32	2.32
radius of curvature range (ft.)	n/a*	n/a*	n/a*	n/a*
meander length range (ft.)	n/a*	n/a*	n/a*	n/a*
meander belt width range (ft.)	n/a*	n/a*	n/a*	n/a*
sinuosity (channel average)	1.14	1.15	1.15	1.15
meander width ratio	n/a*	n/a*	n/a*	n/a*
maximum design velocity (ft./s.)	4.50	4.50	4.50	4.50
runoff coefficient	0.89	0.89	0.89	0.89
Shear stress, bankfull width (lbs/sq.ft.)	0.75 to 5.61	0.57 to 8.15	0.62 to 5.22	0.21 to 5.50
Shear stress, flood prone width (lbs/sq.ft.)	1.07 to 8.05	0.81 to 11.68	0.89 to 7.48	0.30 to 7.88
manual Qpk?	no	no	no	no
bankfull Qpk (cfs)	8.38	18.32	6.92	19.36
flood prone Qpk (cfs)	27.95	61.06	23.08	64.52

*GeoFluv(TM) approach is used for channels steeper than -0.04 in lieu of Williams (1986) approach.

Table 4.2.3: Channel Data for Subwatershed 1 Channels L2R1, R2, R2L1 and R1

Channel Data	L2R1	R2	R2L1	R1
name				
watershed area (ac.)	15.15	19.70	8.50	8.11
add'l watershed area (ac.)	0.00	0.00	0.00	0.00
valley length (ft.)	1500.47	1133.25	843.29	745.47
drainage density (ft./ac.)	99.02	100.33	99.25	91.96
head elevation (ft.)	1845.96	1722.94	1852.72	1932.69
base elevation (ft.)	1642.16	1566.76	1609.84	1636.83
relief (ft.)	203.79	156.18	242.88	295.85
head slope	-0.12	-0.12	-0.26	-0.35
base slope	-0.12	-0.12	-0.17	-0.26
slope range	-0.120 to -0.120	-0.120 to -0.120	-0.259 to -0.168	-0.352 to -0.263
bankfull width range (ft.)	0.53 to 4.26	0.20 to 4.86	0.46 to 3.19	0.32 to 3.11
bankfull depth range (ft.)	0.05 to 0.43	0.02 to 0.49	0.05 to 0.32	0.03 to 0.31
width to depth ratio, when slope < -0.04	12.50	12.50	12.50	12.50
width to depth ratio, when slope > -0.04	10.00	10.00	10.00	10.00
flood prone width range (ft.)	1.23 to 9.87	0.47 to 11.25	1.06 to 7.39	0.74 to 7.22
flood prone depth range (ft.)	0.14 to 1.13	0.05 to 1.29	0.12 to 0.84	0.09 to 0.82
entrenchment ratio	2.32	2.32	2.32	2.32
radius of curvature range (ft.)	n/a*	n/a*	n/a*	n/a*
meander length range (ft.)	n/a*	n/a*	n/a*	n/a*
meander belt width range (ft.)	n/a*	n/a*	n/a*	n/a*
sinuosity (channel average)	1.13	1.15	1.13	1.14
meander width ratio	n/a*	n/a*	n/a*	n/a*
maximum design velocity (ft./s.)	4.50	4.50	4.50	4.50
runoff coefficient	0.89	0.89	0.89	0.89
Shear stress, bankfull width (lbs/sq.ft.)	0.44 to 3.57	0.17 to 4.07	0.83 to 5.34	0.79 to 7.13
Shear stress, flood prone width (lbs/sq.ft.)	0.64 to 5.12	0.24 to 5.84	1.18 to 7.65	1.13 to 10.22
manual Qpk?	no	no	no	no
bankfull Qpk (cfs)	8.16	10.61	4.58	4.37
flood prone Qpk (cfs)	27.20	35.36	15.25	14.55

*GeoFluv(TM) approach is used for channels steeper than -0.04 in lieu of Williams (1986) approach.

Table 4.2.4: Channel Data for Subwatershed 1 Channel L1 and Total Summary Data

Channel Data	L1
name	
watershed area (ac.)	17.59
add'l watershed area (ac.)	0.00
valley length (ft.)	1514.27
drainage density (ft./ac.)	86.09
head elevation (ft.)	1916.53
base elevation (ft.)	1706.33
relief (ft.)	210.20
head slope	-0.12
base slope	-0.12
slope range	-0.120 to -0.120
bankfull width range (ft.)	0.73 to 4.59
bankfull depth range (ft.)	0.07 to 0.46
width to depth ratio, when slope < -0.04	12.50
width to depth ratio, when slope > -0.04	10.00
flood prone width range (ft.)	1.68 to 10.63
flood prone depth range (ft.)	0.19 to 1.21
entrenchment ratio	2.32
radius of curvature range (ft.)	n/a*
meander length range (ft.)	n/a*
meander belt width range (ft.)	n/a*
sinuosity (channel average)	1.16
meander width ratio	n/a*
maximum design velocity (ft./s.)	4.50
runoff coefficient	0.89
Shear stress, bankfull width (lbs/sq.ft.)	0.61 to 3.85
Shear stress, flood prone width (lbs/sq.ft.)	0.87 to 5.52
manual Qpk?	no
bankfull Qpk (cfs)	9.47
flood prone Qpk (cfs)	31.57

*GeoFluv(TM) approach is used for channels steeper than -0.04 in lieu of Williams (1986) approach.

Summary	
Total watershed area (ac.):	241.14
Overall drainage density:	90.62

Subwatershed 2, highlighted in blue, as shown below in Figure 4.2.6, was analyzed second because it was located adjacent to the subwatershed 1 valley-fill that was previously created. The subwatershed 2 analysis used the original topography as well as the created

subwatershed 1 topography so that the created landforms would merge smoothly. The subwatershed covered approximately 32 ac and varied in elevation from 1720 ft to 1995 ft. It also contained over 1180 ft of original stream length. The original topography of Subwatershed 2 showed a ridge running along the southern side of this property and sloped down toward the northern side. The subwatershed connected to the previously created Subwatershed 1 along the eastern side and bordered two other subwatersheds located along the southern and western sides of the property. These subwatersheds were analyzed later in this section.

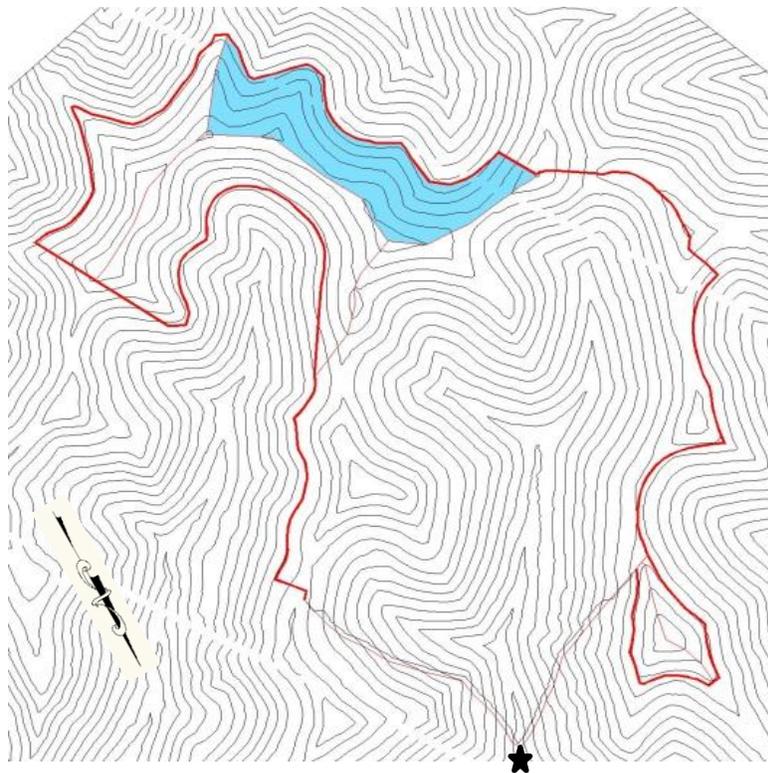


Figure 4.2.6: Second Subwatershed Analyzed: “Subwatershed 2”

Figure 4.2.7, below, shows the stream channel created for the geomorphic design in the area associated with Subwatershed 2. The design was characterized by a single main channel that flowed through the property. Only one channel was needed to satisfy the drainage density requirement due to the watershed area and the length of the main channel. Even though only one

channel was created, the valley-fill created using Natural Regrade[®] still had a greater amount of stream length within the same area compared to the original stream length (Table 6.0.1).

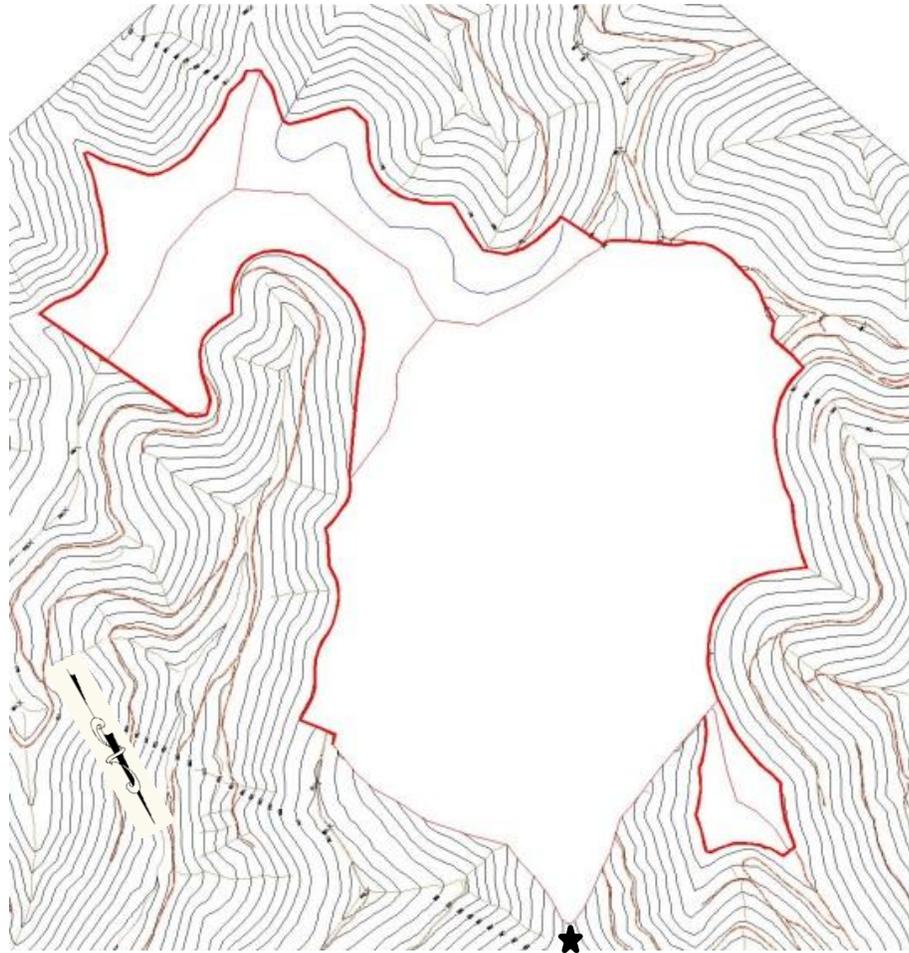


Figure 4.2.7: Subwatershed 2 and Streams Created in that Watershed

Figure 4.2.8 shows a close-up view of the created drainage channel within the subwatershed 2. The main channel was labeled “Main” and was approximately 3500 ft long.

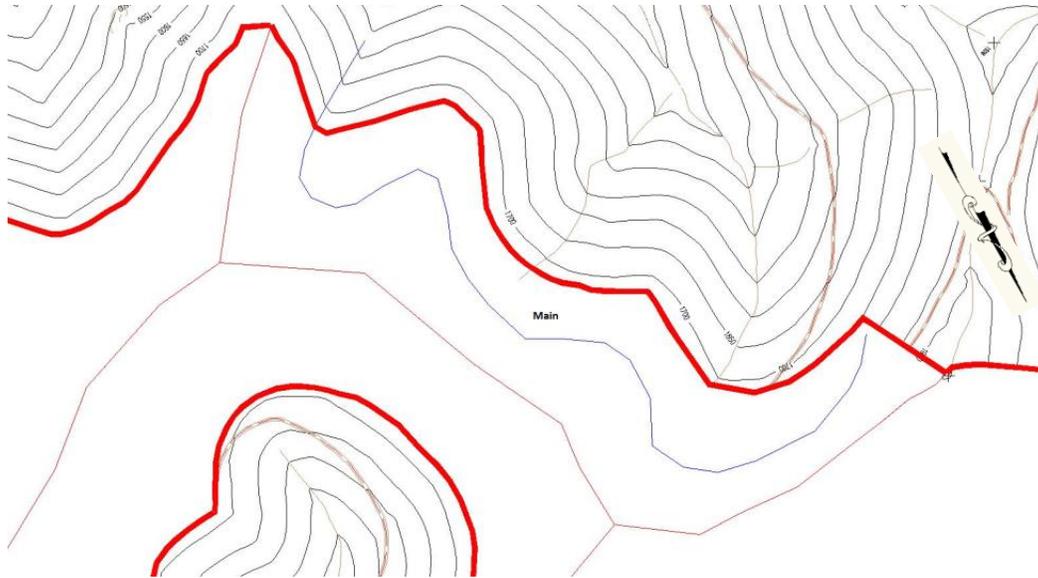


Figure 4.2.8: Subwatershed 2 with Labeled Created Stream

The same geomorphic landform design principles that were applied to the subwatershed 1 were applied to Subwatershed 2 and the following subwatersheds. Next, the drainage density was verified to be within the targeted range of 80-120 ft/ac. Also, the “Method: Step-by-Step Procedure and Method for Design” procedure was applied to this subwatershed and the following subwatersheds, thus creating valley-fills that had the same qualities and advantages such as long-term stability, minimal erosion, and groundwater channelization as the subwatershed 1.

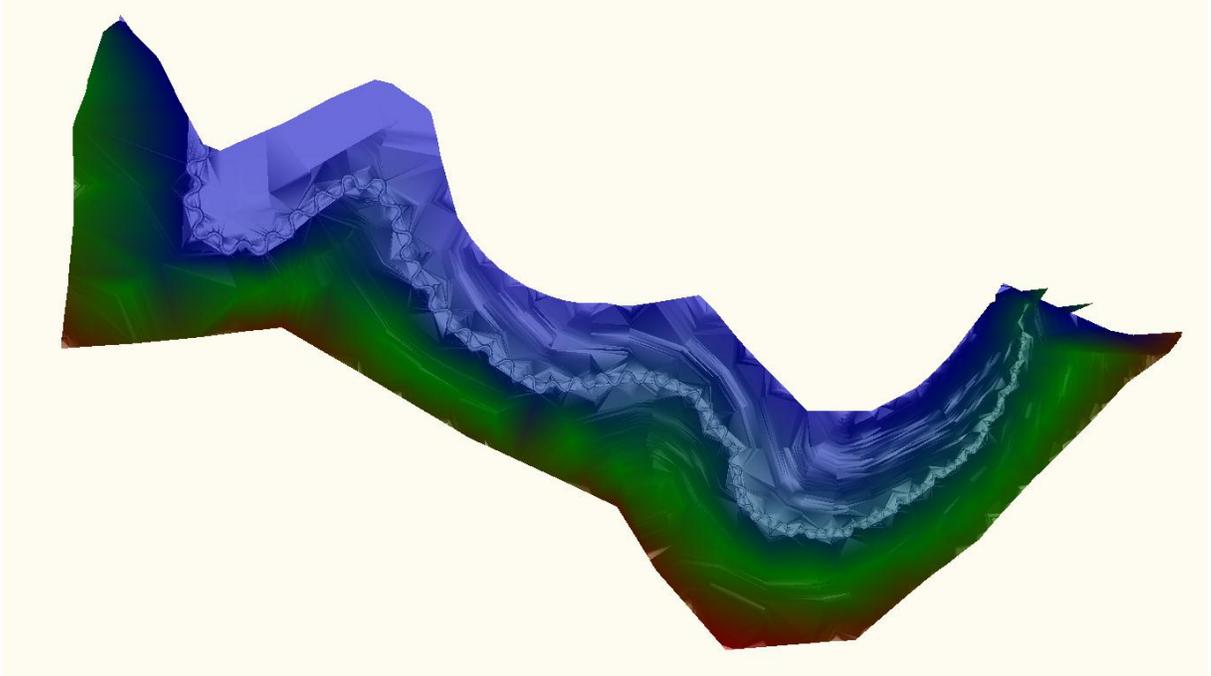


Figure 4.2.9: Completed Subwatershed 2 Geomorphic Valley-fill Design

A large amount of data was obtained from the created subwatershed 2 geomorphic landform reclamation design. This wide range of data is shown below in Table 4.2.5. The watershed area that supplied the stream channel was 31.8 ac for the second subwatershed, which was one of the important data that was obtained. The overall resulting drainage density for the blue subwatershed was 99.35 ft/ac (Table 4.2.5). The design added a total of 3500 ft or two thirds of a mile of channel length (Table 6.0.1), including type A and type C channels.

Table 4.2.5: Channel Data for Subwatershed 2 Channel Main and Total Summary Data

Channel Data	
name	main
watershed area (ac.)	31.80
add'l watershed area (ac.)	0.00
valley length (ft.)	3158.87
drainage density (ft./ac.)	99.35
head elevation (ft.)	1828.15
base elevation (ft.)	1640.00
relief (ft.)	188.15
head slope	-0.12
base slope	-0.02
slope range	-0.120 to -0.020
bankfull width range (ft.)	0.36 to 6.84
bankfull depth range (ft.)	0.04 to 0.55
width to depth ratio, when slope < -0.04	12.50
width to depth ratio, when slope > -0.04	10.00
flood prone width range (ft.)	0.77 to 14.35
flood prone depth range (ft.)	0.08 to 1.49
entrenchment ratio	2.10 to 2.32
radius of curvature range (ft.)	1.33 to 21.70
meander length range (ft.)	6.00 to 97.80
meander belt width range (ft.)	2.83 to 46.20
sinuosity (channel average)	1.32
meander width ratio	6.20
maximum design velocity (ft./s.)	4.50
runoff coefficient	0.89
Shear stress, bankfull width (lbs/sq.ft.)	0.17 to 1.35
Shear stress, flood prone width (lbs/sq.ft.)	0.27 to 1.93
manual Qpk?	no
bankfull Qpk (cfs)	17.12
flood prone Qpk (cfs)	57.07
*GeoFluv(TM) approach is used for channels steeper than -0.04 in lieu of Williams (1986) approach.	
Summary	
Total watershed area (ac.):	31.80
Overall drainage density:	99.35

Subwatershed 3, highlighted in purple, as shown below in Figure 4.2.10, was analyzed third because it was located adjacent to the subwatershed 1 and 2 valley-fills that were previously created. The subwatershed 3 analysis used the original topography as well as the created subwatershed 1 and 2 topography so that the created landforms would merge smoothly. The subwatershed covered approximately 36 ac and varied in elevation from 1650 ft to 1995 ft. It also contained no original stream length. The valley-fill created using Natural Regrade[®] had a greater amount of stream length within the same area compared to the original stream length in order for the target drainage density to be achieved (Table 6.0.1). The original topography of the subwatershed 3 showed a ridge running along the northern and western sides of this property and sloped down toward the southern side. This watershed connected to the previously created subwatersheds 1 and 2 along the northern and eastern sides and bordered one other subwatershed

located along the western side of the property. This subwatershed was analyzed later in this section.

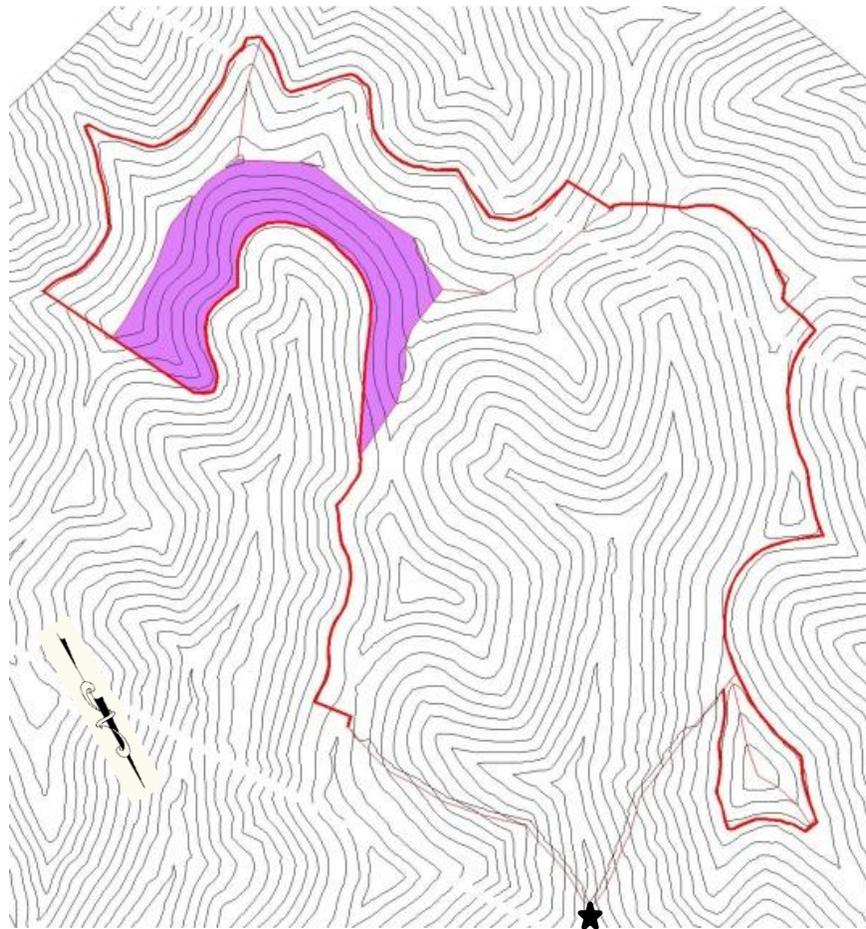


Figure 4.2.10: Third Subwatershed Analyzed: “Subwatershed 3”

The stream channel created for the geomorphic design in the area associated with Subwatershed 3 is shown below in Figure 4.2.11. The design was characterized by a single main channel that flowed through the property.

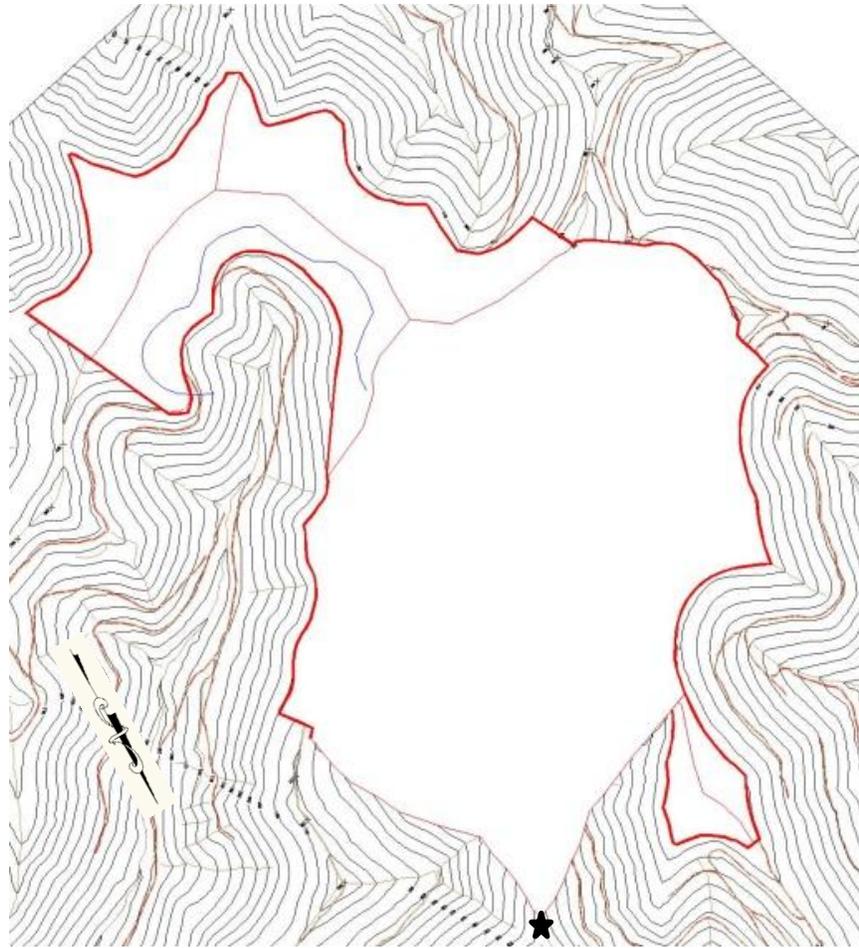


Figure 4.2.11: Subwatershed 3 and Streams Created in that Watershed

A close-up view of the created drainage channel within the third subwatershed is shown below in Figure 4.2.12. The main channel was labeled and was approximately 3700 ft long.

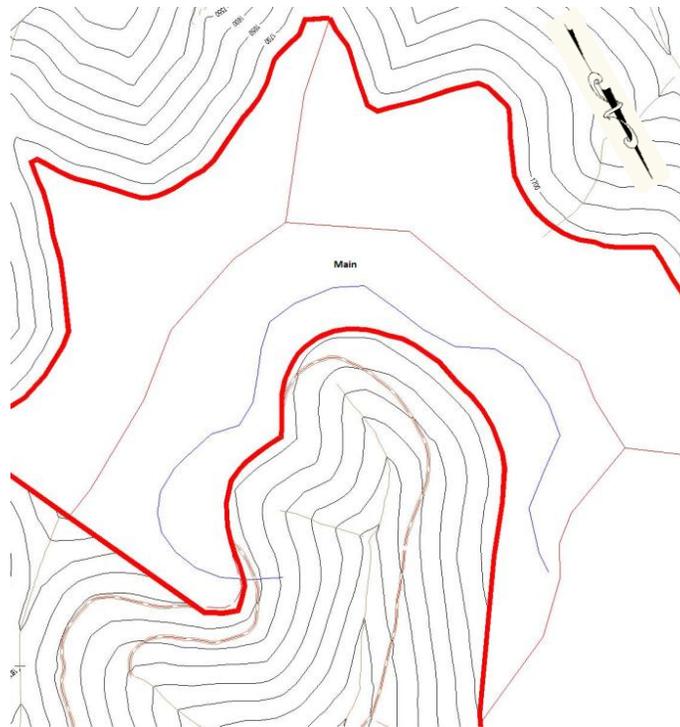


Figure 4.2.12: Subwatershed 3 with Labeled Created Stream

The geomorphic landform valley-fill design created using the previously mentioned methodologies and principles is shown below in the three-dimensional Figure 4.2.13.

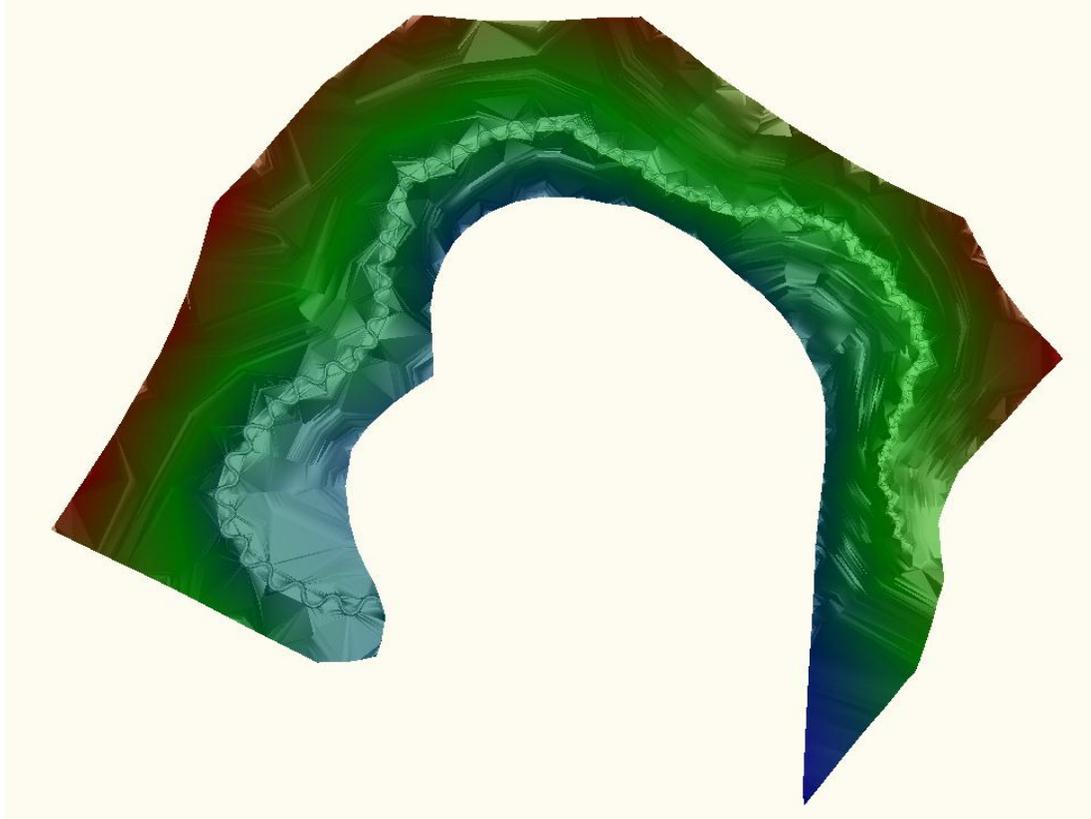


Figure 4.2.13: Completed Subwatershed 3 Geomorphic Valley-fill Design

The wide range of data that was obtained from the created valley-fill design is shown below in Table 4.2.6. The watershed area that supplied the stream channel was 35.95 ac for the subwatershed 3. The overall resulting drainage density for the subwatershed was 98.76 ft/ac (Table 4.2.6). The design added a total of 3700 feet of channel length (Table 6.0.1), including type A and type C channels.

Table 4.2.6: Channel Data for Subwatershed 3 Channel Main and Total Summary Data

Channel Data	
name	main
watershed area (ac.)	35.95
add'l watershed area (ac.)	0.00
valley length (ft.)	3550.85
drainage density (ft./ac.)	98.76
head elevation (ft.)	1849.91
base elevation (ft.)	1734.03
relief (ft.)	115.88
head slope	-0.11
base slope	-0.02
slope range	-0.113 to -0.020
bankfull width range (ft.)	0.35 to 7.28
bankfull depth range (ft.)	0.07 to 0.58
width to depth ratio, when slope < -0.04	12.50
width to depth ratio, when slope > -0.04	10.00
flood prone width range (ft.)	0.73 to 15.26
flood prone depth range (ft.)	0.08 to 1.58
entrenchment ratio	2.10 to 2.32
radius of curvature range (ft.)	1.17 to 23.07
meander length range (ft.)	5.30 to 104.30
meander belt width range (ft.)	2.50 to 49.13
sinuosity (channel average)	1.47
meander width ratio	6.20
maximum design velocity (ft./s.)	4.50
runoff coefficient	0.89
Shear stress, bankfull width (lbs/sq.ft.)	0.14 to 0.72
Shear stress, flood prone width (lbs/sq.ft.)	0.22 to 1.13
manual Qpk?	no
bankfull Qpk (cfs)	19.36
flood prone Qpk (cfs)	64.53
*GeoFluv(TM) approach is used for channels steeper than -0.04 in lieu of Williams (1986) approach.	
Summary	
Total watershed area (ac.):	35.95
Overall drainage density:	98.76

Subwatershed 4, highlighted in pink, as shown below in Figure 4.2.14, was analyzed fourth because it was located adjacent to the valley-fills of Subwatersheds 2 and 3 that were previously created. The subwatershed 4 analysis used the original topography as well as the created 1, 2, and 3 subwatershed topography so that the created landforms would merge smoothly. Subwatershed 4 covered approximately 21 ac and varied in elevation from 1720 ft to 1993 ft. It also contained over 460 ft of original stream length. The original topography of the fourth subwatershed showed a ridge running along the south eastern side of this property and sloped down toward the north western side. It connected to the previously created subwatersheds 2 and 3 along the eastern side of the property.

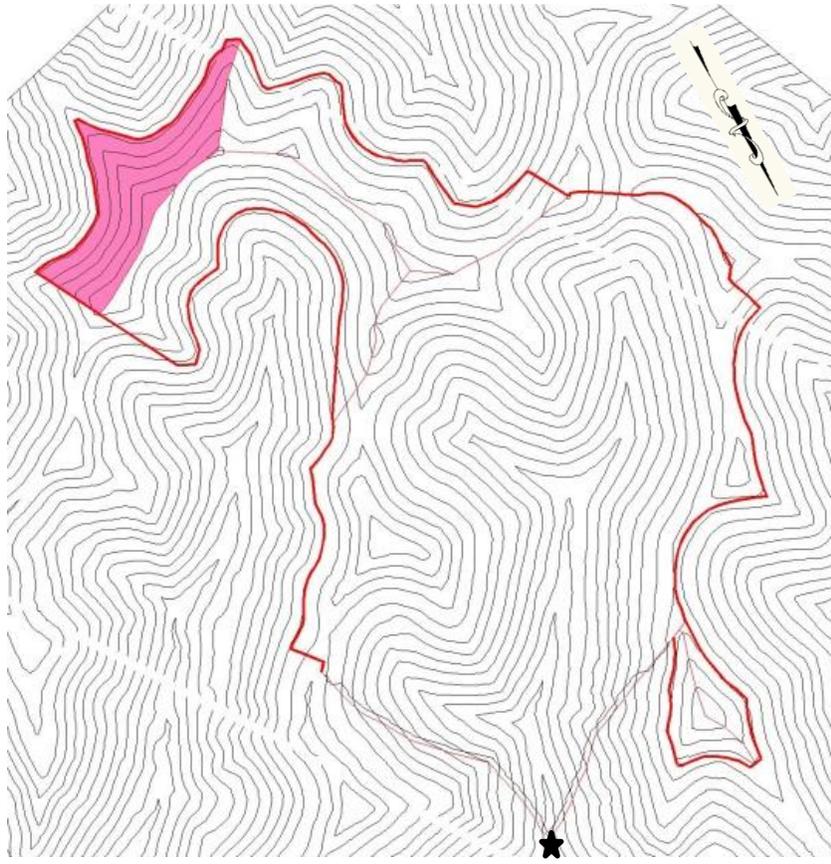


Figure 4.2.14: Fourth Subwatershed Analyzed: “Subwatershed 4”

The stream channels created for the geomorphic design in the area associated with Subwatershed 4 are shown below in Figure 4.2.15. The design was characterized by a single main channel and one tributary channel that flowed through the property.



Figure 4.2.15: Subwatershed 4 and Streams Created in that Watershed

A close-up view of the created drainage channel within the fourth subwatershed is shown below in Figure 4.2.16. The main and tributary channels were labeled “Main” and “L1” according to their position with respect to the main channel. The channels ranged in length from almost 580 ft to 1664 ft.



Figure 4.2.16: Subwatershed 4 with Labeled Created Streams

The geomorphic landform design principles and methods were applied to the subwatershed 4 after the channels were created and the drainage density of each channel was verified to be within the targeted area. The three-dimensional Figure 4.2.17 shows the completed valley-fill design of Subwatershed 4.

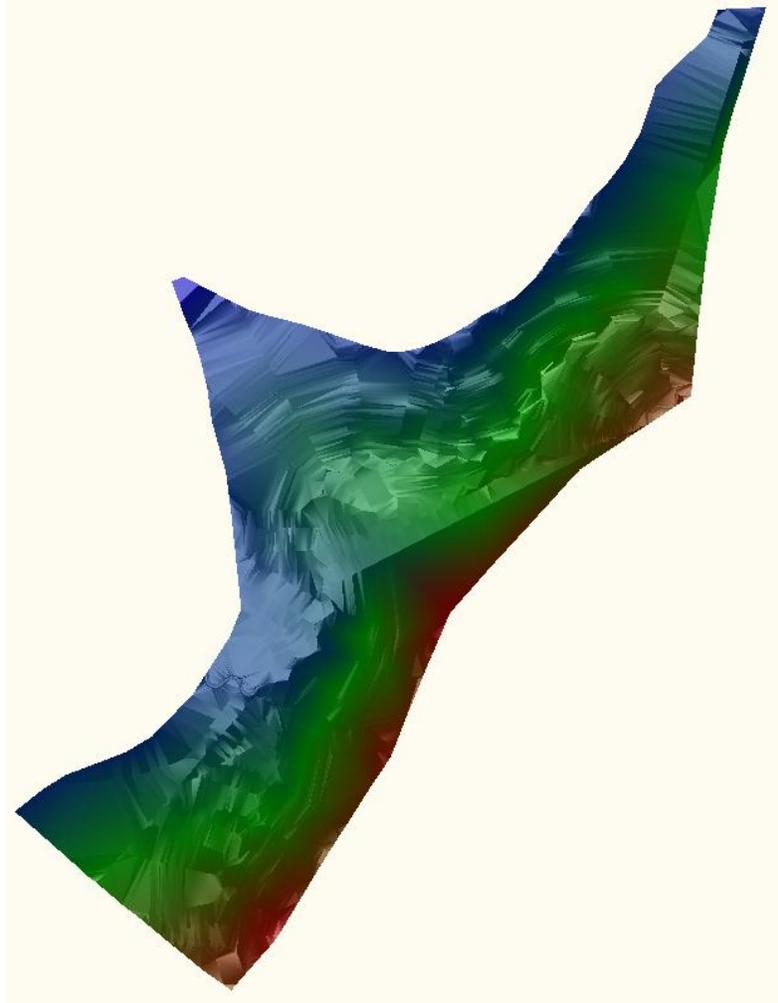


Figure 4.2.17: Completed Subwatershed 4 Geomorphic Valley-fill Design

Table 4.2.7 contains a large amount of data from the created geomorphic landform reclamation design. The watershed area that supplied the stream channel was 21.19 ac for Subwatershed 4. The overall resulting drainage density for the subwatershed was 98.42 ft/ac (Table 4.2.7). The design added a total of 2244 ft of channel length (Table 6.0.1), including type A and type C channels.

**Table 4.2.7: Channel Data for Subwatershed 4 Channels Main, L1,
and Total Summary Data**

Channel Data		
name	main	L1
watershed area (ac.)	21.19	4.99
add'l watershed area (ac.)	0.00	0.00
valley length (ft.)	1505.55	580.10
drainage density (ft./ac.)	98.42	116.33
head elevation (ft.)	1903.10	1954.91
base elevation (ft.)	1740.54	1743.18
relief (ft.)	162.55	211.73
head slope	-0.12	-0.33
base slope	-0.02	-0.16
slope range	-0.120 to -0.020	-0.331 to -0.161
bankfull width range (ft.)	0.41 to 5.57	0.35 to 2.68
bankfull depth range (ft.)	0.04 to 0.45	0.04 to 0.21
width to depth ratio, when slope < -0.04	12.50	12.50
width to depth ratio, when slope > -0.04	10.00	10.00
flood prone width range (ft.)	0.85 to 11.68	0.73 to 5.66
flood prone depth range (ft.)	0.09 to 1.21	0.08 to 0.65
entrenchment ratio	2.10 to 2.32	2.10 to 2.32
radius of curvature range (ft.)	1.19 to 18.32	1.13 to 8.71
meander length range (ft.)	5.36 to 80.19	5.04 to 38.90
meander belt width range (ft.)	2.54 to 39.01	2.40 to 18.54
sinuosity (channel average)	1.17	1.14
meander width ratio	6.25	6.31
maximum design velocity (ft./s.)	4.50	4.50
runoff coefficient	0.89	0.89
Shear stress, bankfull width (lbs/sq.ft.)	0.19 to 2.46	0.46 to 5.03
Shear stress, flood prone width (lbs/sq.ft.)	0.30 to 3.53	0.73 to 7.21
manual Qpk?	no	no
bankfull Qpk (cfs)	11.41	2.69
flood prone Qpk (cfs)	38.03	8.95
*GeoFluv(TM) approach is used for channels steeper than -0.04 in lieu of Williams (1986) approach.		
Summary		
Total watershed area (ac.):	21.19	
Overall drainage density:	98.42	

Subwatershed 5, highlighted in yellow, as shown below in Figure 4.2.18, was analyzed fifth because it was the smallest subwatershed and was located adjacent to the subwatershed 1 valley-fill that was previously created. This subwatershed was located in the south eastern corner of the boundary and bordered Subwatershed 1 by only 1730 ft. The subwatershed 5 analysis used the original topography as well as the created topography of the subwatersheds 1, 2, 3, and 4 so that the created landforms would merge smoothly. The subwatershed covered approximately 4 ac and varied in elevation from 1780 ft to 1897 ft. It also contained no original stream length. The valley-fill created using Natural Regrade® had a greater amount of stream length within the same area compared to the original stream length (Table 6.0.1). The original topography of the subwatershed 5 showed a ridge running along the eastern side of this property

and sloped down toward the northern, southern, and western sides. It connected to the previously created Subwatershed 1 along the northern side of the property.

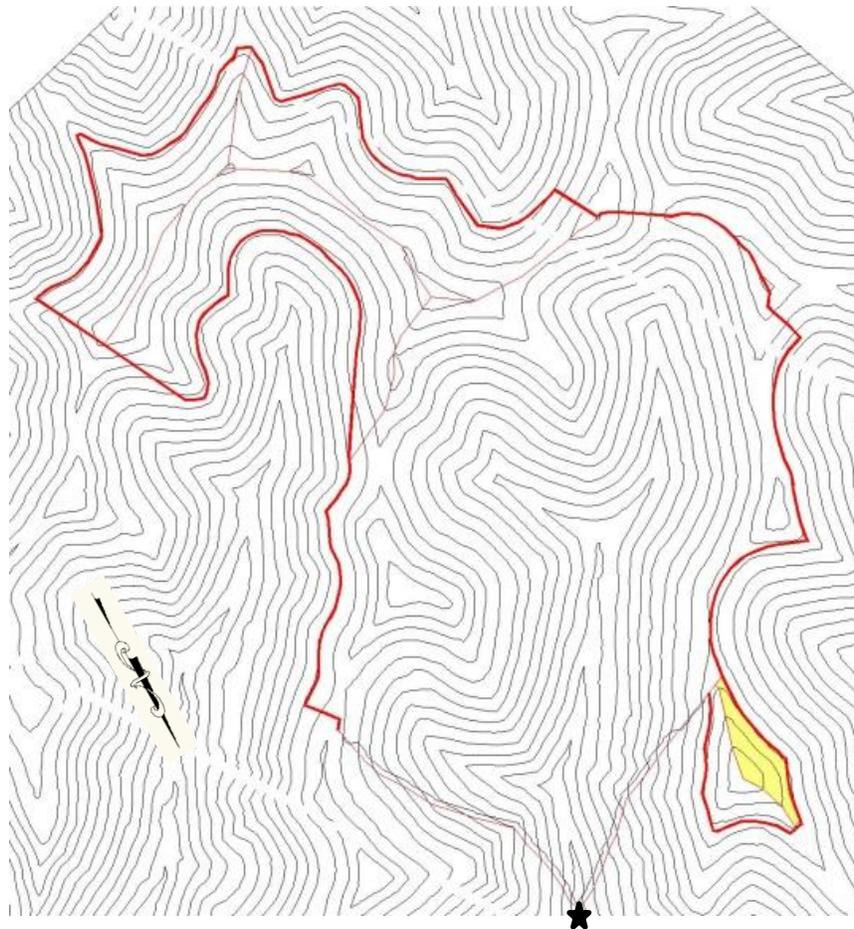


Figure 4.2.18: Fifth Subwatershed Analyzed: “Subwatershed 5”

Figure 4.2.19 shows the stream channel created within Subwatershed 5. The design was characterized by a single main channel that flowed through the property.

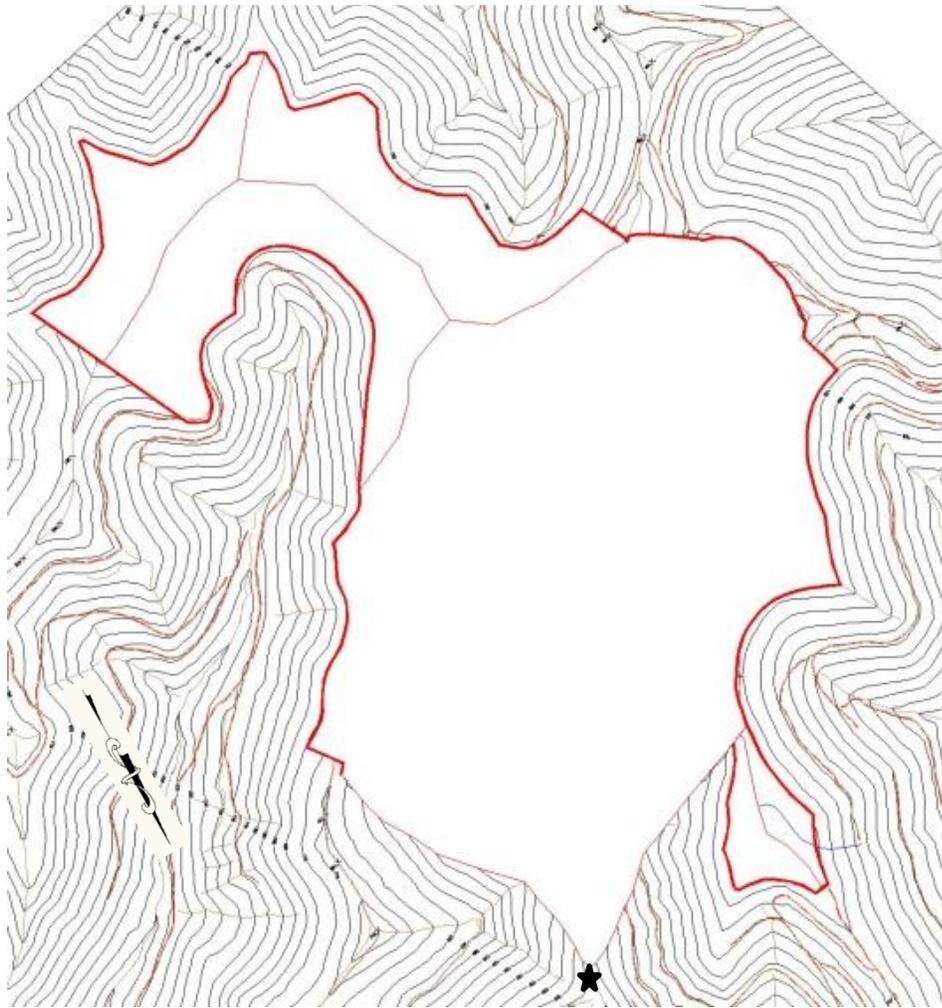


Figure 4.2.19: Subwatershed 5 and Stream Created in that Watershed

A close-up view of the created drainage channel within the fifth subwatershed is shown below in Figure 4.2.20. The main channel was labeled and had a length of 789 ft.

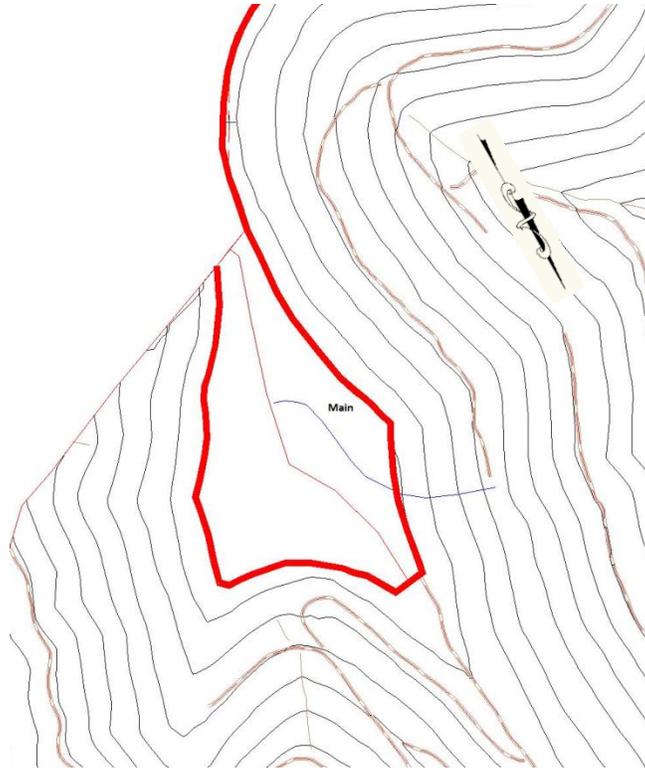


Figure 4.2.20: Subwatershed 5 with Labeled Created Stream

The geomorphic landform valley-fill design created using the previously mentioned methodologies and principles is shown below in the three-dimensional Figure 4.2.21.

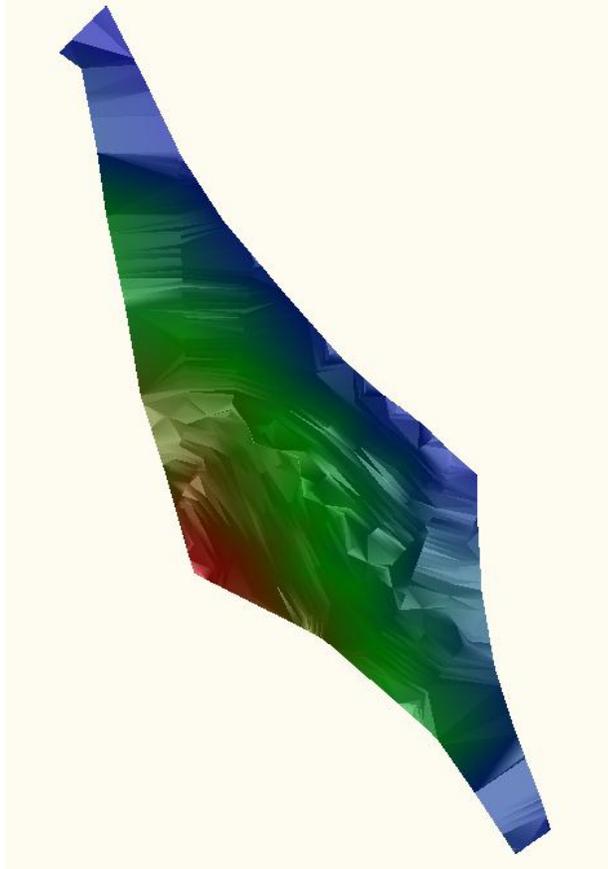


Figure 4.2.21: Completed Subwatershed 5 Geomorphic Valley-fill Design

The large amount of data that was obtained from the valley-fill design is shown below in Table 4.2.8. The watershed area that supplied the stream channel was 4.18 ac for Subwatershed 5. The overall resulting drainage density for the subwatershed was 116.78 ft/ac (Table 4.2.8). The design added a total of 789 ft of channel length (Table 6.0.1), including type A and type C channels.

Table 4.2.8: Channel Data for Subwatershed 5 Channel Main and Total Summary Data

Channel Data	
name	main
watershed area (ac.)	4.18
add'l watershed area (ac.)	0.00
valley length (ft.)	487.62
drainage density (ft./ac.)	116.78
head elevation (ft.)	1850.00
base elevation (ft.)	1760.55
relief (ft.)	89.45
head slope	-0.16
base slope	-0.10
slope range	-0.165 to -0.104
bankfull width range (ft.)	0.31 to 2.45
bankfull depth range (ft.)	0.03 to 0.20
width to depth ratio, when slope < -0.04	12.50
width to depth ratio, when slope > -0.04	10.00
flood prone width range (ft.)	0.73 to 5.18
flood prone depth range (ft.)	0.08 to 0.59
entrenchment ratio	2.10 to 2.32
radius of curvature range (ft.)	1.34 to 8.06
meander length range (ft.)	5.96 to 35.72
meander belt width range (ft.)	2.86 to 17.16
sinuosity (channel average)	1.15
meander width ratio	6.39
maximum design velocity (ft./s.)	4.50
runoff coefficient	0.89
Shear stress, bankfull width (lbs/sq.ft.)	0.24 to 2.27
Shear stress, flood prone width (lbs/sq.ft.)	0.38 to 3.25
manual Qpk?	no
bankfull Qpk (cfs)	2.25
flood prone Qpk (cfs)	7.49
*GeoFluv(TM) approach is used for channels steeper than -0.04 in lieu of Williams (1986) approach.	
Summary	
Total watershed area (ac.):	4.18
Overall drainage density:	116.78

Subwatershed 6, highlighted in orange, as shown below in Figure 4.2.22, was analyzed last because it was the second smallest subwatershed and was located adjacent to the subwatershed 1 and 5 valley-fills that were previously created. This subwatershed was located in the south eastern corner of the boundary and bordered Subwatershed 1 by only 1720 ft. The subwatershed 6 analysis used the original topography as well as the created topography of Subwatershed 1, 2, 3, 4, and 5 so that the created landforms would merge smoothly. The subwatershed covered almost six acres and varied in elevation from 1720 ft to 1900 ft. It also contained no original stream length. The valley-fill created using Natural Regrade[®] had a greater amount of stream length within the same area compared to the original stream length (Table 6.0.1). The original topography of the Subwatershed 6 showed a ridge running along the western side of this property and sloped down toward the northern, southern, and eastern sides. It

connected to the previously created Subwatershed 1 along the northern side of the property and the Subwatershed 5 along the eastern side.

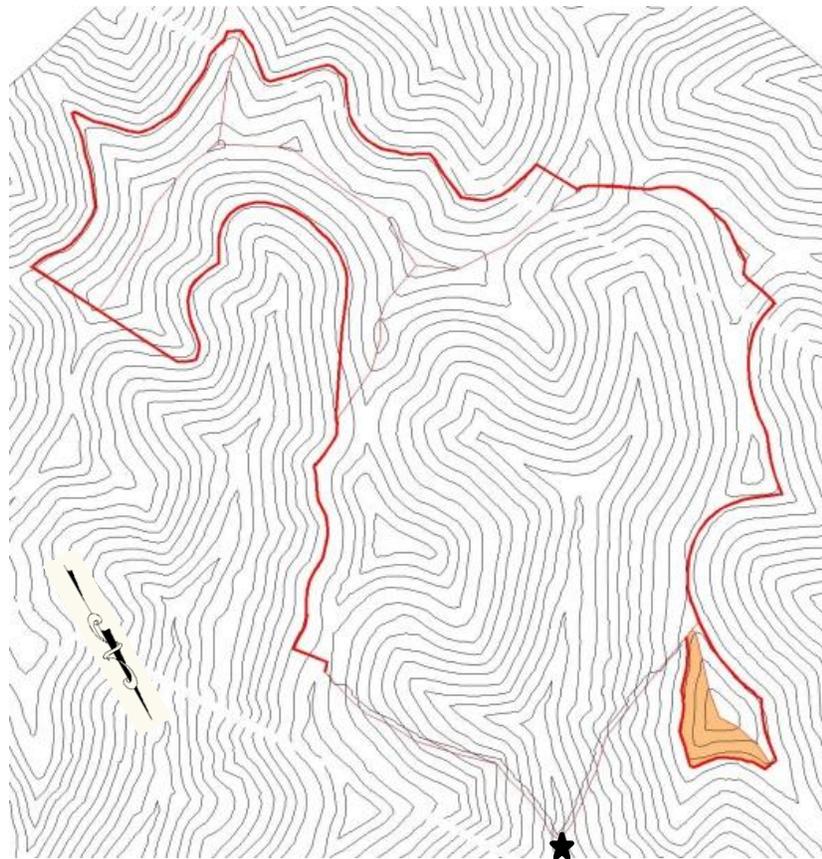


Figure 4.2.22: Last Subwatershed Analyzed: “Subwatershed 6”

The stream channel created for the geomorphic design in the area associated with the sixth subwatershed is shown below in Figure 4.2.23. The design was characterized by a single main channel that flowed through the property.

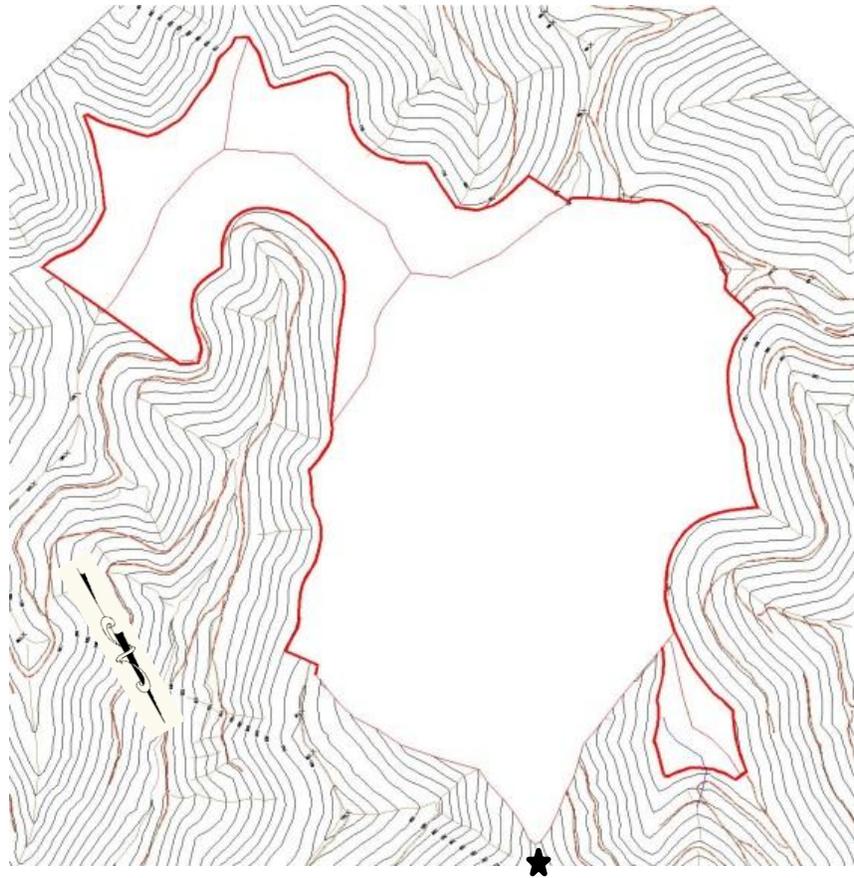


Figure 4.2.23: Subwatershed 6 and Stream Created in that Watershed

Figure 4.2.24 shows a closer view of the created stream channel within the orange subwatershed. The main channel was labeled and had a length of 809 ft.

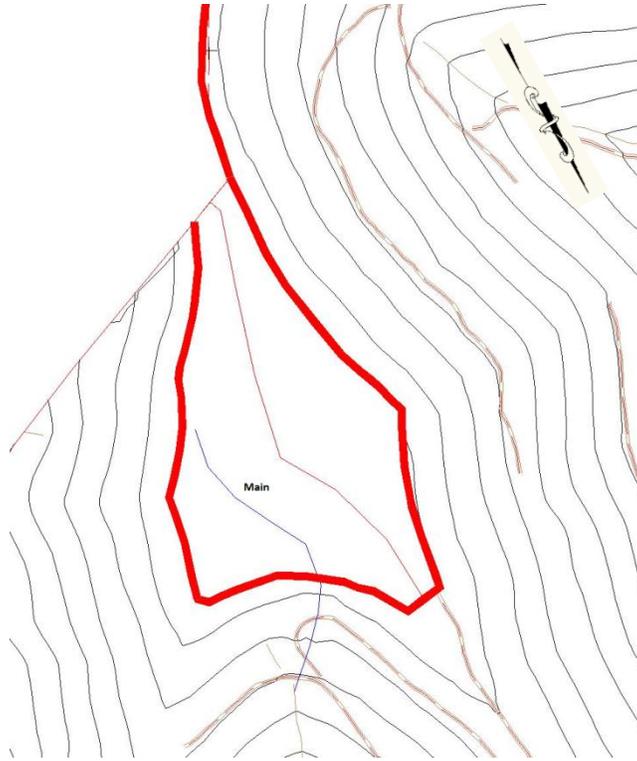


Figure 4.2.24: Subwatershed 6 with Labeled Created Stream

The valley-fill that was created using Natural Regrade[®] with GeoFluv[™] is shown in the three-dimensional Figure 4.2.25 below.

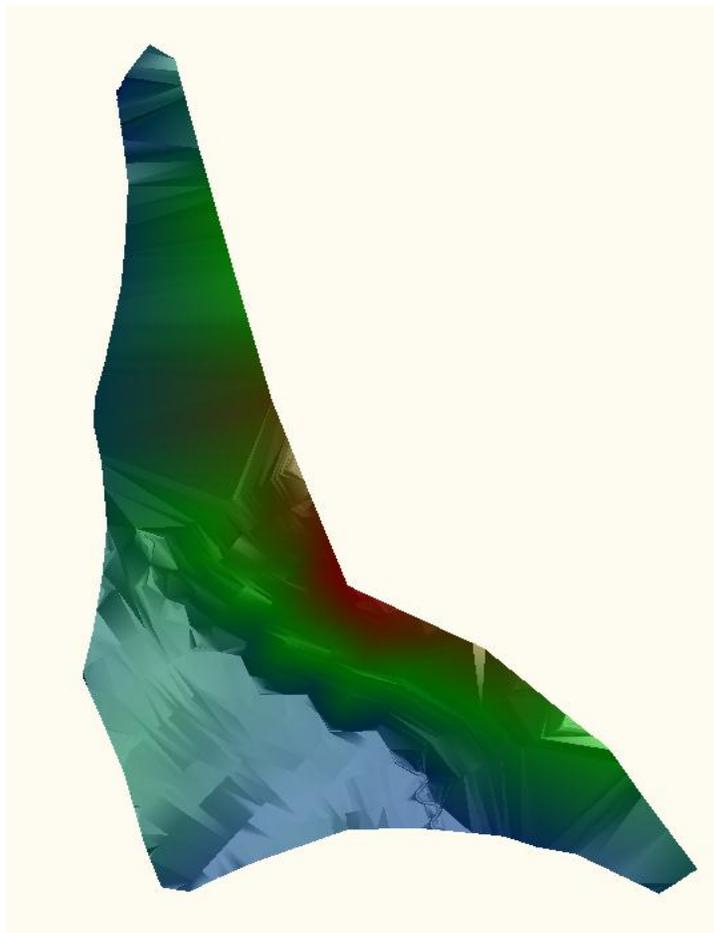


Figure 4.2.25: Completed Subwatershed 6 Geomorphic Valley-fill Design

The data that was obtained from the created geomorphic landform reclamation design of Subwatershed 6 is shown below in Table 4.2.9. The watershed area that supplies the stream channel was 5.67 ac for the subwatershed 6. The overall resulting drainage density for the subwatershed was 90.09 ft/ac (Table 4.2.9). The design added a total of 809 ft of channel length (Table 6.0.1), including type A and type C channels.

Table 4.2.9: Channel Data for Subwatershed 6 Channel Main and Total Summary Data

Channel Data	
name	main
watershed area (ac.)	5.67
add'l watershed area (ac.)	0.00
valley length (ft.)	510.45
drainage density (ft./ac.)	90.09
head elevation (ft.)	1770.12
base elevation (ft.)	1723.25
relief (ft.)	46.88
head slope	-0.12
base slope	-0.02
slope range	-0.119 to -0.020
bankfull width range (ft.)	0.19 to 2.85
bankfull depth range (ft.)	0.02 to 0.23
width to depth ratio, when slope < -0.04	12.50
width to depth ratio, when slope > -0.04	10.00
flood prone width range (ft.)	0.43 to 5.98
flood prone depth range (ft.)	0.05 to 0.63
entrenchment ratio	2.10 to 2.32
radius of curvature range (ft.)	1.32 to 9.46
meander length range (ft.)	5.88 to 41.80
meander belt width range (ft.)	2.81 to 20.13
sinuosity (channel average)	1.18
meander width ratio	6.56
maximum design velocity (ft./s.)	4.50
runoff coefficient	0.89
Shear stress, bankfull width (lbs/sq.ft.)	0.15 to 1.07
Shear stress, flood prone width (lbs/sq.ft.)	0.22 to 1.54
manual Qpk?	no
bankfull Qpk (cfs)	3.05
flood prone Qpk (cfs)	10.17
*GeoFluv(TM) approach is used for channels steeper than -0.04 in lieu of williams (1986) approach.	
Summary	
Total watershed area (ac.):	5.67
Overall drainage density:	90.09

Once all of the subwatershed designs were created using Natural Regrade[®] with GeoFluv[™] they were combined so that the valley-fill design was complete. All of the data for each analyzed subwatershed was compiled so that a proper analysis of the total design was completed.

The overall geomorphic reclamation design of the sample site saved a total of 1200 ft of original stream length at the toe of the valley-fill (Table 6.0.1). Using Natural Regrade[®] principles, almost 33,000 ft or six and a quarter miles of stream length (type A and type C channels as defined by Rosgen) was created on the property (Table 6.0.1). Figure 4.2.26 shows the location of all the created stream channels.

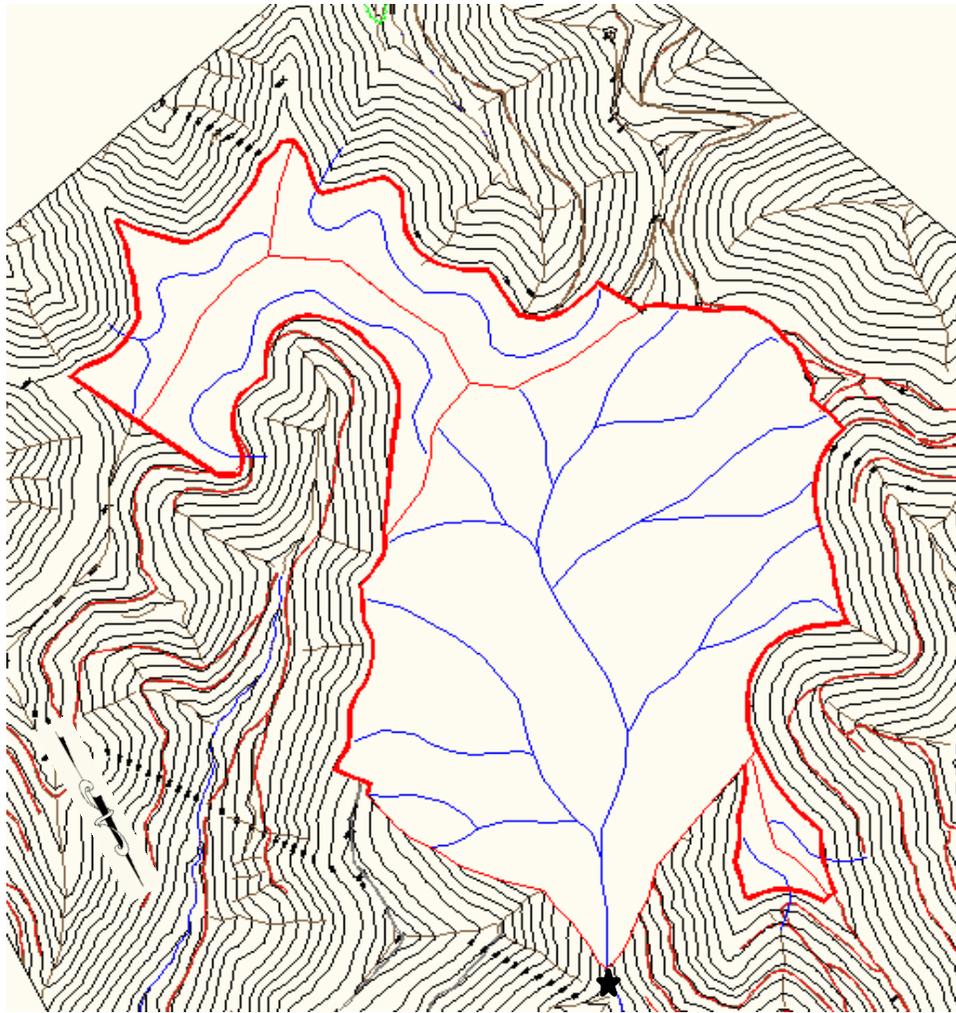


Figure 4.2.26: Stream Channels Created Using Fluvial Geomorphic Principles

4.3 Fill Balance

Since each subwatershed design included the created topographic contours of the previous subwatersheds, once the sixth subwatershed design was completed, all of the contours had been created. The amount of fill was then analyzed and compared to the amount of fill in the traditional valley-fill design of the sample site. The traditional design contained approximately 90 million cubic yards of fill material whereas the geomorphic landform design contained only 60 million cubic yards of fill material. Therefore, the ridges were manually increased using the “Edit Longitudinal Profile” that was located in the “Edit design surface in drawing” tab in order

to increase the fill capacity of the design. Once all of the edits were completed, the valley-fill was increased to 75 million cubic yards. Even though this was still less than the amount of fill in the traditional valley-fill, the cut and fill amounts were balanced in the design, so it was considered to be a comprehensive design. The ridges could not be increased any more, to be closer to the 90 million cubic yards, because the topography would become too steep and unstable. Therefore, creating a stable, balanced design took priority over matching the amount of fill material in the traditional valley-fill design. The topographic contours were then recalculated to match the edited ridgelines. These edited contours are shown below in Figures 4.3.1 and 4.3.2.

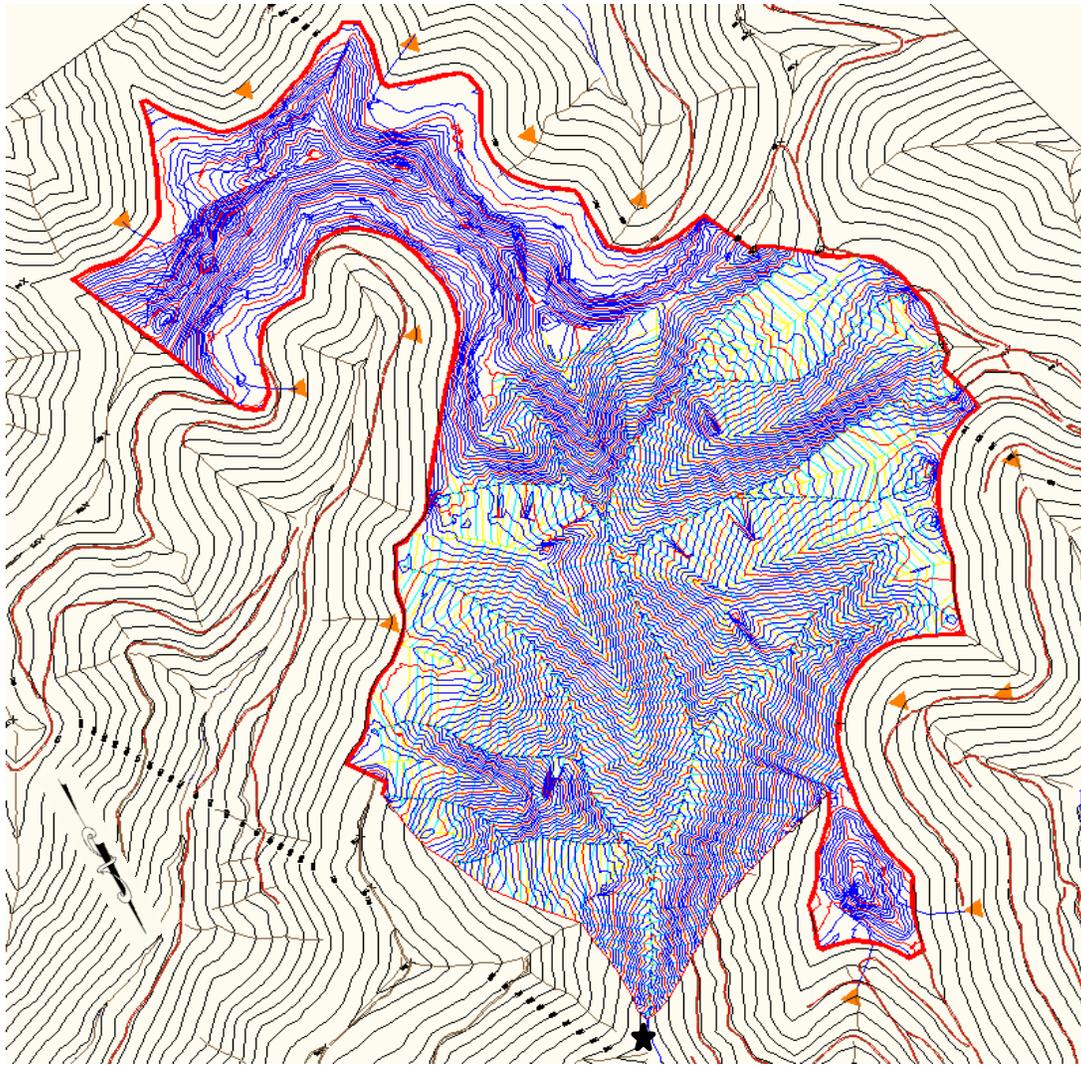


Figure 4.3.1: Contoured Edited GeoFluvTM Surface Created at Sample Site

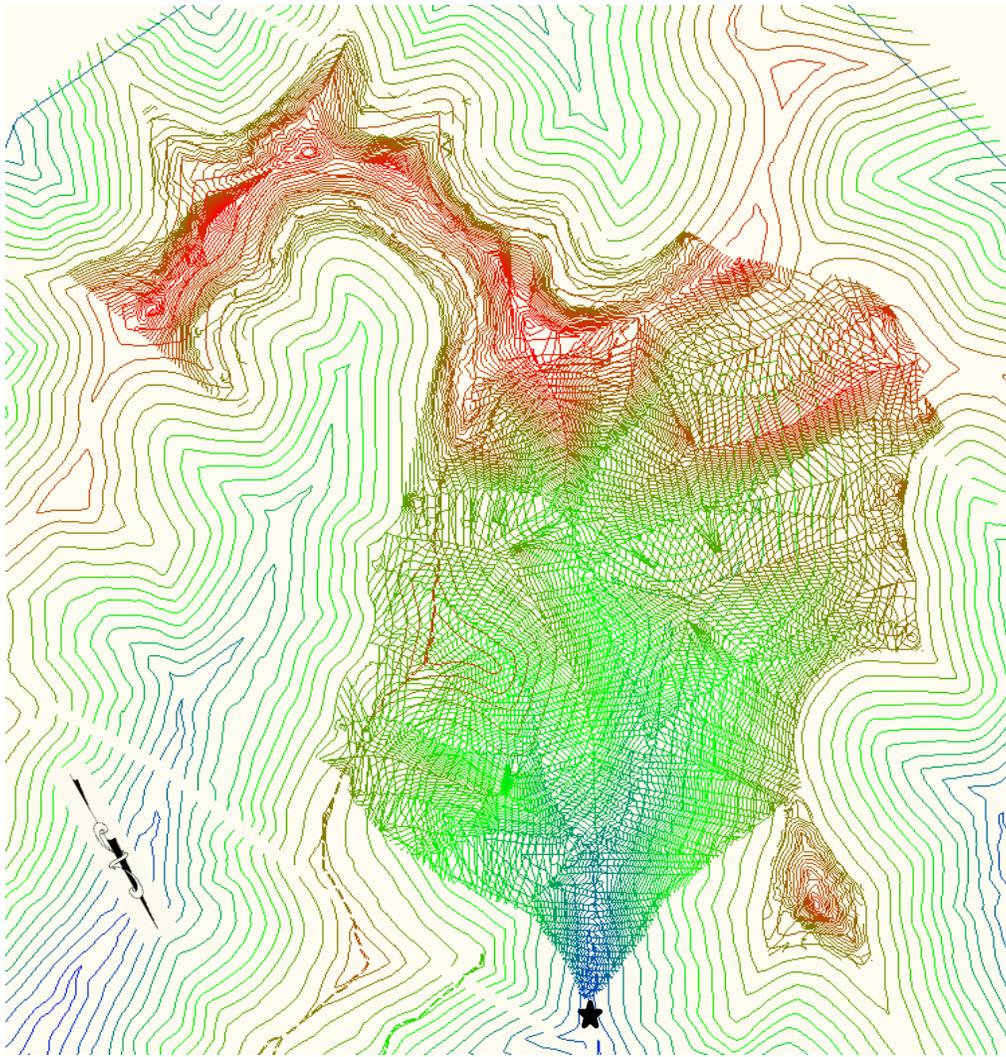


Figure 4.3.2: Colored Contoured Edited GeoFluvTM Surface Created at Sample Site

Features of the completed geomorphic landform valley-fill design include a natural, aesthetically pleasing appearance that includes ridges, valleys, and stream channels that are mature landforms that will have little to no future erosion. These stable landforms reduce the long-term maintenance of the valley-fill as well as mimic the function of the natural landscape that would have naturally evolved over time. The created stream channels control drainage and create stable hydrologic equilibrium over the valley-fill. Figures 4.3.3-4.3.5 illustrate 3-dimensional views of the completed geomorphic landform valley-fill designs that demonstrate all of the features described above.

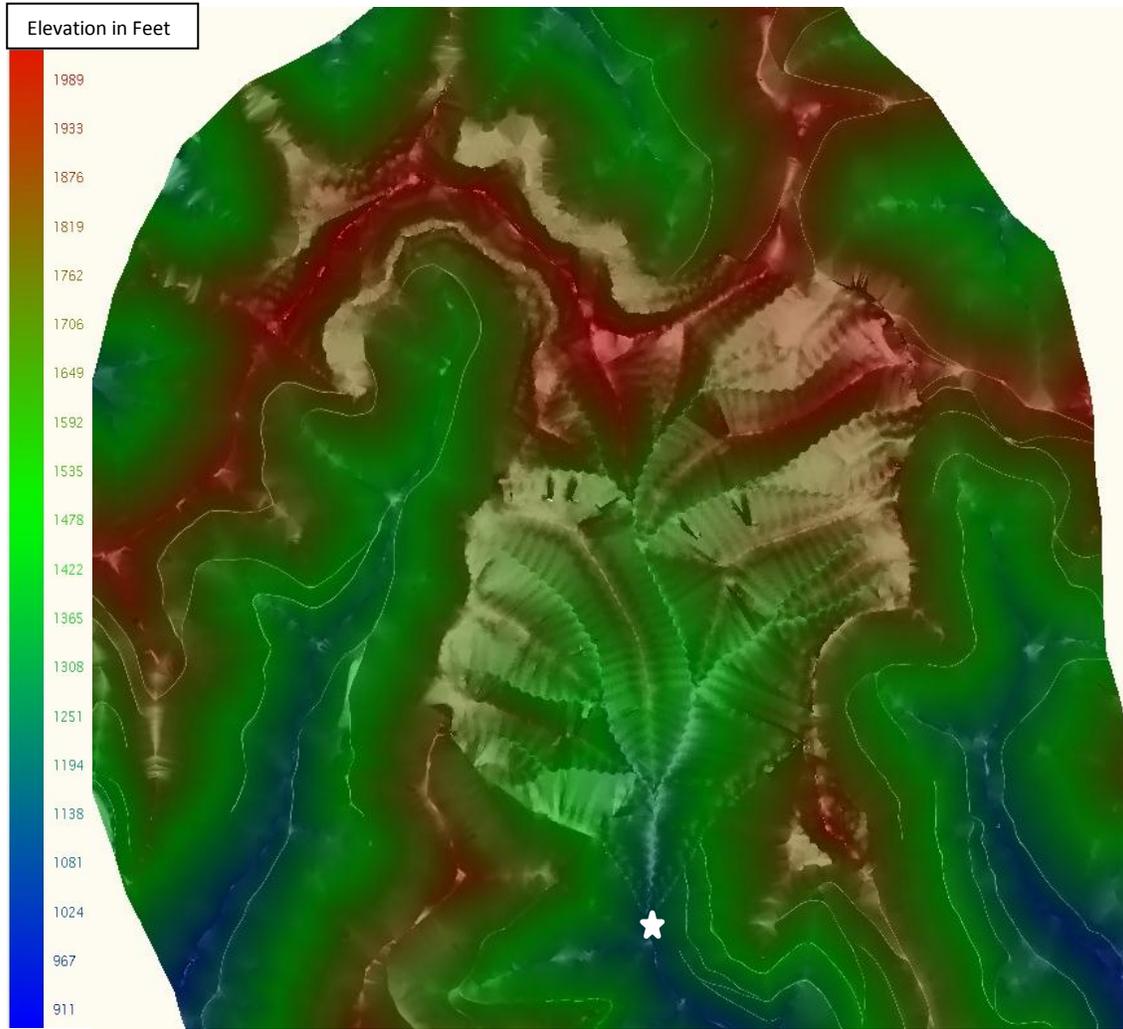


Figure 4.3.3: Completed 3-Dimensional Geomorphic Landform Valley-fill Design

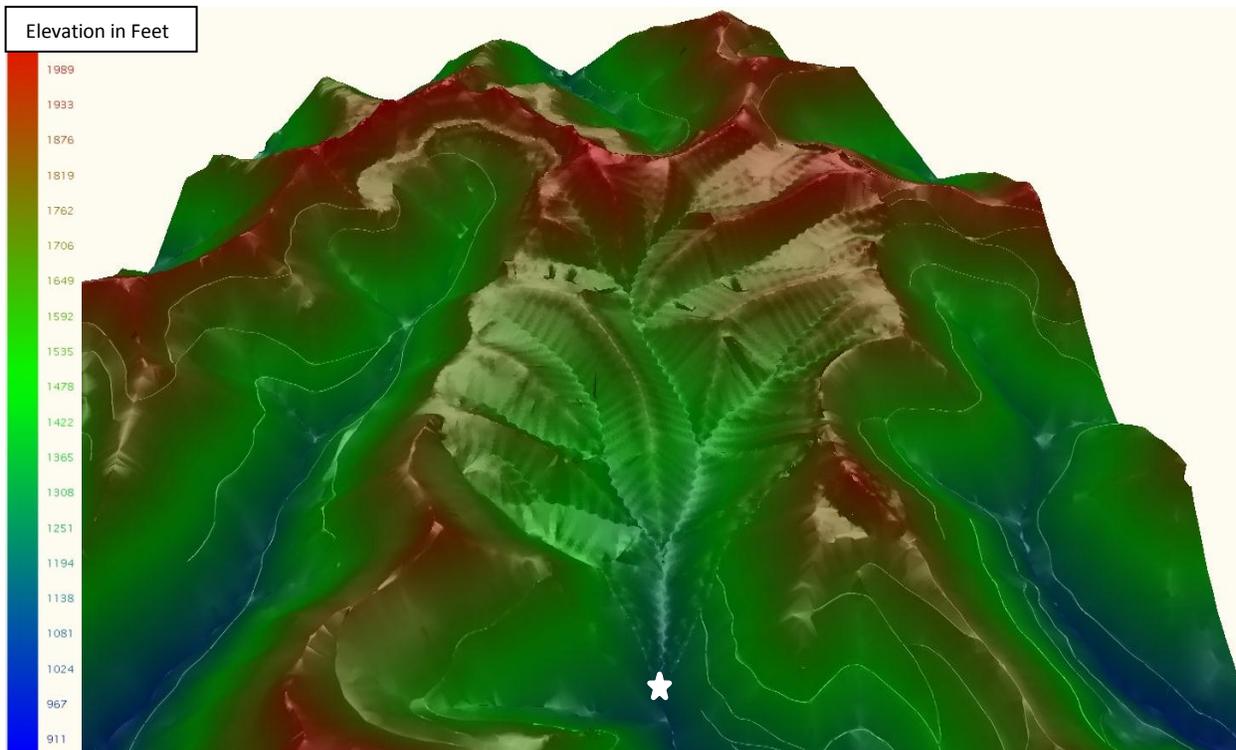


Figure 4.3.4: Completed Projected 3-Dimensional Geomorphic Landform Valley-fill Design

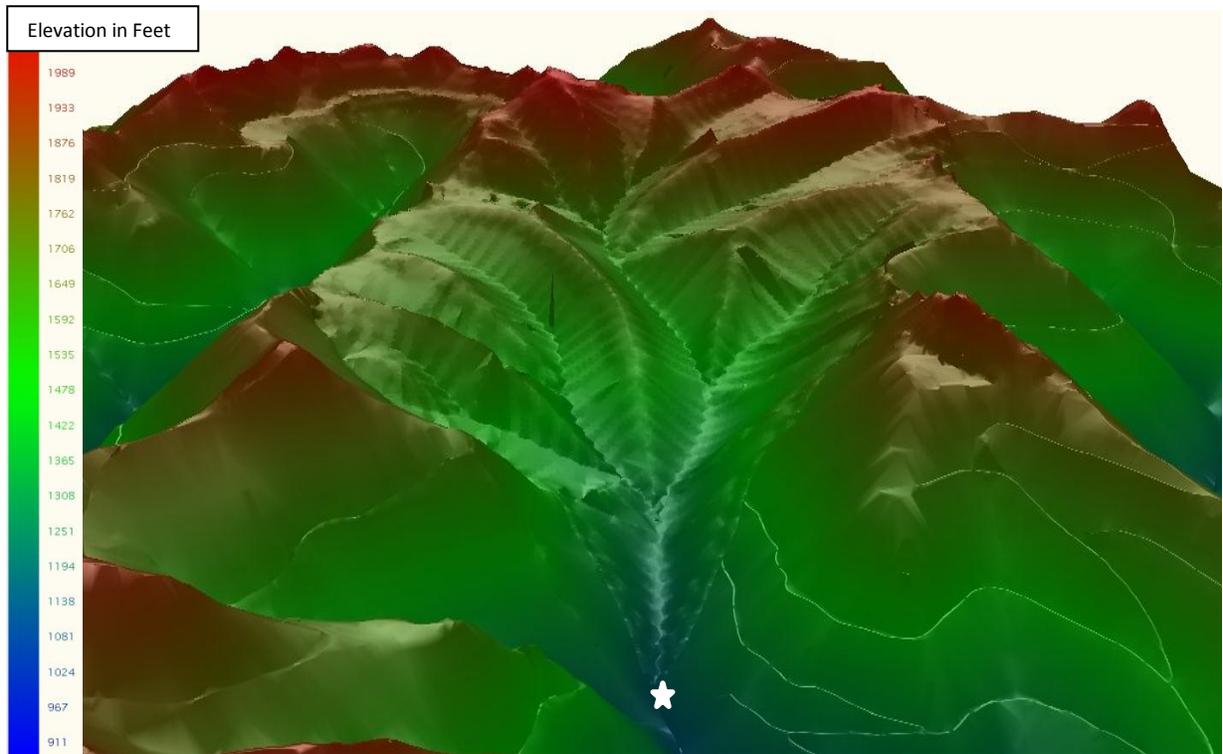


Figure 4.3.5: Completed Rotated 3-Dimensional Geomorphic Landform Valley-fill Design

4.4 Safety

Another focus for this project was the safety of the miners and workers. The geomorphic landform valley-fill design of the sample site optimizes heavy equipment utilization in order to minimize worker exposure to potentially dangerous slope profiles, creates safer and more stable land profiles, and minimizes groundwater infiltration into underground mine workings thus reducing mine inundation possibilities.

Fluvial geomorphic landform design has the potential to decrease operator exposure time in dangerous conditions by minimizing the amount of earthwork that has to be performed. In traditional reclamation practices, the soil has to be moved once during the mining process and again during reclamation. In the geomorphic landform design of the sample site, the soil that is removed during mining is transported directly to a location that was previously mined and is used to create valley-fill landforms. Thus it cuts down on total distance traveled and the number of hours needed to complete the reclamation process making the geomorphic landform design safer for site workers.

5. AOC Variance vs. Geomorphic Design Comparison

5.1 Drainage Systems

Surface water runoff control was incredibly important in any valley-fill design. For the traditional valley-fill, runoff was directed away from the benched face of the fill and into Surface Water Runoff analysis (SWROA) ditches. However, there were also groin ditches that were located on each side of the valley-fill face in case of excess precipitation events. Figure 5.2.1 below illustrates the drainage system of an AOC valley-fill.

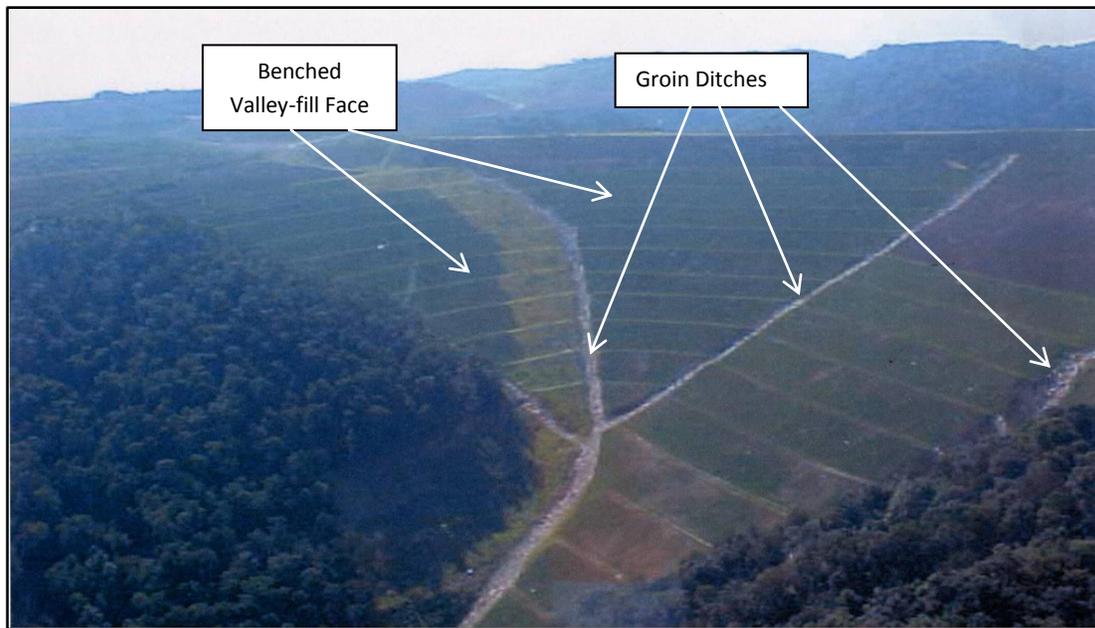


Figure 5.2.1: AOC Valley-fill Face with Labeled Drainage Structures

Drainage system design, by emulating natural processes, was thought of as a superior approach to landform design compared to conventional methods (Sawatsky and Beckstead, 1996). The geomorphic landform valley-fill design assisted in reducing surficial erosion and removed surface water more efficiently from the slope than traditional drainage methods.

Conventional engineered drainage systems did not accommodate flooding because engineered streams typically were not mature landforms and therefore eroded until a hydrologic equilibrium was achieved. Fluvial geomorphic design used concepts which emulated natural processes and created mature landforms which minimized long-term erosion and flooding. This equilibrium was achieved through creating the proper drainage density in the watershed. Drainage density is a concept that attempts to quantify a natural and stable drainage system and is defined as the length of a channel divided by its contributing watershed area. Through geomorphic landform design principles, a targeted drainage density was achieved while replacing rip-rap drainage ditches with naturally vegetated sinusoidal channels (Sawatsky and Beckstead, 1996).

5.2 Infiltration

Infiltration was an important factor analyzed because it was ultimately linked to internal erosion and long-term stability of the structure. If infiltration could be minimized, internal erosion could be minimized and the long-term stability of the structure could be increased.

Given that adequate slope stability design had target density requirements for strength, loose end dumping construction methods typically resulted in landforms that became infiltrated with runoff and resulted in instability. Storm water runoff affects landforms created using end dumping techniques differently than it had before mining had occurred, even if the land was reclaimed to approximate original contour (Martin-Duque et al., 2010). In the past, infiltration and landslides were a common result of end dumping methods in landform construction (Bell et al., 1989).

Geomorphic landform design methods could minimize infiltration by reducing the amount of time surface water runoff is in contact with the surface of the valley-fill. The decrease in infiltration could increase the long-term stability of the structure by reducing internal erosion. Fluvial geomorphic design provides precipitation with quick and easy routes into channels. Therefore, if the runoff contact time was minimized, the time the water had to collect contaminants that were within the fill would be reduced. Decreased infiltration results in slowed seepage rates and lower loading rates of contaminants into streams (Deissmann and Goldsworthy, 2003). Acid mine drainage and leaching of selenium into groundwater and streams are concerns that have received recent emphasis in the mining industry and are proposed to be reduced using geomorphic landform reclamation methods.

5.3 Slope Stability

Slope stability analysis should not be overlooked in surface mine reclamation because slope failure can have significant ecological impacts (Kenney and Lau, 1985). Geomorphic landform designs created using GeoFluvTM principles do not analyze the stability of the slopes. It is important that slope structures remain durable and do not fail when constructed with surface mine overburden for several reasons. If toxic mineralogy exists within the overburden, slope stability becomes an especially critical analysis that should be performed during the design planning process. It is also incredibly important to perform slope stability analysis to ensure the durability of the structure in Appalachia due to its steep terrain. Therefore, all created landforms, whether created using conventional AOC or geomorphic principles, should be analyzed properly in order to limit the steepness of slopes and insure the stability of the landforms because slope failures can have a significant impact on the health and safety of downstream communities as well as the operators constructing the structures.

6. Conclusions

State and Federal regulations directing mine reclamation using the AOC approach have resulted in geotechnically stable designs of valley-fills constructed using waste rock overburden. Environmental concerns at mountaintop mining sites abound because of the loss of headwater stream length and increased flooding risk. One promising technique to lessen the impacts involves fluvial geomorphic landform design applied to the waste rock fill and slope profiles. These innovative geomorphic landforms designs are often created using Carlson[®]'s Natural Regrade[®] with GeoFluvTM software.

The objective was to investigate geomorphic design reclamation approaches applied to surface mining methods in West Virginia. First, components of geomorphic landform design

and associated regulations were collected, noting challenges associated with the application of the technique in West Virginia. Then, a conceptual geomorphic landform design of a mountaintop removal reclamation site was created using geomorphic landform design principles and methodologies. Finally, an analysis of the created valley-fill design with respect to stream length, watershed area, and drainage density was completed in order to compare and contrast the data to a traditional valley-fill design.

The design tool Natural Regrade[®] with GeoFluv[™] was used to apply the geomorphic landform design principles to the sample surface mine site that is located in the southern West Virginia coalfield region. The area was characterized by a system of steep-sloped ridges and valleys. A boundary line was drawn along the perimeter of the property; then the valley-fill was divided into subwatersheds in order to create a natural appearance and balanced design. A majority of the default settings in Natural Regrade[®] were used in order to create the geomorphic landform design for the sample site due to the lack of on-site data because of current mining. However, two of the global settings that were drastically changed for the sample site were that the 2 yr, 1 hr rainfall changed from 0.6 in to 1.41 in and the 50 yr, 6 hr rainfall changed from 2.0 in to 4.03 in. The default rainfall values are based on semi-arid regions of the United States where precipitation is lower as opposed to the higher precipitation region of the United States in which the sample site is located, based on type II storm and precipitation data.

Stream channels were created within each subwatershed boundary and geomorphic landform design principles were then applied to each subwatershed. Once all of the subwatershed designs were created using Natural Regrade[®] with GeoFluv[™] they were combined

so that the valley-fill design was complete. All of the data for each analyzed subwatershed was compiled so that a proper analysis of the total design was completed.

The geomorphic valley-fill design allowed 1300 ft of original stream length to remain undisturbed compared to the traditional valley-fill design and almost 33,000 ft or 6.25 miles of stream length (type A and type C channels as defined by Rosgen) was created on the property (Table 1). In four of the six subwatersheds, only one channel was needed to satisfy the drainage density requirement due to the watershed area and the length the main channel. Even though only one channel was created, the valley-fill created using Natural Regrade still had a greater amount of stream length within the same area compared to the original stream length (Table 6.0.1).

Table 6.0.1: Geomorphic Landform Design Data of Sample Site

	Subwatershed						Total Watershed
	1	2	3	4	5	6	
Area (ac)	241	32	36	21	4	6	340
Elevation range of topography (ft)	1150-1995	172-199	165-199	172-199	1780-1897	1720-1900	1150-1995
Original stream length (ft)	8630	118	NA [‡]	460	NA	NA	10270
Number of created channels	13	1	1	2	1	1	19
Range of created stream length (ft)	814-5290	315-9	355-1	580-150	487-5	510	487-5290
Total created stream length	21902	315-9	355-1	208-5	487	510	31694
Original stream length saved (ft)	1315	NA	NA	NA	NA	NA	1315
Drainage density (ft/ac) [†]	90.62	99.3-5	98.7-6	98.4-2	116.7-8	90.0-9	
Rosgen Channel type	A, C	A, C	A, C	A, C	A, C	A, C	A, C

[†]Target drainage density range: 80-120 ft/ac

[‡]NA = not applicable.

An AOC Variance valley-fill design was being implemented at the sample site in southern West Virginia. The post-mined land use of the area was determined to be pasture land and therefore an AOC variance was obtained in order to leave the land relatively flat at an elevation of approximately 1700 ft. The main feature of the AOC variance valley-fill was a benched valley-fill face. Runoff from the property drained to SWROA ditches that outlined the boundary and out NPDES points into surrounding stream channels. Table 6.0.2 shows that the design filled in almost 21,000 feet of original stream channel length and in return created no stream channels.

Table 6.0.2: AOC Variance Design Data of Sample Site

	Watershed AOC Variance
Area (ac)	339.9
Elevation range of topography	1693
Original stream length (ft)	20,540
Number of created channels	NA [‡]
Range of created stream length (ft)	NA
Total created stream length	NA
Original stream length saved (ft)	NA
Drainage density (ft/ac)	NA
Rosgen Channel type	NA

[‡]NA = not applicable.

The data collected from the AOC variance valley-fill design and the geomorphic landform valley-fill design created using Natural Regrade[®] with GeoFluv[™] were compared.

The AOC variance valley-fill design was intended to ensure slope stability, control drainage, complement the drainage pattern of the surrounding terrain, and prevent stream sedimentation. The design consisted of:

- slope shapes exhibiting uniform benches
- planar slopes having unvarying contours
- drainage ditches located along the perimeter and/or center of the fill

However, the traditional, planar reclamation method can be improved to appear more natural and decrease the drawbacks associated with it.

Features of the resulting Natural Regrade[®] design include:

- long-term stability due to dynamic equilibrium
- suggested reduction in maintenance due to stability
- projected reduced cost due to strategic placement of fill material
- more aesthetically pleasing valley-fill due to a diverse natural habitat with ridges and valleys

These landform designs add variability and aid in establishing a site with a long-term hydrologic balance. The geomorphic landform reclamation approach has potential to extend beyond current industry practices and will improve environmental impacts, flood control, water quality, and human safety.

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