CASE STUDY: GEOMORPHIC RECLAMATION OF ABANDONED COAL MINES NEAR RATON, NEW MEXICO DESIGN AND CONSTRUCTION OVERSIGHT[1]

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Abstract. In order to address hazards and environmental detriments associated with historic coal mining, the New Mexico Abandoned Mine Land Program contracted with Water & Earth Technologies, Inc. Construction for the Swastika Mine and Dutchman Canyon Reclamation Project took place over a six-month period in 2012. The geomorphic reclamation approach coupled hydrologic and hydraulic engineering analyses with geomorphic design tools to stabilize and reclaim the significantly altered landscape. Coal waste piles, a straightened and incised half-mile-long reach of the Dillon Canyon stream channel, and existing wetland features proved to be challenging design elements of this award winning project. The geomorphic landform accommodated nearly 200,000 cu. yds. of coal waste that had been abandoned in unstable piles that were degrading the adjacent stream physically and chemically. The stream reconstruction restored meanders and a functional floodplain to the impaired system. In Dutchman Canyon, road and embankment improvements were designed to allow seepage from closed mine adits to hydrate a constructed salt-tolerant wetland.

In addition to the geomorphic landform and the sinuous stream, a realigned access road was constructed through the narrow valley. Valuable ecological and cultural features including mature trees, wetland areas, utility poles, and over 200 identified archaeological features were preserved. Geomorphic designs were modified as required during construction to accommodate additional archeological discoveries. Geomorphic design was accomplished using Natural Regrade™ with Geofluv™ to incorporate stable drainage and topographic variety into the reconstructed stream and landform. The design used geomorphic criteria developed from measurements of nearby, undisturbed portions of the valley, mimicking stable landforms and stream characteristics that have developed naturally in response to the topographic relief, soils, vegetation, and climate in the project area. The project created an aesthetically pleasing valley with an ecologically rich riparian corridor integrated into a stable landform composed of reclaimed coal waste.

Additional Key Words: Geomorphic reconstruction, stream reconstruction, mine reclamation, GeoRiparian Restoration

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Introduction

The New Mexico Abandoned Mine Land Program (AMLP) contracted with Water & Earth Technologies, Inc for the engineering design and construction oversight of the Swastika Mine and Dutchman Canyon Reclamation Project (Project) near Raton, NM (Figure 1). The Project was undertaken to address mine hazards and environmental detriments associated with historic coal mining of the Raton Coal District. This project was the AMLP's first use of geomorphic reclamation techniques and illustrates some of the benefits associated with using a geomorphic design approach for large-scale abandoned mine reclamation. Construction started in the spring of 2012 and later that summer the project received the 2012 Excellence in Reclamation Award from the New Mexico Energy, Minerals, and Natural Resources Department (EMNRD), presented to Water and Earth Technologies, Inc., Habitat Management, Inc.; Kiewit New Mexico Company; and 814 Solutions, LLC.

In cooperation with the landowner, Vermejo Park Ranch (Ranch), for several years the AMLP had been conducting an extensive archaeological investigation and developing detailed mapping to support safeguarding and reclamation at eight abandoned coal mines in Dillon Canyon. From the onset, the AMLP Program and the Ranch were interested in pursuing a geomorphic design approach for reclaiming these pre-law underground coal mines. The Ranch was familiar with the results of traditional terrace and downdrain reclamation elsewhere on the property, and hoped that a geomorphic approach would reduce maintenance issues associated with localized failures due to erosion, as well as improve aesthetic and habitat values for reclaimed areas. The current land use for the property is wildlife habitat and fee hunting, so improving forage and range health was considered a priority.

Fluvial geomorphology is the study of how water, specifically storm runoff, naturally produces the shape of the landscape given the topographic relief, soils, vegetation, and climate. A geomorphic approach to reclamation uses quantified characteristics of stable natural landforms and stream reaches in the vicinity of the disturbed landform as design criteria for developing a reclaimed surface. Incorporating geomorphic criteria produces topographically diverse landform designs with integrated runoff channels like the surrounding, undisturbed landforms that have developed naturally in response to fluvial geomorphic forces. The goal is to produce a reclaimed area that looks natural, supports diverse vegetation typical of surrounding, undisturbed areas, and

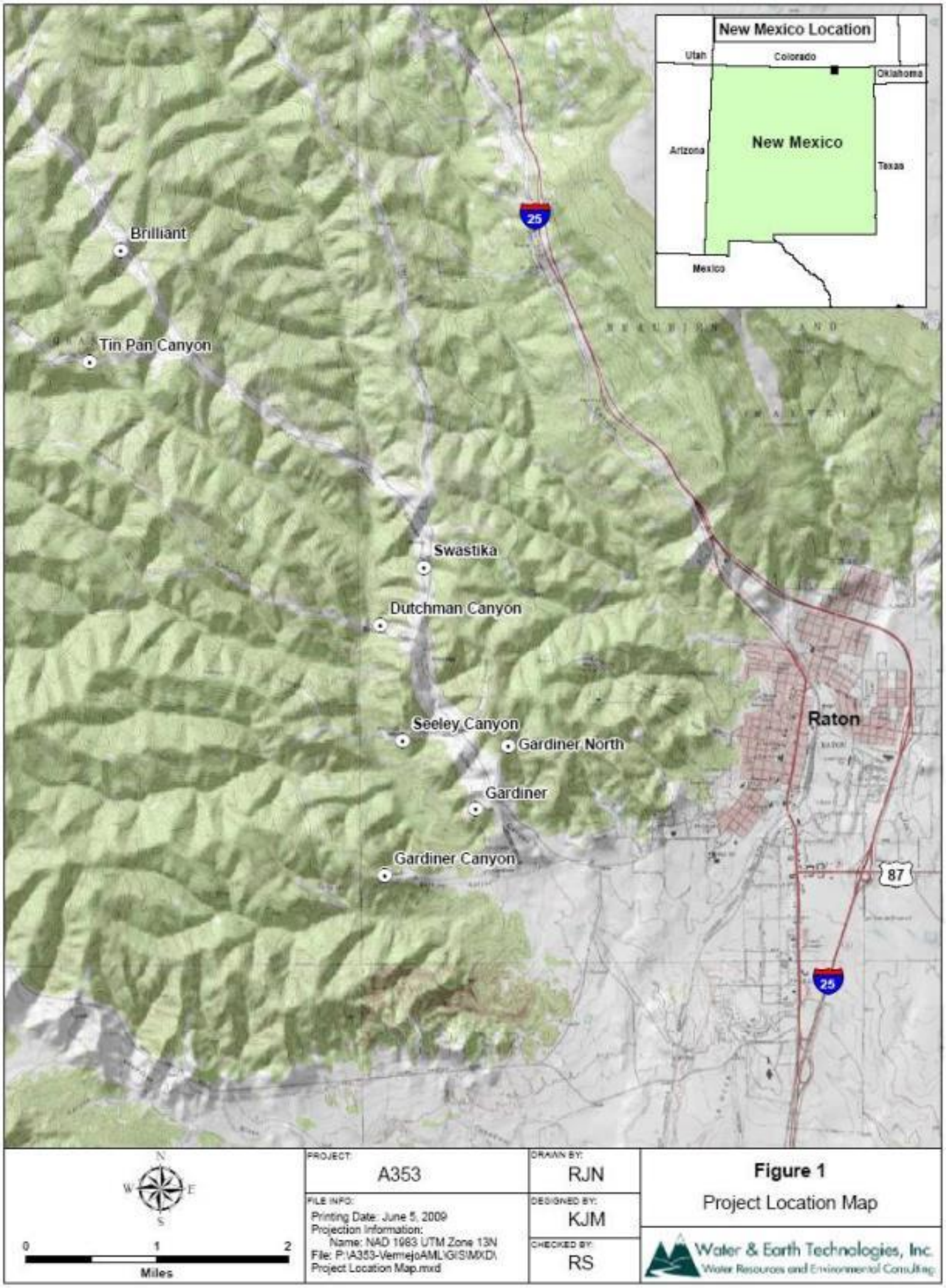

Figure 1. Project Location Map.

achieves "dynamic stability" that allows natural landforms to pass runoff, even from rare, large storm events, without experiencing damage from erosion.

The Swastika Mine and Dutchman Canyon Reclamation Project demonstrates some of the challenges and opportunities inherent in geomorphic landform and stream restoration design and construction. The Swastika and Dutchman Canyon abandoned mines are in close proximity and were reclaimed together. At the Dutchman Canyon site, work was required to reclaim several small areas of coal waste and to improve the treatment and conveyance of seepage from closed mine adits. Work at the Swastika mine site was required to safeguard hazardous mine camp features, to stabilize and reclaim coal gob piles, and to realign and restore a degraded reach of the Dillon Canyon stream channel.

Environmental Detriments from Historic Mining

Dutchman Canyon. At the Dutchman Canyon site (Figure 2), sodic mine seepage was collected in a pair of existing wildlife ponds draining directly to the Dutchman Canyon stream channel through a culvert. The embankments forming the ponds were inadequate to prevent flows from damaging the adjacent dirt access road, and the ponds provided minimal treatment of the seepage prior to its release. The Project included road and embankment improvements as well as a new spillway that directs outflow from the ponds to a constructed passive treatment wetland area in an adjacent meadow before conveying flow across the road and into the channel. Improving the quality of the water that reaches the Dutchman Canyon channel and creating a salt-tolerant wetland area were the primary goals of the work at Dutchman Canyon.

Figure 2. Wildlife pond and outlet culvert at Dutchman Canyon.

Swastika Mine. The Swastika abandoned mine site was the focus of the geomorphic reclamation efforts. At Swastika, and at many other pre-law sites in the Canyon, coal that was mined but could not be sold (coal waste, or "gob") was dumped in angle-of repose piles stretching along the base of the hillsides adjacent to the mines. At the Swastika mine site nearly 200,000 cu. yds. of coal waste had been abandoned in several steep, unstable piles. The largest of these piles was placed immediately adjacent to the Dillon Canyon stream channel and was collapsing into the stream over a significant reach. In locations where the pile blocked drainages serving the subwatersheds on the hillside behind the pile, channels eroded through the coal waste as material was washed into the stream. In addition, visible precipitate in the channel indicated that chemicals leached from the pile by stormwater infiltration were degrading the stream (Figure 3). The goal of the geomorphic reclamation design for Swastika was to restore functional drainage to the landscape and create stable landforms from the coal waste material that could be successfully revegetated and would blend into the surrounding undisturbed topography.

Figure 3. Degraded Dillon Canyon stream channel at Swastika.

In addition to degradation caused by the coal waste, the stream channel had been straightened during the historic mining period to accommodate rail facilities serving the mine, and a half-mile long reach of the channel had become deeply incised between steep, eroding stream banks. The Project was undertaken to halt these ongoing impacts from historic mining by reshaping the unstable piles of coal waste into a geomorphic landform that integrates a relocated and restored stream channel. In addition, preserving wetland areas and improving riparian habitat in the restored stream channel were goals of the project.

Design Methods

Challenges for geomorphic design at the Swastika site included the presence of many valuable cultural and natural resources lying within a valley that is narrow relative to the significant volume of gob material requiring reclamation (Figure 4). The design was required to preserve more than 183 archaeological features, including the adit, the buildings and facilities that served the mine, and the relics of the coal camp where as many as 500 miners lived at the height of coal production in the late 1920s. Archaeological features associated with the mine line the hillside behind the coal waste pile, preventing the material from being flattened back into the hillside to achieve stable land slopes. To make space for a geomorphically stable landform, realigning the stream and the road, which ran parallel at the toe of the gob pile, was required. The stream and the road were moved into the valley to the east in a design that preserved, in addition to the archaeological features, two existing power line rights-of-way and scattered areas with desirable established wetland vegetation or mature trees.

Figure 4. A significant volume of coal waste relative to the width of the valley at Swastika.

Geomorphic Analysis and Design

Geomorphic design was accomplished using Natural Regrade™ with Geofluv™ to incorporate stable drainage and topographic variety into the reconstructed portion of Dillon Canyon (Carlson, 2006). The design used geomorphic criteria developed from measurements of nearby, undisturbed features of the valley to mimic stable landforms and stream characteristics that have developed naturally in response to the topographic relief, soils, vegetation, and climate of the project area. The approach also ensures that the reclaimed landform is visually compatible with the surrounding valley. In addition to climate characteristics for the project area, features measured in the undisturbed or "template" streams and landforms that are used as design criteria to create a geomorphic design include:

- **Landform** ridge-to-head-of-channel length, drainage density, and interdependent slope and maximum slope length (lower slopes allow stable landforms to exhibit longer maximum slope lengths, while higher slopes require shorter slope lengths).
- **Channel** gradient, sinuosity, meander frequency and radius of curvature, as well as cross-sectional characteristics like bottom width, width-to-depth ratio, bankful discharge, and channel side slopes.

Geomorphic Landform Design

Natural Regrade™ with Geofluv™ is an AutoCAD® (Computer Aided Design) based software system that incorporates geomorphic analyses with 3-dimensional civil design for developing reclaimed land and stream forms. Geomorphic design criteria for landforms in Natural Regrade™ with Geofluv™ result in a design characterized by an irregular landform surface and non-uniform slopes. The diverse topography and varied aspect of the resulting landform is conducive to the establishment of diverse vegetation, improving aesthetics, and the habitat value of reclaimed areas. Whereas traditional reclamation design sought to concentrate flows at hydraulic conveyance structures like downdrains, geomorphic design strives to prevent flows from concentrating as long as possible. Runoff channels that develop naturally exhibit concave longitudinal slopes; i.e., they start steeper and become flatter as they proceed downstream, in spite of the occasional appearance of a "step" or waterfall feature. Therefore, providing many small conveyances and preventing flows from concentrating has the result that the channels with the steepest slopes will convey very little discharge, thereby reducing erosive forces. With increasing distance from the ridgeline, discharges increase as flow converges in collector channels, but channel gradients decrease.

For the Swastika reclamation project template, undisturbed landforms were measured to determine geomorphic characteristics. The ridge-to-head-of-channel length specifies the maximum drop from a ridgeline that can be served by overland flow given rainfall and soil properties, before the appearance of visible rivulets in the landform. Drainage density measurements quantify how many channels per unit of land surface area are required to prevent erosive concentrations of flow. Steeper topography produces and requires a higher drainage density to limit both the concentration of flow and flow velocities. The drainage density dictates the number of channels input into the Natural Regrade™ with Geofluv™ model. The model designs ridges in the output landform to create subwatersheds that are each served by an integrated designed channel (Figure 5). Each subwatershed is further dissected by smaller ridges. The geomorphic landform design ties into undisturbed topography at the disturbance boundary.

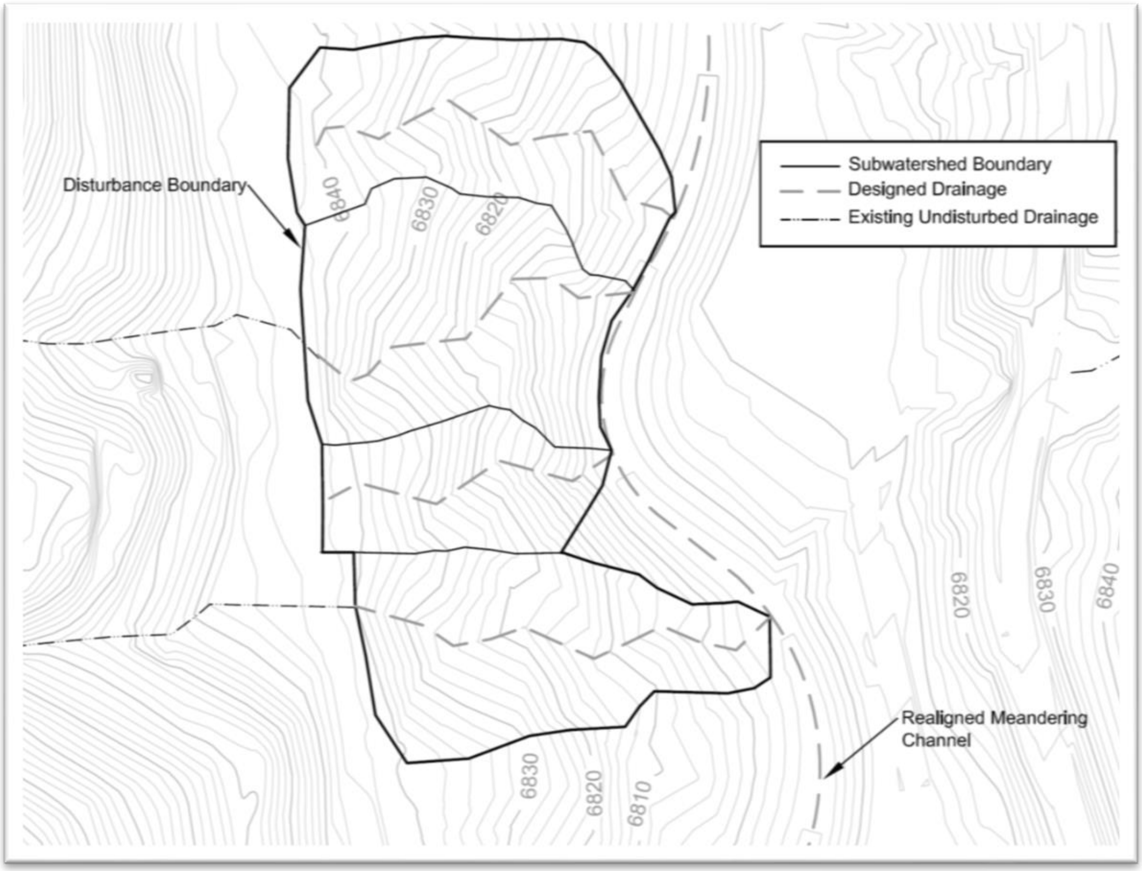

Figure 5. Design topography for a geomorphic landform at Swastika.

Steep but well-vegetated, stable slopes are commonly observed in conjunction with bedrock outcrops and rocky gullies in undisturbed portions of Dillon Canyon. However, the reclaimed landform was composed of reshaped coal waste without underlying geologic structure, and capped with soil material borrowed from alluvial areas at the base of the hillsides. The small drainage channels integrated into the reclaimed landform were designed to be constructed without rock lining or riprap. Therefore, Revised Universal Soil Loss Equation (RUSLE) analysis using the characteristics of these construction materials was also performed to determine maximum slope and slope length combinations that would meet soil detachment criteria (Toy et al., 1998). The maximum allowable slope in the design was 2.5H:1V, but slopes of 3H:1V and 4H:1V or flatter are typical of the majority of the reclaimed landform. These slopes are a significant reduction over the 1H:1V or steeper vertical slopes frequently observed in the unreclaimed coal waste piles.

Geomorphic Stream Restoration

Realigning the stream channel served to provide space for reshaping the adjacent coal waste into landforms with more moderate slopes, both by moving the channel farther out into the valley and because the old channel was backfilled with coal waste above the elevation of the local water table. However, stream restoration for its own sake was a primary reclamation activity at Swastika, undertaken to address environmental degradation that was ongoing as a result of artificial channelization of the stream during the historic mining period. During mining, the stream was rerouted from a meandering alignment in the center of the valley to a straight alignment at the extreme west side of the valley, with rail facilities serving the mine running along the east channel bank (Figure 6). Straightening a reach of stream channel shortens the flow path and increases the slope of the channel bottom, producing faster flow capable of eroding the channel bottom during periodic high flow events. The soils in the Dillon Canyon valley are neither rocky nor clayey, and the fine silts with occasional cobbles composing the straightened channel bed and banks have little cohesion to resist shear stresses associated with high-velocity flood flows. High flow events scoured the channel bed and increased the channel depth. The additional conveyance capacity further concentrated high flows in the channel and established a tendency towards ongoing channel erosion during subsequent high flow events. The straightened reach of the Dillon Canyon channel had become deeply incised within vertical, unstable stream banks (Figure 7).

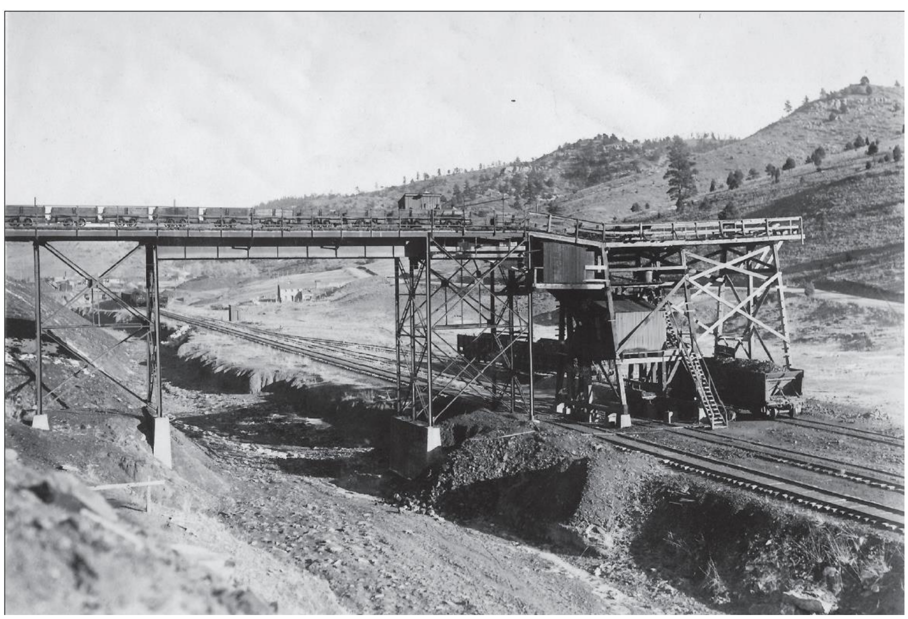

Figure 6. Historic photograph of the straightened stream channel, tipple and rail facilities at Swastika.

Figure 7. Degraded Dillon Canyon channel and adjacent coal waste.

The geomorphic stream restoration design was integrated with the landform design within Natural Regrade™ with Geofluv™. The restored stream was designed to look (and function) like the stream reaches that develop naturally within Dillon Canyon given the area's climate, soils and vegetation. In Dillon Canyon, stable portions of the undisturbed stream channel are meandering and broad, with gentle vegetated stream banks surrounding a narrow low flow channel armored with small rocks (Figure 8). The relatively flat channel banks ensure that the channel is hydraulically connected to a functional floodplain that provides areas of slower, shallower flow even during high flow events. Where the low flow channel is overtopped, flow spreads out across an adjacent overbank and the erosive force of the flood flows is reduced. Vegetation able to withstand infrequent flood events can become established. The establishment of vegetation provides additional stabilization of the overbanks. For the Dillon Canyon channel, geomorphic criteria were applied to the longitudinal profile of the channel, the realignment layout or shape of the channel in a plan view, and the cross-section geometry.

Figure 8. Typical undisturbed Dillon Canyon stream channel.

Channel Profile

As previously indicated, maintaining a concave shape to the channel profile is an important characteristic of natural streams and therefore a geomorphic design criteria. For the Swastika project, the stream restoration was designed with a channel gradient transitioning from 2.2% at the upper end to 1.3% at the downstream end, with an average gradient of approximately 1.4%.

Channel Layout

Geomorphic layout parameters specified by Natural Regrade™ with Geofluv™ for the Dillon Canyon channel included a target sinuosity of 1.18, meander radius of curvature of 100 ft, and meander length of 420 ft (Figure 9). The layout was required not only to avoid disturbing archaeological features and power line poles during construction, but to ensure that these features would not be inundated by the design storm. To accommodate all of these design constraints, the layout geometry suggested by the program was altered slightly to better fit the available space in the valley, while incorporating the target values for geomorphic criteria. Approximately 3,050 ft of existing straight channel was replaced by approximately 3,350 ft of restored channel, with the increased length resulting from the restoration of a meandering stream path.

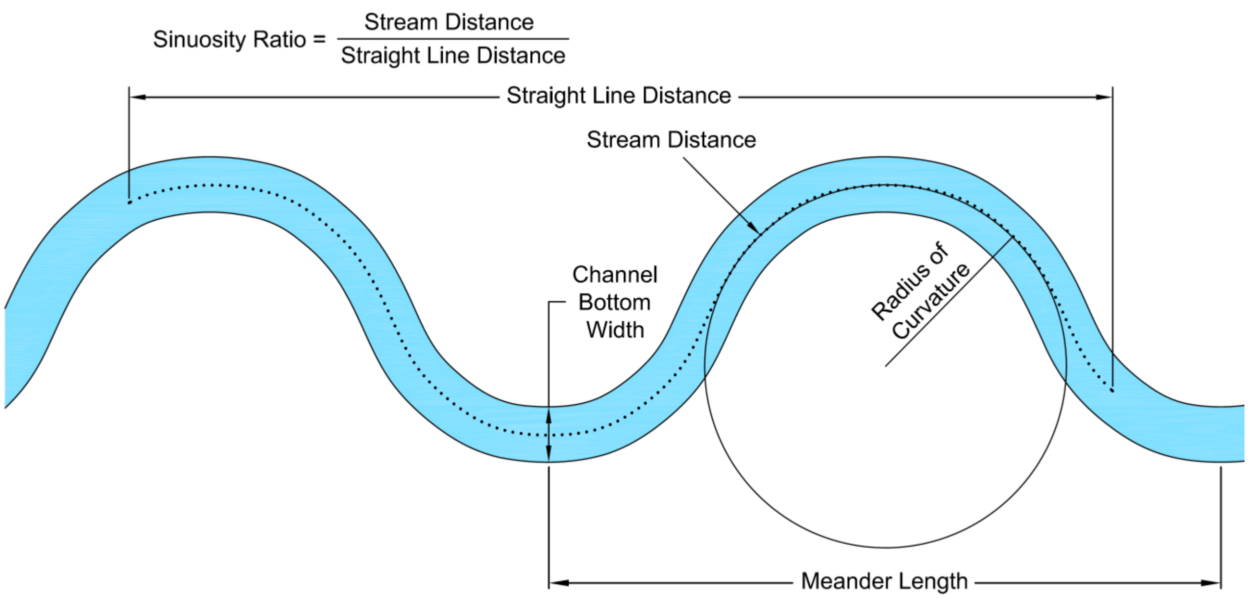

Figure 9. Geomorphic criteria included channel sinuosity, meander length, and meander radius of curvature.

Channel Cross Section Geometry

A very important aspect of geomorphic channel design is the channel cross section, or how the channel looks from the perspective of water moving through it. Cross-sectional geometry for the bankful channel was based upon dimensions observed in the geomorphic reference reach, including a bottom width of 13 ft and bank-full flow depth of about 3 ft, resulting in a cross-sectional area of 72 sq. ft and a maximum bankful velocity between 7.5 and 8 fps, assuming a Manning's n of 0.039. The flow depth for the floodprone discharge will approach 10 ft. Side slopes for the restored channel vary depending upon the location of the cross section within the meander pattern, as they do in undisturbed reaches of the Dillon Canyon channel (Figure 10).

Figure 10. Undisturbed reach in Coal Canyon showing variable side slopes for channel banks.

Natural stream meanders are created by fluvial geomorphic processes that balance erosion at outside meander banks with the formation of depositional features at inside meanders. Inside meander banks are slowly built at the same time that outside meander banks are eroding, and although the stream may migrate within the meander belt, the balance prevents wholesale channel degradation and the contribution of excess sediments to downstream reaches. The redistribution of sediments prevents the channel from becoming deeply incised through ongoing scour or headcutting, and baseflows are conveyed at a flow depth high enough to support vegetation on the stream banks. The occasional inundation of inside channel meanders does not prevent the establishment of large woody vegetation, which further slow flows and helps protect and anchor the bank. The restored channel has dynamic stability and improved stream function and habitat value.

The restored channel was designed with variable side slopes, like undisturbed natural channels in Dillon Canyon (Figure 11). The bank slope on the inside of each meander is flatter

(5H:1V) than the slope at the outside bend of each meander (3H:1V). Moving downstream from a meander, both bank slopes transition to 4H:1V in the straight reach between meanders, and then transition again for the next meander. The steeper bank on the outside of the meander may experience some erosion and become steeper, but the shallower slope on the opposite, inside meander ensures that flood flows are distributed onto the overbank and slowed, allowing suspended sediments to drop out.

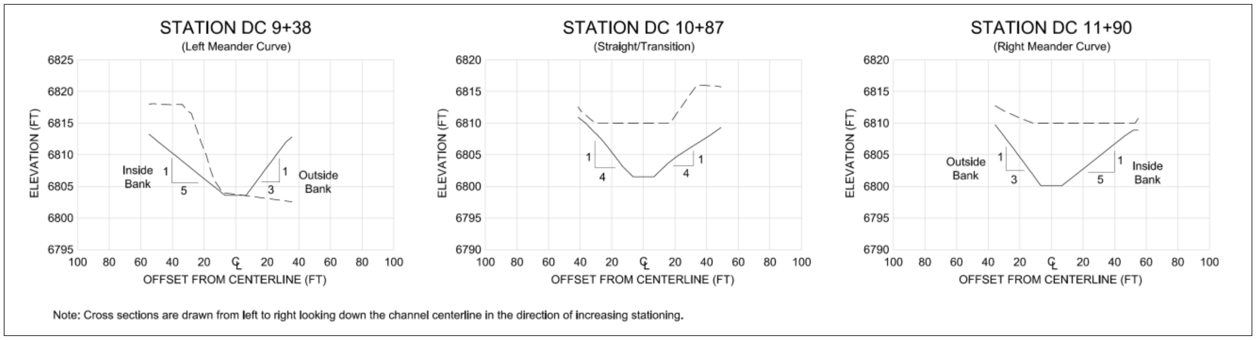

Figure 11. Excerpt from plan set illustrating typical differential side slopes for channel cross sections.

Because the restored reach of the Dillon Canyon stream channel will convey relatively large flows from a 23-square mile undisturbed watershed upstream of the project site, independent analyses were conducted to incorporate hydrologic and hydraulic engineering analyses with the geomorphic design for stream restoration. Hydrologic analysis and peak flow determination were analyzed using SEDCAD (Sediment, Erosion, Discharge by Computer Aided Design) version 4.0 (Warner et al., 1998). The U.S. Army Corps of Engineers' Hydrologic Engineering Center-River Analysis System (HEC-RAS) was used for hydraulic analyses including determination of the channel capacity and verification of flow velocities (USCOE HEC, 2002).

Hydrologic Analyses

Although the landscape in this mountainous region of northern New Mexico looks arid and many of the channels convey only intermittent or ephemeral flow, heavy precipitation delivered by short-duration, high-intensity thunderstorms during the summer monsoon season can result in significant peak flows. The Swastika abandoned mine lies just below the confluence of Dillon Canyon with Coal Canyon, and the stream channel through the project site conveys runoff from a tributary watershed more than 23 square miles in size. The peak discharge values reported by Natural Regrade ™ with Geofluv™ are not developed from a unit hydrograph routing procedure, so an independent analysis of watershed response was conducted to develop peak discharge values for design. Precipitation data for the project site were gathered from NOAA Atlas 14. Dillon Canyon was broken into subwatersheds at critical flow locations and analyzed to determine hydrologic parameters based upon soil and vegetation factors influencing infiltration and runoff (Mockus et al., 1985). The watersheds were modeled in SEDCAD 4.0 to obtain peak flow values for various duration and recurrence interval storms using the New Mexico Type II-60 rainfall distribution. The design storm for the channel restoration was based upon a 100-year-6-hour precipitation event and produced a peak discharge of 6,400 cubic feet per second (cfs).

Hydraulic Analyses

Hydraulic modeling using HEC-RAS was used to estimate velocities at design discharges, both as an input to the geomorphic model and to independently verify the channel's hydraulic capacity. Using bankful geometry calculated by Natural Regrade ™, a HEC-RAS model was developed to estimate flow velocities and predict water surface elevations along the restored reach of channel for the design discharge. The design channel provides adequate hydraulic capacity, mimics undisturbed stream characteristics and geometry, and ties into existing channel elevations at the upstream and downstream end of the degraded reach.

Road Realignment

To make space for reclamation of the coal waste, not only the channel but the road running atop its east bank had to be rerouted. This rural, unpaved road provides access for maintenance and repair to the primary power line supplying electricity to the City of Raton, as well as access to private land in upper Dillon Canyon. During the historic mining period, when the valley had been served by both a rail line for transporting coal and a road, the road took an historic route at the east side of the valley. It was rerouted to follow the abandoned rail alignment when the rails were removed and sold at the close of mining. However, with drainage improvements and some minor cut and fill to improve sight distances and provide a consistent minimum width, the abandoned road was returned to service as part of the project. Utilizing the abandoned road allowed the project to capitalize on an alignment that kept the road above the design storm inundation and out of the restored channel's meander belt.

The design of drainage improvements complied with the methods and criteria specified for rural unpaved roads in the "Drainage Design Criteria for New Mexico Department of

Transportation Projects" (NMDOT Drainage Design Bureau, fourth revision, June 2007). The road is designed to be overtopped during large floods at locations where culverts large enough to convey the peak design flow could not be properly bedded. The road and embankments in those areas received rock surfacing. The old bridge at the mouth of Coal Canyon was seriously undersized for the flows from a watershed nearly seven square miles in area, so it was replaced by two 72-in. culverts (Figure 12) to allow the realigned road to make a perpendicular crossing of the culverts. Culvert improvements or additions were designed for six other locations to bring runoff under the realigned road and into the restored channel.

Figure 12. Culverts that convey the Coal Canyon channel under the realigned road.

Geomorphic Landforms at Combination Soil Borrow / Coal Waste Repository Sites

Because of the significant estimated volume of coal waste material to be reclaimed, every opportunity to use coal waste for fill was exploited by the design. Above the estimated maximum groundwater level, the degraded channel was backfilled with coal waste. The landform flanking the restored channel was also constructed of coal waste, except within the meander belt, where coal waste was precluded to prevent its exposure by downstream migration of the meanders. Whenever it was possible, the geomorphic reclamation design for Swastika reshaped steep or unstable coal waste piles into geomorphic landforms without requiring the removal of material to other locations. However, the volume available in the immediate vicinity of the largest waste pile was insufficient to accept the total estimated volume of gob requiring reclamation. Waste material had to be partially removed to achieve stable slopes for geomorphic landforms designed to accommodate the remaining coal waste.

However, given the archaeological features scattered throughout the valley, the power line rights-of-way, the road, and the space devoted to meandering stream restoration, little space was available for accepting this coal waste material or for other uses, including excavation for borrow soils. Combination soil-borrow/repository areas were one solution to the dilemma. Small areas free of archaeological resources were excavated to the maximum depth possible to obtain borrow soils for capping, and to accept coal waste material as backfill. Then, geomorphic landforms composed of coal waste were constructed above the native ground level at these locations, tying into the adjacent hillsides. These geomorphic landforms, like the ones located at abandoned coal waste piles, were then capped with the topsoil that was either originally excavated at the combination borrow/repository areas, or excavated from the new channel realignment.

Wetlands Preservation and Mitigation

The design at Swastika sought to preserve a portion of the straightened channel that had been downcut through a sandstone ledge at the base of the hillside. On both sides of the straightened channel in this area, springs and seeps emanating from the fractured sandstone and upstream channel bed were observed to persist throughout the year. Within a small, protected reach of the otherwise degraded channel, diverse mature wetland vegetation and habitat for riparian species had developed. That portion of channel was not backfilled, although the realigned channel meandered away from the hillside at that point. The area was preserved and resembles an "oxbow" (Figure 13) that might develop adjacent to a meandering stream naturally after a meander is severed from the stream path.

The oxbow is separated from the realigned channel on the upstream end by a backfilled section of the channel and a sturdy embankment to prevent the realigned channel from reestablishing flow into the area. A hydraulic connection between the oxbow wetland and the natural springs and seeps was provided by designing a French drain to convey the flow from the backfilled seep and spring locations, thus maintaining the existing water source to the oxbow.

Figure 13. The “oxbow” area.

A second existing wetland area, located east of the oxbow, was preserved by the design. This wetland likely formed when the channel was moved to the west and the adjacent railroad embankment was constructed, preventing flow from Coal Canyon from efficiently reaching the Dillon Canyon channel. Wetland vegetation became well-established in this area of localized poor drainage. Although the project re-established a confluence for the two stream channels upstream of the wetland area, runoff from a small watershed was designed to flow into the wetland area and it was otherwise left undisturbed.

Revegetation Methods

Soil science and reclamation design, including plans for amendment and seeding schedules using native species, were provided by Habitat Management Inc. (HMI) under contract to WET. A close collaboration from the beginning of the project ensured that factors impacting reclamation success were considered in the engineering design from the outset.

Construction Methods

Construction of the Swastika Mine and Dutchman Canyon Reclamation Project took place over a six-month period in 2012. Construction engineering oversight was provided by WET, and oversight of reclamation activities was provided by HMI. Construction was provided by Kiewit New Mexico in collaboration with their revegetation subcontractor, 814 Solutions, LLC.

Equipment was mobilized and the installation of erosion control and construction support facilities had begun by early April.

Changes to the design during construction had been anticipated due to the potential for field conditions to impact the design. A total coal waste volume had been estimated using conservative assumptions, but it was expected that the actual volume of coal waste encountered would differ from the estimated volume. It was neither physically nor economically feasible to drill extensively to determine the depth of fill over the native landform under the largest, steepest coal waste pile. It was also expected that groundwater, bedrock outcrops or buried archaeological artifacts could be encountered during excavation. The project was structured to allow flexibility for design changes on the fly and to provide alternative work activities if construction in a particular area was halted due to weather delays or to respond to field conditions. As the project progressed, a number of archaeological features were exposed, including in areas that had been planned for use as combination soil-borrow/coal-waste repositories and in the channel realignment excavation. When possible, geomorphic designs were modified as required and alternative locations for placing coal waste and borrowing capping soil were identified to preserve these newly discovered archaeological features. However, preserving two service pits constructed beneath the rail line was fundamentally incompatible with stream restoration at the site (Figure 14). These features were fully excavated and documented before construction in their vicinity resumed. The construction team cooperated to shift work areas and maintain progress even when work was halted for archaeological documentation. It was helpful that the work at Swastika had been combined with work at Dutchman Canyon, so that equipment and labor could be moved there. Close coordination between the State and the contracted entities was required to ensure a successful construction outcome in spite of the project's complexity.

<u>Geomorphic Landform Construction</u>

A major challenge in the construction of geomorphic reclamation projects is to communicate their unique requirements to operators with years of experience building traditional features such as long flat slopes, terraces and down-drains. In addition, because of the interdependent requirements for slope stability, channel gradients and lengths, swale profiles, and bringing the channel bottoms all together at the correct confluence points, construction tolerances for this type of work are unusually tight. Construction utilizing GPS machine control was specified for the

Figure 14. Buried railroad service pit encountered during channel excavation.

project from the outset (Figure 15). Digital files were generated in AutoCAD® Civil 3D in an XML format that represented the 3-dimentional design in Triangular Irregular Network (TIN) format. Ridge and valley lines were particularly important and were emphasized when creating the TIN. These XML files were uploaded on the equipment computers so that a precise construction tolerance could be met. Ultimately it was necessary to adjust the topographic contours in the TINs to better accommodate the channel layouts superimposed on the topography by Natural Regrade™ with Geofluv™. The high level of resolution in the TINs allowed the equipment operators to efficiently construct both the geomorphic landforms and their integrated drainage channels.

To the greatest extent possible, simple means of distributing material were employed. Once equipment was able to reach the top of the coal waste piles, the bulk of the coal waste and stockpiled topsoil material was simply pushed down and into place with D-9 bulldozers. The final surface shaping was completed with a D-6 bulldozer equipped with GPS machine control. Coal waste that had to be transported to repository areas was loaded into haul trucks by a stationary loader accessing a pile of material replenished by a bulldozer moving material from

Figure 15. Landforming with GPS machine control.

higher on the pile (Figure 16). Utilizing push construction methods for geomorphic landforming not only reduces the cost of moving material, but has proven to be most effective in achieving the desired landform results as well. Looking at a geomorphic landform design, it is easy to focus on constructing channels to excavate those zigzagging forms first. Subsequent efforts to finalize the surrounding landform, however, are prone to disturbing the channel form and frustrating the operators. A more reliable technique to approximate the final landform is to simply push material from the channel into alternating ridges on either side of the channel, allowing the channel's zigzag shape to emerge from that process and building both the channels and the landform simultaneously.

At least one foot of clean fill was placed over the coal waste land form, with appropriate amendments, to provide a surface for reclamation. Coal waste was excavated from the geomorphic landforms in the immediate vicinity of tributary channels and swales conveying runoff from the hillside across the reclaimed land and into the restored channel. In these areas the coal waste was replaced with clean fill to avoid the exposure of gob if the channels and swales experience some degradation.

Figure 16. Removing coal waste to combination soil borrow/repository areas.

The construction specifications required that the landform be ripped on the contour prior to seeding, but the small D-5 dozer used for ripping was not equipped with GPS control. Operators struggling to simultaneously monitor the depth of the ripping while following the contour of the hillside ahead were far more successful when a visual path was provided. This was accomplished by placing pin flags at 10-ft contour intervals using a survey-grade GPS unit.

Many of the soil-borrow/repository areas at Swastika were eliminated or reduced in size by archaeological finds during construction. Therefore, a repository several miles south of the project site, but still within Dillon Canyon, was identified, and even there the buried remains of historic features were encountered during excavation.

<u>Stream Restoration Construction</u>

The channel was built in a direction from downstream to upstream (Figure 17) to facilitate drainage if any groundwater was encountered. Material excavated during construction of the relocated and restored channel was stockpiled to cap coal waste. In several locations bedrock was encountered at channel invert elevations. To allow bedrock grade control to provide extra stability to the banks and bed of the restored channel, the bedrock was incorporated into the channel design rather than removed. Weathered and fractured material was removed using a D-9, and competent material was retained.

Minor modifications to the restored channel layout were made to preserve archaeological features identified during construction. A larger change to the downstream tie-in location was required when it became apparent that the highest, steepest portion of the coal waste pile was not supported by an underlying bedrock outcrop, as had been suggested by geological features visible on the surrounding hillside. Moving additional coal waste volume to the repositories was precluded by the archaeological restrictions there. So the realigned channel's tie-in with the existing channel was moved farther downstream and an additional meander was constructed to create enough space to lower slopes and accommodate the volume of coal waste in this portion of the pile.

Figure 17. Realigned and restored channel construction.

The existing channel was not backfilled until rock and vegetation that could be moved to the new channel was salvaged. Because the geomorphic design relies on dynamic stability rather than engineered structural control with riprap or grouted concrete structures, the meanders constructed for the restored stream may migrate as a result of low-frequency high flow events. To avoid the exposure of coal waste if the restored stream's meanders migrate over time, coal waste was not placed within a meander belt representing the maximum likely extent of meandering for the restored stream, including those locations where the realigned stream meanders approached the old channel. An embankment of clean fill was established to mark the extent of fill with coal waste (Figure 18). Coal waste was also withheld from those locations where substantial tributary drainages were constructed to convey runoff from the hillside across the reclaimed landform to the restored channel.

Figure 18. Embankment preventing coal waste fill within the meander belt of the restored channel.

Results and Discussion

The project created an aesthetically pleasing valley, with stable rolling ridges composed of capped coal waste surrounding an ecologically rich riparian corridor (Figure 19). The geomorphic landforms constructed accommodated a total of 200,000 cu. yds. of coal waste (Figure **20**). A

Figure 19. Restored channel with tributary side swales visible in background

3,050-ft section of the Dillon Canyon stream channel was restored with a meandering alignment closer to its original route in the center of the valley (Figure 21). The stream relocation and restoration produced a new functional floodplain and riparian habitat. Geomorphic reclamation flattened the pre-existing steep slopes and provided a stable surface to support vegetation, convey storm water, and minimize landform and stream channel erosion and sedimentation. Infiltration of runoff through coal waste was minimized and degradation of water quality was eliminated. Utility poles, and valuable ecological and cultural features including mature trees, wetland areas, and over 200 identified archaeological features were preserved (Figure 22). Access was improved by moving the road out of the floodplain and improving road drainage.

Figure 20. Coal waste reclaimed in geomorphic landforms at Swastika.

Figure 21. Realigned meandering channel through Dillon Canyon.

At Dutchman Canyon, channel head-cutting (Figure 23) was eliminated by redirecting wildlife pond outflow through a constructed spillway to supply water to a new salt-tolerant wetland. An increase in wildlife pond embankment height added a significant factor of safety to prevent overtopping and embankment failure (Figure 24). Better access was provided through road and drainage improvements and vegetative cover was enhanced by treating and seeding remnant coal waste piles.

Figure 22. Completed geomorphic reclamation and stream restoration at Swastika.

Figure 23. Culvert conveying outflow from the wildlife ponds to the Dutchman Canyon channel.

Figure 24. Embankment improvement increases freeboard, provides a spillway, and directs outflow to a new salt-tolerant wetland.

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