A CASE HISTORY: LIMESTONE QUARRY RECLAMATION USING FLUVIAL GEOMORPHIC DESIGN TECHNIQUES[1]

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Abstract: Geomorphology is the study of landforms and development of an understanding of the processes that shape them. Reclamation of mined land, including drainage system reconstruction, is evolving through increased use of geomorphic principals and site specific environmental conditions to design and construct surface topography that is geomorphically and hydrologically stable, aesthetically pleasing, and suitable for and capable of supporting post-disturbance land uses. A case study that exemplifies the benefits of using this fluvial geomorphic design and construction approach is reclamation of a surface quarry at GCC Rio Grande, Inc.'s Tijeras Cement Plant and Limestone Mine, Tijeras, New Mexico; a semi-arid region of the United States.

Surface quarrying removes burden and mineral resources that normally results in the mined area becoming significantly lower in elevation than surrounding undisturbed land. Typically, backfill materials are limited in availability at the conclusion of mining; backfilling frequently requires earthen materials to be hauled into the reclamation area. Fluvial geomorphic post-mining topography ("PMT") designs should: 1) Incorporate mined-out quarry features; 2) Aesthetically blend reclaimed surfaces into adjacent undisturbed lands; 3) Optimize the use of *in situ* with imported backfill materials; 4) Establish reconstructed soil depths adequate to support growth of desired vegetation communities; 5) Produce a stable landform; 6) Reconstruct adequate drainage features; and consider post mine land use goals.

This case study compares the latest fluvial geomorphic PMT design method with conventional terrace and drain PMT methods. Potential fluvial geomorphic method cost advantages are identified in design, permitting, construction and reclamation liability period maintenance activities. This project is a 2008 Portland Cement Association award finalist which recognizes leaders in the industry for use of innovative technologies relevant to environmental preservation.

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Introduction and Project Background

Grupo Cementos de Chihuahua (GCC) of America operates the Tijeras Cement Plant and Limestone quarry which is located twenty miles east of Albuquerque in Tijeras, NM. Annual cement production at this plant can be upwards of 450,000 tons per year. The Tijeras mine permit area encompasses 2,118 acres of which over acres have been disturbed. The reclamation of Quarry 4 in mining area L, located in the southeastern portion of the mine permit area shown in Fig. 1, is the project described herein. Thirty-two acres were quarried for limestone which was used in cement production. Seven of those thirty-two acres occupy United States Forest Service (USFS) property with their own site-specific reclamation requirements. The design process for this project required approximately 6 weeks and a permit approval for construction was granted by the agencies in less than one month after submittal.

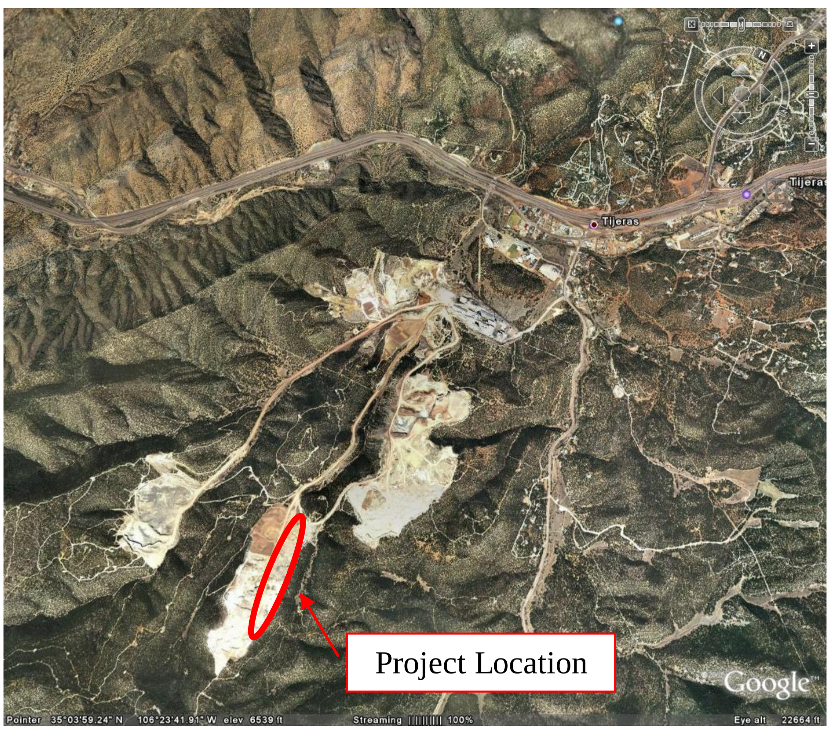

Figure 1: Site Location Map (Courtesy of Google Earth)

Reclamation in the southwest United States presents unique challenges associated with its arid and semi-arid climate. Other challenges include windy conditions, erosive soils, a variable climate that can inhibit vegetation growth, and storm patterns characterized by short duration, high intensity precipitation. To address these conditions, mine quarry reclamation has historically used a combination of terraces and down drains to establish hydrologic stability and route stormwater runoff through reclaimed lands. Mine personnel observed problems with terraces overtopping and breaching, and drain riprap linings failing on a nearby reclamation site. In response to these identified problems, a geomorphic approach to reclamation was proposed by the mine. Based on documented maintenance requirements for terraces and down drains (Brown 2006; Schor and Gray 2007), the primary regulatory agency (New Mexico Mining and Minerals Division) encouraged the use of a site-specific geomorphic approach for reclamation planning in Quarry 4.

The Problem

Quarry disturbance resulted in highwalls up to 30-feet high (Fig. 2), a pit floor that consisted primarily of a hard limestone component, an overall site gradient of 10% and a highly erodible substitute soil material used as topsoil.

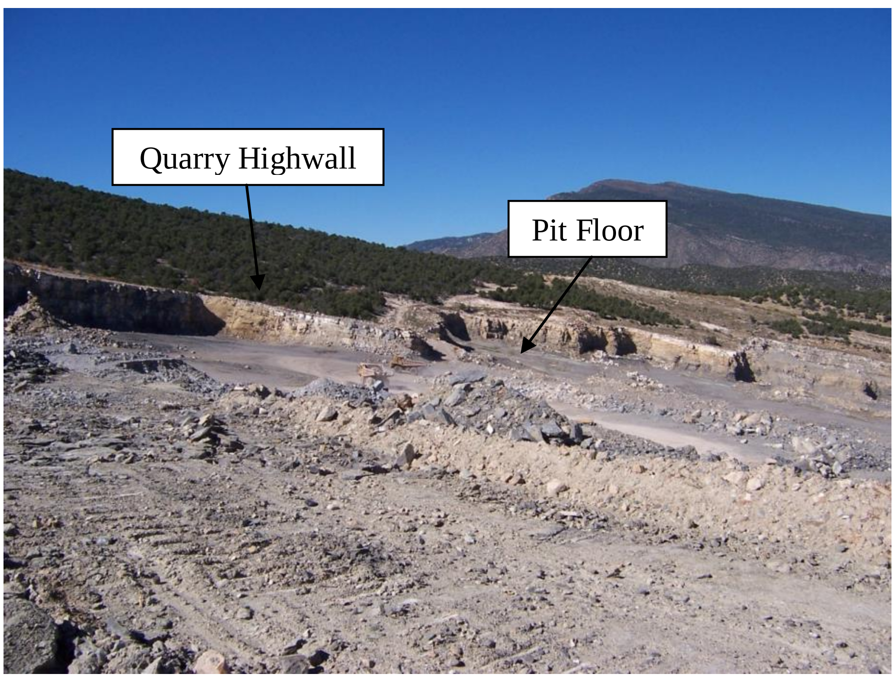

Figure 2. Disturbed surface after limestone is quarried.

All disturbed areas were required by the mine permit to be overlain by at least two feet of cover consisting of a subtitute soil material, making the final reclamation surface a “fill only” application. Major project goals for this reclamation effort included:

- Design of a naturally stable landform that would minimize erosion potentials, require little or no maintenance, and provide a habitat for vegetative diversity,

- Design of a drainage system that would be stable, self-cleaning and capable of routing surface runoff into existing undisturbed drainages,
- The addressing of regulatory agency concerns including proper channel design and erosion control and support of reclamation bond release, and
- Development of a design that could be integrated with GPS machine control for construction and would limit expensive blasting, minimize the volume of imported material needed and shorten the haul and push distances during construction.

The Solution

Water and Earth Technologies, Inc. (WET) in conjunction with Habitat Management, Inc. (HMI) has developed an integrated approach to surface reclamation that uses a variety of software tools specified in the Office of Surface Mining T.I.P.S (Technical Innovation and Professional Services) tool box (USDOI 2009). This multi-tool approach uses software including Natural Regrade with Geofluv™, SEDCAD, RUSLE and HEC-RAS to develop a reclaimed surface that is hydrologically, hydraulically, and geomorphologically stable, requires little maintenance and provides good habitat diversity.

Natural Regrade with GeoFluv™ is a computer-aided design tool that uses the principles of geomorphology applied to landform grading to develop a surface that is naturally stable and could be sustained with little or no maintenance into perpetuity. Major software input parameters for reclaimed landform design are determined by observing field parameters native to the undisturbed surrounding areas, including:

- Drainage Density: The ratio of Valley Length to Reach Area,
- Ridge to Head of Channel: The shortest distance from the ridgeline to the head of a stable channel,
- A-Channel Reach Length: One-half a meander length for a Rosgen-classified A channel, and
- Sinuosity: The meander characteristics of a channel based on the valley slope.

Six self-contained subwatersheds were designed using Natural Regrade (Fig. 3). The design incorporated rolling hills and a series of ridges, valleys, small channels and tributaries with channel side slopes of 4:1. A photo of the design surface while under construction can be seen in Fig. 4.

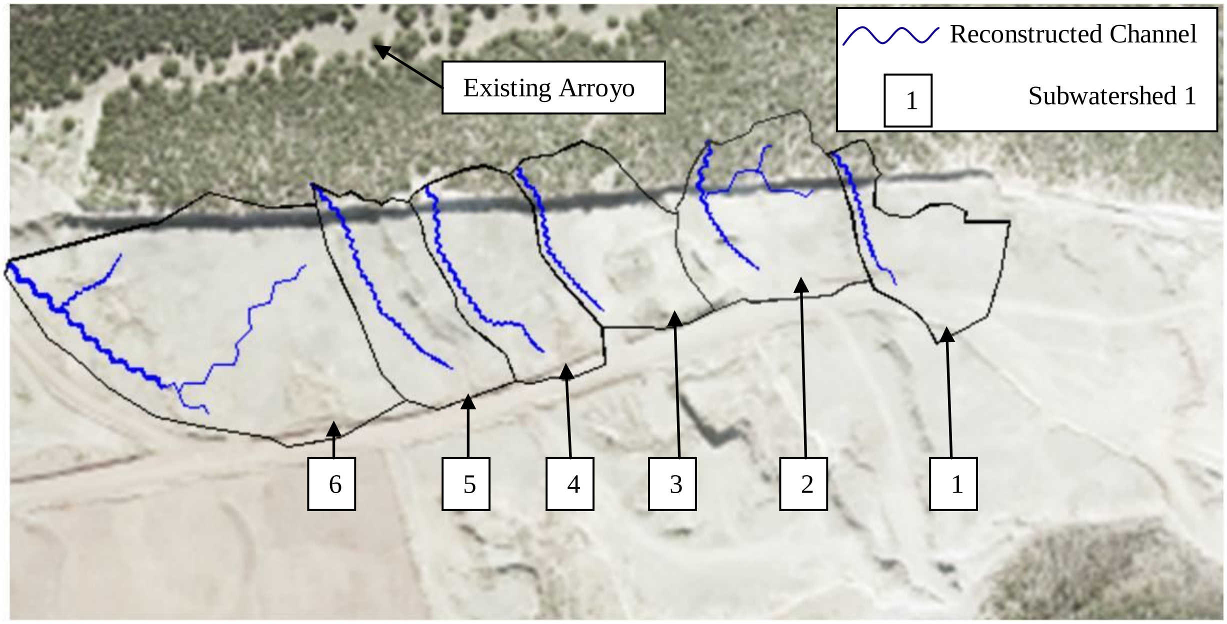

Figure 3: GeoFluv™ Watershed Configuration

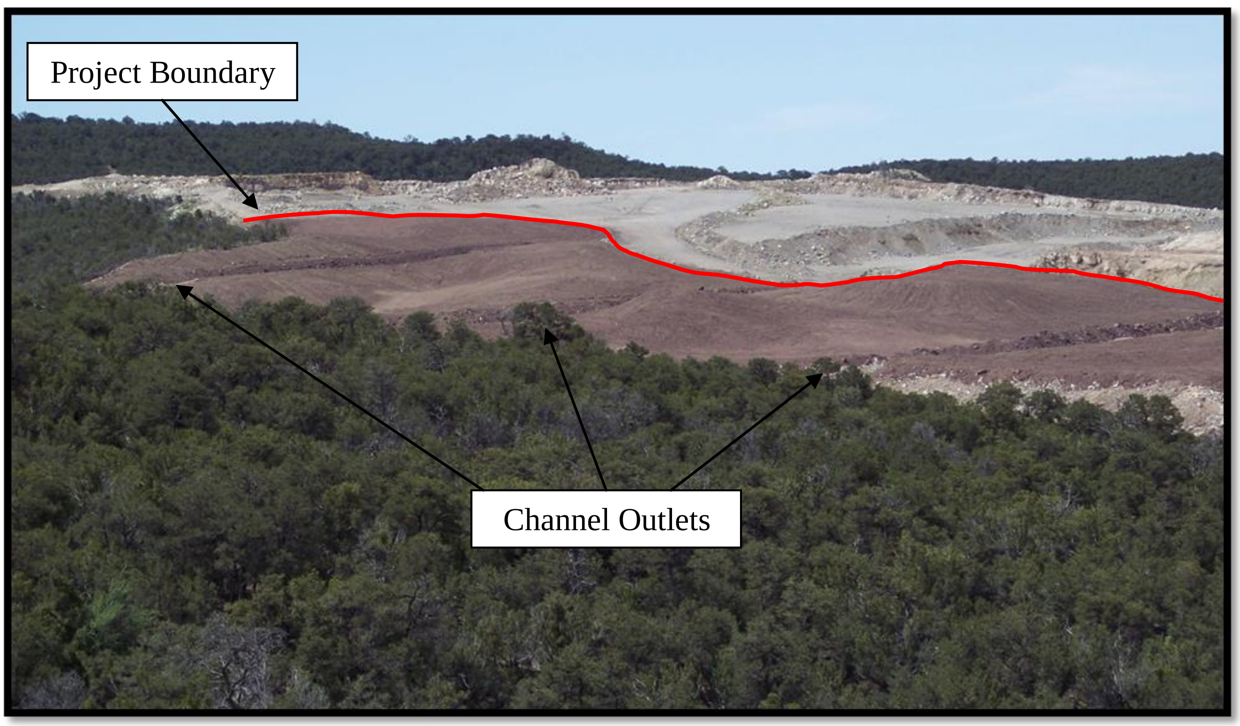

Figure 4. Reclamation Surface (Under Construction).

Regulatory requirements specified that the reclamation design must accommodate the runoff from the 100-year, 24-hour precipitation event for sizing channels and determining the erosion potential of the design surface. These precipitation criteria are not incorporated into Natural Regrade, however. The algorithm applied by Natural Regrade uses the 2-year, 1-hour precipitation to size bankfull features and the 50-year, 6-hour precipitation to size flood-prone features, but consistently overestimates design flow peaks because the model applies the entire precipitation from the design storms over a 1-hour period. Natural Regrade cumulatively adds the flows calculated in subwatersheds without considering peak flow attenuation based on channel routing and time of concentration, which typically results in Natural Regrade peak flow estimates that are much greater than those calculated for the same subwatershed using traditional hydrologic modeling. To satisfy the requirements of the regulatory agencies evaluating the design at the Tijeras quarry, a secondary analysis was conducted using a model that had been typically used to design channels in this area. Sediment, Erosion, Discharge by Computer Aided Design (SEDCAD) (Warner, Schwab & Marshall 1998) was used to demonstrate the overestimation of peak flows that is inherent in Natural Regrade. Discharge values from both Natural Regrade and SEDCAD were compared at the outlet of each subwatershed, and the flows produced by Natural Regrade were comparable to those predicated by SEDCAD for the 100-year, 24-hour precipitation event (Table 1).

Table 1: Flow Comparison

Subwatershed	Peak Flow (cubic feet per second) Natural Regrade (50-year, 6-hour = 2.89")	Peak Flow (cubic feet per second) SEDCAD (100-year, 24-hour = 3.55")
1	5.66	5.49
2	9.34	9.14
3	7.6	7.38
4	7.94	7.7
5	7.64	7.43
6	21.95	21.3

Regulatory requirements set forth in the mine permit for the Tijeras site limit allowable soil loss to 4.4 tons/acre/year . A primary component of the geomorphic approach to reclamation is that the gradient and length of slopes are minimized by utilizing interconnected compound slopes instead of the singularly-graded planar slopes typically observed in traditional reclamation. The Revised Universal Soil Loss Equation (RUSLE) (Toy et al. 1998) was applied to the worst-case slope in each subwatershed to demonstrate that the maximum allowable soil detachment rates were not exceeded (Table 2).

Table 2: RUSLE Results

Subwatershed	Worst-case RUSLE sediment particle detachment (tons/acre/year)
1	3.4
2	4.2
3	3
4	2
5	3.6
6	3.3

From Design to Construction

The design surface called for 220,000 cubic yards of fill. Redbed growth medium was chosen for the construction because it could be salvaged on-site at a location west of the quarry. A soils study was conducted on the Redbed material to evaluate its suitability as a topsoil material. Soil testing results indicated that pH levels, infiltration rates and nutrient and mineral concentrations were within acceptable limits rating the soil as a good growth medium. Mapping was produced using the Carlson Civil module in conjunction with AutoCAD to show differential cut and fill values around the quarry to indicate the most efficient locations to dump materials so that push distances could be minimized during final grading. A Triangulated Irregular Network (TIN) digital file, in a format compatible with GPS machine-control software, was uploaded to the bulldozer GPS system for grading accuracy to within a few inches. The design surface was built in the summer of 2007, and completed in a one-month timeframe. A topography map of the before and after surfaces is shown in Fig. 5.

The regulatory agencies agreed to allow the newly created landform to remain fallow for one year, providing an opportunity for soil moisture recharge, and to assess the surface for significant erosion problems and confirm the overall functionality of the watershed system. In response to observations during this period, additional grading work could address any issues with the landform before vegetation was established. The reclamation site was subjected to a large precipitation/runoff event shortly after construction was completed. Inspection revealed that negligible rill and gully erosion had occurred, with the exception of one small gulley that had formed. One year later in the spring of 2008, prior to conducting revegetation operations, one small rock lined drain was placed within the reclaimed area to stabilize the gulley and minor grading work was completed to prevent runoff from an adjacent undisturbed watershed from running onto the designed surface.

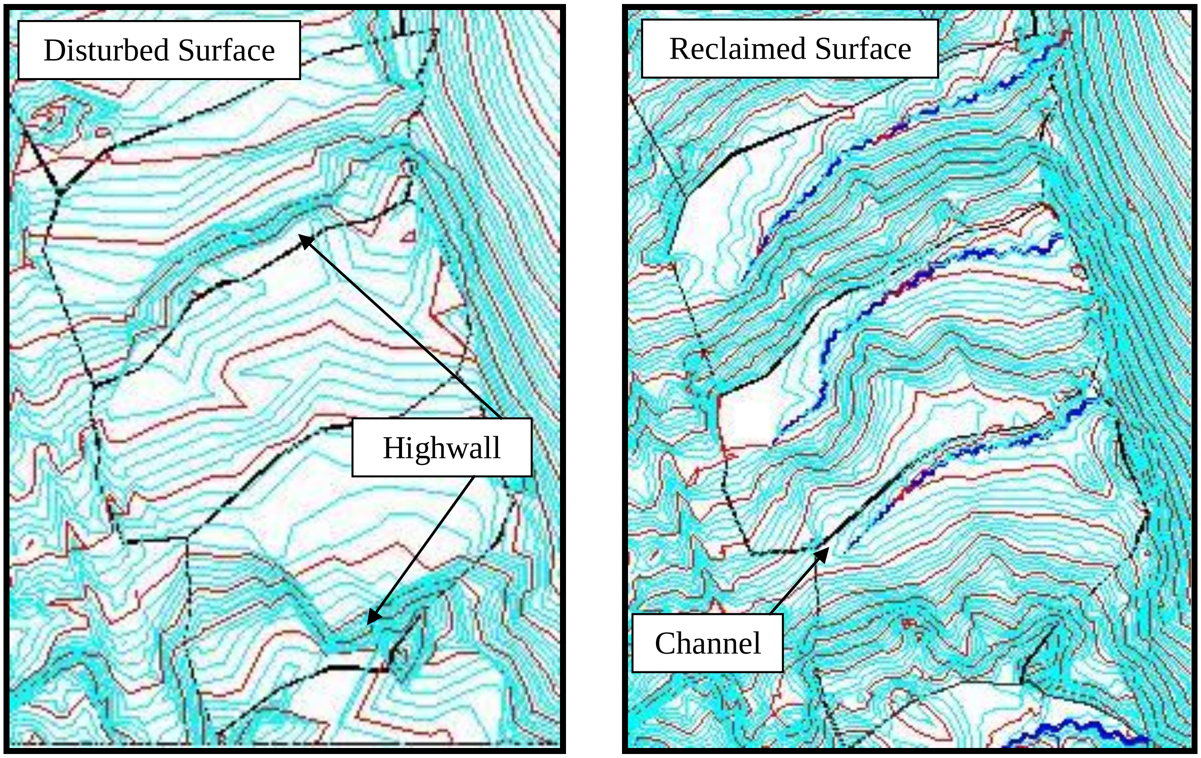

Figure 5: Pre- and Post- Reclamation Surfaces

Revegetation and Final Reclamation

In the spring of 2008 the area was contour furrowed, broadcast seeded and transplants were planted. Contour flagging was set at periodic intervals on the slope and furrows were established by ripping along the contour with a D-5 bulldozer. An all native plant species seed mixture composed of 7 grasses, 4 forbs and 5 shrubs was broadcast seeded at a target rate of 20 pure live seeds per square foot (5 pounds of pure live seed per acre). Twelve tree and shrub species (Table 3) were planted within strategic planting locations to promote the development of plant communities and wildlife habitat at an approximate density of 666 per acre. These transplant locations collectively represent about 4 acres of the 32-acre site.

Table 3: Tree and Shrub Species

Tree or Shrub Name	Scientific Name
Ponderosa Pine	*Pinus ponderosa*
Pinyon Pine	*P. edulis*
Oneseed Juniper	*Juniperus monosperma*
Mexican Cliffrose	*Purshia mexicana*
Antelope Bitterbrush	*P. tridentata*
Gambel Oak	*Quercus gambelii*
Wood's Rose	*Rosa woodsii*
Rubber Rabbitbrush	*Ericameria nauseosa*
Yellow Rabbitbrush	*Chrysothamnus viscidiflorus*
Mountain Mahogany	*Cercocarpus montanus*
Winterfat	*Krascheninnikovia lanata*
Skunkbush Sumac	*Rhus trilobata*

Per USFS stipulations, trunks from dead pinyon and juniper trees located in adjacent lands were cut and imported onto the eastern slope of the area. These trunks were placed on the contour to help with soil stabilization and provide wildlife habitat on the steeper outslopes observed in this area.

Conclusion

The reclamation completed in the spring of 2008 at the GCC Tijeras limestone quarry was a finalist in the Innovation category at the 2008 Cement Industry Energy & Environmental Awards, which honors the use of sustainable manufacturing practices. The awards are presented by the Portland Cement Association and Cement Americas magazine. The Innovation category recognizes the development and application of innovative technologies and techniques for environmental protection. While traditional terracing and drain reclamation would have been appropriate to satisfy all permit stipulations, significant environmental benefits and cost savings were realized using this geomorphic approach.

Costs were generated for a reclamation effort of approximately the same magnitude using traditional berm terracing and drains, and were compared with the costs for the completed reclamation using the geomorphic approach as shown in Table 4.

Table 4: Cost Benefit Analysis

	Conventional Design	Geomorphic Design
Engineering Design and Permitting	$10,000	$20,000
Regrading and Placement of Growth Medium	$250,000	$250,000
Rock Mulch	$20,000	$0
Construction of Berms Terraces and Downdrains	$150,000	$0
Current Maintenance Costs	$50,000	$0
Future Maintenece and Repair	???	$0
Total Cost	$480,000 +	$270,000

The analysis compared costs in multiple categories, including design costs associated with engineering, construction costs incurred to complete regrading, placement of growth medium, rock mulch and riprap, recent maintenance costs and projected future maintenance costs. The cost analysis showed a 44% savings achieved using the geomorphic design over using traditional reclamation techniques.

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