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COMPUTERIZING THE FLUVIAL GEOMORPHIC APPROACH TO LAND RECLAMATION[1]

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Abstract. The fluvial geomorphic approach to land reclamation is a means of creating the landforms to which the land would naturally tend to erode under the climatic conditions, soil types, and slopes present at the site. The resulting slopes and stream channels are stable because they are in balance with these conditions, and are a reclamation alternative to uniform slopes with terraces and down-drains. Reclamation landscapes created using fluvial geomorphic principles provide stability against erosion with runoff waters that meet water quality criteria, and support a diverse vegetative community. These landscapes offer the benefits of lower initial cost and no long-term maintenance costs. This award-winning fluvial geomorphic approach was successfully introduced to the largest mining company in the world at their New Mexico operations, where the landscapes have remained stable through extreme storms.

Now this innovative fluvial geomorphic approach (presented as a symposium short-course at the 2003 Billings Reclamation Symposium/ASMR Annual Meeting) has been computerized. This "user friendly" computer design software allows many users without advanced training in fluvial geomorphology to use this approach to create stable landscapes. The fluvial geomorphic landscape computer-design software replaces lengthy and tedious manual calculations and allows rapid evaluation of many landscape design alternatives. This allows the user to easily select the optimum landscape design for his needs. The computer design software allows the user to view topographic maps and three-dimensional images of the resulting landscape design. The computer automation is useful for designing reclamation, or for evaluating proposed reclamation designs for bond estimation. Computer automation helps users quickly and cost-effectively designs and build reclamation landscapes from spoil piles to seeded reclamation.

Additional Key Words: bond, channel pattern, cross sectional area, drainage density, longitudinal profile, sinuosity, stable, subwatershed, -width to depth ratio

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Introduction

Traditional landscape design is often based on the subjective judgment of landscape appearance or desired land use with little consideration for proper hydrologic function for balanced conveyance of water and sediment from the land surface. Alternately, traditional design methods might use engineering principles to create structural controls for water and sediment conveyance (Bugosh, 2000). Over the last several decades, fluvial geomorphic research has identified distinct relationships among several important factors including climate, discharge, slope, and earth materials that define stable stream channels (Bloom, 1978) (Dunne and Leopold, 1978) (Williams, 1986). This new innovative approach applies fluvial geomorphic principles to upland landforms through computer software. It creates a landscape design that mimics the functions of the natural landscape that would naturally evolve over time under the physical and climatic conditions present at the site to convey the water and sediment from the land surface in a stable hydrologic equilibrium.

Purpose

The purpose of this paper is twofold: to provide a summary of why the fluvial geomorphic approach benefits reclamation landform design and to describe how computerizing the approach provides a value multiplier by allowing detailed designs to be made and evaluated quickly.

Scope of Problem

Conventional land-shaping practices are often based on conveying or capturing runoff from an extreme event. These conventional practices include grading slopes to a uniform gradient, building gradient terraces across slope faces, and constructing rip-rapped down drains to convey runoff as shown in Fig. 1.

Use and Cost Limitations of Conventional Approach

Conventional designs often do not address the hydrologic balance during less extreme flow conditions. This results in problems with reclamation success for vegetation, livestock, and wildlife post-disturbance land uses, high maintenance costs, and reclamation bond complications.

Figure 1. Conventional steep slope reclamation with uniform slope gradient, gradient terrace, and rip-rap lined downdrain.

The unnatural configuration of these designs does not provide the terrain diversity that creates spatial variation in water harvesting and slope aspect. The result is that vegetation tends toward a monoculture and animal habitat is minimized. The native land in the foreground of Fig. 1 has forbes and shrubs growing near minor gullies, whereas the uniformly-graded slopes above them do not favor these plants, despite having been seeded with them.

Conventional land-shaping practices have high construction, maintenance, and liability costs. Terraces can be difficult and expensive to grade on steep side slopes. The rip-rap material may have to be procured off site and transported to the site. After construction, regular maintenance is often required as the terraces and ditches sized for extreme flows become clogged with sediment at lower flows, or are penetrated by burrowing animals. Clogged or burrowed terraces can result in catastrophic diversions of runoff from the terraces straight down the slope, often requiring major repairs.

Bonding Limitations of Conventional Approach

The conventional approach to reclamation landform design affects reclamation bonding liability and costs. The damage to the slope from the blowout and repair work can result in a reclamation bond clock being restarted, which prolongs the operator's period of liability. The expense of creating land form designs has often limited an operator's ability to propose incremental reclamation bonding for various stages of a project's disturbance. For example, an operator may determine that his greatest disturbance will occur at year four of a five-year permit and he may post a bond for that maximum disturbance, even though his liability will be lower for the first four years. This creates an unnecessary financial burden for the operator.

The Fluvial Geomorphic Solution

The fluvial geomorphic landscape computer-design software uses an algorithm based on fluvial geomorphic principles. The essence of this approach is to identify the type of drainage network, i.e., stream channels and valleys, which would tend to form over a long time given the site's earth materials, relief, and climate to achieve a stable landform, and to design and build that landform. The resulting slopes and stream channels are stable because they are in balance with these conditions (Rosgen, 1996). They are a reclamation alternative to uniform slopes with terraces and down-drains. Rather than fight the natural forces that shape the land, the algorithm helps the user create a landscape that harmonizes with these forces.

The channel and swales in the foreground, and the steep slope ridges, valleys, and channels in the center of Fig. 2., are examples of portions of a 115-acre coal mine reclamation project completed using this innovation fluvial geomorphic approach.

Figure 2. Steep slope reclamation using the fluvial geomorphic approach shown during the second growing season.

Natural Stability

Over the last thirty-some years hydrologists have observed and measured stable natural streams and determined mathematical relationships that describe these stable stream types. Essential among these determinations is that channel morphology is directly related to a relatively small, but frequently recurring annual flood event. The natural channel is shaped to keep its sediment load and stream flow in balance during these low-flow events, as well as during extreme events. This fluvial geomorphic approach to land reclamation relates the upland landforms to the stream channel form. Both can be formed similarly by flowing water. Reclamation landscapes created using fluvial geomorphic principles provide stability against erosion with runoff waters that meet water quality criteria, and support a diverse vegetative community. These landscapes offer the benefits of lower initial cost, no long-term maintenance costs, and they promote bond release (Bugosh, 2002, 2003).

Promotes Bond Release

The fluvial geomorphic approach provides a high degree of confidence that reclamation projects will demonstrate long-term stability against erosion similar to adjacent undisturbed lands because the reclamation channels are designed to maintain the hydrologic balance, as the natural channel does. This means that the reclaimed land does not have to be regularly disturbed to repair erosion problems. Additionally, the varied landform provides niches for different plants, wildlife, and livestock. These benefits demonstrate to regulatory authorities that the site will remain stable and productive; that demonstrated stability can promote bond release.

Benefits of Computerizing the Fluvial Geomorphic Approach

Previous application of alternative land-shaping practices may have been limited for several reasons, including the limited extent of training in fluvial geomorphic principles of the designers, the complexity of the design calculations to create a thoroughly integrated land form, and the difficulty of guiding the heavy equipment operators to build more sophisticated designs.

This new computer software addresses all these potential limitations. This software creates a draft landform based on empirically determined fluvial geomorphic mathematical relationships. The draft landform is an idealized solution that uses the input parameters to create a stable landscape.

The designer can then modify this idealized draft landform to conform to special site conditions, such as an archaeological site, landmark, or other feature, or to create a more natural appearance.

User Friendly. Existing computer software for earth-moving designs does not incorporate this innovative approach, is often not "user friendly", and does not have the broad applications for landscape designs that are stable against erosion offered by this new computer software. A primary objective was to make "user friendly" computer design software (to complement a computer-aided design environment, i.e., SurvCADD) that uses the innovative fluvial geomorphic approach to creating stable landscapes available to a large body of users that do not have advanced training in fluvial geomorphology. This software has been designed to be as "user friendly" as possible; with minimal input needed and with guidance provided in the "Help" resource and documentation.

Minimizes Training. Another objective in creating this software is to minimize the training necessary to immediately use the fluvial geomorphic approach for reclamation at disturbed sites, or when evaluating proposed reclamation designs. Users can compress design time and build reclamation landscapes from spoil piles to seeded reclamation. The author has successfully introduced this reclamation approach to the largest mining company in the world at truck-and-shovel and dragline operations. This software is designed to quickly make the design approach available to the widest range of users including professional hydrologists, environmental scientists, and engineers responsible for reclamation design at mine sites, and for regulatory personnel responsible for evaluating reclamation designs.

Simplifies numerous complex calculations. An important advantage of this computerized approach is the ease by which the user can create landscapes that are functional, stable against erosion, low-maintenance, aesthetically pleasing, and cost-effective. The fluvial geomorphic computer design software offers several options for developing input parameters from climatic and hydrologic data, and several options for creating landscape features, e.g., ephemeral, intermittent and perennial stream channels, complex slopes, ridges and valleys, and calculating material balances for the resulting design. The user can design channels with appropriate characteristics, including channel patterns, sinuosity, longitudinal profiles, cross sectional areas, width to depth ratios, etc. and uplands as functional components of a stable topography. The computer design software allows the user to view topographic maps and three-dimensional images of the resulting landscape design. The fluvial geomorphic landscape computer-design software replaces lengthy and tedious manual calculations and allows rapid evaluation of many landscape design alternatives. This allows the user to select the optimum landscape design for his needs.

Promotes Bonding Alternatives. The ability to quickly create and evaluate alternative reclamation designs provides great utility for both industry and regulatory personnel working on reclamation bonds. Because designing a reclamation surface has been such a lengthy and expensive process, often only a 'worst case scenario' design has been created for setting a reclamation bond. This 'worst case scenario' may have been based on the disturbance in year four of a five-year permit. The ability to quickly create design surfaces and conduct mass balance comparisons makes it practical for the user of this software to propose bonds for several stages of mine development, i.e., incremental bonding, that can reduce bond costs and promote release of more acres from bond.

Interface with GPS and Machine-control Software. This software also is ideal for integrating with Global Positioning System and laser machine control to simplify and speed construction and reduce costs. The need to survey and stake the designs in the field is eliminated using these technologies.

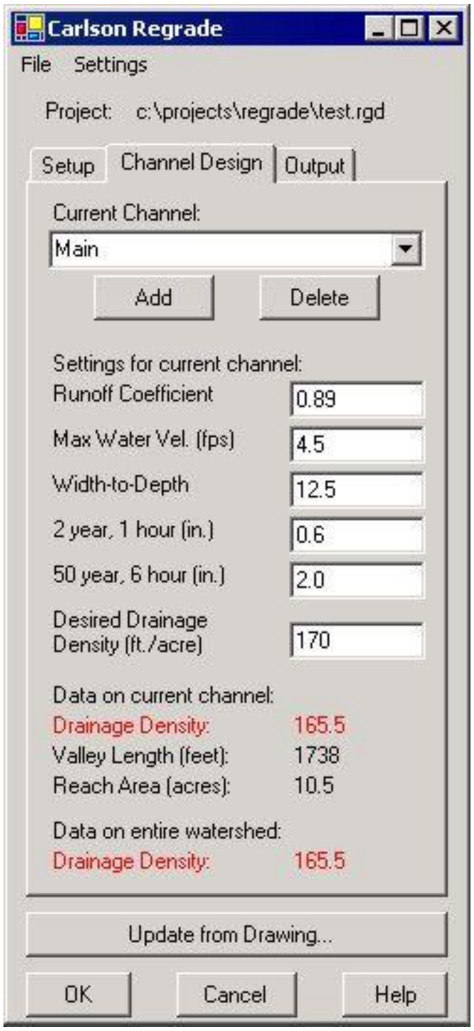
Description of Software

This software requires only minimal input parameters to produce a draft surface and the material balance associated with creating that surface. The software outputs a draft landform that provides a solution for a stable landform that satisfies the input parameters. The software also displays the cut/fill balance achieved when building the draft landform.

The user can focus his design energy on testing alternative designs for enhanced suitability to site-specific conditions. Those site-specific conditions can include post-disturbance land use considerations, community relations, equipment constraints, material constraints, bond costs, visual aesthetics, etc. The resulting three-dimensional surface map can be exported in a variety of electronic formats to other programs, or printed as two-dimensional hard copy. The completed design can be taken to the construction site using survey and stakes, or output electronically to GPS and laser-guided construction equipment. The designed topography can then be constructed with available equipment and earth materials.

Discussion of Input Parameters

This software helps the user create a stable landform based on minimal local input variables. These include site elevations (from a survey grid), a watershed boundary, a local stream base level for the watershed, a desired drainage density, design maximum discharge velocity, precipitation from the 2-yr, 1-hr and 50-yr, 6-hr storms, and runoff coefficient. The user will also select a desired cut/fill balance tolerance. Fig. 3 shows an example of the minimal input data needed for the software to design the landform using this fluvial geomorphic approach.



Project: c:\projects\regrade\test.rgd

Current Channel: Main

Settings for current channel:

Runoff Coefficient	0.89
Max Water Vel. (fps)	4.5
Width-to-Depth	12.5
2 year, 1 hour (in.)	0.6
50 year, 6 hour (in.)	2.0
Desired Drainage Density (ft./acre)	170

Data on current channel:

Drainage Density:	165.5
Valley Length (feet):	1738
Reach Area (acres):	10.5

Data on entire watershed:

Drainage Density:	165.5

Figure 3. Example of Channel Design input dialog box

The user can then edit this idealized landform for any number of reasons. The site may have boundaries that must be avoided. The user may want to bend a channel around an archaeological or historic sites, or local landmark. The user may want to alter slope aspects to promote vegetation diversity, wildlife niches, or to harvest moisture by retaining snow. Aesthetic considerations, such as view sight line, may prompt the user to edit the draft landform. Material movement planning may require the user to evaluate factors including the cut/fill balance and haul distances associated with various alterations of the draft landform. The user may wish to create several interim landform designs leading to the final design for submission for incremental reclamation bonding. The ease and speed by which the software creates a draft design solution facilitates these and other edits. The software frees the user to focus on site-specific design considerations and finding an optimal solution to creating a stable site landform, rather than being immersed in ponderous calculations for each subwatershed.

Drainage Density. The drainage density input is the valley length (without meanders) divided by the subwatershed area (Dunne and Leopold, 1978). This value will vary depending on factors such as earth materials, slope aspect, storm intensity, and vegetation type and coverage. It is important because it represents the subwatershed size that will be stable for the local conditions. Drainage density and the ridges that form between channel meanders work together to break up the landform into many small subwatersheds, as can be seen in the natural subwatershed shown in Figure 4. The subwatersheds minimize both slope length and catchment area and thereby minimize erosion.

Figure 4. Natural "A" channel meanders and ridges break slope length into a series of subwatersheds.

This software suggests a default drainage density value, but the user can improve the draft design by using site-specific values. By using empirically determined drainage density values, the user can have a very high degree of confidence that the resulting design will behave similar to the areas from which the drainage density measurements were taken. The user can determine a desired range of site-specific drainage density values. Local drainage density measurements taken from the undisturbed land with earth materials similar to the project area, and from nearby areas with earth materials that are similar to the project's disturbed earth materials, can define the range. The drainage density measured on undisturbed earth materials provides a lower end-of-range value, while the drainage density measured on nearby areas similar to the project's disturbed materials provides an upper end to the range of desirable drainage density input values. The user sketches a draft channel pattern, and the software calculates and displays the drainage density sketched. Designing the landform using an appropriate drainage density for the project area conditions is an important step toward achieving a stable landform design.

Channel Pattern and Sinuousity. This software will then draw a draft channel pattern with suggested sinuosity appropriate to the channel slope. The default drainage pattern is a dendritic pattern, because this “branching tree” pattern is the type that typically forms in unconsolidated materials (Bloom, 1978)(Dunne and Leopold, 1978), such as those existing at a disturbed site. Sinuosity is the ratio of channel length to valley length. Channels on steeper slopes generally are less sinuous than those on lower gradients in stable land forms. This software then calculates channel longitudinal profiles for each channel in the draft drainage pattern.

Longitudinal Profile. The longitudinal profile of a natural channel is typically concave (Dunne & Leopold, 1978), that is, steeper gradient in the headwater reaches and lower gradient near the channel mouth. That is because the headwaters of the watershed have less area, and therefore generate less runoff and erosive energy than the reaches near the channel mouth. Steeper channel gradients can be stable in the upstream reaches and lower channel gradients are appropriate in the downstream reaches for this reason. Stable slope profiles also tend toward this profile as can be seen in Fig. 5.

Figure 5. Concave longitudinal profiles in stable natural slopes.

This software designs the longitudinal profiles for the draft landform to grade concave profiles to each local base level. For example, the main valley bottom channel in the draft watershed grades to the user-input local base level (the lowest elevation in the design's main channel, typically where all runoff leaves the design watershed). Each valley wall channel grades, at its confluence with the main valley bottom channel, to the main valley bottom channel slope at the confluence. The headwater slope for the design profile is determined by the elevation of the design watershed boundary and a default distance from that boundary over which the ridgeline can have a convex profile and be stable. The ability of agricultural machinery to operate across slopes steeper than 3:1 is also a constraint on headwater slope for reclamation designs. The default distance from watershed boundary to channel headwaters can be edited by the user to suit local conditions. The result of the software's longitudinal gradient solution is a network of sinuous channels that have concave profiles and smoothly transition from steeper headwater gradients to the gradient at the design watershed's local base level elevation. Figure 6 shows an example of a natural network of slopes and channels graded together from steeper ground to a lower gradient valley bottom.

Figure 6. Stable natural channels and slopes grade from steep to flatter gradient by a network of concave longitudinal profiles.

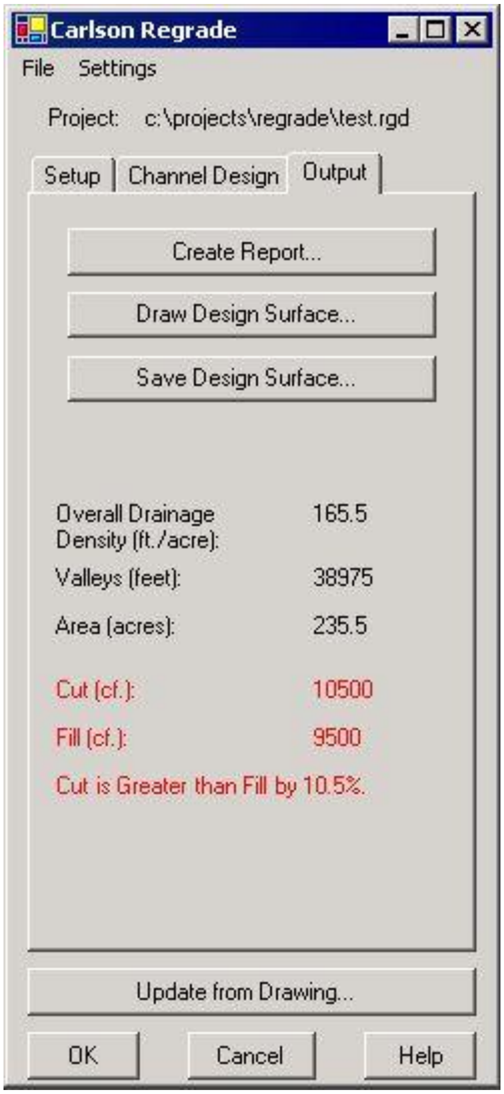
<u>Channel Cross-section</u>. This software calculates the channel cross-sectional profiles for channel reaches. The bankfull width (Dunne and Leopold, 1978) (Rosgen, 1996) for the mean annual flow is

used to create a hydrologically balanced cross section. As the watershed area increases downstream, more water is present in the channels and the channel cross sectional area must increase to convey the discharge within the user-specified design velocity range. Other channel pattern dimensions, i.e., meander length, meander belt width, radius of curvature, related to the bankfull discharge (Williams, 1986) increase concurrently. This software's cross sectional area increase occurs at reach breaks that are based on the practicality of construction by large earth moving equipment. Channel flood-prone area has been related to a 50-year recurrence interval event (Rosgen, 1996) and the software uses this value to design the flood-prone area of the channel. The resulting dimensions define the channel banks for the draft landform.

<u>Ridges, Slopes, and Volumes</u>. This software designs ridgelines between the channels at elevations that create side slopes less than a default 5:1 gradient for the draft landform. The user may alter the elevation and placement of the ridgelines to adjust slope gradient and material balance. This software then contours the ridgelines and channels to reveal the draft landform. Fig. 7 shows a reclamation project midway through construction that used this fluvial geomorphic approach. The mine pit highwall that ends at the graded gray spoil used to continue trending to the right of the figure and then turned ninety degrees toward the lower right of the figure. The steep slope reclamation with four subwatersheds immediately to the right of the end of the pit is the same slope shown in Fig. 2 above. This project was designed over a period of months without the benefit of the computerized software; with this software the design time would be measured in hours.

Figure 7. Fluvial geomorphic reclamation is underway at the 115-acre Cottonwood Reclamation Project, Farmington, New Mexico.

This software displays the material balance needed to create the draft landform. Fig. 8 is an example output dialog box that compares the cut to the fill needed to create the landform. The dialog box reports whether or not the balance is within the user-specified tolerance.



Project: c:\projects\regrade\test.rgd

Overall Drainage Density (ft./acre): 165.5

Valleys (feet): 38975

Area (acres): 235.5

Cut (cf.): 10500

Fill (cf.): 9500

Cut is Greater than Fill by 10.5%.

Figure 8. Output dialog box gives immediate cut/fill balance to guide landform design editing.

The draft landform is an idealized solution to creating a stable landform according to fluvial geomorphic principles based on the user-specified input values. The user may modify the draft landform, for example to reduce the fill volume by lowering a ridgeline, and the software can almost instantaneously recalculate the cut/fill balance to meet the user's design.

Links with other Software

The computerized landform design can further improve operational efficiency by interfacing with computerized machine guidance software. The landform design can literally be sent from the designer's computer screen to the machine operator's guidance screen by radio transmission and the designs can be implemented "on the fly". Design editing can also be done expeditiously. For example, if unforeseen conditions emerge, such as shallow bedrock near the edge of disturbance that hinders a dozer cut, the designer can adjust the channel's and related subwatershed design during the shift.

Additional efficiency can be achieved by integrating the computerized landform design with software, such as Carlson's Productivity Tools, that provide real-time equipment monitoring and data capture during construction. This software determines material movement volumes and distances over time for associated equipment. The information that this software provides to decision makers was previously not available and can help them identify the most efficient operational methods for maximum cost savings.

Software Compatibility

This software is a module of the SurvCADD XML Release 2 family. As such, it functions in tandem with the widely-used AutoCAD drafting software. SurvCADD XML2 is application software for the civil engineering, surveying, mine engineering, and GIS disciplines that use AutoCADD as the graphics engine and drawing editor. SurvCADD XML2's system requirements are no greater than that of the AutoCAD version with which it operates.

SurvCADD XML2 will operate with the following versions of AutoCAD:

- AutoCAD 2000/2000i/2002/2004/2005
- AutoCAD Map R4/R4.5/R5/R6/2004/2005
- Land Development Desktop R3/2004/2005

Data Entry

The SurvCADD XML2 software accepts data downloads from any data logger, or other data file. Once the data are imported into SurvCADD XML2, they are stored as a coordinate grid (.crd) file. The entire Regrade module project can then be designed from the .crd files without leaving SurvCADD XML2.

Summary

Computerization of this fluvial geomorphic approach to land reclamation makes the applied science from a relatively obscure body of knowledge available to a wide range of users. The approach helps the designer to build the landform that would tend to form under the existing physical conditions. The benefits of this approach include stability against erosion, hydrologic function and plant and animal habitat that are similar to undisturbed natural lands, lower construction cost for steep slopes, mitigation of maintenance concerns, and improved aesthetics. This approach also links with machine control and management software to further improve the efficiency of land reclamation.

Table 1 summarizes the advantages gained by using this computer-aided fluvial geomorphic design software to reclaim disturbed lands.

These benefits will not be realized in the mining reclamation field alone, but will similarly help those designing subdivisions, golf courses, ski areas, parks, etc. For example, storm water catchments do not have to be a rectangular pond surrounded by a chain link fence, but can serve the storm water control purpose and also be a hydrologically functioning and esthetically pleasing park. This technology will help designers, developers, and regulators evaluate more options, help companies save production and bond dollars, and promote better land reclamation and use.

Table. 1. Comparison of old methods of reclamation to landscape designed using this computer-aided fluvial geomorphic design method.

Old method	Regrade software with GeoFluv™
Based on conveying a single extreme discharge event	Based on all discharges
Conveys only water discharge effectively at lower Q	Natural channel morphology conveys water and sediment discharge; hydrologic balance
Requires expensive off-site earth material, e.g., rip-rap	Built with on-site materials
Expensive on steep slopes	Cost is significantly lower than gradient terraces and down drains on steep slopes
Requires long-term maintenance	Self-maintaining
Requires maximum backfill to lower slopes	Can reclaim steep slopes in stable and suitable configurations, save money on material moving
Provides minimal slope aspect diversity	Increased slope aspect diversity promotes vegetation success and animal habitat
Visual affront	Natural beauty
Rigid design sideboards limit landscape alternatives	Landscape designs can vary and provide alternatives
Regulatory agencies not satisfied	Regulatory agencies embrace*
	**(approach is award-winning)*

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