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Inspecting the functionality of geomorphic reclamation designs

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Abstract

Efforts at rehabilitating disturbed lands have accelerated since the late 1970s. Geomorphic-based rehabilitation designs have demonstrated, over the last two decades, the ability to provide sediment yield comparable to surrounding undisturbed land, establish ecological niches favourable for diversity of flora and fauna, and meet designated post-rehabilitation land uses, at costs similar to or lower than traditional design methods at sites around the world. Constructed and monitored geomorphic designs have demonstrated these benefits at locales ranging from the most-erosive, semi-arid conditions to temperate and humid forested regions, to sub-arctic conditions. Computer-modelled erosion predictions, and quantitative sediment yield field research have verified the success of geomorphic designs, but have also indicated that rehabilitation designs that do not properly integrate geomorphic elements provide no additional benefit compared to traditional methods. Fully functioning geomorphic design rehabilitation projects have correctly integrated the fluvial geomorphic elements that developed over time to make stable natural landforms in the project areas into the designs. This integration cannot be assumed because a design approximates natural landform appearance. A geomorphic design must be thoroughly inspected to determine if its geomorphic elements have been correctly integrated before proceeding to construction, both to assure full fluvial geomorphic functions that provide the desired environmental benefits, and to eliminate expenses for failure repairs resulting from incorrect designs. Rehabilitation designs can be inspected in the office to verify that the necessary elements are both present and have been correctly integrated. Complex slope profiles, channel profiles, overland flow routing to channels, slope steepness, stream tractive force values, and more can be inspected in the design by using manual calculations or computer programmes. The SIBERIA erosion modelling programme can indicate where erosion will occur on a design and also estimate the erosion sediment yield for specified time periods. The designer or reviewer that understands how stable geomorphic landforms function, what landform elements enable those functions, and how these elements must be integrated, can inspect and verify design functionality to promote successful geomorphic land rehabilitation.

Keywords: *geomorphic, rehabilitation, fluvial geomorphic, sediment yield, SIBERIA*

1 Introduction

Efforts at rehabilitating disturbed lands have accelerated since the late 1970s (Dunne & Leopold 1978; Stiller et al. 1980; Bugosh 2000; Toy & Chuse 2005). As constructed reclamation projects were monitored, it became apparent by the mid-1980s that the landform designs in use were frequently failing (Department of Industry, Tourism and Resources 2006; Goudie 2009; Loch 2010). These designs were inspired by agricultural slope cultivation and used terraces that incorporated relatively long constant-gradient slopes that were interrupted at intervals by near-horizontal terraces or benches, and used rock-lined downdrains to convey water collected on the terraces to the bottom of the slopes. Rill and gully erosion of the slopes, and mass movement terrace failures by slumping and sliding, were often seen on the reclamation surfaces. Water that collected above the slopes on large drainage areas that lacked a functional channel network could move through the landforms by piping and emerge as blowouts on the slope face, or at the slope toe promoting mass movement failures. Landforms designed and constructed using these approaches also often stood as monolithic pyramids in sharp contrast to the surrounding natural landforms and the public felt that this lessened the area’s aesthetic appeal. The observed failures motivated searches for alternate landform reclamation methods.

Some stakeholders pointed to natural landforms as a guide for achieving the desired reclamation stability and performance (Stiller et al. 1980; Sawatsky & Beckstead 1996; Bugosh 2000; Toy & Chuse 2005; Schor & Gray 2007; Martin-Duque et al. 2015). Reclamation employing geomorphic-based landform elements has been generally well received. Sediment yield is the amount of sediment carried out of a catchment by water expressed as tonnes per area per year. Recent study using both erosion modelling software, as well as actual measured sediment yields, have verified the effectiveness of geomorphic reclamation, using a specific fluvial geomorphic-based methodology, at producing sediment yield similar to natural, undisturbed land adjacent to the reclamation sites.

The successes of geomorphic-based reclamation can inspire designers to emulate the appearance of geomorphic reclamation without adhering to fundamental geomorphic principles. Landforms employing shapes similar to natural geomorphic surfaces can satisfy the desire for more natural-appearing reclamation and overcome public opposition to the un-natural appearance of traditional slope/terrace/downdrain reclamation. Yet, a design that is presented as a geomorphic design may not be made correctly and be incapable of providing full hydrologic function. The designer may not properly integrate the geomorphic elements, sophisticated design software can be used incorrectly, good designs may be constructed incorrectly, or merely simple mistakes that were not caught can result in project failures.

Researchers made comparative evaluations of the expected sediment yield from different reclamation designs using the SIBERIA erosion modelling software on four alternative designs:

- Traditional gradient terrace/contour banks.
- An improperly constructed fluvial geomorphic design.
- ‘Natural contouring’ – a design that was made to look like the surroundings.
- The improperly-built fluvial geomorphic design adjusted to correct dimensions.

The results of these evaluations are shown in Table 1.

Table 1 SIBERIA-modelled erosion rates as sediment yield for four landscape design methods

Landscape design method	SIBERIA-modelled erosion rate t ha^{-1} yr^{-1}
Gradient terrace/contour banks	25.6
Improperly-constructed fluvial geomorphic	23.4
‘Natural contouring’	21.7
Improperly-constructed fluvial geomorphic adjusted to design dimensions	13.9

The SIBERIA-modelled erosion rates were very similar for the first three cases, but the corrected fluvial geomorphic design had far lower rates, nearly half that of the traditional designs. These results indicate that reclaimed lands can look more natural but, if they lack the proper fluvial geomorphic design elements of stable natural lands, they will provide little or no functional benefit when compared to the traditional practices (Hancock et al. 2019).

A study that actually measured sediment yield was consistent with these SIBERIA estimates. This study was taken in 2012, 2013, and 2014 in a highly erosive area to quantify sediment yield from drastically-disturbed land reclaimed by an integrated fluvial geomorphic design method and compare it to the measured sediment yield from adjacent undisturbed land. The catchments were matched in physical characteristics so that the differences among them would be limited to whether they were native, undisturbed (N7), reclaimed geomorphic design with topdressing and poor to moderate vegetation (MV5), or reclaimed geomorphic design with topdressing and significant vegetation establishment (WV3). The results of this study are presented graphically in Figure 1. The sediment yield over the entire study period from the undisturbed native site was 9.53 t ha^{-1} yr^{-1}, while the fluvial geomorphic design with topdressing and poorly established vegetation site averaged 13% lower than the native site, and the fluvial geomorphic design with topdressing and significant vegetation establishment averaging 41% lower sediment yield than the native site.

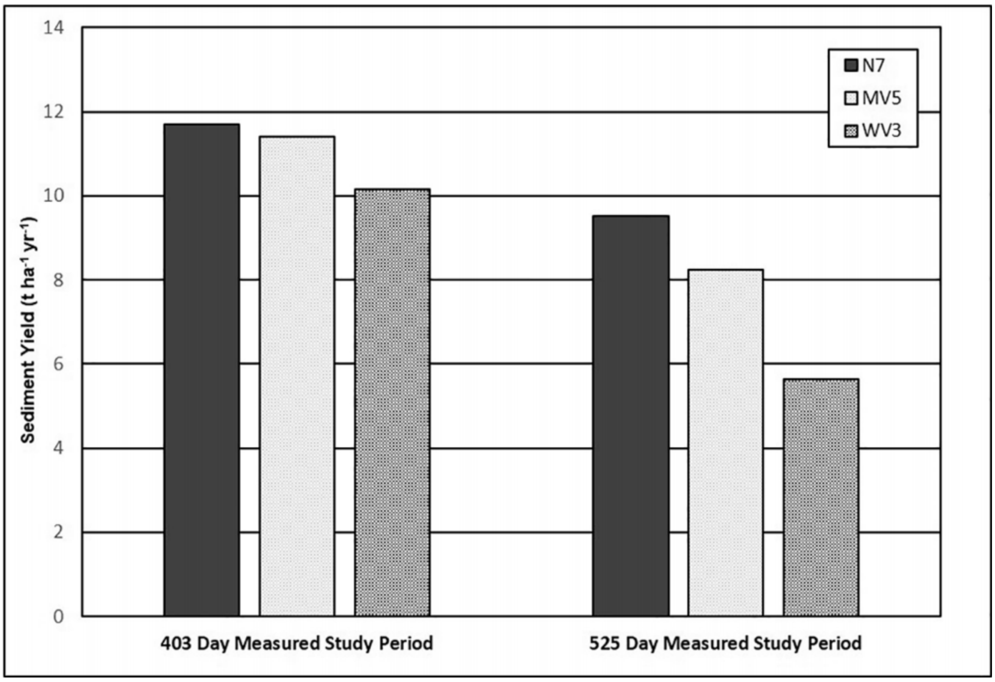

Figure 1 Quantified fluvial geomorphic reclamation sediment yield. Measured sediment yields for the 403-day monitoring period most representative of the 2013 water year and for the entire 525-day study monitoring period

The results of this study, conducted in a semi-arid area that produces peak erosion rates, is the first, and of this publishing date, only study known to quantitatively measure sediment yield from land reclaimed using an integrated fluvial geomorphic design method and an adjacent undisturbed, natural land (Bugosh & Epp, 2019). The results are consistent with the early subjective evaluations, grab samples, and predictive equations and models.

2 Inspecting geomorphic designs for key functional elements

Inspecting a proposed geomorphic reclamation design for key design elements will reveal if the design can have full fluvial geomorphic function or not. The slope configurations, slope steepness, and erosive energy of the stream channels are some of the main elements that must be integrated in a stable, natural landform. These elements are the same around the world, but their dimensions change in response to the local earth materials, climate and vegetation.

Early geomorphic reclamation designs were being made before the advent of personal computers and powerful design software. These early designs were made and inspected ‘manually’, often using an assortment of available tools that could include paper maps of different scales, pocket calculators, and planimeters. The designs had to follow geomorphic principles and draft designs had to be inspected for potential problems that could impair the constructed reclamation’s functionality. Since then, purpose-built computer programmes have greatly aided both making geomorphic designs and inspecting them. We will discuss the importance of key functional elements and then provide examples of how inspections of those elements can be made manually and using purpose-built computer programmes.

2.1 Inspecting slope configurations

Stable natural slopes are not constant-gradient (e.g. 3:1 or 4:1) but have complex profiles. Their upper portions are convex and then they transition to a concave lower portion as shown by the solid line in Figure 2 at site-specific distances.

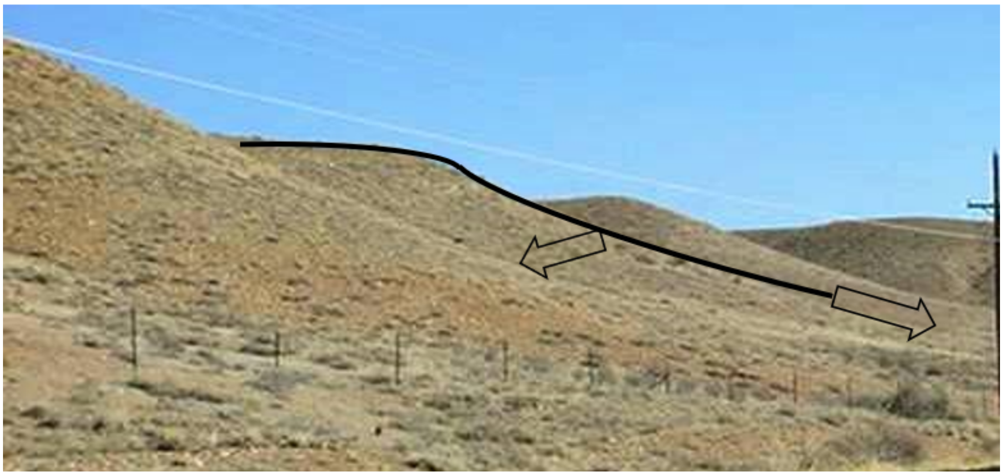

Figure 2 Stable, natural slopes develop complex longitudinal profiles that are predominantly concave with a transition to an upper convex portion at site-specific distances. The slopes also have concavity across the slope face into swale depressions and valleys

The open arrows indicate that stable natural slopes are complex not only in the downslope direction (arrow on right), but across the slope as well (arrow on right). They are complex in three dimensions.

Stable natural land areas are divided into smaller catchments as illustrated by the circled areas in Figure 3. This is a way nature balances the local water runoff to the local earth materials. The resulting drainage density is a site-specific value that must be used to get a stable reclamation landform design.

Figure 3 The overall land area is divided into smaller catchments (examples are circled) in stable, natural lands that have a specific valley length per land area in response to the local earth materials, climate, and vegetation

A reference area of stable, natural land with similar earth materials, climate, and vegetation to the disturbed project area can be used to determine the valley length needed per area of land to convey storm runoff waters from the land surface without accelerated erosion. A design's valley length can be divided by the catchment drainage area to determine the design drainage density and that value can then be compared to the drainage density values of stable, natural reference areas. If the design drainage density is too low and the project is constructed, the needed valley length will be added by erosion. If the design drainage density is too high, erosion to add valley length will not be expected, but care must be taken that the channels are sized to convey the lesser runoff flowing overland to the channels from the smaller catchment areas or sediment deposition can result and block channel flow.

Stable natural stream channels have plan-view and cross-sectional dimensions that are mathematically related to the flow, or discharge, at each point along a channel (Williams 1986). The catchment area stormwater runoff must be conveyed to the channels without causing erosion of the upland areas outside of the channels. Steep channels present a zigzag pattern that carved swale depressions on the valley walls as they formed (Rosgen 1996). Valley bottom channels develop a site-specific sinuous meandering pattern that is a function of the flow. The slope of the valley walls, or the valley bottom upland areas above the channel banks, must the greater than the adjacent channel slope to convey the design's storm runoff to channels or erosion problems on the upland areas can be expected as the runoff seeks a path to the channels.

The upland surface slope can be calculated all along the channels and compared to the adjacent channel slope in each catchment to ensure proper hydrologic function. This necessary inspection can be time-consuming and tedious when done manually. High speed computer programmes like SIBERIA or Natural Regrade can perform these calculations efficiently, and also indicate the path of water flowing over the design surface. An example of such an inspection made using Natural Regrade is shown in Figure 4.

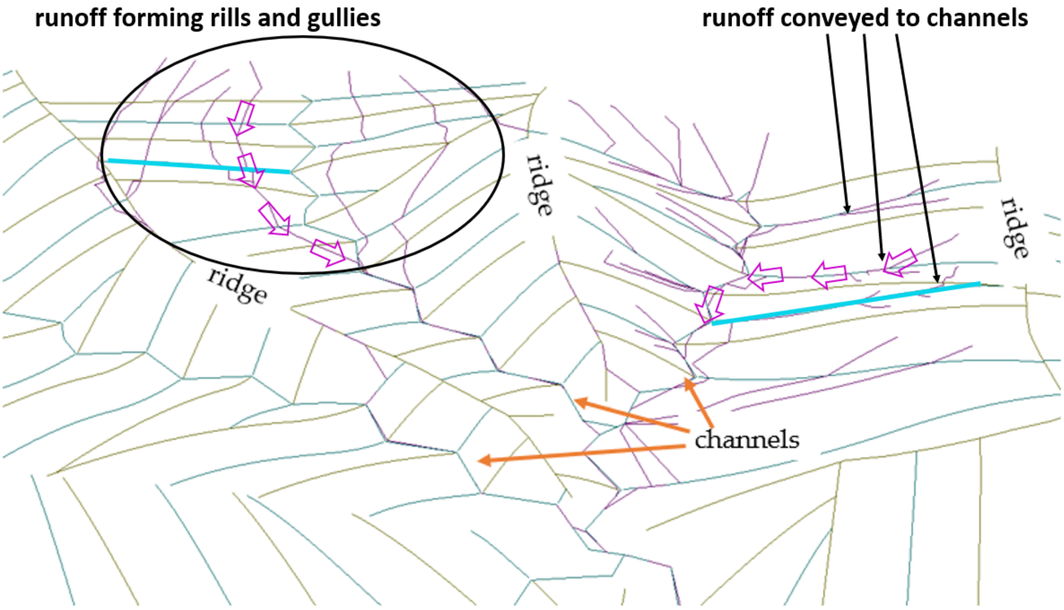

Figure 4 The stormwater runoff must be conveyed down the valley wall swale depressions (wider blue lines accentuate a swale in each catchment) into the designed channels as shown on the right in this 3D-perspective view of a geomorphic design. The runoff in the circled area in the catchment on the left is not conveyed into the channel and rill and gully erosion subparallel to the channel can be predicted in these areas

The 3D-perspective view in Figure 4 uses a 3D surface file of the draft design, a command that draws the paths of rain drops over the surface, and a 3D graphic viewer of the design with the main 3D polylines that define the surface displayed (polylines are 3D entities having x, y, and z coordinates). It shows two adjacent catchments in a draft geomorphic design, one functioning correctly and the other requiring editing. The higher elevations are at the top of the drawing and the lower elevations are at the bottom of the drawing in this perspective view of the design. The main ridges separating the catchments are represented as long polylines. The steep channels are shown as zigzagging polylines between the main ridges. The complex valley wall slopes are defined by 3D polylines extending from the channels up to the main ridges. These polylines alternately define the tops of sub-ridges on the valley walls and the bottoms of the swale depressions between the sub-ridges. The site-specific convex to concave longitudinal profiles define the complex valley wall forms. The paths of the raindrops flowing downslope from top towards the bottom are shown as magenta 3D polylines.

The runoff in the catchment on the right is conveyed down the valley wall swales to the channel as accentuated by the open arrows in one swale, whereas in the catchment on the left, runoff in the circled area is not conveyed in the valley wall swales to the channel but instead flows subparallel to it as indicated by the open arrows there. These upland and channel landform elements are not integrated in the catchment on the left and this will produce rill and gully erosion, similar to the valley wall gully erosion shown in Figure 5.

Figure 5 Valley walls that are not properly configured to convey stormwater runoff to stream channels are subject to rill and gully erosion. Note that a knee-deep gully has formed in this reclamation at a very short distance from the top of the catchment

2.2 Inspecting slope steepness

A draft geomorphic design should also be inspected for functional problems related to slope steepness. Vegetation has not been shown to prevent rill and gully erosion on slopes incorrectly shaped for local conditions as shown in Figure 6 that shows an attempt at geomorphic reclamation by making constant-gradient slopes against a steep rock wall. Rills and gully erosion has formed all across the green vegetated slope.

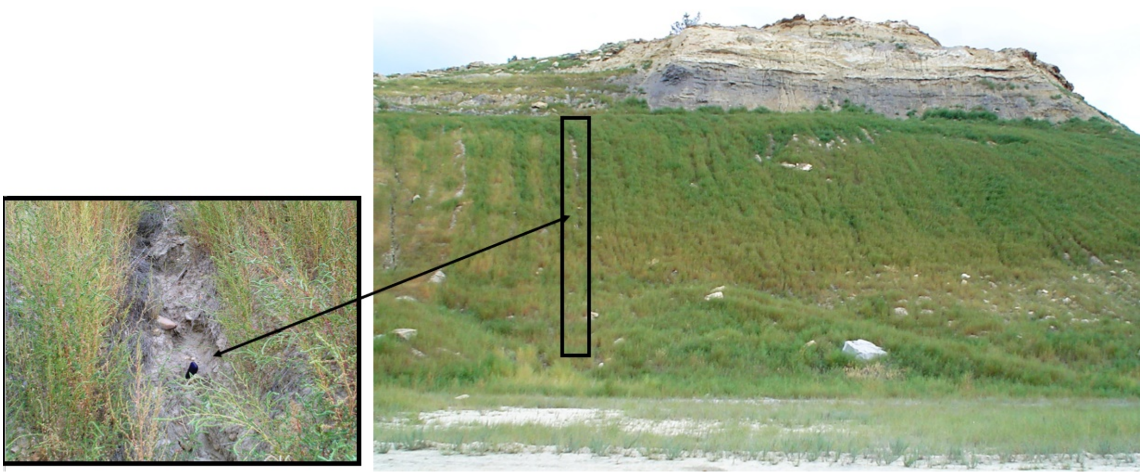

Figure 6 These constant-gradient slopes do not have the complex three-dimensional shapes that would be stable in this locale and are covered with rills and gullies despite being covered with vigorous vegetation

Over-steepened areas in a draft geomorphic design can slide or slump as shown in Figure 7 frustrating growth medium placement and seeding, or raising safety concerns. Attempts to mitigate these areas, as shown in the example in Figure 8 can include expensive engineering intervention that can require special material handling and placement, and possibly long-term maintenance.

Figure 7 Over-steepened areas in a geomorphic design can result in slope failures that frustrate revegetation efforts, require expensive maintenance and repair, and may present safety concerns

Figure 8 Engineered mitigations for over-steepened slope areas can be expensive and not satisfy reclamation land use goals

Observations of slope stability and measurements of slope elements such as maximum convex length and steepness in project reference areas can inform the designer as to the appropriate values for a stable reclamation design. When drafting a design working with two-dimensional images, it is possible to inadvertently place a low-elevation design element, like a stream channel, too close to a much steeper element, like a highwall or waste rock pile, resulting in over-steepened slopes. After making the design with the stable reference area values set as design criteria, the designer should inspect the draft design to verify that the design layout did not result in over-steepened areas that will cause functional problems.

A designer can inspect the draft design slopes manually by determining the number of contours that fit in a given distance to produce a maximum slope target value. If, for example, a one metre contour interval is used and 20 percent is the targeted maximum slope value, then six contours will depict a 5 m elevation difference and a 25 m horizonal distance between them at the map's scale will depict a 20 percent slope. The designer can make a template on the edge of a paper, or on clear plastic, marked for this 25 m interval that they can move over the design to inspect for areas with tighter contour spacing; when these are identified they can be marked on the draft design for editing to reduce the slopes.

The maximum convex slope length can be determined by a similar contour inspection, but in this case the designer will have to generate longitudinal profiles using the drawing's contour interval and scale to construct an inspection template. Here again, this necessary inspection can be time-consuming and tedious when done manually. The high-speed computer programmes like SIBERIA or Natural Regrade can perform these calculations efficiently, and SIBERIA can also make an estimate of the sediment yield from the identified rill and gully erosion areas on the design surface over specified time intervals.

The upper portion of Figure 9 shows an example of the Natural Regrade dialog in which the user can specify slope ranges of interest and specify colours to aid identification of the various ranges on the drawing. The lower portion of Figure 9 shows an example of the command output colouring the specified slope zones on the draft design. The left valley wall (from the perspective of flowing downstream) can be seen to be much steeper than the right valley wall and this area has been circled for further inspection to evaluate its effect on the landform's function.

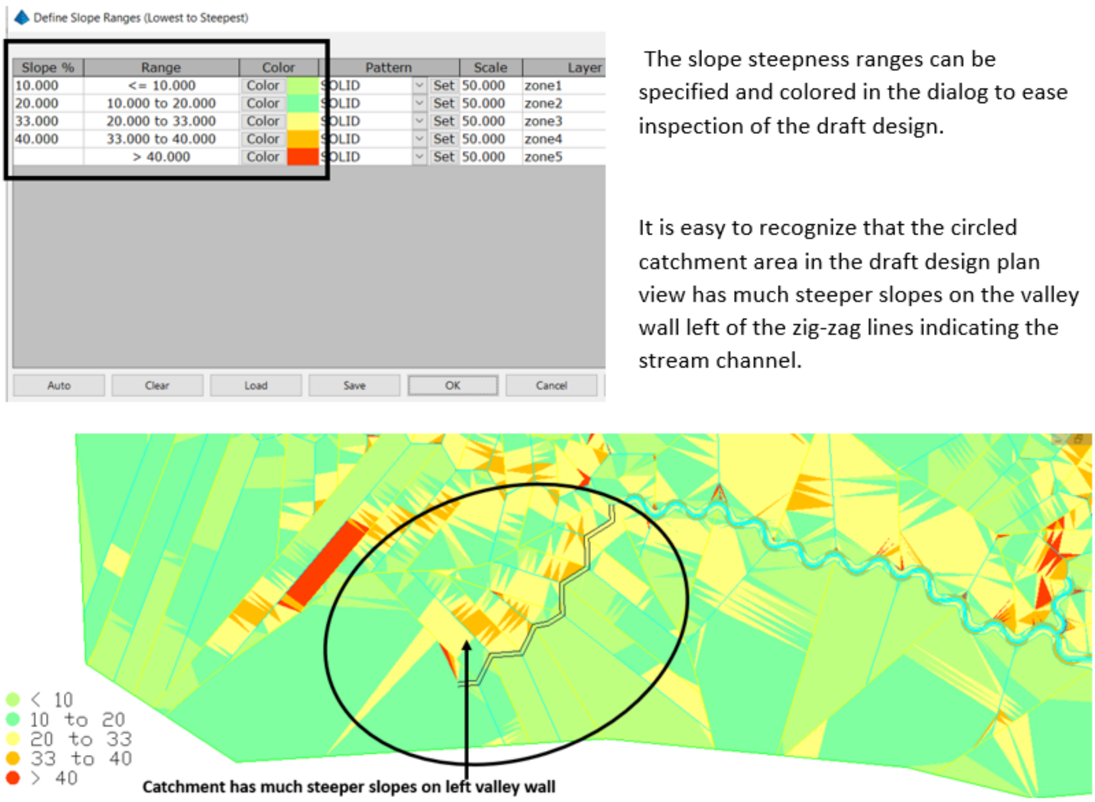

Figure 9 Example of the slope zone analysis command input and output that can be used to inspect draft geomorphic designs

When this area is viewed in 3D perspective view as shown in Figure 10, a functional problem is apparent. Runoff water will flow from the steeper left valley wall towards the channel, but the right valley wall slopes away from the channel and the water will continuing flowing to the right. A designer might correct this problem by moving the channel closer to the right catchment divide to steepen that valley wall (simultaneously reducing the left valley wall slopes), or editing the right valley wall catchment divide to a higher elevation; each circumstance can have different solutions that can optimise the design functions.

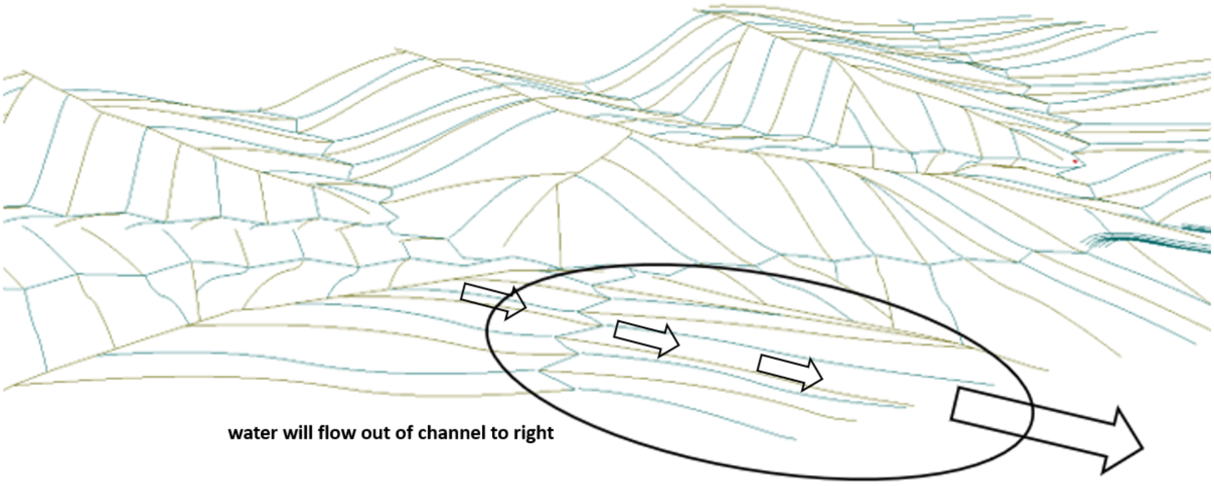

Figure 10 The darker grey lines indicate the tops of main ridges separating catchments and sub-ridges on the complex valley walls. The lighter blue lines between the sub-ridges indicate the bottoms of the swale depressions on the valley walls. The zigzag blue lines indicate the centrelines of channels having greater than four percent slope. The open arrows indicate the downslope flow direction of storm runoff on the draft design that is not conveyed in the desired channel flow direction. The oval indicates the area needing editing to achieve the desired function

This slope inspection example addressed the functional problem of containing the stream discharge within the channel banks, but the slope inspection can also identify areas that have slope length and steepness that will be subject to erosion when compared to the observed values on stable reference areas, and areas having slopes that are too steep for tilling and vegetation establishment, or that are unsuitable for the designated reclamation land use, etc.

2.3 Inspecting channel erosive energy

It is necessary to inspect the channels for stability during flow events. The designer will want to verify that the stream channels are not subject to erosive energy that will cause instability. Figure 11 shows three examples of disturbed land reclamation channels that were destroyed overnight by single storms.

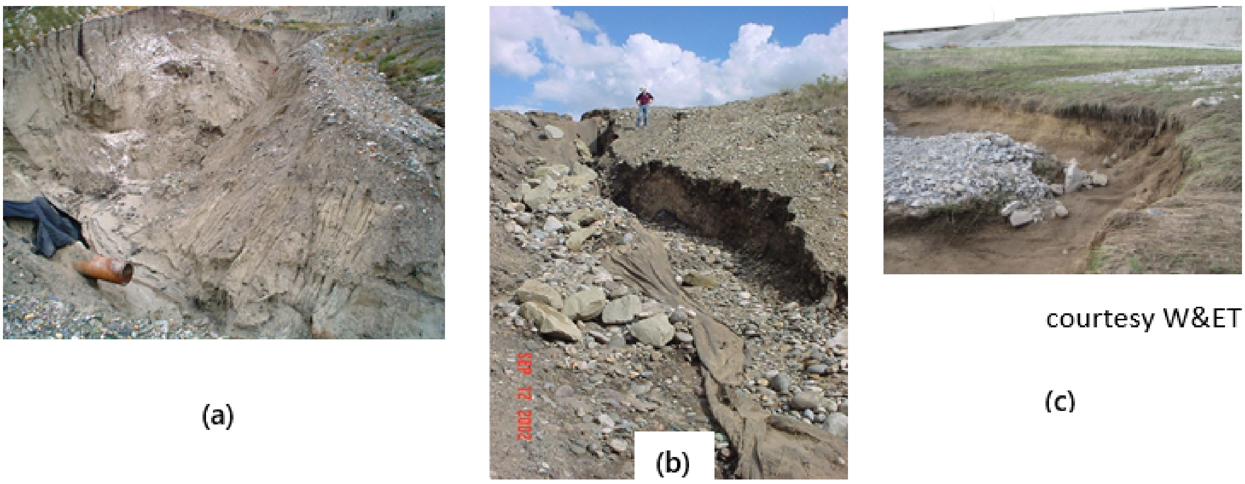

Figure 11 Single-storm reclamation channel erosion examples: (a) Greater than 1,000 year event, over 7 m incision – Alaska; (b) 25 year, 3 hr storm, 3.7 m wide by 2.4 m deep – New Mexico; (c) Slightly greater (63.5 mm versus 59.9 mm) than 100 year, 40 min storm, over 1 m incision – Colorado

Their designs were based on criteria, like 100-year recurrence interval events, that are calculated from relatively short weather records. Today, people are growing more aware of climate changes that involve events much greater than calculated 100-year events. Stable natural landforms are the earth's response to the entire range of climate that has happened over the last 12,000 or so years. A fluvial geomorphic design, based on a reference area having these stable natural landforms that resulted from all the climate variation and related weather that has happened over these thousands of years, is adjusted to this much greater range of storm events.

Tractive force (also called shear stress) is a measure of the streamflow energy against its stream bed (Shields, 1936). The general form of the relationship is written as:

$$\tau = \gamma RS \tag{1}$$

where:

τ	=	tractive force.
γ	=	density of water.
R	=	hydraulic radius.
S	=	channel slope.

It is mainly the product of the channel's slope and discharge. Water flowing down a steeper channel will have greater energy than if the channel were flatter, and more water flowing in a channel will have greater energy than less water in the channel. The channel cross-sectional dimensions of stable natural channels are mathematically related to the flow, or discharge, present at each point along a channel and are generally increasing in the downstream direction, but can suddenly increase at the confluence of a tributary. Similarly, the channel slope in stable natural channels is not constant, but adopts a concave profile that is steeper in the headwaters and flatter at the mouth. Irregular channel profiles can have slope changes at random intervals. Greater tractive force values relate to more erosive energy. Because tractive force is a function of both the discharge and slope variables, and both of these can change along a channel's length, the channels in a draft design need rigorous inspection to verify that tractive force values are in a range that will provide stability and not cause accelerated bank or bed erosion. The designer can set a maximum value for the channel tractive force and then inspect the draft design to verify that nowhere along all the channel's lengths is the targeted maximum value exceeded. This is a necessary, but tedious process to do manually.

Here we comment that there are many methods for estimating stream bed particle transport and critiquing them is beyond the scope of this paper. We have found that making a field determination of the particle sizes in transport on reference area channel bars and then calculating the tractive force present at that point in the channel for bankfull (and flood-prone) events can provide useful information about the bed material that is moving in the channel and corresponding tractive force values. The reference area channel substrate particle size distribution can be compared to the reclamation material size distribution to help decide how the reclamation material can be expected to respond to stream storm events, and their resulting tractive force values, in the project area.

Purpose-designed computer software can greatly expedite inspecting the draft design's channel tractive force values. Natural Regrade can make text reports of tractive force values, can highlight channel reaches above specified tractive force values, and has an inspection tool that will calculate and report values on the computer screen at any point along the channel over which the cursor hovers. These tools are made to work seamlessly with designs made using Natural Regrade, but also can be used to inspect designs made by other methods. Examples of these design inspection tools are shown in Figures 12 to 14.

watershed area (Ha)	45.81
add'l watershed area (Ha)	0.00
valley length (m)	663.31
drainage density (m/Ha)	25.28
head elevation (m)	127.55
head elevation (m)	61.78
relief (m)	65.77
head slope	-0.12
base slope	-0.01
slope range	-0.120 to -0.013
width to depth ratio, when slope < -0.04	16.00
width to depth ratio, when slope > -0.04	10.00
maximum design velocity (m/s)	4.50
runoff coefficient	0.89
bankfull width range (m)	0.04 to 1.29
bankfull depth range (m)	0.00 to 0.10
flood prone width range (m)	0.14 to 3.54
flood prone depth range (m)	0.02 to 0.39
entrenchment ratio	2.74 to 3.41
Tractive force, bankfull width (kg/m^2)	0.48 to 5.45
Tractive force, flood prone width (kg/m^2)	1.02 to 11.53
manual Qpk?	no
bankfull Qpk (m^3/s)	0.49
flood prone Qpk (m^3/s)	3.53

Figure 12 The designer can query Natural Regrade and produce a report that presents the range of channel design parameters, including tractive force values as outlined, on any channel, or for all channels, in a project made with the software

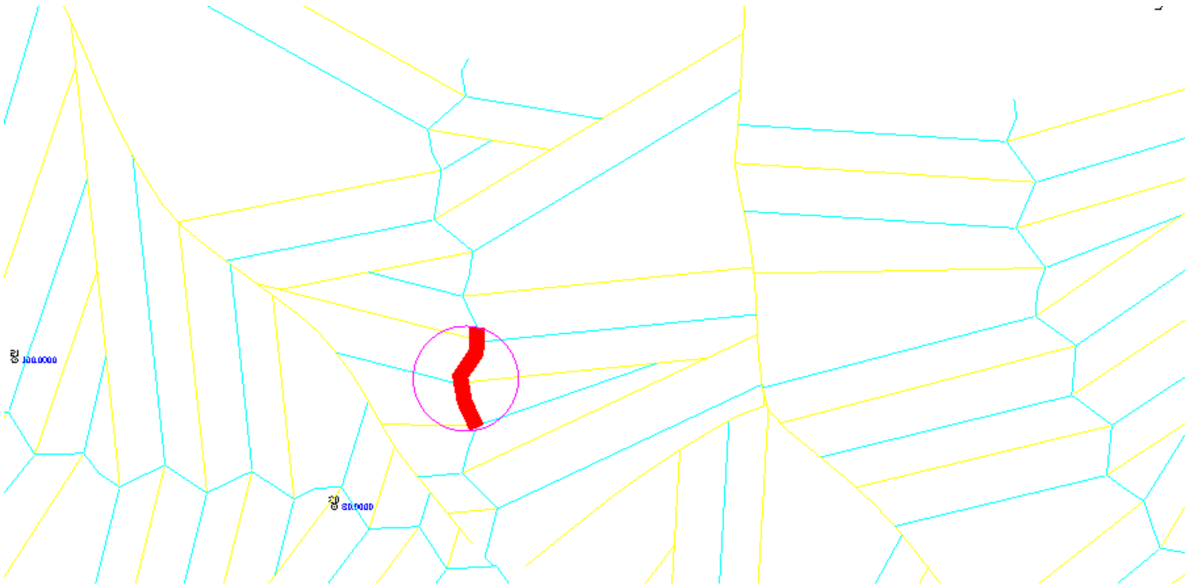

Figure 13 The tractive force zone that has values above the designer's specified maximum is highlighted on the design. It can be helpful to circle the identified reach to evaluate the effect of design edits to reduce the tractive force in the reach

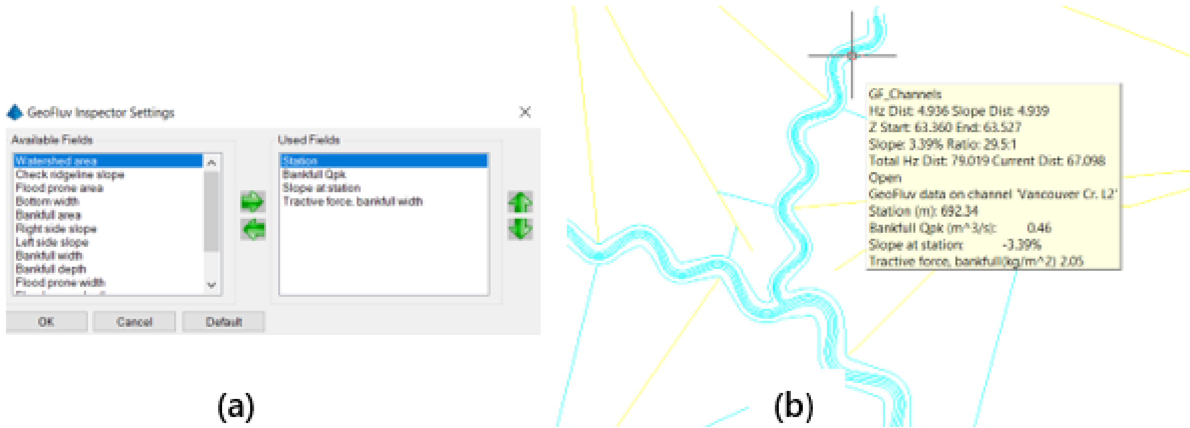

Figure 14 The project inspector tool settings dialog and example output: (a) the user specifies parameters of interest that will be displayed on the computer screen; (b) when the cursor is moved along the channel design polyline the specified parameters are displayed. Here the distance downstream (station), and the bankfull peak discharge, slope, and calculated tractive force at that station have been selected and are displayed

If the tractive force inspections discover stream reaches that exceed the maximum values that will provide the desired stream function, then accelerated erosion can be expected to begin in these reaches. The draft design can be edited to reduce the tractive force values in the problem reaches and achieve the steady-state hydrologic equilibrium of stable natural channels. Depending on the situation, the designer may decide to edit the design to redirect some of the discharge, lower the reach slope, or a combination of both.

When inspecting a draft design using analyses like those presented here, the reviewer can evaluate if an area presenting a potential problem requires design editing, or if the identified area is insignificant. For example, the mathematical calculations may identify an area that is steeper than desirable, but if the steep area is very short and at the very top of a ridge, then it is only subject to the runoff from the incident precipitation and may not generate sufficient overland flow to cause erosion; the reviewer may also conclude that construction tolerances for the large equipment used to construct the design would not be able to build the small, steep area and it would be flattened during construction.

Estimating the amount to erosion manually can be accomplished by applying an erosion rate to the potential problem areas and then iteratively calculating the erosion for successive periods and then summing the estimated sediment yield from all of the areas. This is a tedious and time-consuming task that can be aided by computer programmes. The SIBERIA programme essentially automates the process described above, locating the areas where overland flow is not conveyed to channels designed to handle it, and then applying erosion rates to these areas for the specified period to predict the sediment yield (Hancock et al. 2019). Design software, like Natural Regrade can quickly identify potential problem areas in a design, but it was designed to help the user make reclamation landforms having the acceptable sediment yield of stable natural lands, not to estimate sediment yield. However, this design software can be used to estimate the maximum erosion in potential problem areas of designs made with the software, or made by other means, by comparing the design of interest to a stable design, i.e. one that honours input values taken from a stable reference area.

As an example of using the design software to estimate erosion, consider that the reviewer can use it to compare a stable geomorphic design to a submitted design made by another method. The example shown in Figure 15 uses a valley bottom stream channel design.

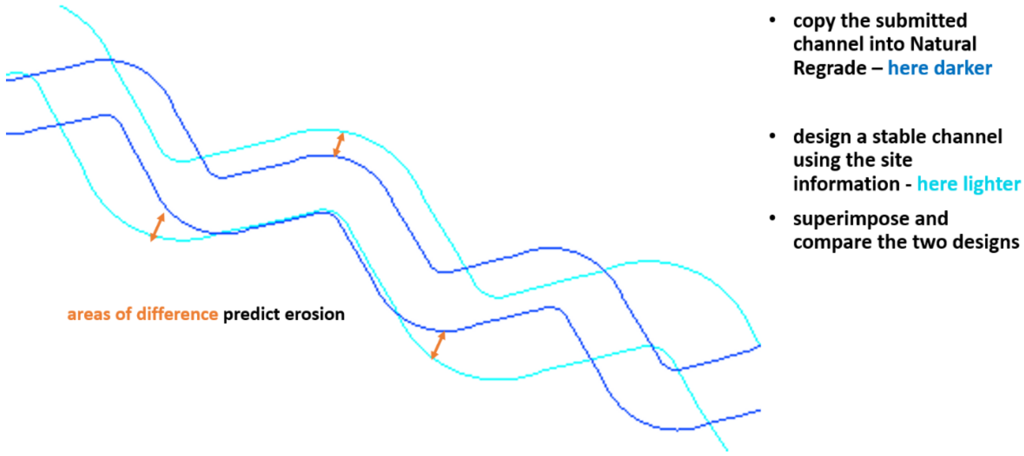

Figure 15 Example of using geomorphic design software to inspect a draft channel design made by another method

The reviewer can copy the submitted channel design into Natural Regrade. The reviewer can then use the site information to make a stable channel design, and then superimpose the stable channel design over the submitted channel and compare them as shown in Figure 15. Areas where the stable channel needs a wider valley than the submitted design predict erosion because the stable channel needs that width to function. When the water begins flowing, the stream will erode the banks to get the width it needs for stability. The reviewer can then measure the area of difference and decide if it is incidental and not requiring editing, or must be addressed to avoid problems. Similar approaches can be used with design software to compare channel longitudinal profiles, channel cross-sections, slope profiles, and so on, to identify landform areas that deviate from the form that a stable, natural landform takes, and if these deviations are incidental or must be addressed through design editing.

2.4 Inspecting the draft design for the desired functional outcome

The reclamation problems depicted in Figure 16a and 16b did not have to happen. Thorough design inspection would have detected the potential problem areas, and allowed for solutions that did not require expensive 'band aid' repairs, like specially-handled rock. Editing the draft designs to correct the identified problems would have resulted in the full functionality of the geomorphic reclamation shown in Figures 16c and 16d at lower cost.

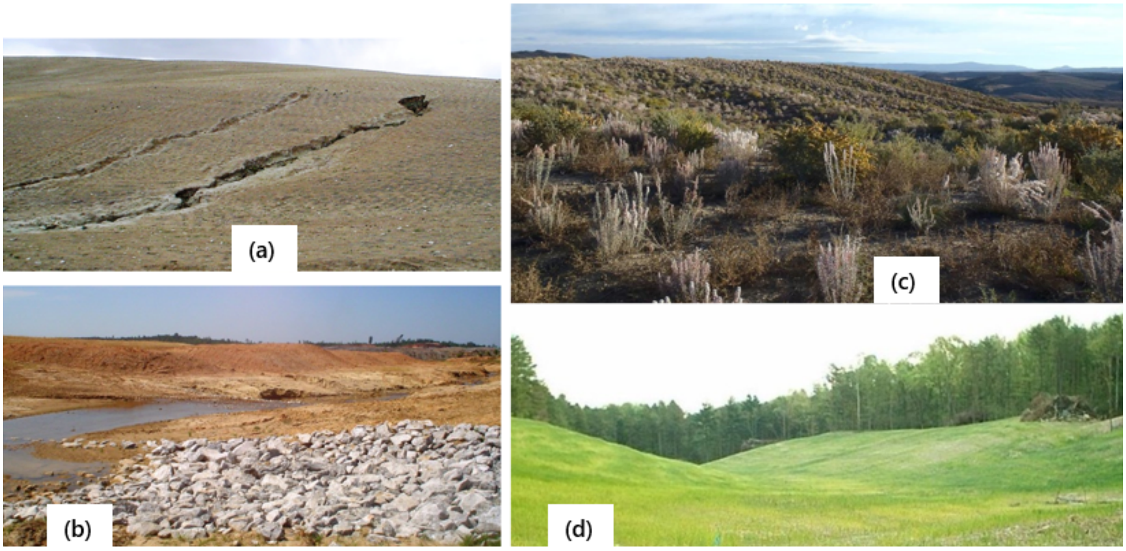

Figure 16 Comparison of reclamation outcomes: (a and b) Reclamation designs not applying geomorphic principles; (c and d) Reclamation that correctly integrated geomorphic principles

3 Conclusion

Geomorphic design has been demonstrated to provide functional, stable reclamation landforms at sites ranging from semi-arid to sub-arctic climatic zones on continents around the world. As geomorphic reclamation design's benefits have been recognised, its use has increased, and that increase is accompanied by the potential for misuse if the relevant fluvial geomorphic principles are not understood and properly integrated into the design to make a fully, functional reclamation landform. Studies have shown that a geomorphic design must integrate various elements to achieve the functionality of stable natural land; it cannot simply approximate the appearance of natural lands in the project area. Draft geomorphic designs must be carefully inspected before construction to ensure the desired landform function and to avoid environmental and safety hazards and costly maintenance and repairs.

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