Geomorphic mine rehabilitation
‘Natural’ drainage basins as fundamental planning units

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Most of the Earth’s land surface has been shaped, for thousands (at minimum) of years, by a combined action of fluvial and associated slope processes.

Drainage patterns


Natural drainage networks are extensively altered, disrupted, obliterated, destroyed, truncated, transformed, degraded, buried... by surface mining.

Limestone quarry in Alhaurín de la Torre (Málaga, Spain)

1956 2009
But also by mine rehabilitation

Pre-Mining Drainage Network

Green = Mined & Reclaimed Area

Orange = Undisturbed


Post-Reclamation Drainage

1st and 2nd Order Streams truncated from Rest of Drainage Network


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In most cases, traditional mine rehabilitation, either lacks a drainage network or has a deficient drainage design

A study of 57 rehabilitated mines in North America illustrated that deficient drainage design is a common reason for failure (McKenna and Dawson 1997)

Uniform linear slopes and gradient terraces lead to rill and gully formation. This rehabilitated landscape is trying to re-establish a drainage network.

Drainage re-establishment is one of the main cause of gully erosion in mined lands (either rehabilitated or not).

A typical engineered solution for drainage management in mine rehabilitation.
Failures of engineered drainage in mine rehabilitation in East Spain

Rip-rap downdrains blown out at Tijeras Limestone Quarry, NM, US
(Source Earth and Water Technology)

Any other disadvantages?
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- The SMCRA 1977 introduced the APPROXIMATE ORIGINAL CONTOUR (AOC) concept
- AOC means that the rehabilitated area “blends into and complements the drainage pattern of the surrounding terrain…”
- SMCRA 1977 introduced the geomorphic (and catchment) approach to mine rehabilitation
- Concept of drainage basins as fundamental basic planning units for mine rehabilitation

The NSW coal industry played a key role in the pioneering (global) development of drainage basins as basic planning unit.


Formation of an integrated drainage system

“This is perhaps the most difficult task aspect of landform design”.

“It demands a whole-of-mine approach and identifying (in the early stages) sites for locating the new major watercourses that can be connected to natural streams on surrounding land.”

From Hannan (1984)

(Environment Australia, 1989, page 10).
Eyeball / guessing “natural landforms and channels” is not A SCIENTIFIC-BASED GEOMORPHIC REHABILITATION METHOD (AND THEREFORE, NOT RELIABLE)
An example from Chile

Just “looking less engineered” or “to have a more natural appearance” does not guarantee stability

An example from Israel

The early writings (SMCRA, 1977; Stiller et al., 1980; Hannan, 1984; EA, 1998…) claimed the need of replicating the patterns and complexity that stable landforms have in natural catchments.

However, the possibility of designing such complex 3D landforms and drainage networks has not been possible until the development of geomorphic design methods and software.

A) integrated 3D channel network (1) draining to a local base level (2) with concave profiles (3)

B) cross sectional channel geometry based on bankfull discharge and extreme events (4) Cross section increases downstream as water increases downstream (5)

C) slopes between channels have predominantly concave slope profiles (6)
4. Methods for mine catchment rehabilitation design (scale independent, universal application)

4.1. The Geomorphic Approach for the Design of Drainage Systems on Reclaimed Mined Areas (Oil Sand Reclamation, Canada)


Landform reconstruction including sustainable drainage systems at oil sands mining in Alberta (Canada)

Advantages of designing drainage networks that replicate natural channels (Sawatsky and Beckstead, 1996)

• Floodplains and meandering channels significantly reduce flow velocities.

• Instead of rigid bed and banks, designed ‘natural’ streams have a mobile bed composed of natural armour, which moves in response to flood events.

• Natural drainage systems have an equilibrium of sediment supply and transport and is more stable, because of its morphological history during which the channels have built stable regimes.


4.2. River and streams fluvial restoration based on Rosgen classifications

http://www.rivermorph.com/

Climax Mine, Colorado, USA
Earth and Water Technology

4.3. The GeoFluv method and the Natural Regrade software

Based on hillslope and fluvial geomorphology
It allows designing stable catchments with:

A) integrated concave profile 3D channel network

B) plan view and cross sectional channel geometry based on bankfull discharge and extreme events

C) predominantly concave slope profiles with convex to concave inflection

The New Mexico state regulation considers that a geomorphic approach to backfilling and grading is the Best Technology Currently Available (BTCA) for stabilizing coal mine reclamation (NMMMD, 2010)
A broader concept for geomorphic rehabilitation

Geomorphic rehabilitation seeks to create steady-state landscapes. With steady-state configurations, adjustments by geomorphic processes after rehabilitation decrease. Therefore, the prospect for rehabilitation success increases and the demand for post-rehabilitation site maintenance decreases (Toy and Chuse, 2005).


One more geomorphic mine rehabilitation method...The Talus Royal® - http://www.2g.fr/

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5.1. GeoFluv – Natural Regrade examples at the US

An estimate of 50 large built examples and a similar number of designs (not built)
La Plata Mine, New Mexico (US)

GeoFluv rehabilitations at La Plata
5.65 - 8.25 t/ha/yr

Neighbour undisturbed native site
9.53 t/ha/yr

Bugosh, N. and Epp, E. 2017. Evaluating Sediment Production from Native and Fluvial Geomorphic-Reclamation Watersheds at La Plata Mine and Its Relationship to Local Precipitation Events (submitted to CATENA)
5.2. GeoFluv – Natural Regrade examples at the EU

Spain and Portugal

(small scale; mostly demonstration projects)
Abandoned sand quarry (Somolinos, Guadalajara)

El Machorro, active kaolin mine (Alto Tajo, Guadalajara province)
Sediment yield monitoring for 5 years (2012-2017) 4.02 t/ha/yr


National Award (Spain) on Sustainable Mining, 2015

Clay quarry (Tortosa, Tarragona)
1) Geomorphic Rehabilitation recognized as Best Available Technique for the Management of Waste from the Extractive Industries (EU)

2) Cobre Las Cruces, http://www.cobrelascruces.com/ the largest open pit mine in Europe, will adopt GeoFluv-Natural Regrade

5.3. GeoFluv–Natural Regrade Examples in South America

Still in a pioneering state, but with a successful example in Colombia, and training in Colombia, Chile and Peru

- High precipitation (>1,000 mm/yr)
- Ecologically and visually sensitive landscape
The Traditional reclamation landform had three main features:

1. Final Void-Pit to Lake
2. Regraded overburden (backfilling)
3. Out-of-Pit Waste Dump

5.3. Australia

Lack of a good inventory, but in a clear state of spreading. An estimate of around 15 projects, of different sizes, between designed, already built, or on-going construction.

Benefits at some of these projects: reversing more drainage into natural fluvial networks
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1. Geomorphic rehabilitation seeks to reestablish a steady-state or dynamic equilibrium, where hydrological and erosive – sedimentary functionality operate at rates comparable to the surrounding natural land.

Abandoned Mine Lands Project 16 N-3 rehabilitated with GeoFluv – Natural Regrade. Images from Harold Hutson, Project Engineer, BRS Inc.- Engineering Consultants, Wyoming, USA

2. Geomorphic Rehabilitation offers a sustainable pathway:

- Reduces risk
- Restores ecological functions and promotes biological and habitat diversity
- Improving post-mining land use
- Minimise maintenance (self-maintaining)
- Aesthetically pleasing landscapes
- Built with on-site materials
- High acceptance by public and regulators
- Cost-effective
3. Best integration occurs when a mine plan operates toward a durable geomorphic landform design (progressive rehabilitation)

It also provides cost-effective solutions for abandoned mines

4. Geomorphic–catchment rehabilitation is central to ecological, hydrological and visual integration of post-mining landscapes

**CONVERSELY**

5. Any mine rehabilitation solution without proper reconstruction of the natural drainage network will be limited
On average, a 500-ha rehabilitated mine would need 25 km of fluvial channels!

BUT...Traditional landform designs of waste dumps, landfills..., are designed to minimize the footprint. This process creates large monolithic accumulations of waste in the landscape, with flat-top areas and terraced slopes or contour bank slopes. THEREFORE...
6. It is critical differentiating between designing and modelling tools

**FAQ (1) – which tool is better?**

**FAQ (2) - how physical properties of earth materials are considered in a design?**


7. Geomorphic-catchment rehabilitation is NOT a single technique, method, software or model.

HOWEVER, there are still very few truly geomorphic tools able to design (i.e., GeoFluv – Natural Regrade) or model (i.e., SIBERIA) the complexity of a catchment in mine rehabilitation.

Hancock GR, Martín Duque JF, Willgoose GR. 2017. Geomorphic design and modelling at catchment scale for best mine rehabilitation – the Drayton mine example (New South Wales, Australia). Submitted to *Environmental Modelling and Software*
8. Room for improvement - future research – state of art

- Recognize that Geomorphic Rehabilitation, as a practice, is in a very early stage. We need many more experts, training, networking, examples (successes and failures)...

- We know very little about how these new landscapes will evolve. The role of Landscape Evolution Models (LEM) is critical here.

- There is a need for inventorying and monitoring the geomorphic rehabilitated mine sites and publish the outcomes (share as much information as we can)

- Set long-term erosion monitoring (plots, field sites, experiments), including baseline (CZO)

- A need for making economic, cut/fill, footprint comparisons and assessments

- Improved solutions for highwalls and final voids; integrate with river restoration and river diversion

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Thank you!