Geomorphic mine rehabilitation

‘Natural’ drainage basins as fundamental planning units

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RESTAURACIÓN GEOMORFOLÓGICA


Geomorphic rehabilitation at La Plata (NM, USA). Photo by Edward Epp

Contents

1) Disruption of the natural drainage fluvial network by mining

2) Problems of engineered drainage solutions

3) Geomorphic reconstruction of sustainable drainage systems

4) Fluvial geomorphic rehabilitation methods

5) GeoFluv-Natural Regrade examples

6) Summing up

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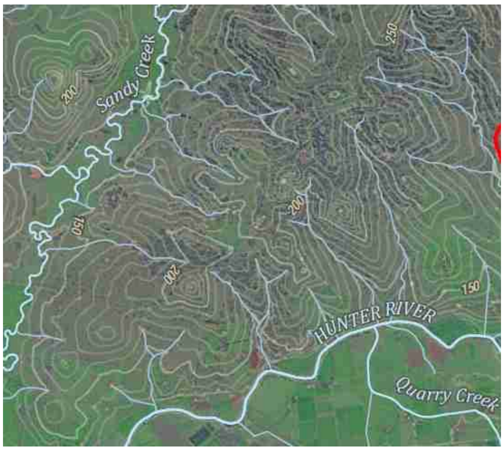
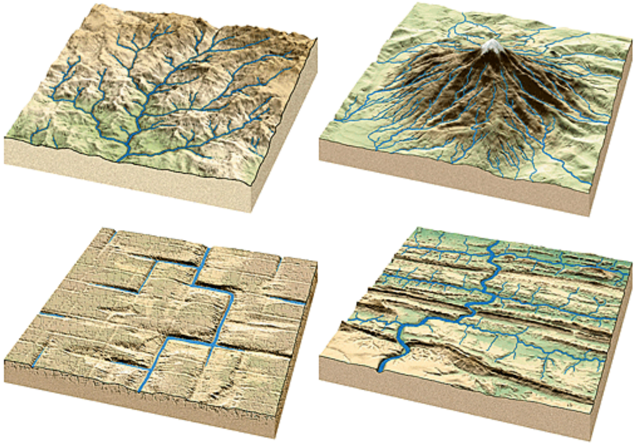
Most of the Earth's land surface has been shaped, for thousands (at minimum) of years, by a combined action of fluvial and associated slope processes



Drainage patterns



Hamblin, W.K. & Christiansen, E.H. (2001) Earth's Dynamic Systems. Ninth Edition. Prentice Hall, Upper Saddle River.

3

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

1956

2009

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

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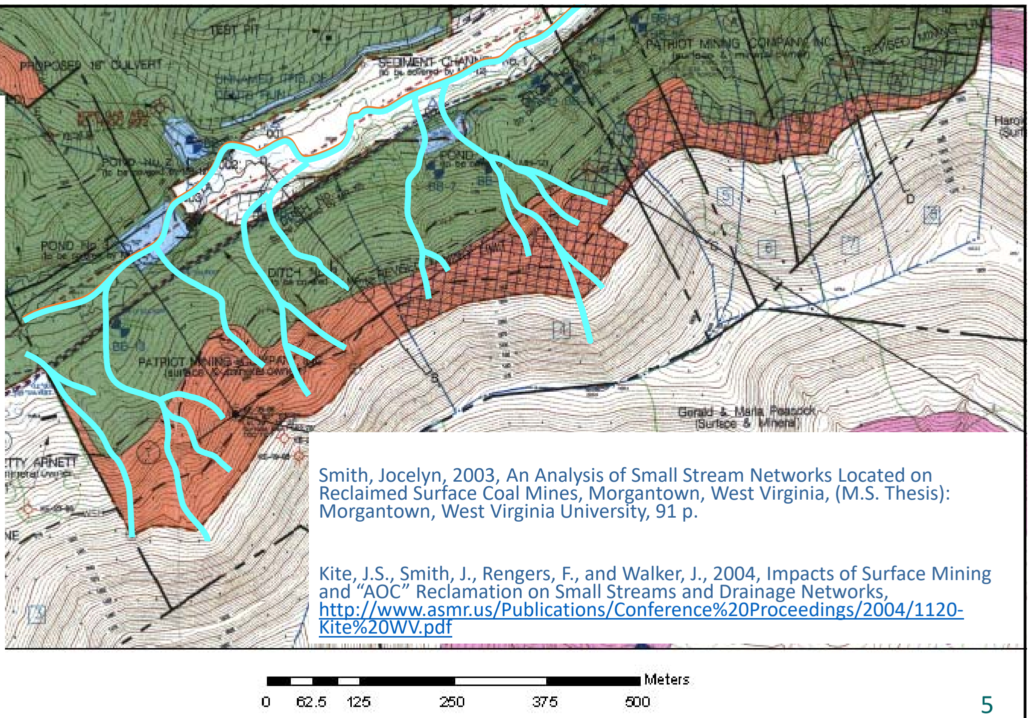
But also by mine rehabilitation

Pre-Mining Drainage Network

Green = Mined & Reclaimed Area

Orange = Undisturbed



Smith, Jocelyn, 2003, An Analysis of Small Stream Networks Located on Reclaimed Surface Coal Mines, Morgantown, West Virginia, (M.S. Thesis): Morgantown, West Virginia University, 91 p.

Kite, J.S., Smith, J., Rengers, F., and Walker, J., 2004, Impacts of Surface Mining and "AOC" Reclamation on Small Streams and Drainage Networks, http://www.asmr.us/Publications/Conference%20Proceedings/2004/1120-Kite%20WV.pdf

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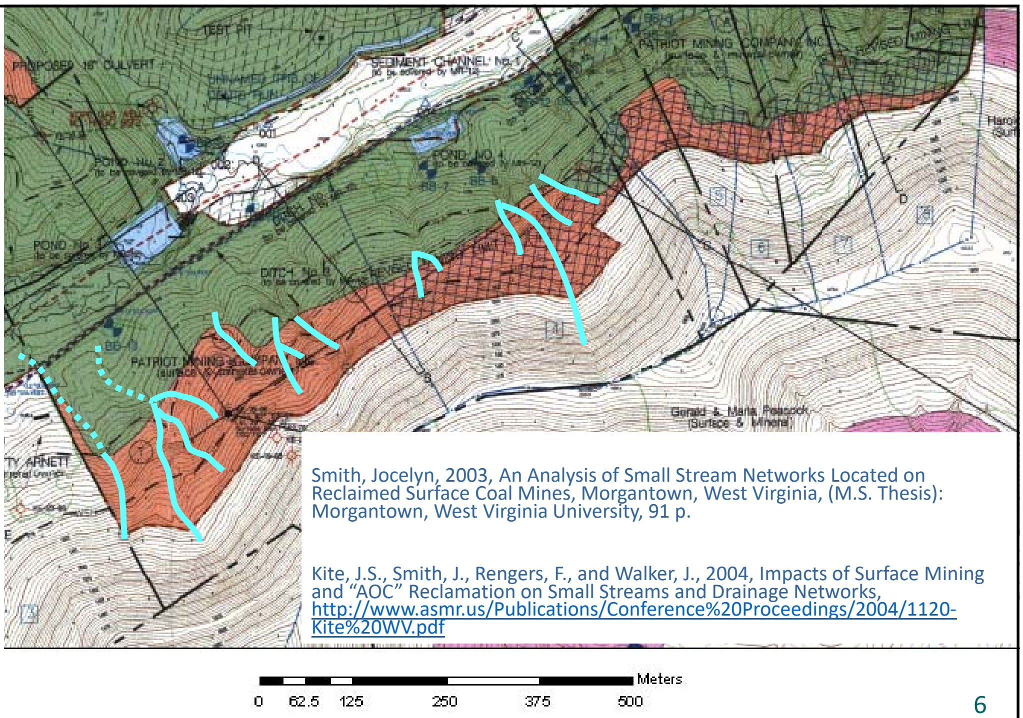
Post-Reclamation Drainage

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



Smith, Jocelyn, 2003, An Analysis of Small Stream Networks Located on Reclaimed Surface Coal Mines, Morgantown, West Virginia, (M.S. Thesis): Morgantown, West Virginia University, 91 p.

Kite, J.S., Smith, J., Rengers, F., and Walker, J., 2004, Impacts of Surface Mining and "AOC" Reclamation on Small Streams and Drainage Networks, http://www.asmr.us/Publications/Conference%20Proceedings/2004/1120-Kite%20WV.pdf

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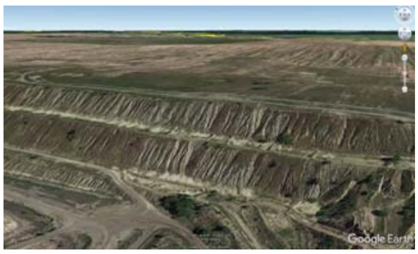
In most cases, traditional mine rehabilitation, either lacks a drainage network or has a deficient drainage design



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

McKenna, G., Dawson, R., 1997. Closure planning practise and landscape performance at 57 Canadian and US mines. In: Proceedings of the 21 st Annual British Columbia Mine Reclamation. Symposium in Cranbrook, BC, 1997. BCTRCR, British Columbia Technical and Research Committee on Reclamation, Cranbrook. pp. 74–87.

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Understanding gullying in mine rehabilitated lands

Why this happens?

This rehabilitated landscape is trying to re-establishe a drainage network

Uniform linear slopes and gradient terraces lead to rill and gully formation

expensive *re-do* and sediment loss

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

Gully erosion of graded terraces at Gas Hills uranium district in Wyoming (US). Photos by Harold Hutson

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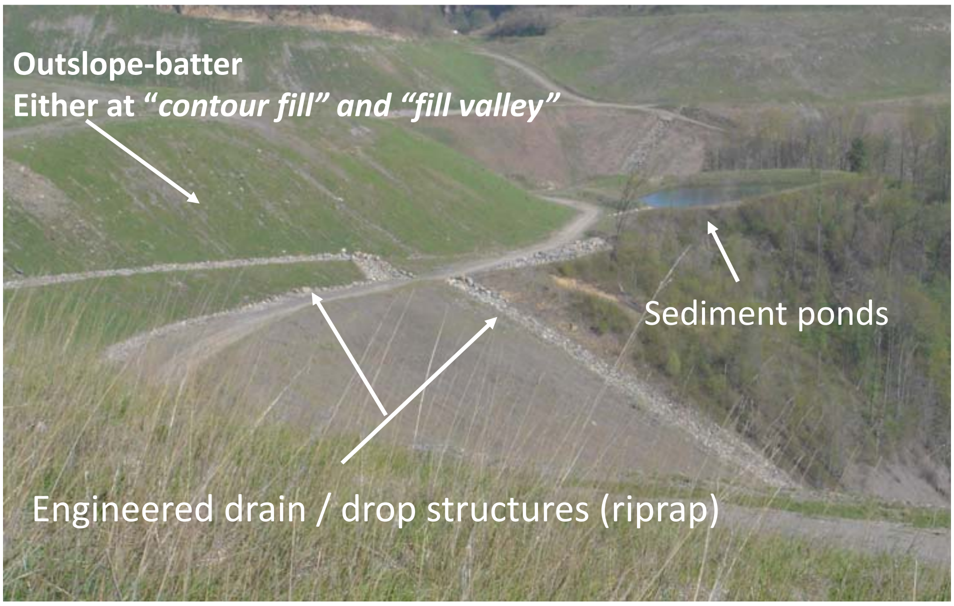
A typical engineered solution for drainage management in mine rehabilitation



BLACK BEAR Nº1 Paramount Coal CO (West Virginia, United States)

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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)

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Any other disadvantages?

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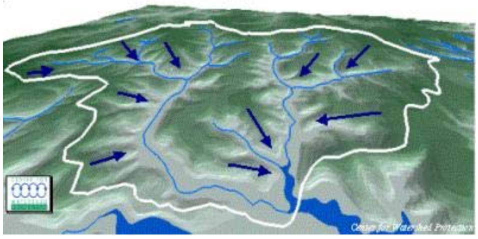
SMCRA 1977. Surface Mining Control and Reclamation Act. Public law, 95–87, Statutes at Large, 91 Stat. 445. Federal Law. United States

- 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…***"

http://basin.fxgreenpips.net/what-are-drainage-basins-separated-by/



- SMCRA 1977 introduced the geomorphic (and catchment) approach to mine rehabilitation
- Concept of drainage basins as ***fundamental basic planning units*** for mine rehabilitation landform (Stiller et al.,1980)

Stiller, D.M., Zimpfer, G.L., and Bishop, M. 1980. Application of geomorphic principles to surface mine reclamation in the semiarid West. *Journal of Soil and Water Conservation*, 274-277.

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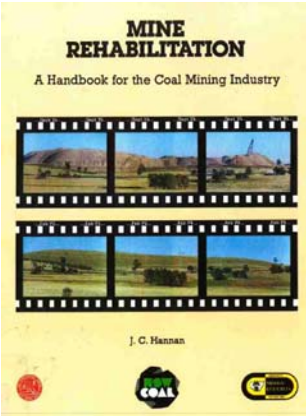
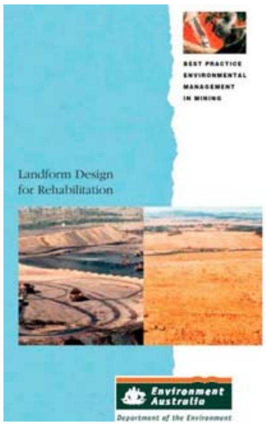
The NSW coal industry played a key role in the pioneering **(global)** development of drainage basins as basic planning unit





Hannan, J.C. 1984. Mine Rehabilitation. A Handbook for the Coal Mining Industry. New South Wales Coal Association, Sydney, 124 pages. (second edition of 1995).

Environment Australia. 1998. Landform Design for Rehabilitation. Department of the Environment, Canberra.

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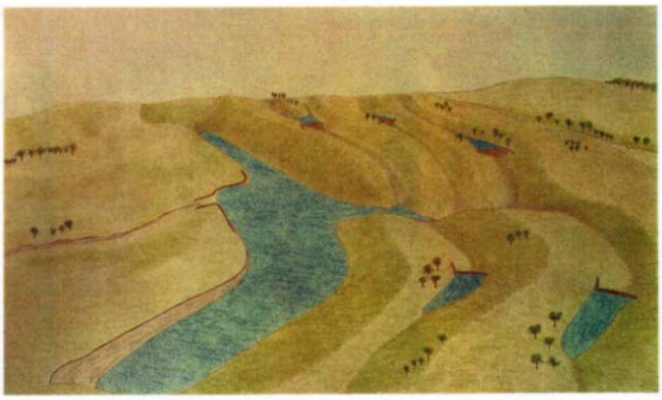
Formation of an integrated drainage system

"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).

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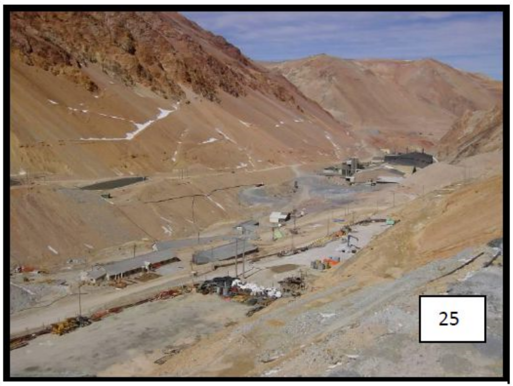
Eyeball / guessing "natural landforms and channels" is not

A SCIENTIFIC-BASED GEOMORPHIC REHABILITATION METHOD (AND THEREFORE, NOT RELIABLE)

An example from Chile



Before Mine Closure

⇨

After Mine Closure

SOURCE:http://www.enm.ucn.cl/intranet_enm_ucn/claroline1107/programas/EGAMGM78/document/JORGE_D%C3%8DAZ/ENM_GA-3_Cierre_de_Faenas_Mineras.pdf

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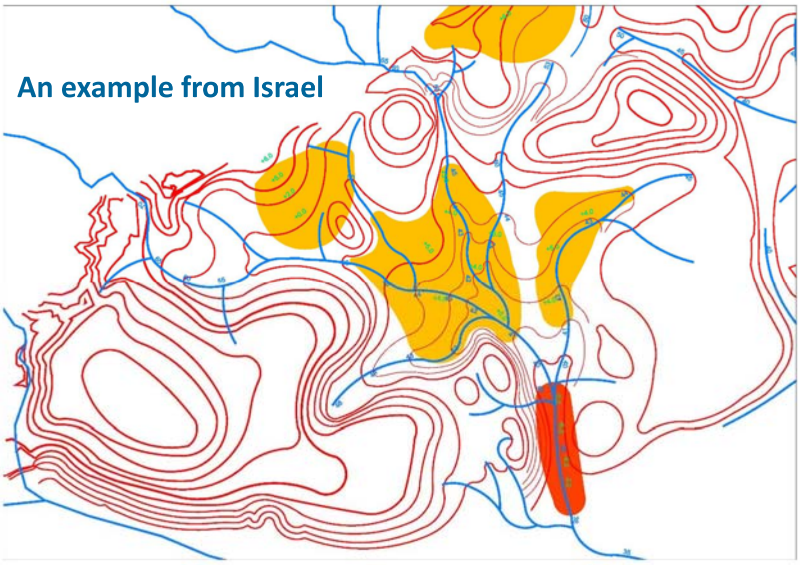
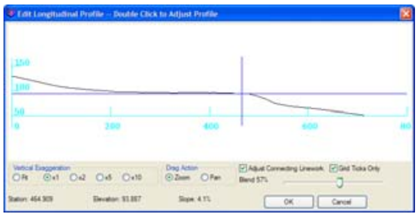
Just “looking less engineered” or “to have a more natural appearance” does not guarantee stability





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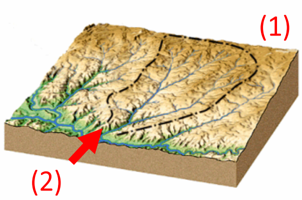
- The early writings (SMCRA, 1977; Stiller et al., 1980; Hannan, 1984; EA, 1998…) claimed the need of replicating the patterns and complexity that stable landforms have in natural catchments
- However, the possibility of designing such complex 3D landforms and drainage networks has not been possible 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)

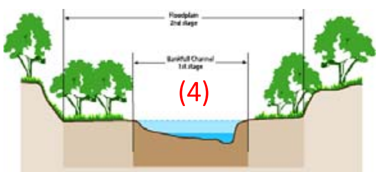
B) cross sectional channel geometry based on bankfull discharge and extreme events (4) Cross section increases downstream as water increases downstream (5)

C) slopes between channels have predominantly concave slope profiles (6)

(1)

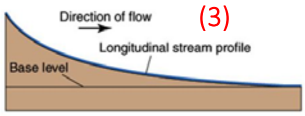


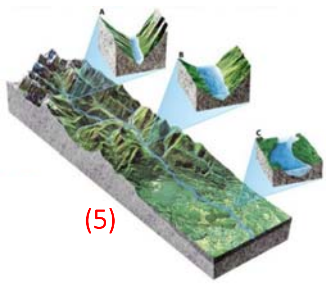
(2)



(4)

(3)





(5)

(6)

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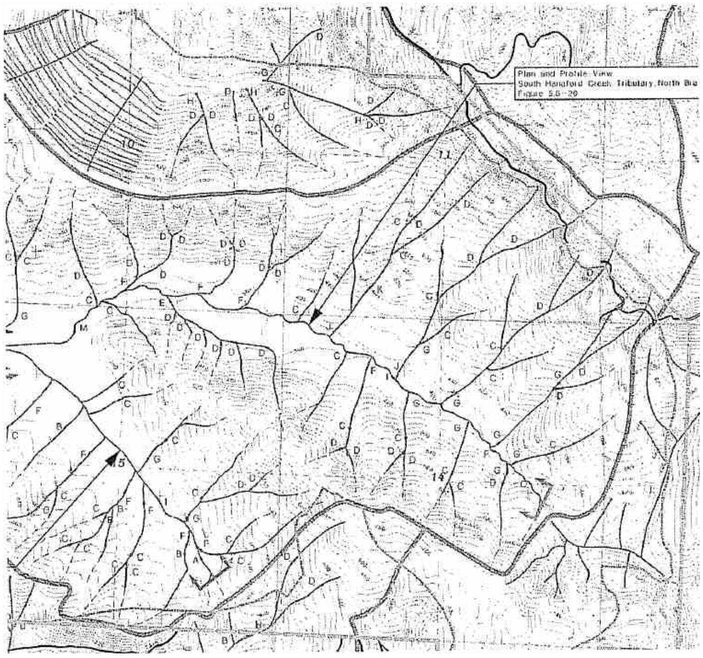
4. Methods for mine catchment rehabilitation design (scale independent, universal application)

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

Beersing et al. (2014). A Geomorphic Approach for the Design of Drainage Systems on Reclaimed Mined Areas.
http://www.infomine.com/library/publications/docs/Beersing.pdf



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

https://www.desmog.ca/2016/07/13/strange-bedfellows-alberta-brings-former-adversaries-together-new-oilsands-advisory-group

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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.

Sawatsky, L.F. and Beckstead, G.R.E. (1996). Geomorphic approach for design of sustainable drainage systems for mineland reclamation. International Journal of Surface Mining, Reclamation and Environment 10: 127-129.

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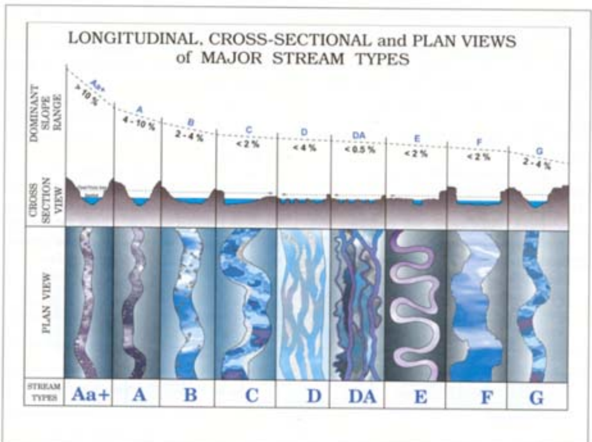
4.2. River and streams fluvial restoration based on Rosgen classifications

RIVERMorph Stream Restoration Software http://www.rivermorph.com/

Climax Mine, Colorado, USA
Earth and Water Technology



Rosgen DL. 1994. A classification of natural rivers. Catena, 22:169-199; Rosgen DL 1996. Applied River Morphology. Wildland Hydrology, Pagosa Springs, Colorado.

4.3. The GeoFluv method and the Natural Regrade software

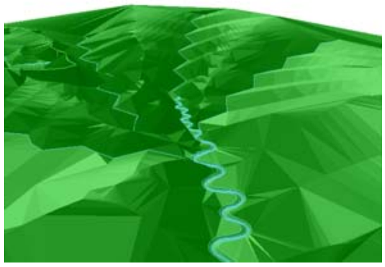
GeoFluv

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



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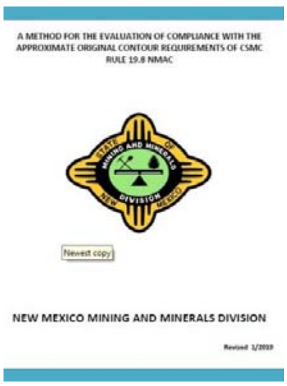
Geomorphic rehabilitation and sustainable drainage network design at the US

Geomorphic Reclamation is within the OSMRE Technology Development and Transfer (TDT) program - http://www.osmre.gov/programs/tdt/geomorph.shtm

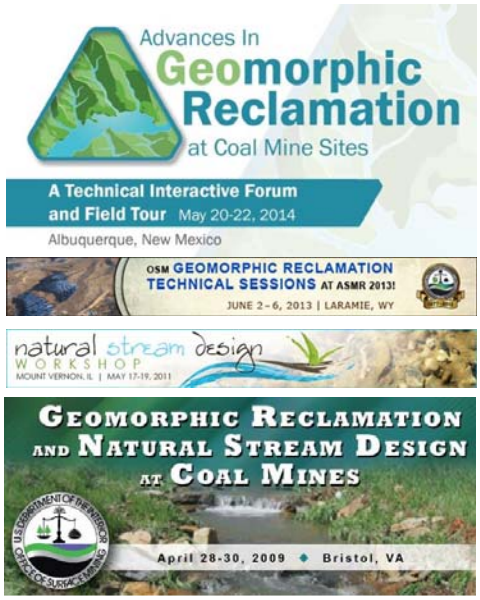
The New Mexico state regulation considers that a **geomorphic approach to backfilling and grading is the Best Technology Currently Available (BTCA) for stabilizing coal mine reclamation** (NMMMD, 2010)


A METHOD FOR THE EVALUATION OF COMPLIANCE WITH THE APPROXIMATE ORIGINAL CONTOUR REQUIREMENTS OF CSMC RULE 19.8 NMAC

Newest copy

NEW MEXICO MINING AND MINERALS DIVISION

Revised 1/2010



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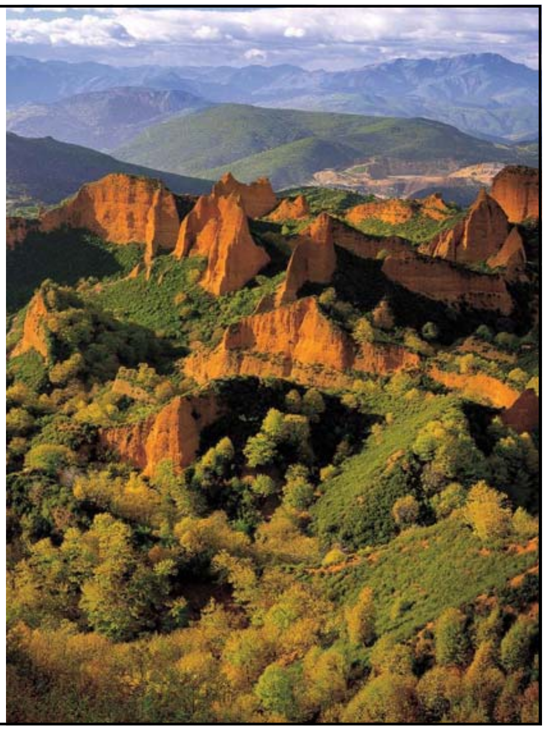
A broader concept for geomorphic rehabilitation

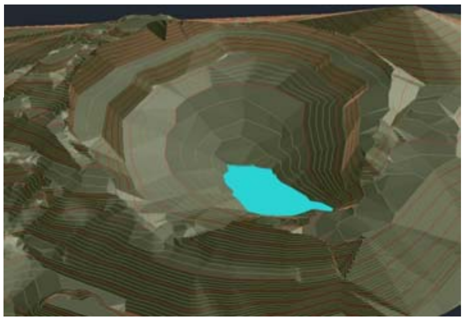
Geomorphic rehabilitation seeks to create steady-state landscapes. With steady-state configurations, adjustments by geomorphic processes after rehabilitation decrease. Therefore, the prospect for rehabilitation success increases and the demand for post-rehabilitation site maintenance decreases (Toy and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

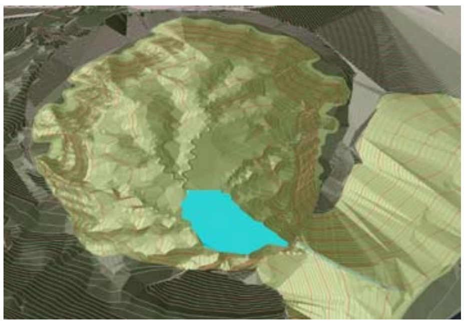
Toy TJ, Chuse WR. 2005. Topographic reconstruction: a geomorphic approach. Ecological Engineering 24: 29-35.



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

SOURCE: By Wilson44691 - Own work, Public Domain, https://commons.wikimedia.org/w/index.php?curid=7859465





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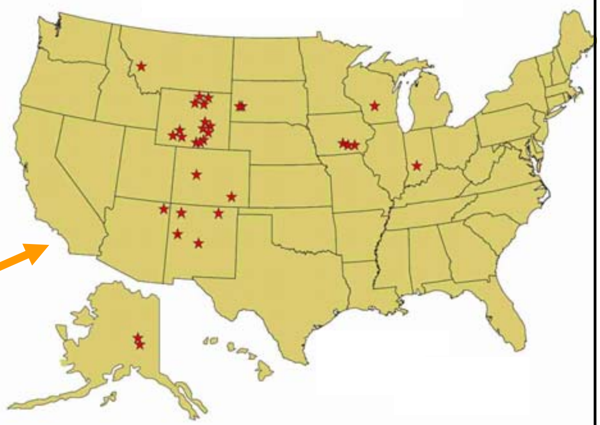
5.1. GeoFluv – Natural Regrade examples at the US

An estimate of 50 large built examples and a similar number of designs (not built)

GeoFluv-Natural Regrade inventoried built rehabilitations (as for April 4, 2018)



Sands Mine in Wisconsin (US) in humid, temperate environment

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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)



Photos by Nicholas Bugosh

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La Plata Mine, New Mexico (US)

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San Juan Mine, New Mexico (US)

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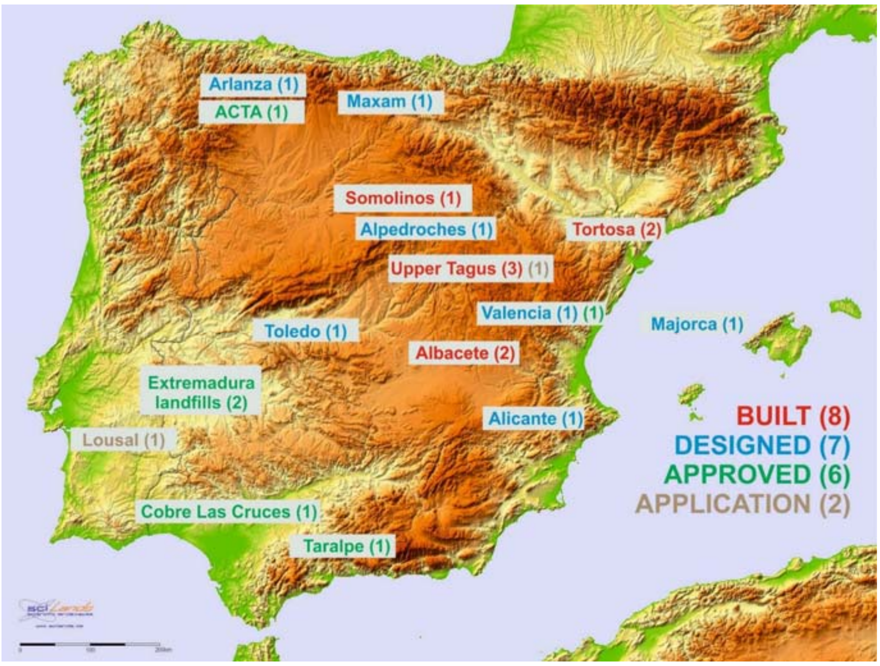
5.2. GeoFluv – Natural Regrade examples at the EU

Spain and Portugal

(small scale; mostly demonstration-projects)



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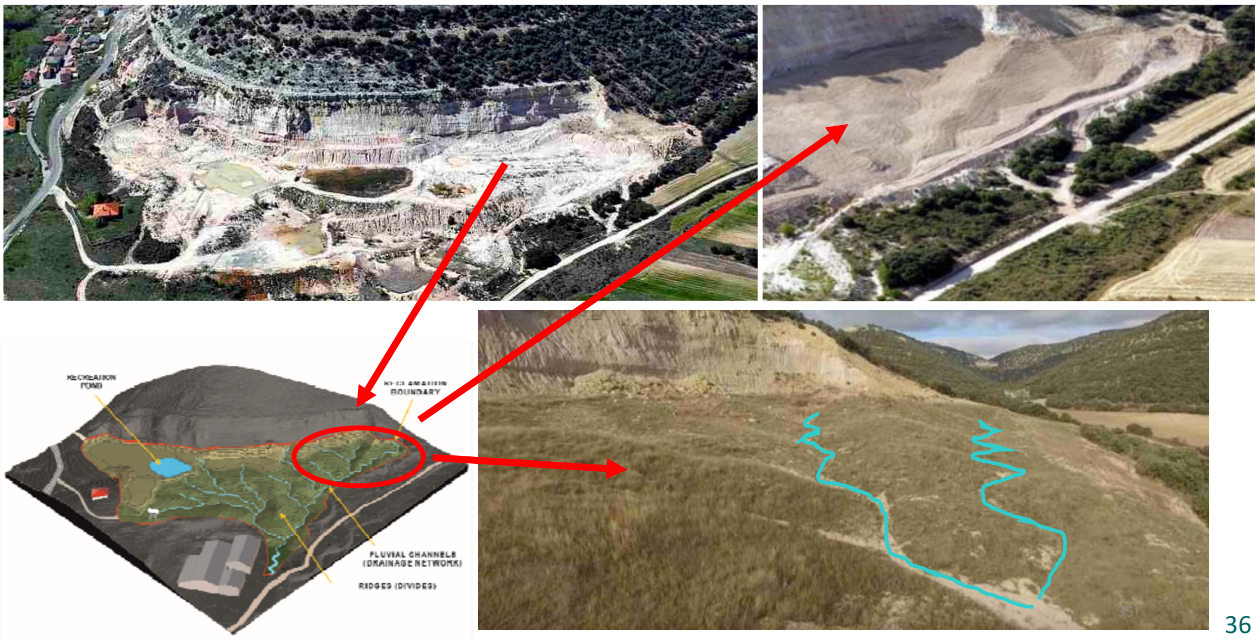
Abandoned sand quarry (Somolinos, Guadalajara)



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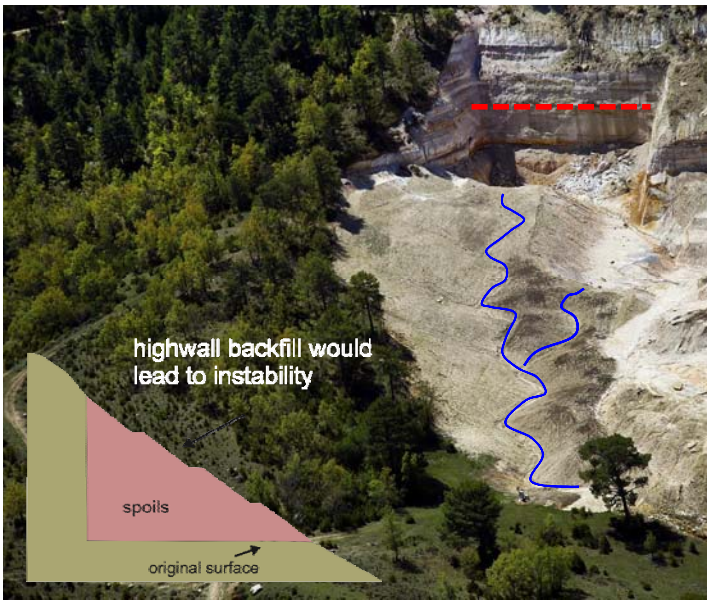
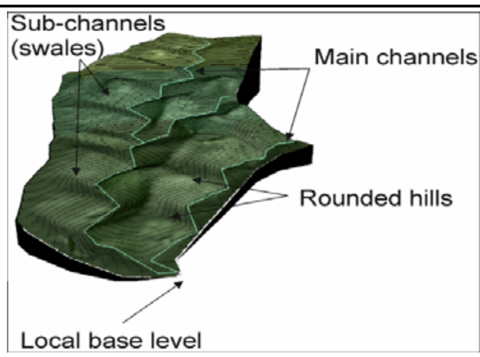
El Machorro, active kaolin mine (Alto Tajo, Guadalajara province)





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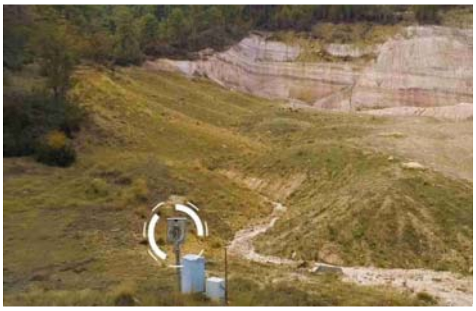
Zapico I, Martín Duque JF, Bugosh N, Laronne JB, Ortega A, Molina A, Martín-Moreno C, Nicolau N, Sánchez L. 2018. Geomorphic Reclamation for reestablishment of landform stability at a watershed scale in mined sites: the Alto Tajo Natural Park, Spain. Ecological Engineering, 111: 100-116.



Sediment yield monitoring
for 5 years (2012-2017) 4.02 t/ha/yr

National Award (Spain) on Sustainable Mining, 2015

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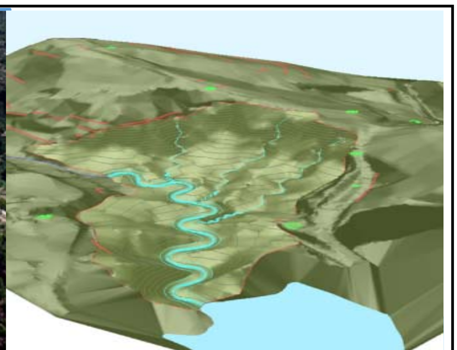
Clay quarry (Tortosa, Tarragona)






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


European Commission

Best Available Techniques Reference Document for the

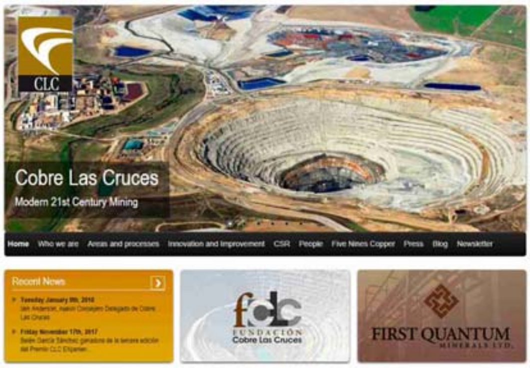
Management of Waste from the Extractive Industries

in accordance with Directive 2006/21/EC

JOINT RESEARCH CENTRE
Directorate B – Growth and Innovation
Circular Economy and Industrial Leadership

Revised DRAFT DOCUMENT

October 2017



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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

Puerto Libertador, Córdoba

- High precipitation (>1,000 mm/yr)
- Ecologically and visually sensitive landscape

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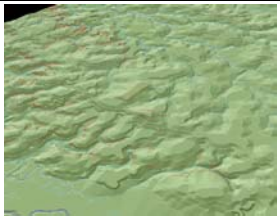
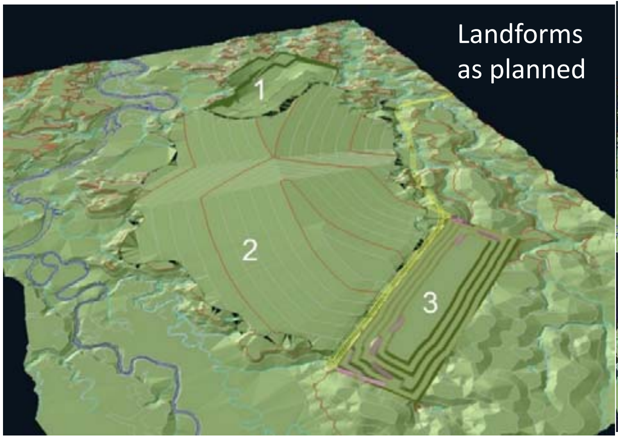
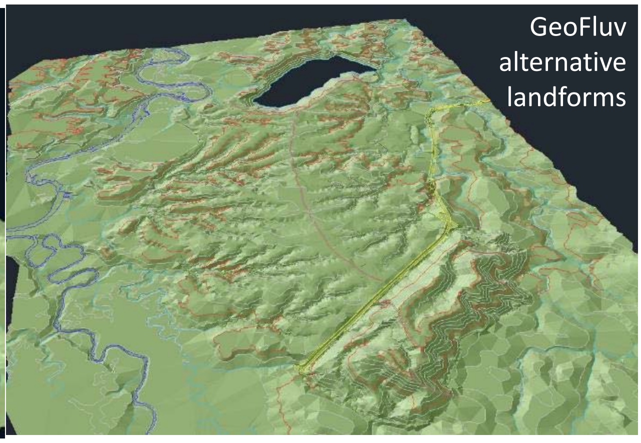
Coal mine geomorphic (GeoFluv) rehabilitation in a tropical environment with grazing (Bijao mine, SATOR, Argos Group, Colombia)



The Traditional reclamation landform had three main features:

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

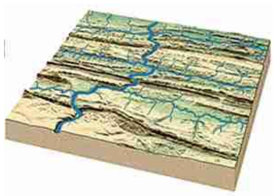


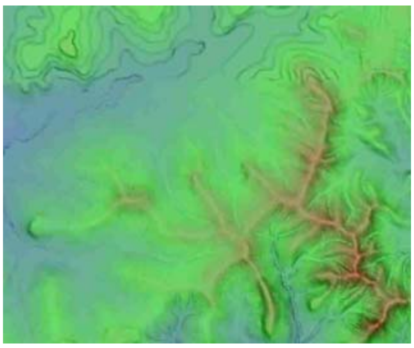


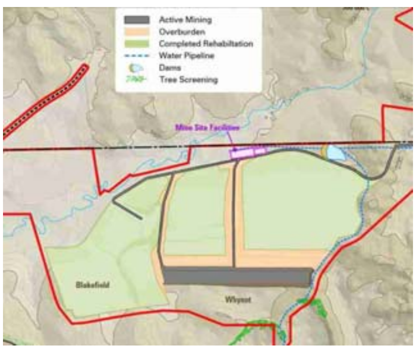
Bugosh, N., Martín Duque, J.F., and Eckels, R. 2016. The GeoFluv Method for Mining Reclamation: Why and How it is Applicable to Closure Plans in Chile. In: Planning for Closure 2016. First International Congress on Planning for Closure of Mining Operations, Santiago de Chile.

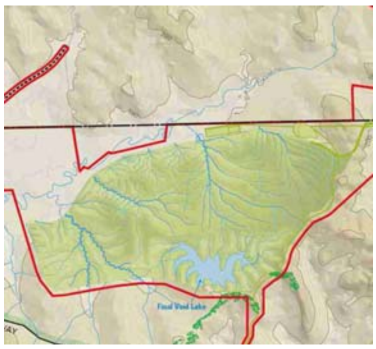
5.3. Australia

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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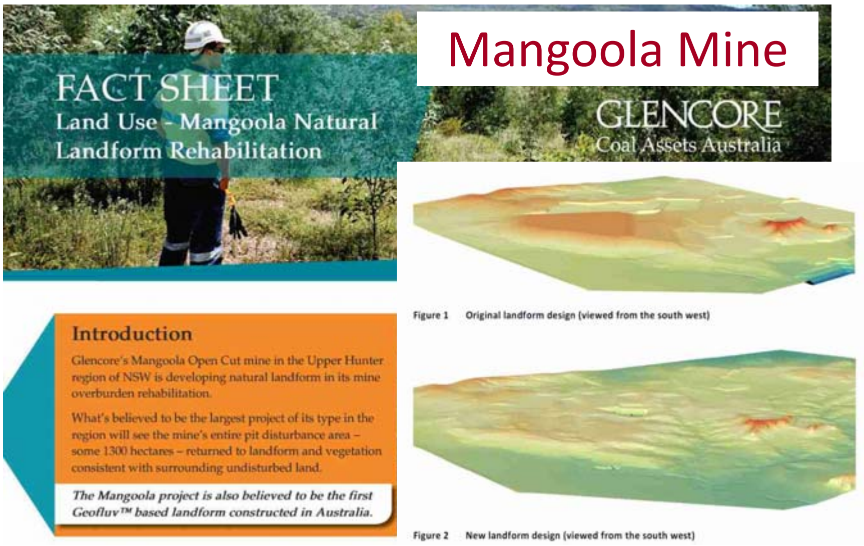
Demonstration project at Drayton Mine

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



Waygood, C. 2014. Adaptative landform design for closure. Mine Closure 2014, Weiersbye et al. (eds), University of the Witwatersrand, Johannesburg, 12 pg.

Kelder I, Waygood C. 2016. Integrating the use of natural analogues and erosion modelling in landform design for closure. Mine Closure 2016 – AB Fourie and M Tibbett (eds), Aust. Centre for Geomech., Perth

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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

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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

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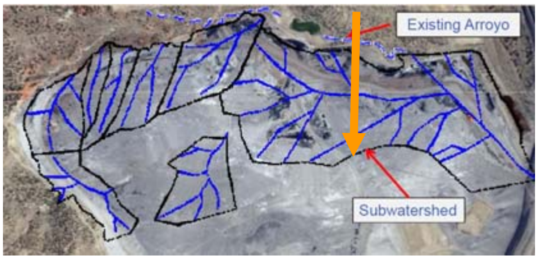
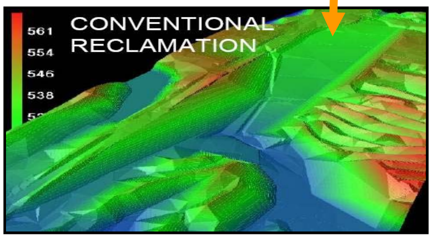
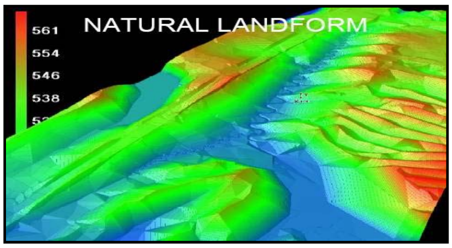
3. Best integration occurs when a mine plan operates toward a durable geomorphic landform design (progressive rehabilitation)

It also provides cost-effective solutions for abandoned mines



Chevron Mckinley Coal Mine NM, US, EWT





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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

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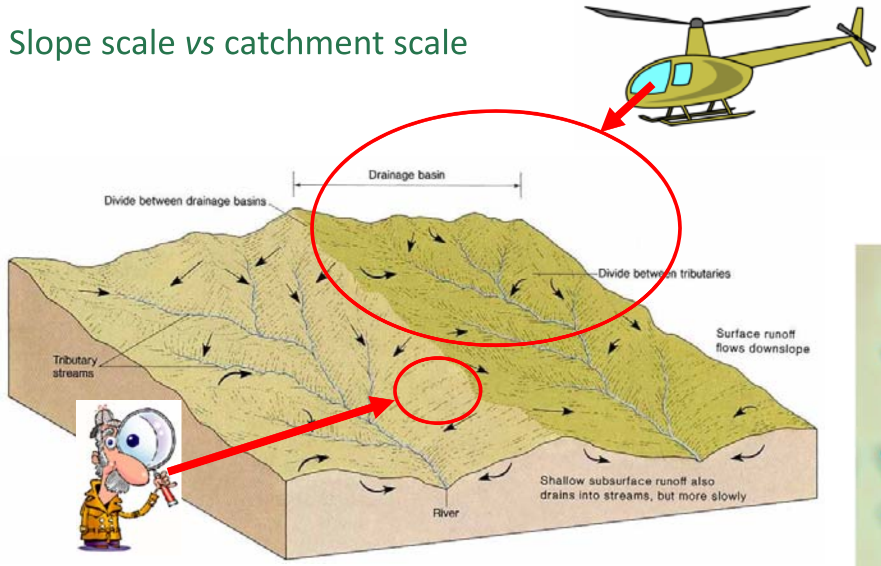
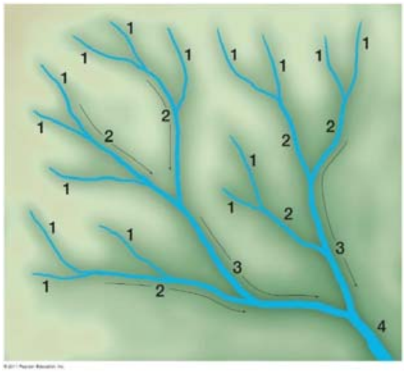
Slope scale *vs* catchment scale



On average, a 500-ha rehabilitated mine would need 25 km of fluvial channels!



http://www.bedfordcountyconservation.com/Watersheds/wsheds.htm

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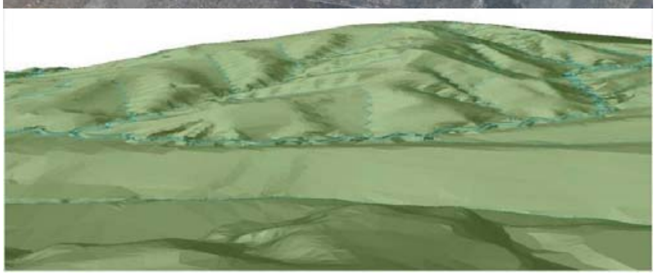
BUT…Traditional landform designs of waste dumps, landfills…, are designed to minimize the footprint. This process creates large monolithic accumulations of waste in the landscape, with flat-top areas and terraced slopes or contour bank slopes. THEREFORE…



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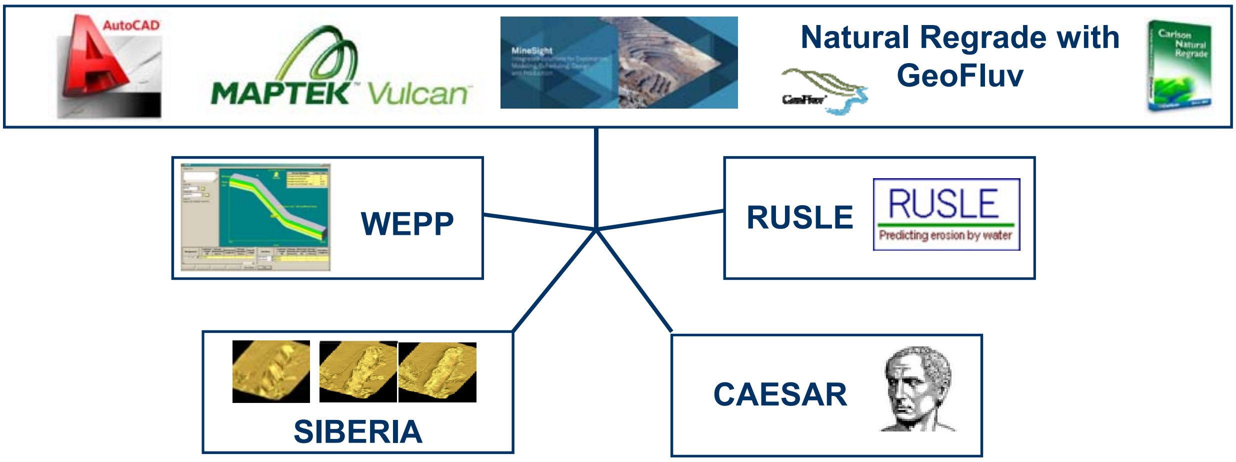
6. It is critical differentiating between designing and modelling tools

FAQ (1) – which tool is better?

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



Hancock, G. 2004. The use of landscape evolution models in mining rehabilitation design. Environmental Geology 46:561–573.

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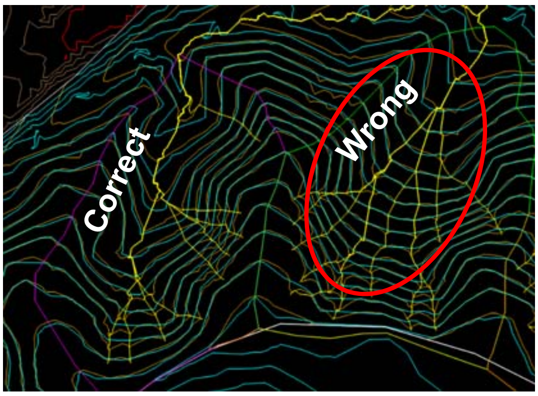
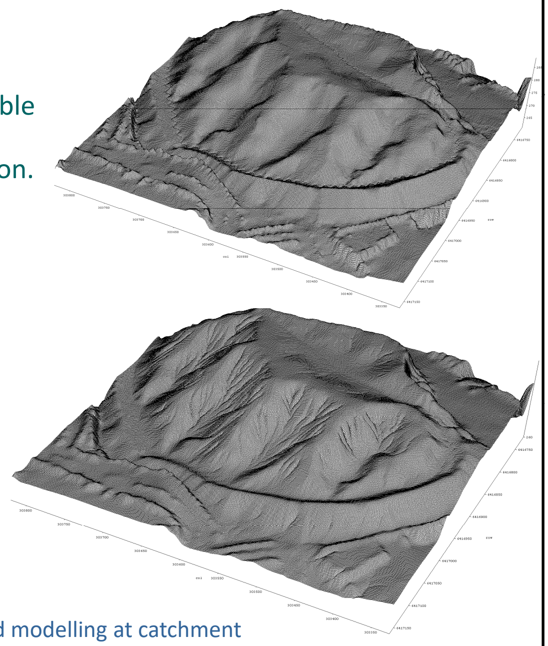
7. Geomorphic-catchment rehabilitation is NOT a single technique, method, software or model.

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*

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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!

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