A Geomorphologist's Perspective on Stream Restoration in Mined Lands

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National International Technical Forum

"Geomorphic Reclamation and Natural Stream Design at Coal Mines"

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Sponsored by the Office of Surface Mining

Brief History of Stream Restoration

See

Lave, Rebecca, 2008, The Rosgen Wars and the Shifting Political Economy of Expertise (Ph.D. Dissertation), University of California, Berkeley, 251 p.

Restoration = 3rd Wave of the Environmental Movement

Reaction to "highest and best use" of water resources

Wild & Scenic Rivers Act: 1968, National Environmental Protection Act: 1969, Clean Water Act: 1972, Flood Control Act: 1990

~ 1978-1982: Stream restoration consulting firms

Brief History of Stream Restoration

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Lave, Rebecca, 2008, The Rosgen Wars and the Shifting Political Economy of Expertise (Ph.D. Dissertation), University of California, Berkeley, 251 p.

1986: Rosgen Natural Channel Design short courses (>15,000 students by 2008)

1994, 1996: Rosgen classification system published

Academia (& others): "War" on Rosgen, but asleep at the wheel in selling alternatives to an established industry

1990s: Government funding explodes; >$1,000,000,000/ year industry

2000s: Stream mitigation banking: private-sector source of restoration funding

Who is this cowboy Dave Rosgen?

Lave, 2008:

- “Rosgen has been so successful … because he has provided structure that the stream restoration field desperately needs: a common language for communication, a set of shared methods and standards of practice, and the primary means of disciplinary reproduction and training.”

Who Rides a White Horse?

Lave, 2008:

> "The Rosgen Wars are thus not simply a conflict over truth* and practice, but also a struggle for control over the field of stream restoration, and the authority to produce new knowledge."

Kite, 2009:

> "… no single profession or discipline should assume to possess ownership of the certification process for watershed restoration professionals."

* Dylan, Bob, 1964: "… there are no truths outside the Gates of Eden."

Volume of Material Removed in Surface Mining of Coal (2007)

Correction based on conference comments follows

Short Tons of Coal	Metric Tons of Coal	Coal Density	Coal Volume (m^3)	Overburden Ratio	Overburden Volume (m^3)	**Volume Coal + Overburden** (m^3)
Appalachian Basin						
150,000,000	136,077,600	1.32	103,089,091	~~10~~	~~1,030,890,909~~	~~**1,133,980,000**~~
Powder River Basin						
479,496,000	434,991,099	1.30	334,608,538	2	~~669,217,076~~	~~**1,003,825,614**~~

Info Sources:

Production: National Mining Asociation: http://www.nma.org/pdf/c_production_method.pdf

Coal Density: Wood, G.H., Kehn, J., Carter, T.M., and Culberston, W.C., 1983, Coal resources classification system of the U.S. Geological Survey: U.S. Geological Survey Circular 891, 65 p.

Overburden Ratios: (Includes Interburden) I pulled them out of a hat!

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Appalachian Basin: Coal Density 1.32						
150,000,000	136,100,000	**15**	2,250,000,000	1,856,000,000	103,000,000	**1,823,000,000**
Powder River Basin: Coal Density 1.30						
479,496,000	434,991,000	**2**	959,000,000	733,000,000	335,000,000	**1,068, 000,000**

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Overburden Ratio = Overburden Volume (yd^3) / Clean Coal Production (Short Tons)

Overburden Includes Interburden for multiple-seam mines!

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Compare to 1980 Mt. St. Helens Eruption: 1,010,000,000 m^3

Info Source:
Mt. St. Helens data: U.S. Geological Survey:
http://vulcan.wr.usgs.gov/Volcanoes/MSH/Publications/MSHPPF/MSH_past_present_future.html

Mt. St. Helens image: U.S. Geological Survey:
http://vulcan.wr.usgs.gov/Imgs/Jpg/MSH/Images/MSH80_eruption_mount_st_helens_05-18-80_bw.jpg

“The Rosgen Wars”

Critiques of Scientific Basis of Natural Channel Design
After Lave, 2008

Issue Raised by Rosgen Opponents	Relevance to Mined Lands
Infers processes & predicts channel evolution from form.	Form reflects regulations and costs, not fluvial processes
Relies on incorrect models for calculating sediment transport	Needs work
Focuses too narrowly on isolated reaches	Must be watershed based
Overemphasizes channel stability	Stability is essential
Too interventionist	No choice!
Relies too heavily on bank-full discharge	Typically over-designed to PMF

Completed Fill, Kayford Mountain, WV: Stable through >100 mm (>4 in) Rainfall, July 2001

Mountain-Top Mining *vs.* Long-Term Erosion

Mining Outcome	Natural Rate of Erosion	Geologic Time Equivalent
Pottsville Group Sandstone Erosion at Mountain Tops		
Summit Lowering – 50 to 100 m	5.7 m (~20 ft) / million years	9 to 18 million years
Appalachian Plateaus Bedrock Valley Incision		
Valley Filling – 50 to 200 m	27-63 m (~90-210 ft) / million years	0.8 to 7.4 million years

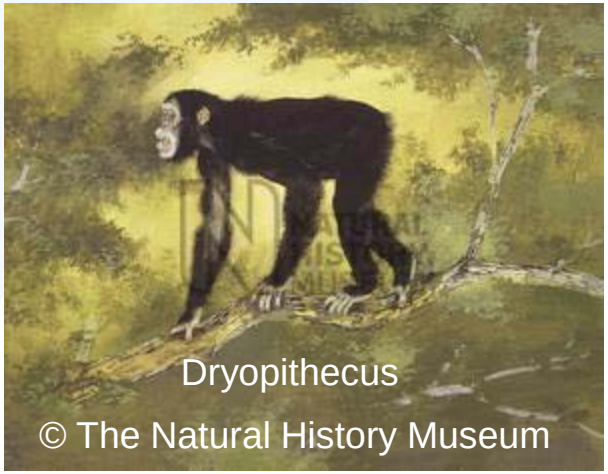
Mining will lead to accelerated erosion, so "recovery" will be sooner than suggested by geological rates.

Even if rates accelerate 100 fold, "recovery" will take tens of thousands of years or longer.

Info Sources:

Natural Rates of Pottsville Sandstone Erosion: Hancock & Kirwan, 2007

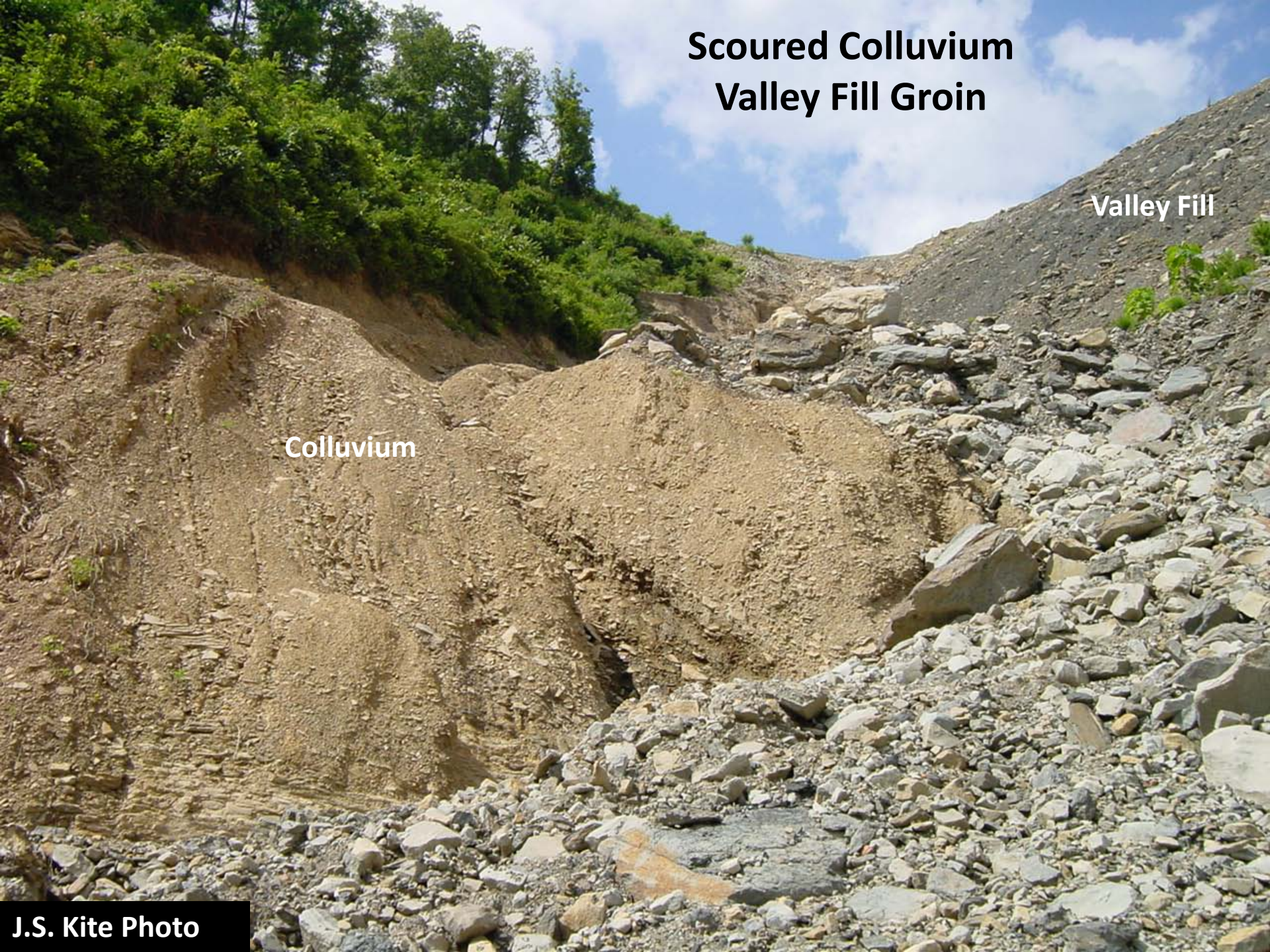
Natural Rates of Valley Incision: Granger et al., 1997, Springer et al., 1997

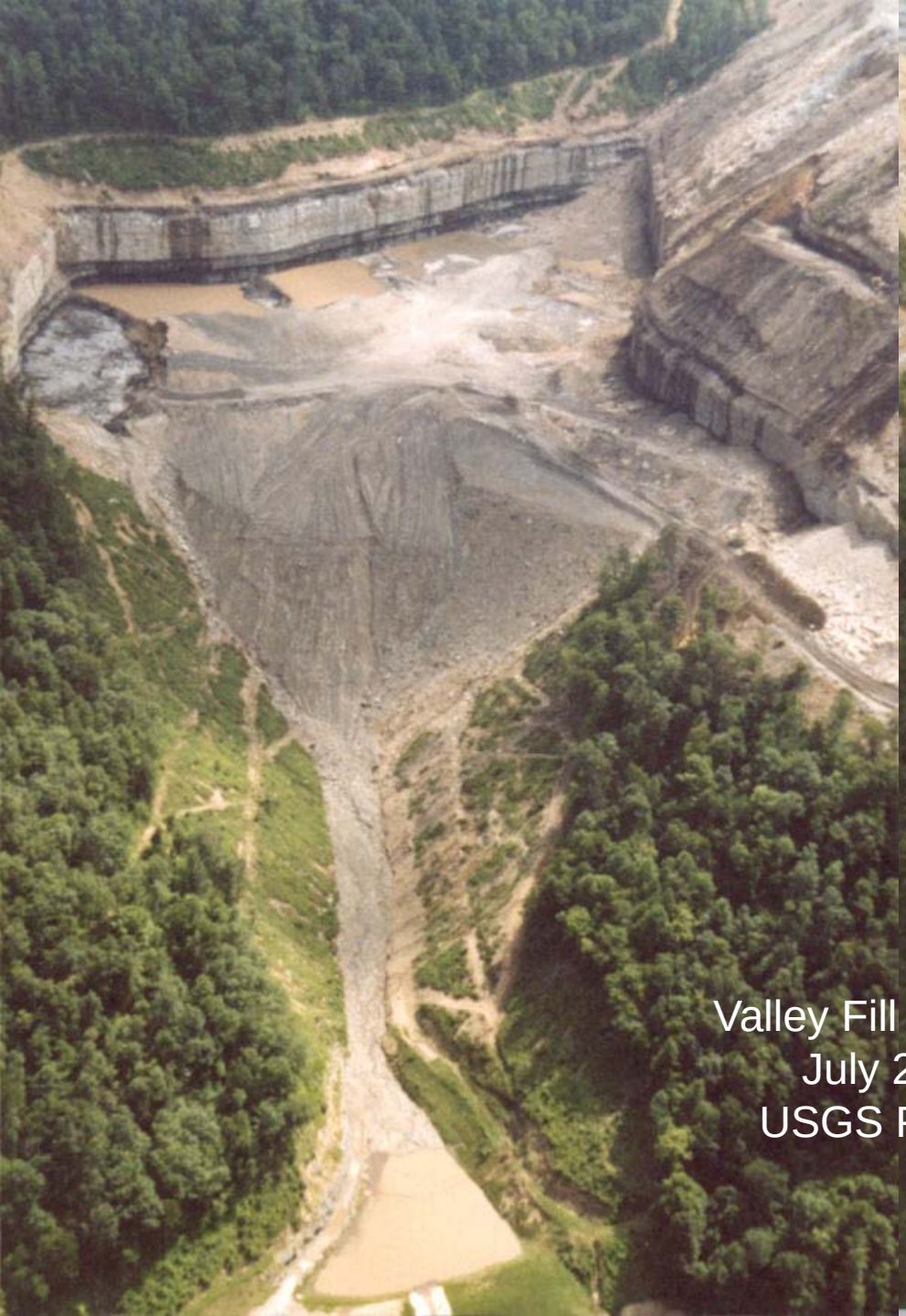


http://piclib.nhm.ac.uk/piclib/webimages/0/1000/900/1972_med.jpg

Valley Fills after >100 mm (>4 in) 6 hr Rain, July 2001

Scour of Colluvial Slope in Valley Fill "Groin," July 2001

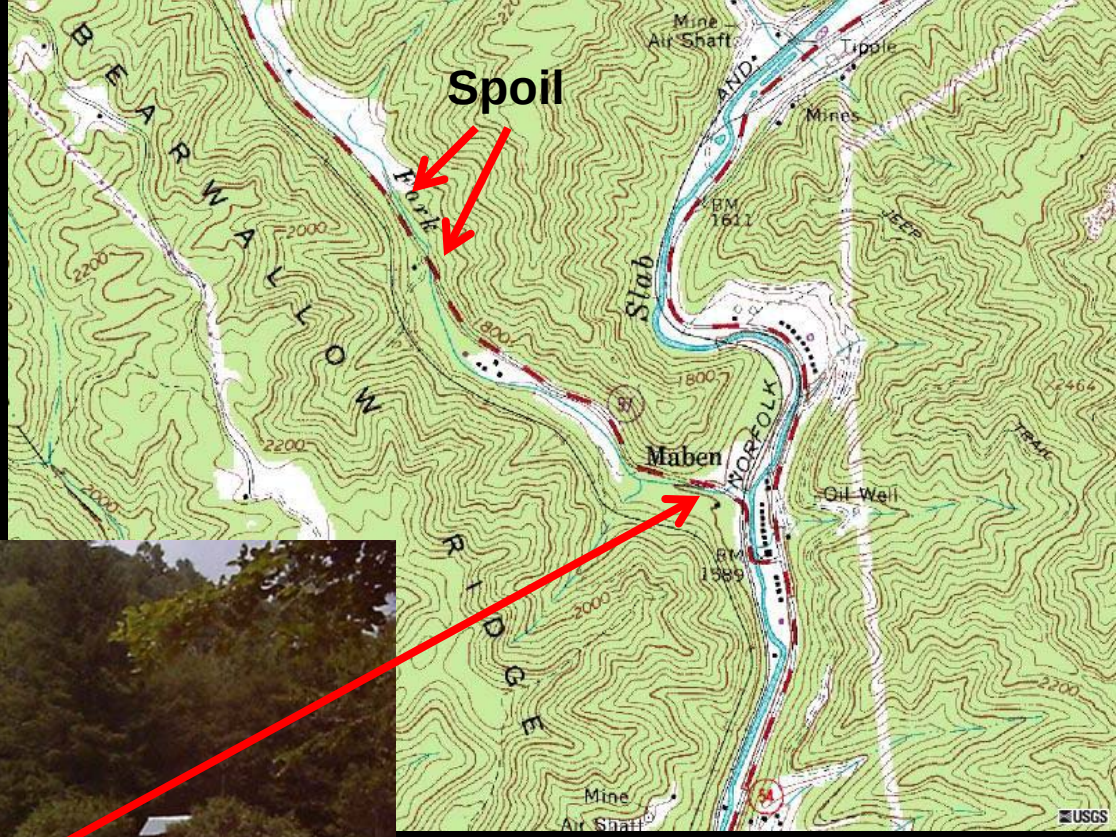

Scoured Colluvium
Valley Fill Groin
Valley Fill
Colluvium
J.S. Kite Photo



Valley Fill Failures
July 2001
USGS Photos

Old Mine Lands Present Restoration Challenges:

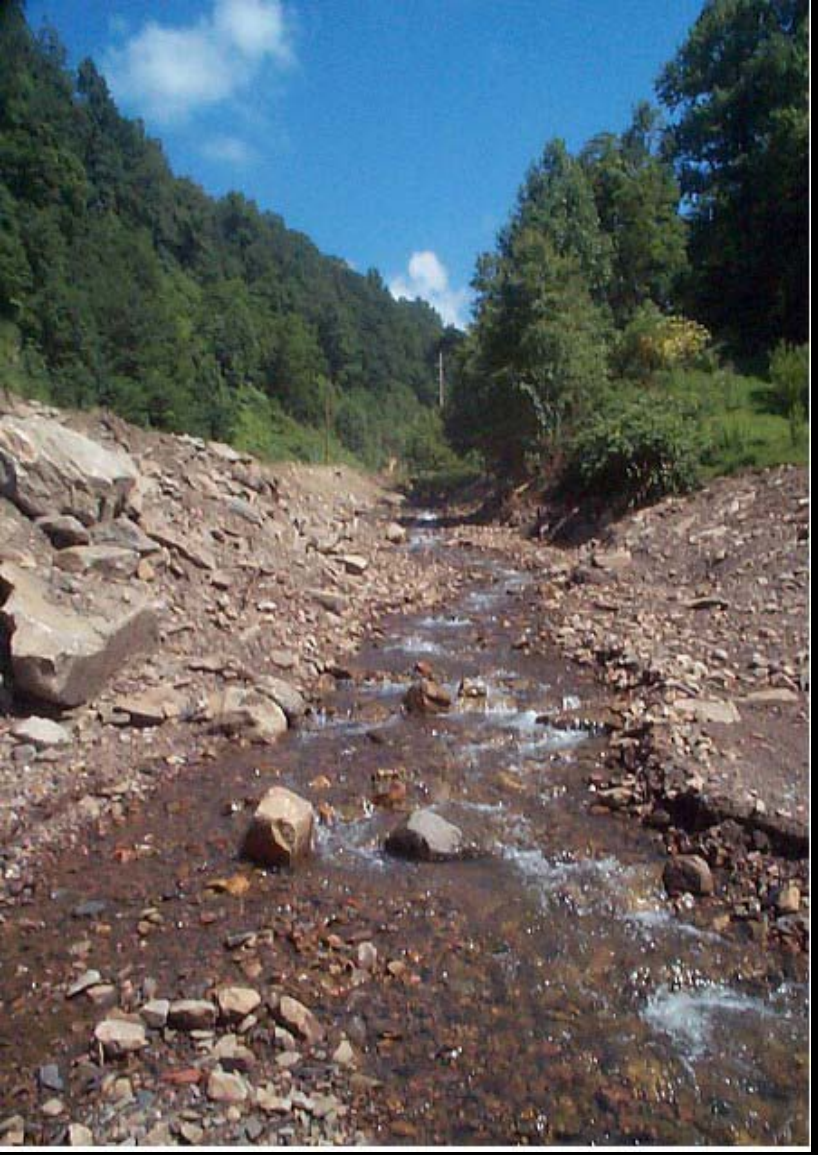
Marsh Fork near Maben, WV: July 2001



Mine spoil yielded bedload that extended far out of expanded channels and on to floodplains.

Runoff (1200 cfs/mi^2) neared the record for similar-size stream in the Ohio River basin.

Sediment Mobilized from Pre-SMCRA Mines July 2001



Wholesale modification of lower Laurel Creek, NPS Photo

Legacy Sediment Mobilized by July 2001 Debris Flows in Mined Lands

Delta bar in Kanawha River *at* the mouth of Loop Creek, Deepwater, USGS Photo

Minden Hyper-Concentrated Flow (2001)

J.S. Kite Photos

Triggered by runoff from a suburban neighborhood draining over mine spoil that was reclaimed to AOC (Approximate Original Contour) in 1994.

AOC Reclamation is Very Unstable
in High-Rainfall Events
Minden (2001)
NPS Photo

Where is Stream “Restoration” Need Greatest?

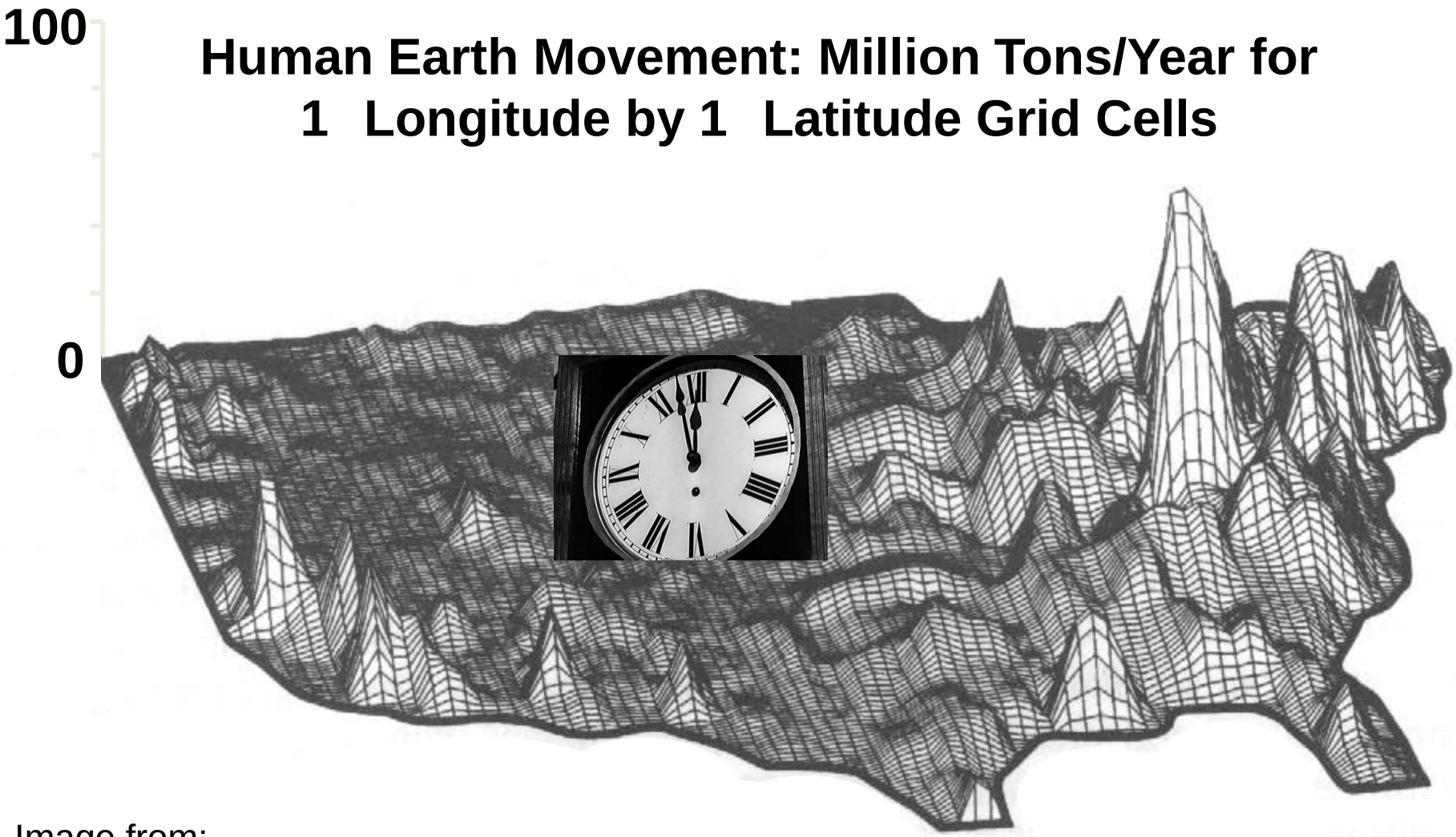


Image from:

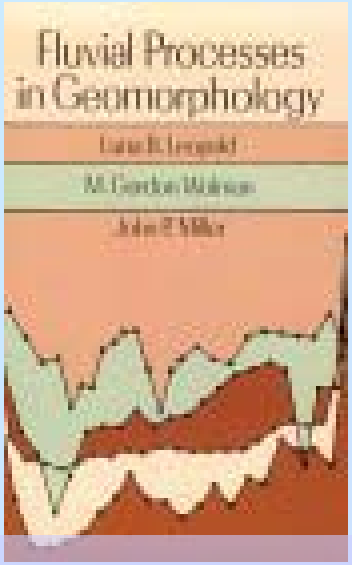
Hooke, R. L., 1999, Spatial distribution of human geomorphic activity in the United States; comparison with rivers: Earth Surface Processes and Landforms, v. 24, p. 687-692.

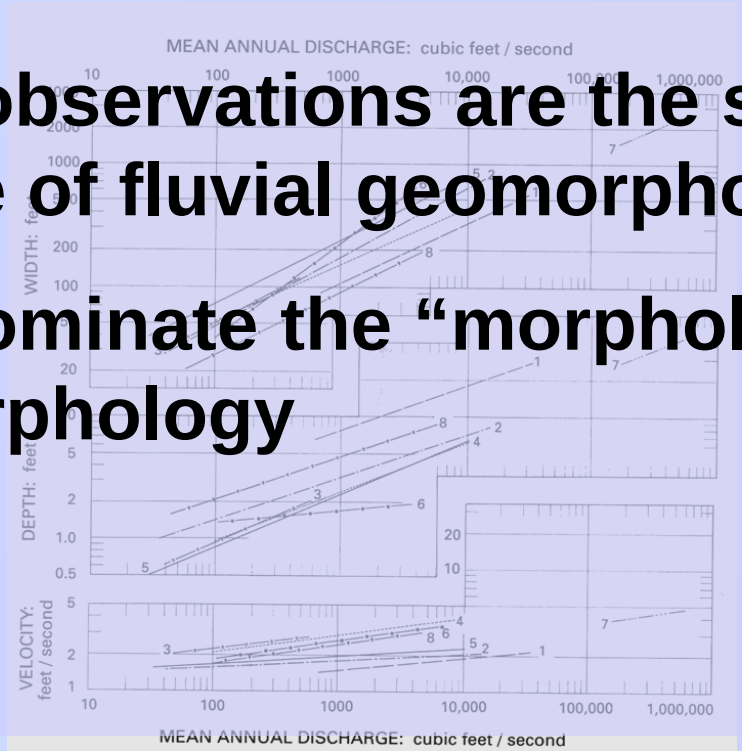
NATIONAL CENTER FOR EARTH-SURFACE DYNAMICS

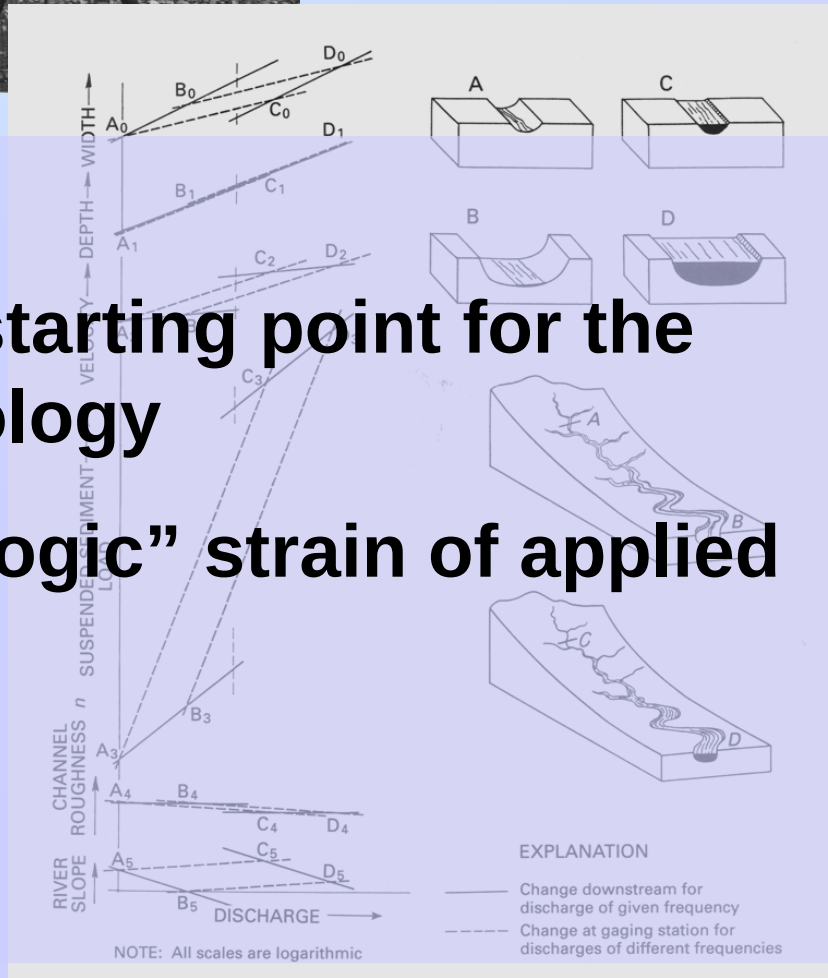
A NATIONAL SCIENCE FOUNDATION SCIENCE & TECHNOLOGY CENTER

Science Basis for Reclamation of Low-Order Streams

Peter Wilcock
Geography & Environmental Engineering
National Center for Earth-surface Dynamics
Johns Hopkins University
Baltimore MD



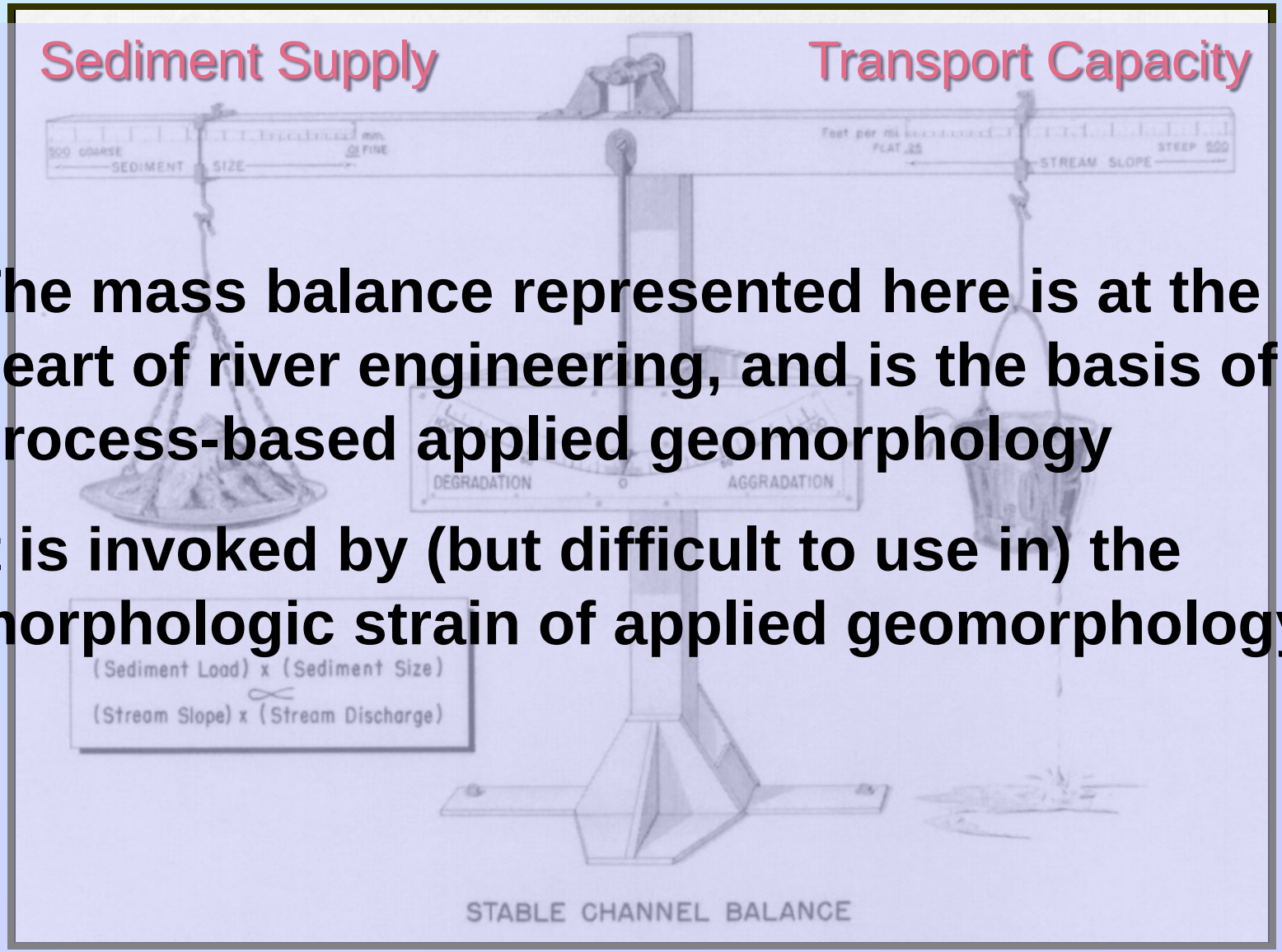




These observations are the starting point for the science of fluvial geomorphology

They dominate the “morphologic” strain of applied geomorphology

The Lane/Borland Stable Channel Balance



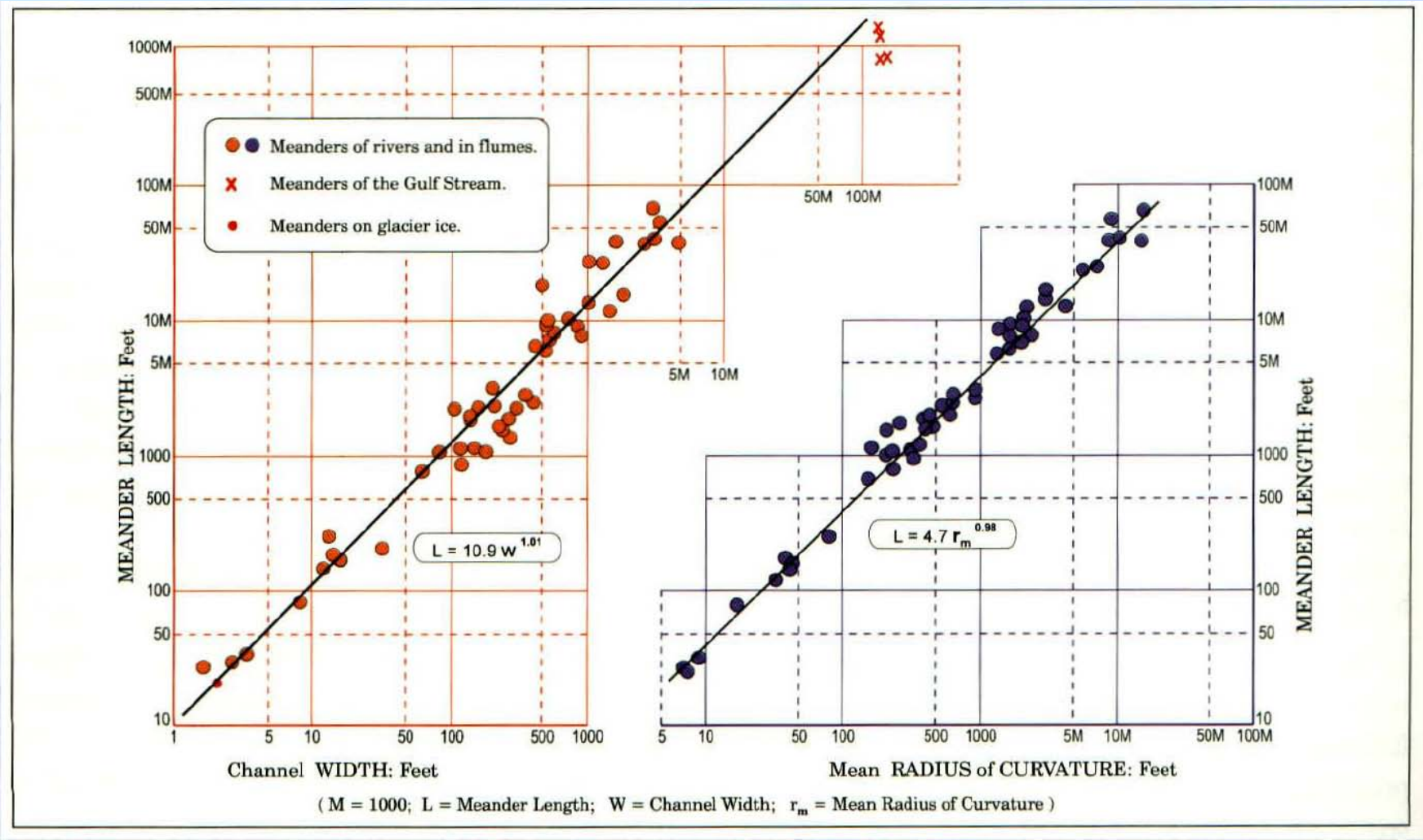
The mass balance represented here is at the heart of river engineering, and is the basis of process-based applied geomorphology

It is invoked by (but difficult to use in) the morphologic strain of applied geomorphology

Borland's stable channel stability relationship illustrated by James Vitaliano, BOR, in 1960.

From Pemberton, E.L. and R.I. Strand, 2005, "Whitney M. Borland and the Bureau of Reclamation, 1930–1972", J. Hydraulic Engineering, May 2005, pp. 339-346.

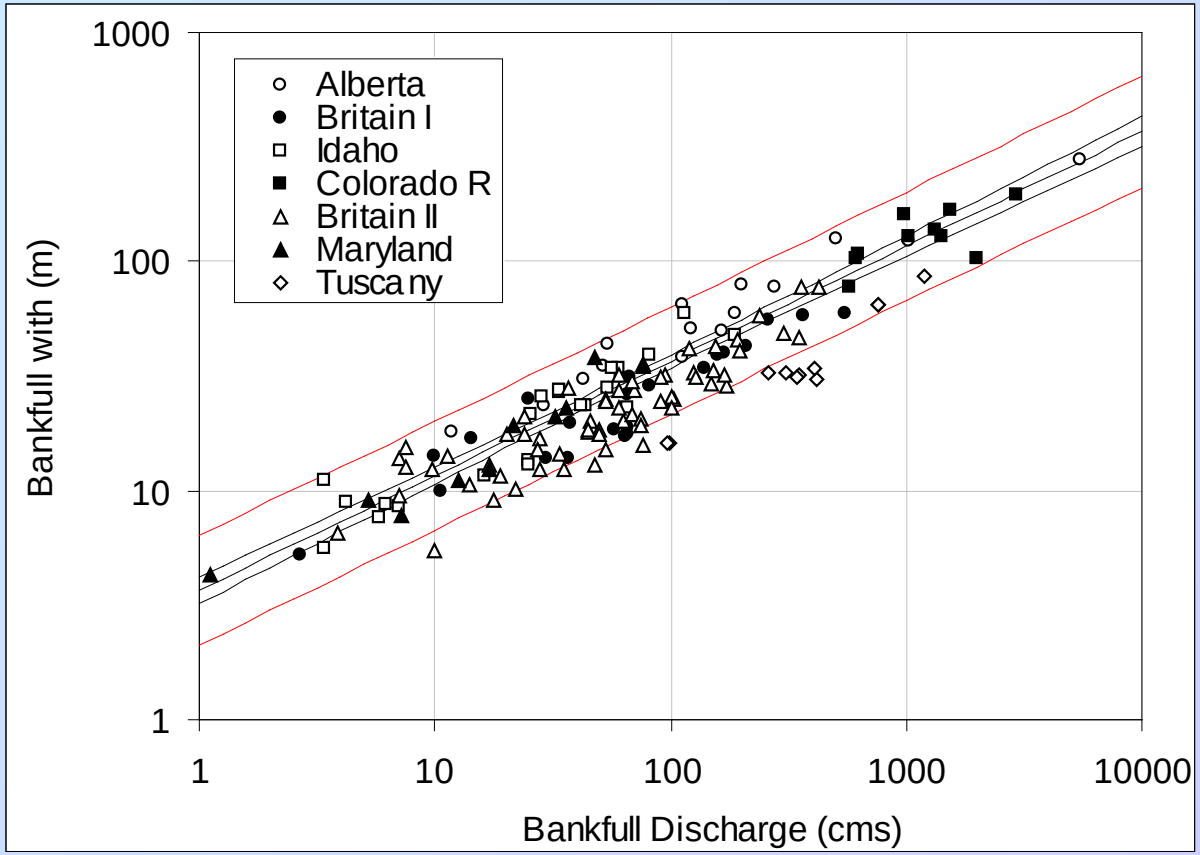
At the core of the template approach is a ***correlation*** between channel geometry, flow, and sediment supply



Leopold, Wolman, & Miller 1964

The width of channels increases very consistently with the square root of discharge.

The flow that moves the most sediment, over time, tends to just fill the channel and occurs ever year or few.



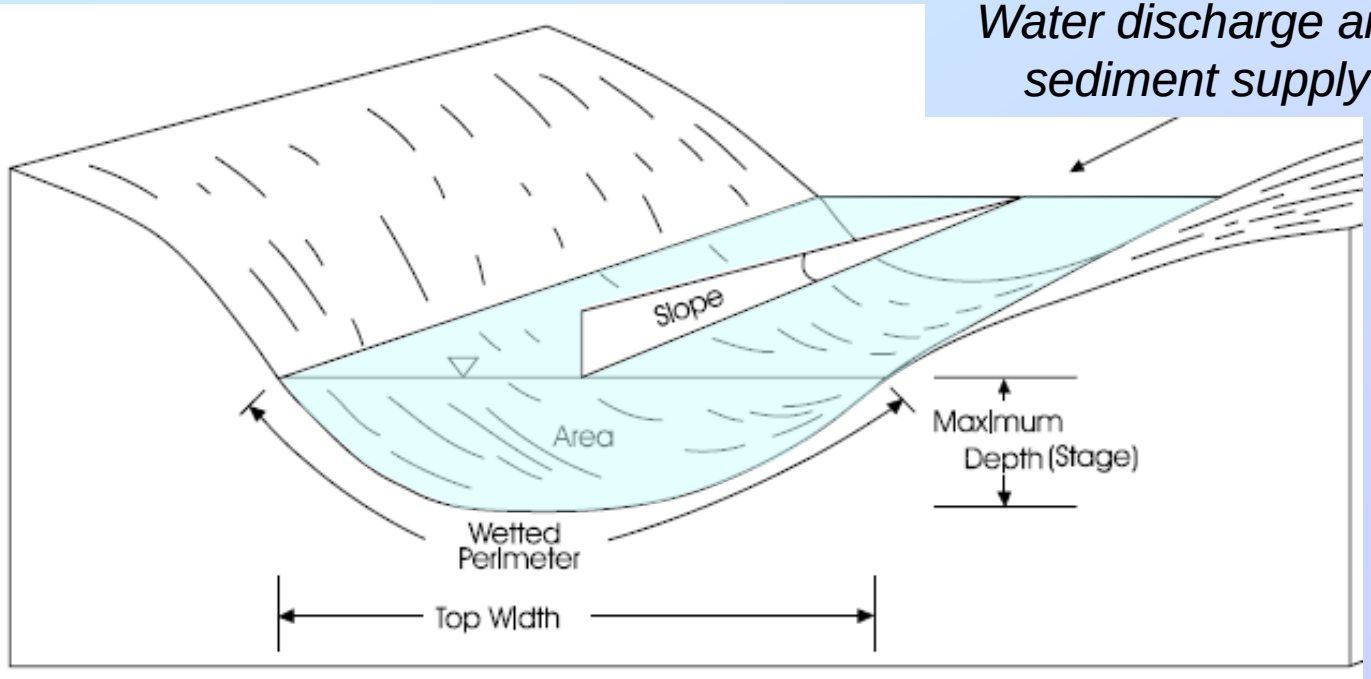
At the core of the template approach is a ***correlation*** between channel geometry, flow, and sediment supply

The correlation ***requires*** that the channels have ***adjusted*** to their water and sediment supply.

Application of process approach: how big the channel?

Given

Water discharge and sediment supply



Find

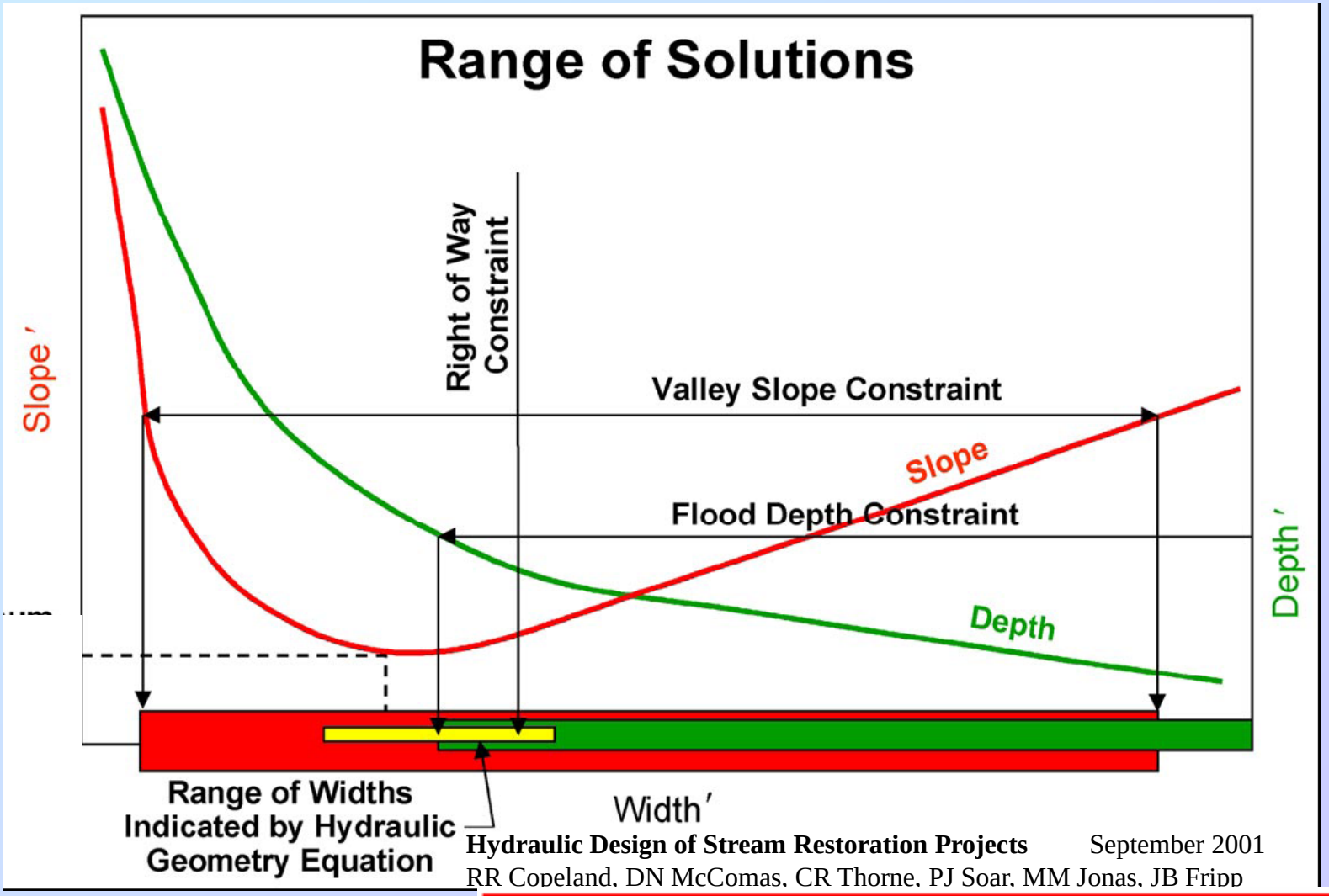
(i) channel slope
(ii) channel depth
(iii) channel width
(iv) mean velocity
(v) boundary shear

We have enough FOUR general relations available
we can solve for all but one of these unknown variables

If we specify channel width, we can solve for the rest of the variables

What slope is needed to transport the supplied sediment with the available water?

For a specified discharge & sediment supply …

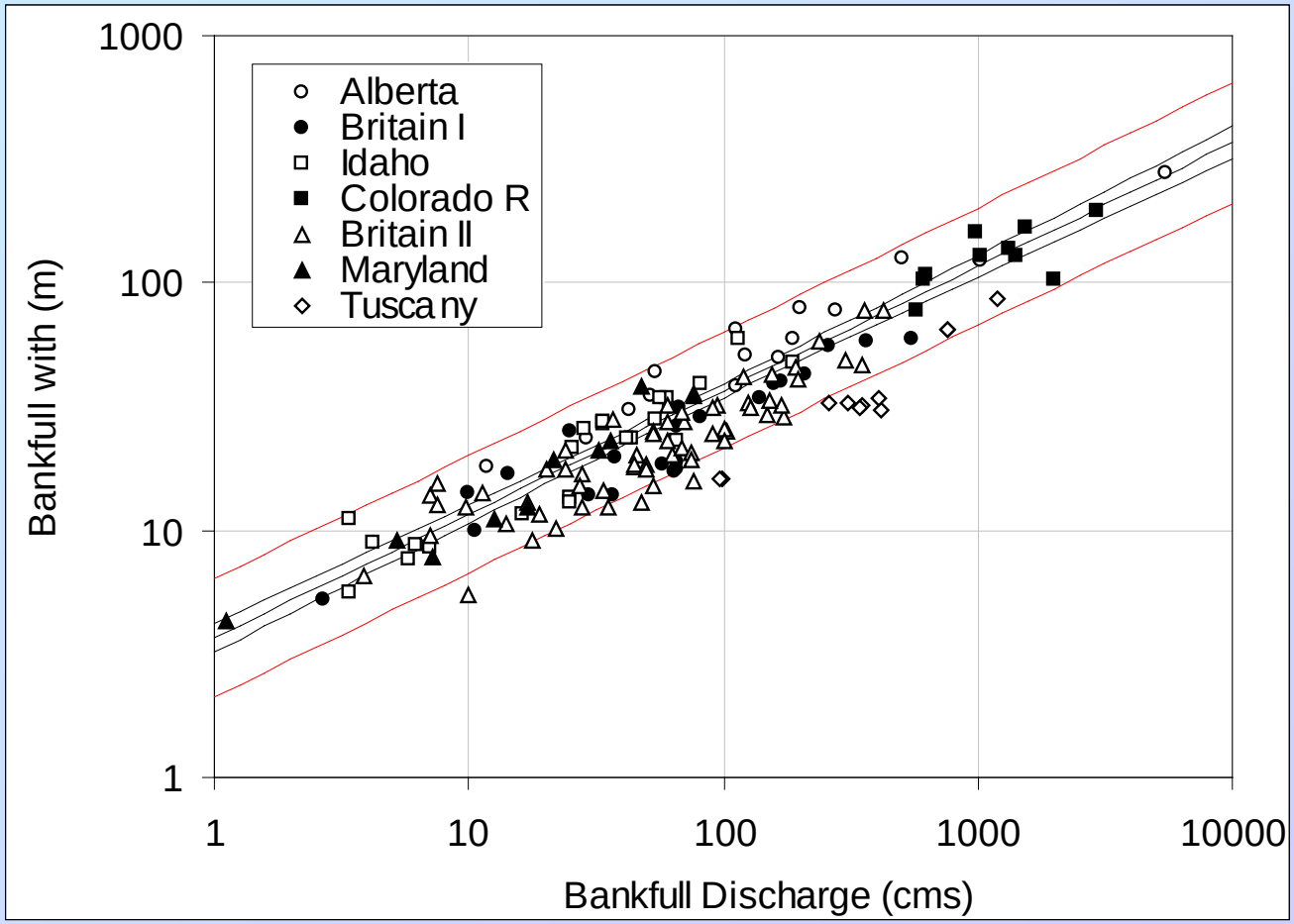


Hydraulic Design of Stream Restoration Projects September 2001
RR Copeland, DN McComas, CR Thorne, PJ Soar, MM Jonas, JB Fripp

Coastal and Hydraulics Laboratory ERDC/CHL TR-01-28

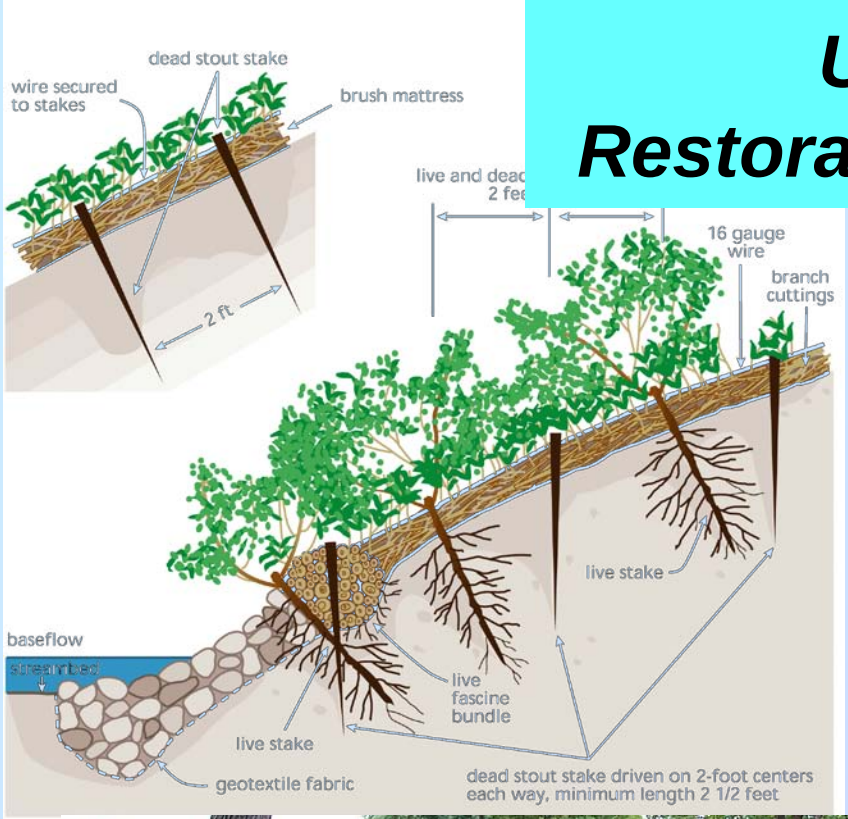
Where does sediment supply fit in the morphological approach?

Hydraulic Geometry = *f*(discharge, not sediment supply)

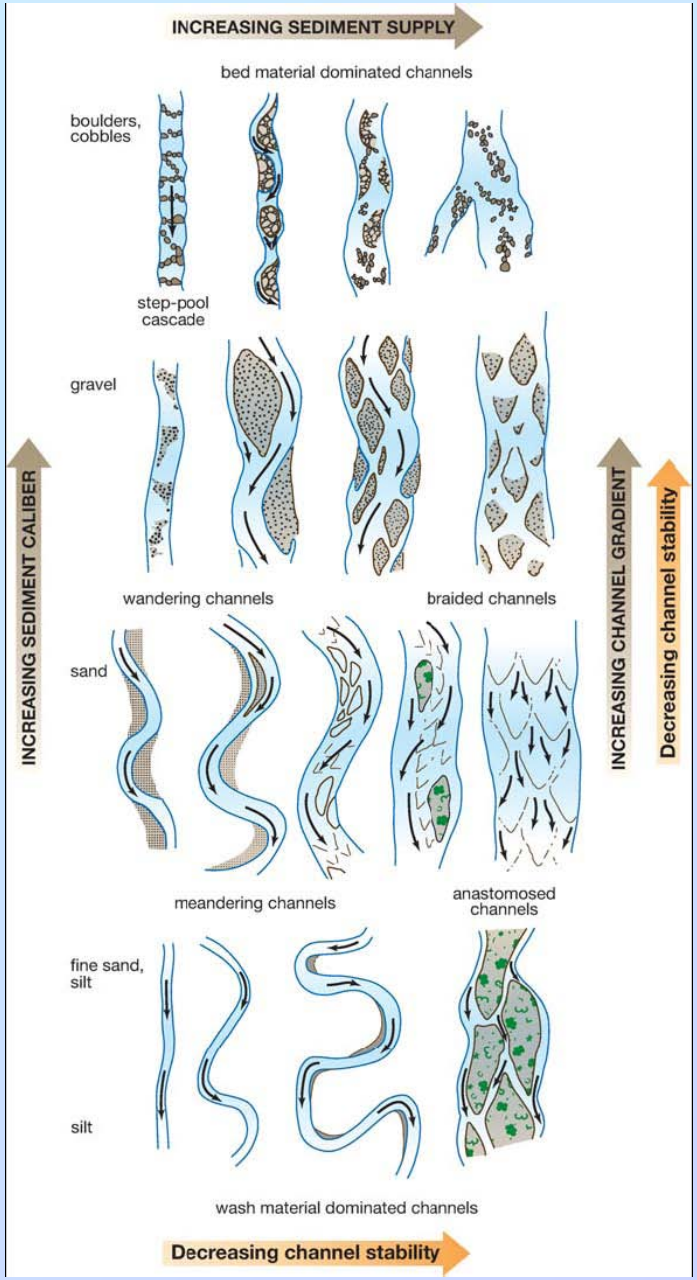


Do we even need to worry about sediment transport?

Urban Restorations



Sediment supply does matter …



Church, Michael. 2006. Bed material transport and the morphology of alluvial river channels. Annu. Rev. Earth. Planet. Sci. 34:325-354.

So, there must be a boundary between cases where sediment supply matters or not

Threshold	**Alluvial**
Bed & banks immobile	Active transport
Easier to model & design Bed & banks must only be strong enough	Harder to design Requires a balance between transport capacity & sediment supply

Nothing new under the sun …

Why we can ‘neglect’ small sediment supply rates

1. Small sediment supply rates → many storms (and many decades) req’d to produce significant aggradation and degradation.
2. Small sediment supply rates → channel morphology and slope required to transport the supplied sediment can be negligibly larger than that of a threshold channel.

So, what is a SMALL sediment supply rate?

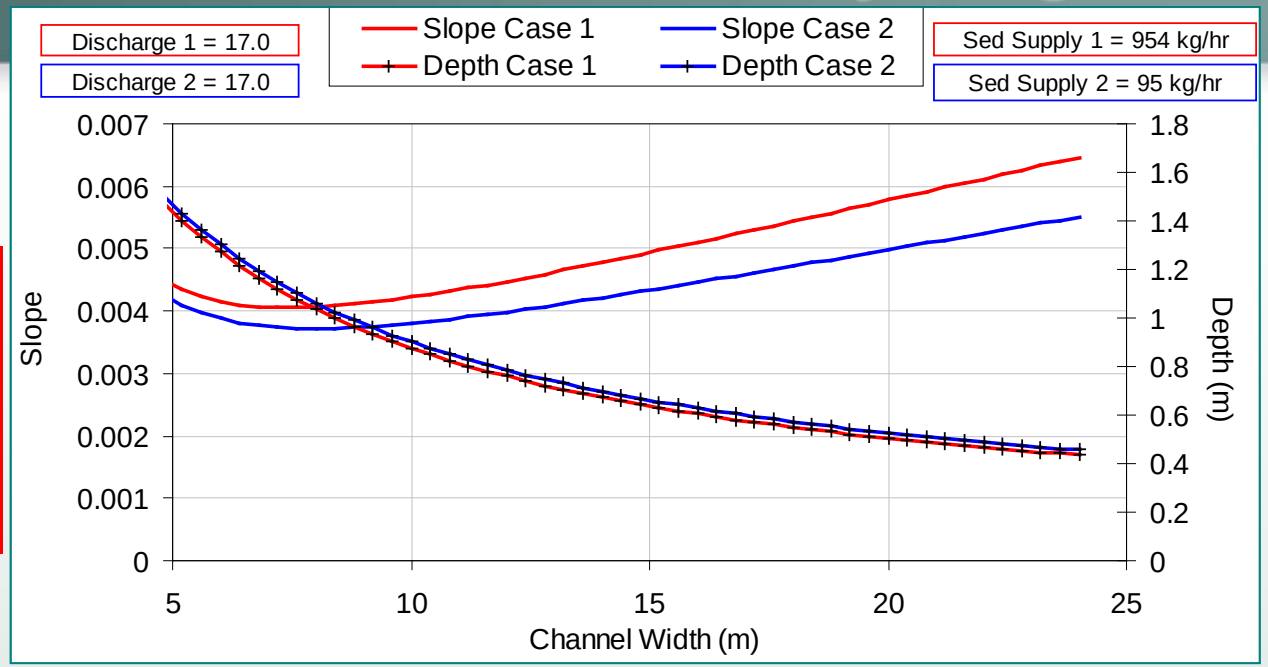
That sounds dangerously like a real question, so first, lets deal with real sediments, which contain a mixture of sizes

For mixed-size sediment, there are complications …

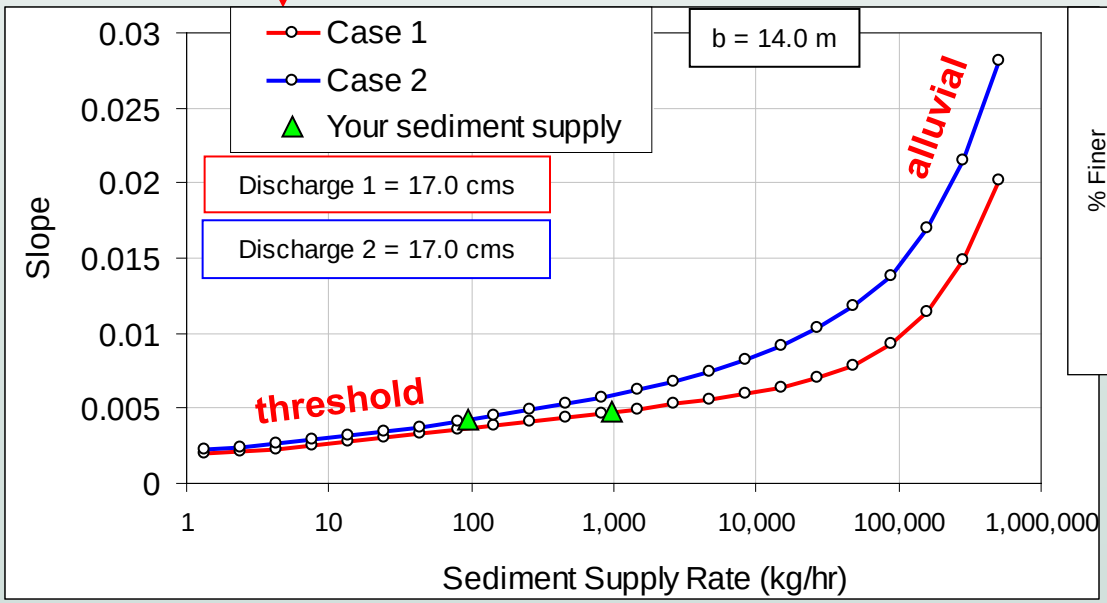
- Grain size of bed ≠ grain size of transport
- Bed is sorted spatially and vertically

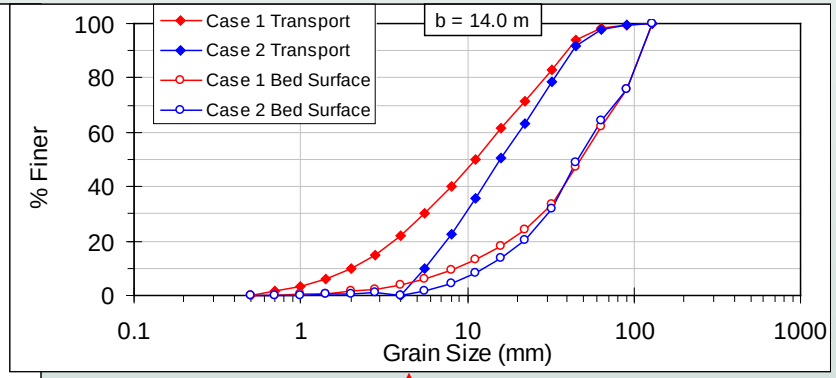
- **Forward**: predict transport rate & grain size
  as function of flow and bed surface grain size
- **Inverse**: predict flow and bed surface grain size
  as function of transport rate & grain size

iSURF Channel Stability Diagram



And get a basis for evaluating consequences of uncertainty in sediment supply!





As a bonus, you get a measure of bed armoring!

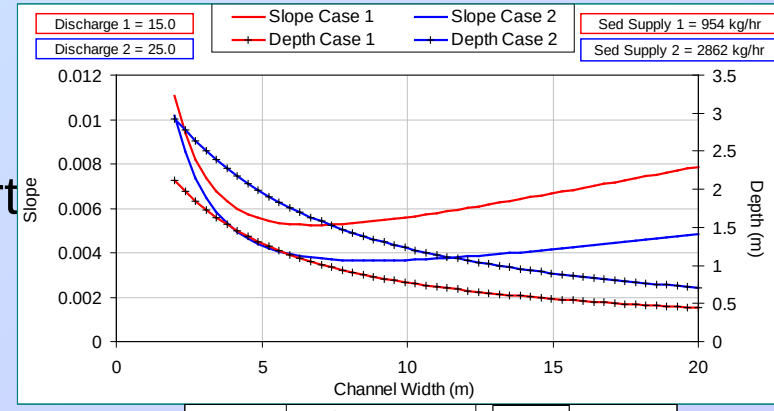
Design steps incorporating sediment supply

1. **Reconnaissance phase**: What is the trajectory of the stream? How has it responded to changes in water and sediment supply over the years?

$$\frac{S_2}{S_1} = \sqrt{\frac{q_{b2}}{q_{b1}}}\left(\frac{D_2}{D_1}\right)^{3/4}\left(\frac{q_1}{q_2}\right)$$

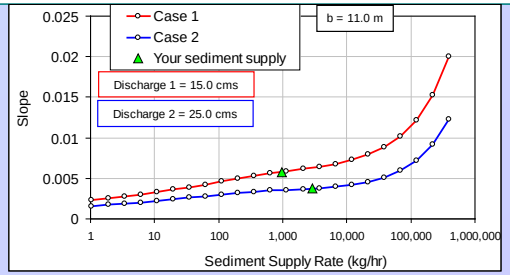
iSURF State Diagrams

2. **Develop flood series, specify flood frequency → Design *Q*.**
   {*Select Q_{bf} for flood frequency specified to maintain riparian ecosystem & prevent vegetation encroachment*}



3. **Estimate sediment supply**

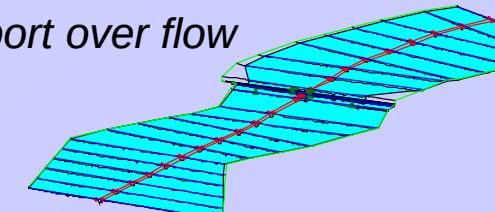
4. **Planning phase**: What slope *S* will transport the sediment supply with the available Q_{bf}? Calculate (b, S) combination {S and valley slope determine sinuosity}



Check if alluvial *v.* threshold channel

5. **Develop flow duration curve**

6. **Design phase**: Evaluate trial designs. Will the sediment supply be routed through the reach over the flow duration curve?
   {*Build 1-d hydraulic model for trial design. Calculate cumulative transport over flow duration curve at each section; evaluate sediment continuity.*}



7. Bottlenecks or blowouts? Adjust for sediment continuity

Linking the two approaches

"Morphological" Approach: Reference reach + hydraulic geometry

Bankfull geometry → Test for flow competence and transport capacity, then match to water & sediment supply

"Process" approach: specify water and sediment supply

Governing physical relations → Bankfull geometry then compare to typical channel geometry

Design channel from a template, then check for transport? OR Incorporate water & sediment supply into the design process?

In either case: the balance between sediment supply & transport capacity needs evaluation.

I

At the core of the template approach is a ***correlation*** between channel geometry, flow, and sediment supply

The correlation ***requires*** that the channels have ***adjusted*** to their water and sediment supply.

But what if channel is currently adjusting, or perpetually adjusting?

How would you know? How long will it take?
Will two channels with the same flow regime
& different sediment supply have the same geometry?

!

A template approach provides no basis for ***linking cause and effect*** in a logically complete and ***testable*** framework.

If a template-designed project "fails",
how is the method to be improved?

If a template approach works in one place,
how do you know it will work in another?

Stream Design Framework

Are objectives & outcomes connected to environmental drivers in an explicit, predictive fashion?

Are objectives linked to design in a quantitative and testable fashion?

Drivers

Water & sediment supply
Pollutant loading
Introduced species

Objectives

Reduce sediment, pollutant loads
Restore aq. & riparian populations
Protect infrastructure & property
Improve aesthetics

Design Variables

Channel geometry & composition
Floodplain elevation & extent
Riparian vegetation
type, density, location

Outcomes

WQ standards
Physical performance
Accepted appearance
Species recovery

Why Predict?

(1) tradeoffs
(2) project costs
(3) judging success
(4) ***learning***

Prediction includes uncertainty

Uncertainty

Is not an excuse

Does not = ignorance

Is pervasive and unavoidable

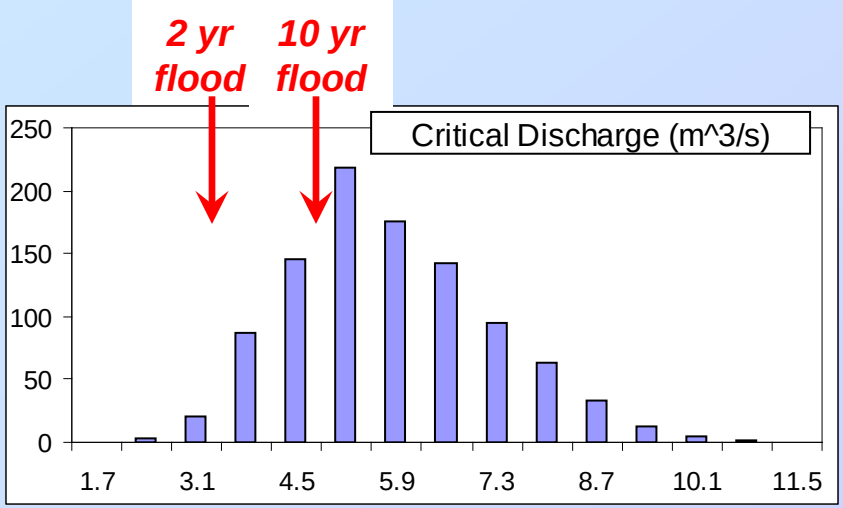
Incorporating Uncertainty in Channel Design

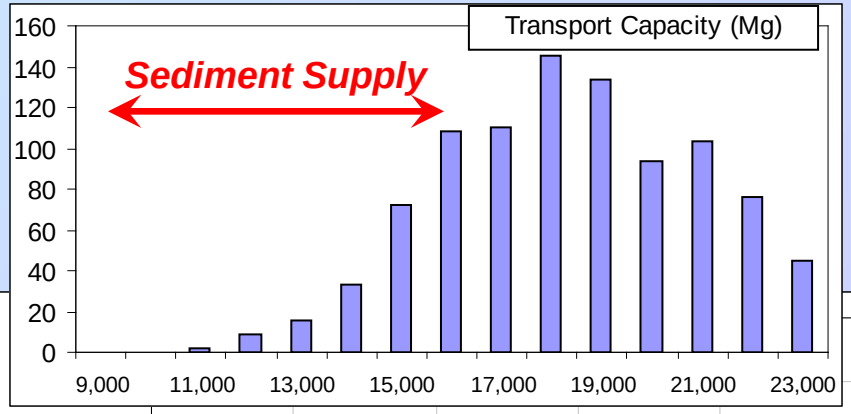
(Large Uncertainty ≠ Unpredictable)

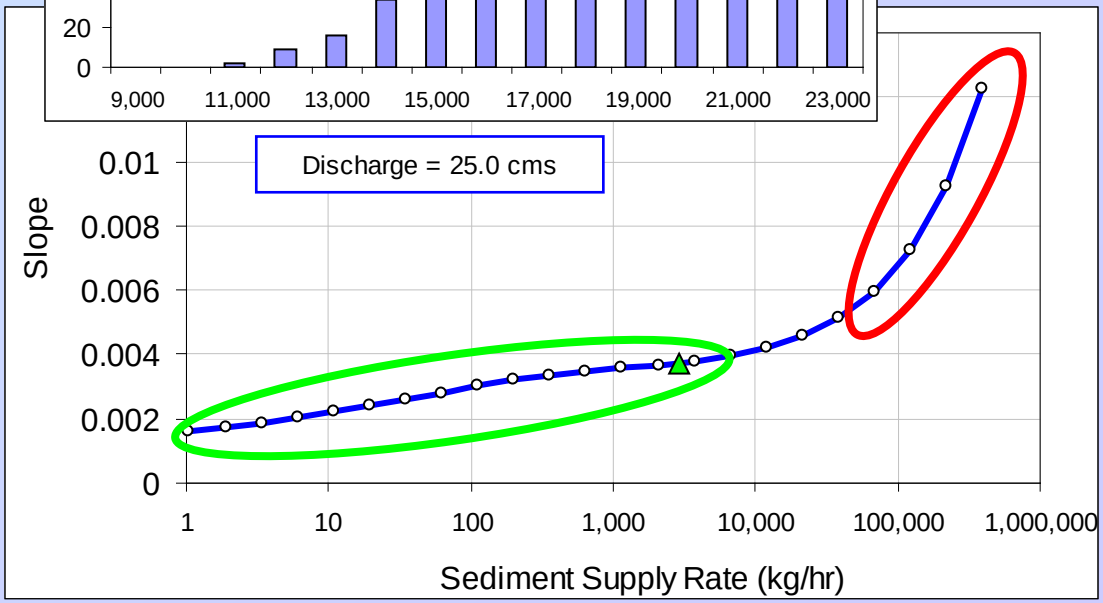
We can evaluate channel stability for flows of specified likelihood.

Or transport capacity relative to uncertainty in sediment supply

We can evaluate whether there is much of a chance that slope is sensitive to sediment supply such that further study is warranted







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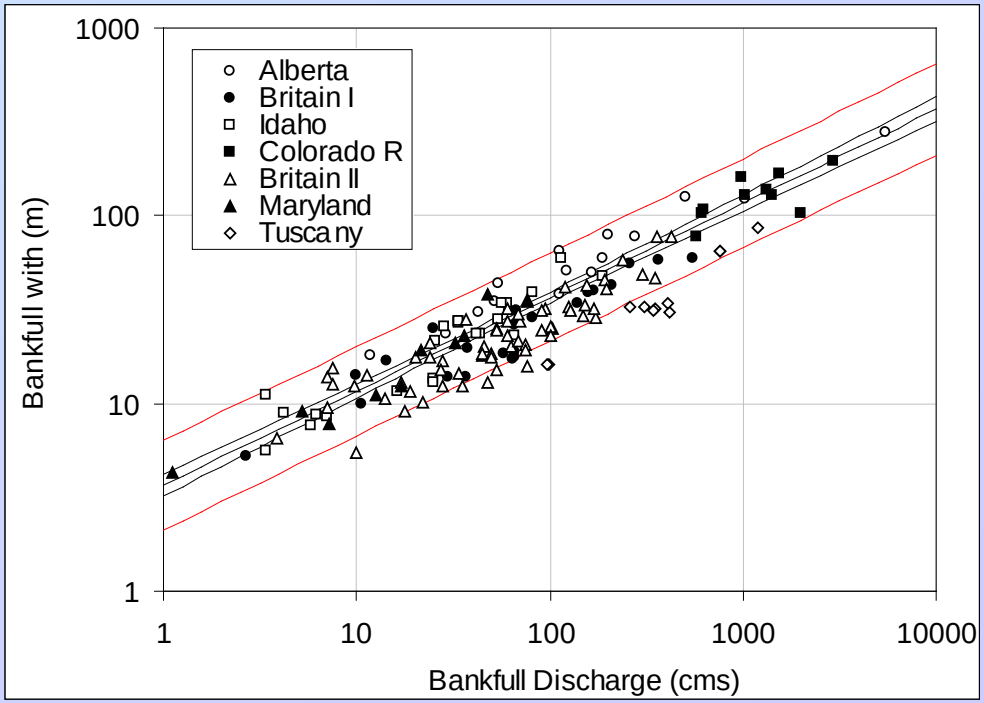
If we expect a channel to adjust to a particular geometry, why not bypass the adjustment process and just put the channel in its final equilibrium form?

What sets the equilibrium form?

- What flow and sediment supply is used?
- Do you get the same form for any sediment supply?
- In any region? How is this demonstrated?
- If the design performs poorly, what do you change?



If we expect a channel to adjust to a particular geometry, why not bypass the adjustment process and just put the channel in its final equilibrium form?

Will the ‘final’ form be stable with the post-construction riparian vegetation?

If we expect a channel to adjust to a particular geometry, why not bypass the adjustment process and just put the channel in its final equilibrium form?

What about the algae and bugs and fishes and trees?

Using modern design tools and the geomorphic reclamation approach, it's possible to reclaim highly disturbed lands and create fully functional natural systems virtually indistinguishable from their surrounding landscapes.

Morphologic stream design is not ecologic stream design

The classic observations of river geometry provide the observations that have fueled geomorphic research for the subsequent 60 yrs (and counting)

Defined in terms of equilibrium , they are unable to predict transient conditions

Devoid of mechanism, they have no basis for predicting new conditions

With no explicit linkage between cause and effect, they do not support learning by doing

All of these – predicting transient or new conditions and learning – must be and are supported by additional explanation

Hydrological Functioning of Surface-Mined Watersheds in Western Maryland: Restoration or Reclamation?

Keith N. Eshleman and Brian C. McCormick

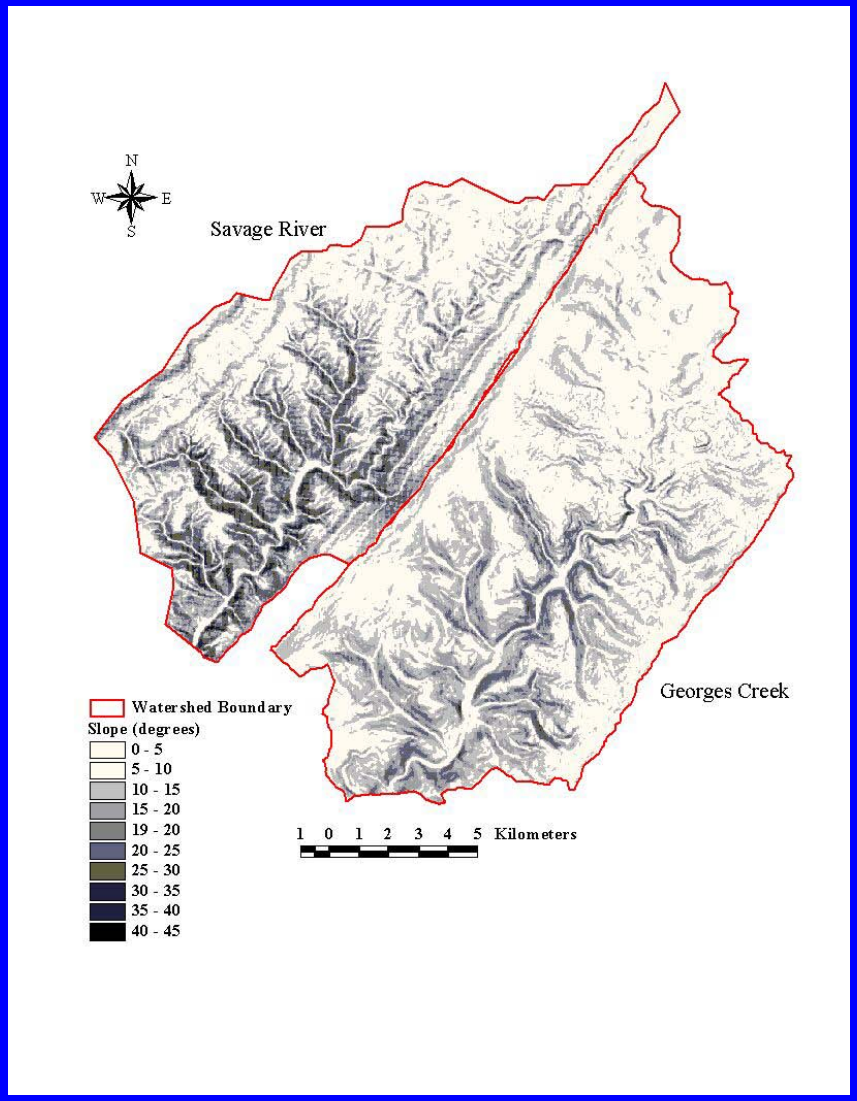
Appalachian Laboratory, University of Maryland Center for Environmental Science, Frostburg, MD

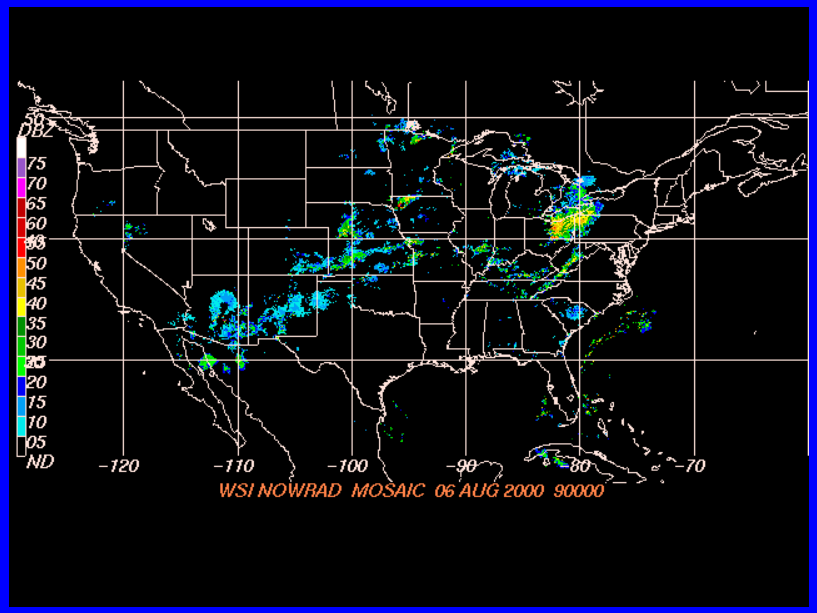
Geomorphic Reclamation and Natural Stream Design Forum: Bristol, VA; April 2009

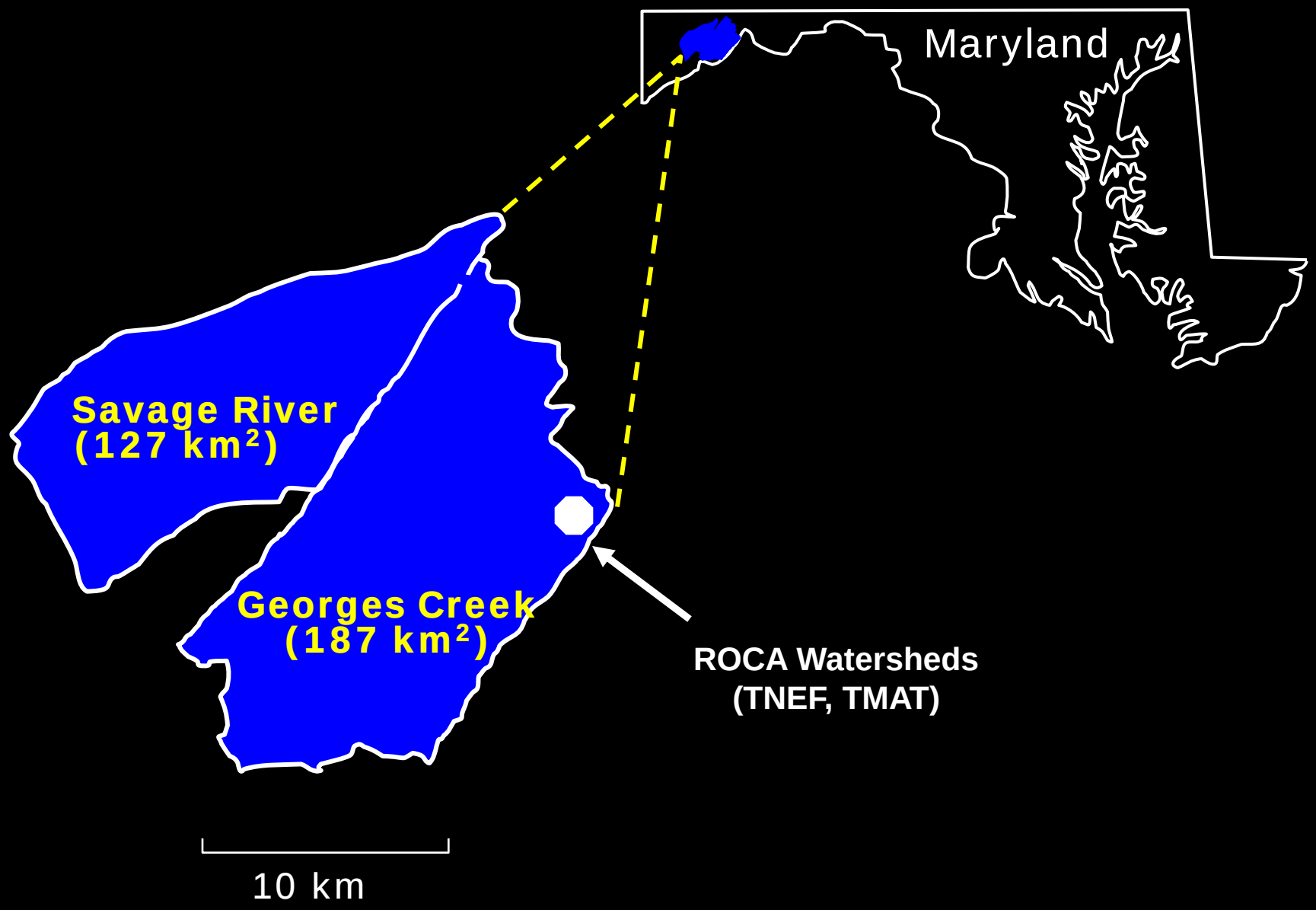
Research Questions

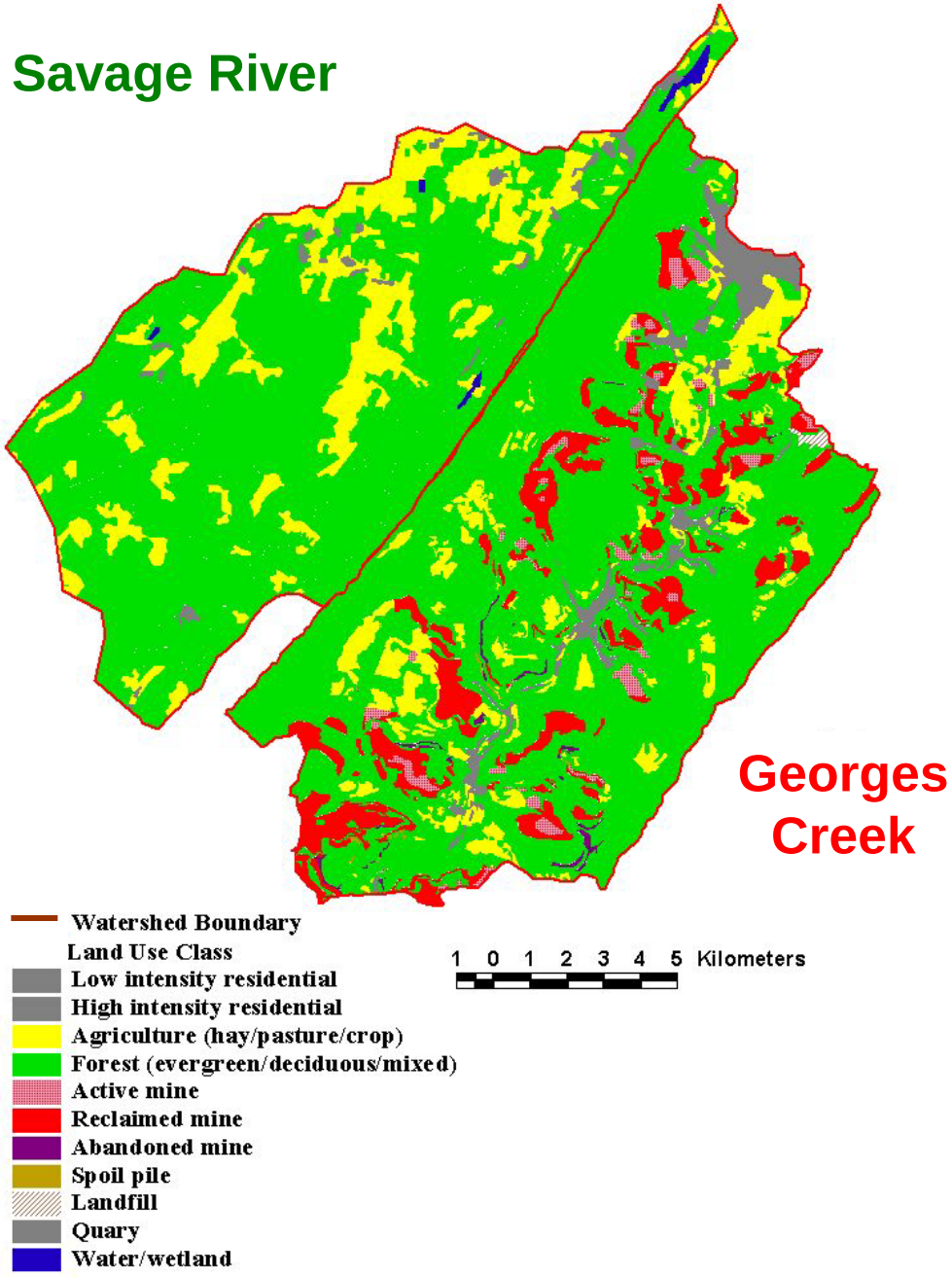
- What changes in the hydrologic balance of mined lands can be attributed to surface mining?
- Are normal hydrologic functions typically restored by current reclamation practices?
- How well does the SCS-CN method accurately predict storm runoff responses of mined/reclaimed watersheds?
- Is the SCS-CN method biased in any way?
- How might we improve land reclamation in a way that reduces disturbances to the hydrologic balance both on-site and to the larger basins within which the mining has occurred?

Flooding on the Central Appalachian Plateau (CAP): interaction among precipitation, topography, and land use change






Maryland
Savage River
(127 km²)
Georges Creek
(187 km²)
ROCA Watersheds
(TNEF, TMAT)
10 km



2006 Land Use/Land Cover

Georges Creek

69% Forested
17% Mined/Reclaimed
8% Agriculture
7% Developed

Savage River

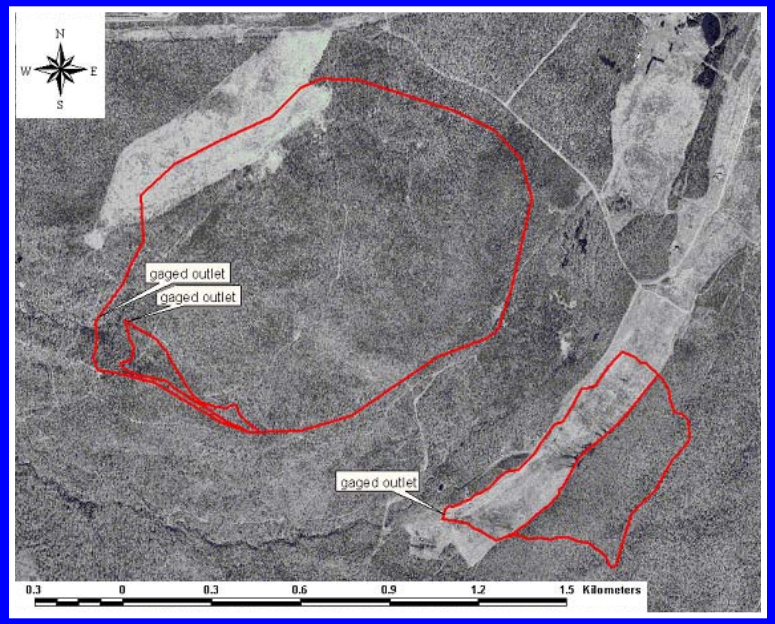
82% Forested
15% Agriculture
3% Developed

TNEF (Tributary to Neff Run)

TMAT (Tributary to Mathews Run)

Results: ROCA Watersheds[1,2]

- Similar annual and long-term water balances
- No significant difference in timing of stormflow
- Similar unitgraphs
- Higher peak runoff and total storm runoff due to mining/reclamation (on average by a factor of 2-3)
  - Reduced soil infiltration capacity due to loss of forest floor and topsoil; soil compaction
  - Overland flow vs. subsurface stormflow
- Observed differences are conservative



[1]Negley and Eshleman (*Hydrological Processes*, 2006)
[2]Simmons *et al.* (*Ecological Applications*, 2008)

Zero-Order Watersheds

TSSR (Tributary to Seldom Seen Run)

TSNR (Tributary to Squirrel Neck Run)

Watershed Characteristics

Site	Area (ha)	Map HSG	Mined Area	Year reclaimed[1]	Elevation (m MSL)	Flume Installed	Flume Removed
Tributary Matthew Run (TMAT)	27.1	C	47%	~1982	830m	10/1999	10/2008
Tributary East Branch Neff Run (TNEF)	3.0	C	0%	-	720m	10/1999	Active
Tributary Squirrel Neck Run (TSNR)	11.1	B/C	100%	~1982	580m	1/2005	Active
Tributary Seldom Seen Run (TSSR)	5.1	C	100%	~2002[2]	630m	9/2004	Active

1) All mined areas reclaimed by regrading to approximate original contour and replanting with grasses per PL95-87
2) Reclamation in this watershed has continued with the planting of some woody vegetation (black locust trees), regrading including filling of rills and gullies, and liming and reseeding.

Small Watersheds: Runoff Results

TSSR > TMAT > TNEF ≈ TSNR

Watershed	Events	Date	Rainfall (mm)	Runoff (mm)
TMAT	64	6/2000-9/2008	18-170	0-93
TNEF	65	6/2000-9/2008	18-170	0-35
TSNR	29	1/2005-9/2008	18-90	0-11
TSSR	30	9/2004-9/2008	18-107	0-50

MINELAND RUNOFF FROM SCS METHOD

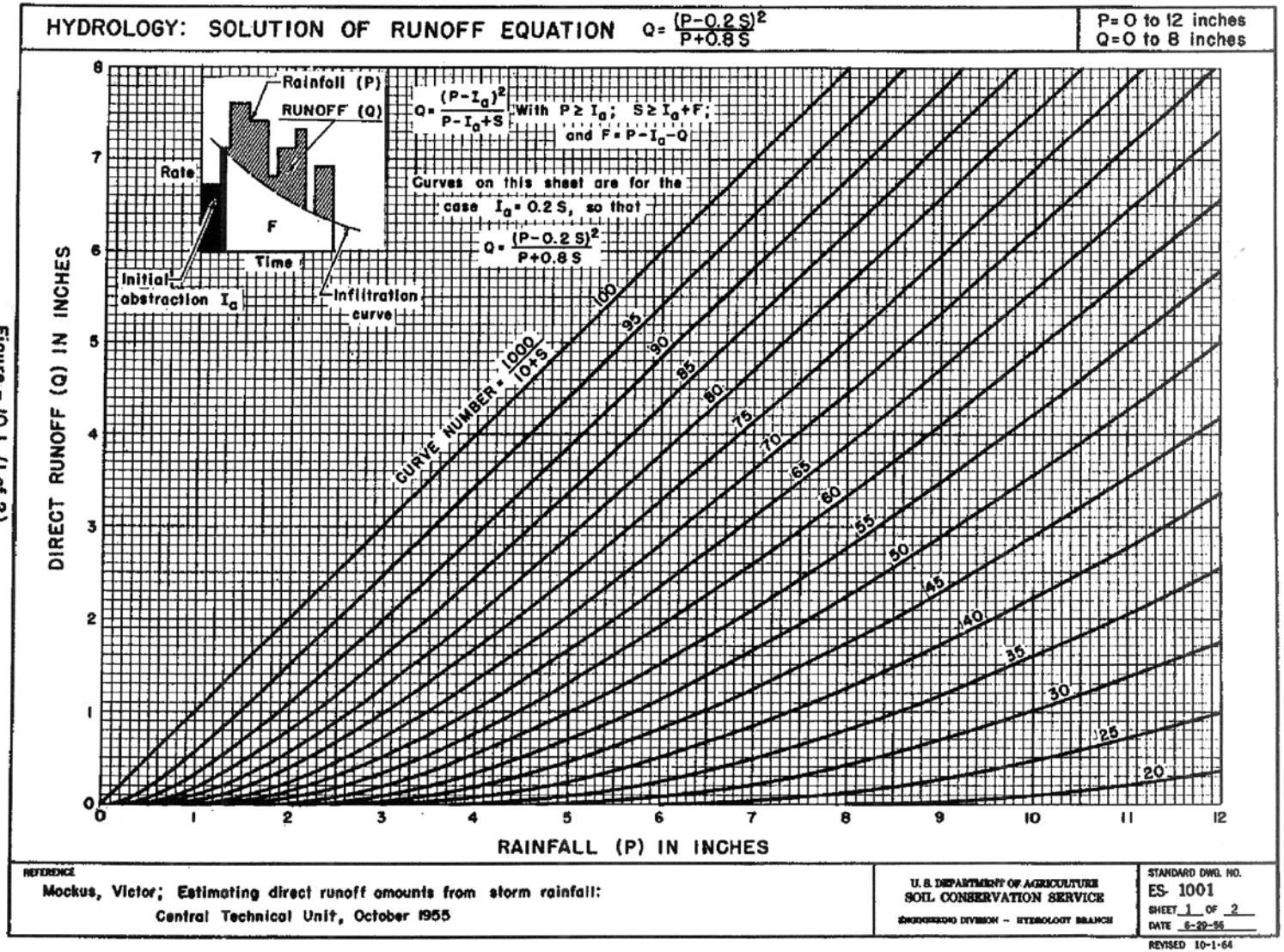


Figure – 10.1 (1 of 2)

MINELAND RUNOFF FROM SCS METHOD

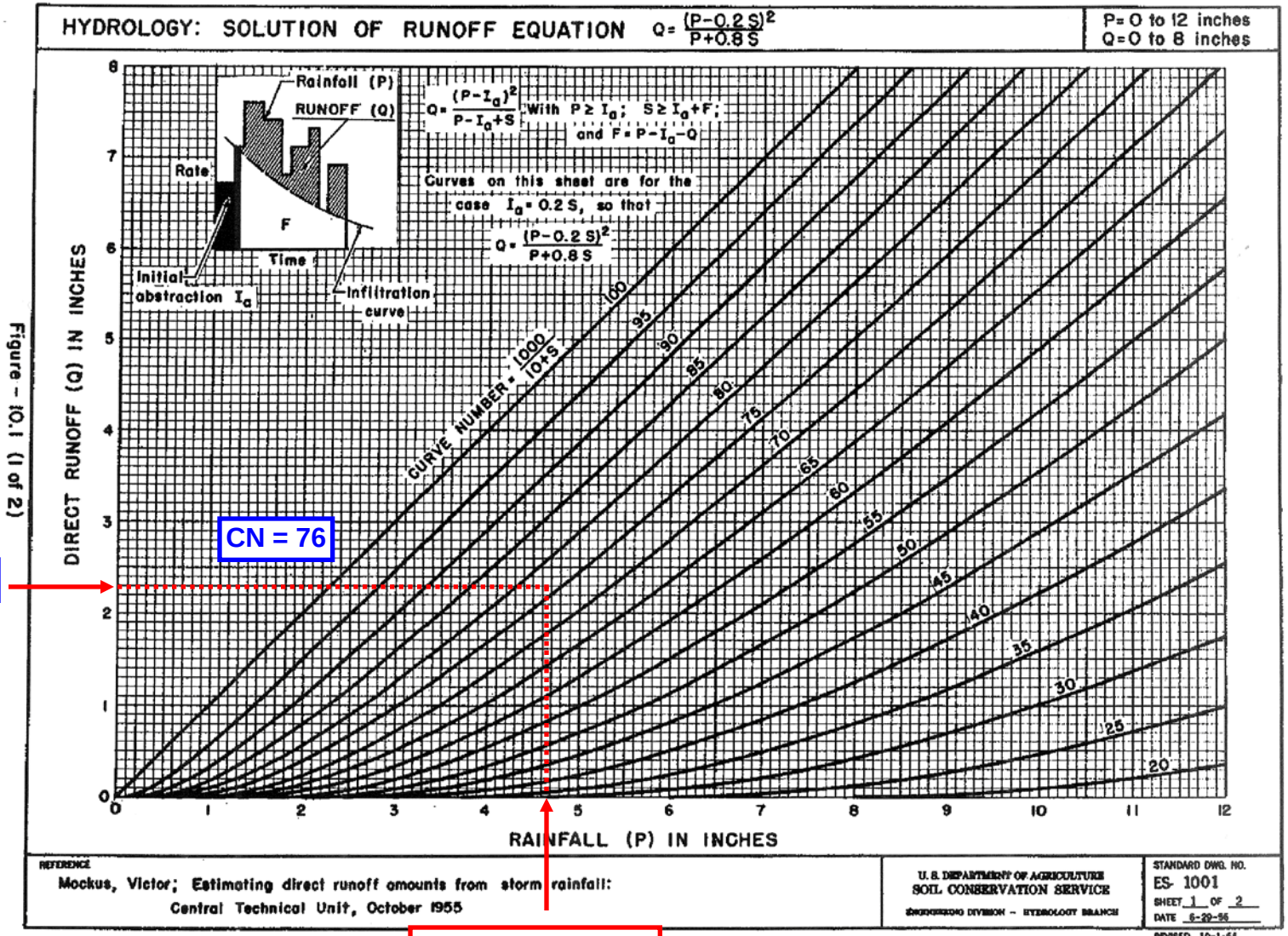


Figure – 10.1 (1 of 2)

Runoff = 2.3”

Rainfall = 4.67”
(25 yr/24 hr storm)

TR-55 Tabulated Value

Observed Value

TNEF

TR-55 Tabulated Value

Observed Value

TSNR

TR-55 Tabulated Value

Observed Value

TMAT
(reclaimed)

TR-55 Tabulated Value

Observed Value

TSSR

Estimated and Observed CNs for Reclaimed Watersheds

Source	Location	Watershed	TR-55/ NEH-4*	Observed
Ritter and Gardner (1991)	Central PA	Browncrest	74	88
		Moshannon	75	83
		Snow Shoe	77	88
Bonta et al. (1997)	East Central OH	C06	-	87
		M09	-	91
		J11	-	88
McCormick and Eshleman (this study)	Western MD	TMAT	74	81
		TMAT (Reclaimed Area)	74	92
		TSNR	68	64
		TSSR	74	87

Peak Runoff Rates

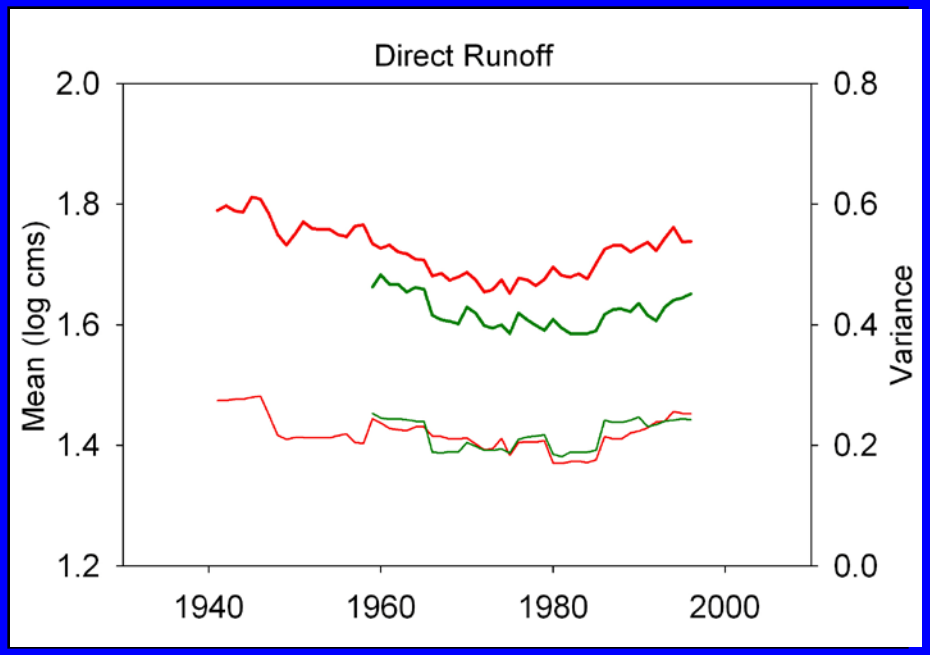
Watershed	Area (ha)	Tc (min)	CN			Peak Runoff Rates (m^3/s)								
						Qp 2yr			Qp 10yr			Qp 100yr		
			TR-55	*Obs*	Error	TR-55	*Obs*	Error	TR-55	*Obs*	Error	TR-55	*Obs*	Error
TNEF	3.0	20	70	*72*	**+2**	0.13	*0.16*	***23%***	0.38	*0.41*	***8%***	0.68	*0.73*	***7%***
TMAT	27.1	30	74	*81*	**+7**	1.29	*2.03*	***57%***	3.26	*4.28*	***31%***	5.62	*6.80*	***21%***
TSNR	11.1	27	68	*64*	**-4**	0.24	*0.21*	***-13%***	0.89	*0.84*	***-6%***	1.78	*1.71*	***-4%***
TSSR	5.1	11	79	*87*	**+8**	0.54	*0.80*	***48%***	1.15	*1.47*	***28%***	1.86	*2.20*	***18%***

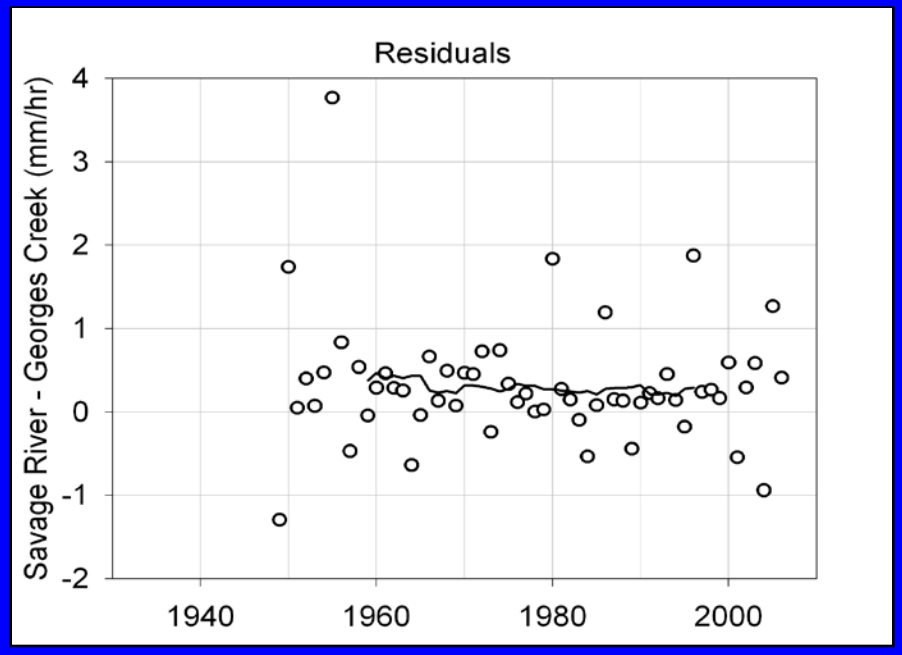
River Basins: Method #1

Comparison of flood frequency distributions (log Pearson Type III = LP3 w/ weighted skew) computed using the annual maximum series of daily streamflow (AMSS)

a) Differences for 2 time periods (1949-1975; 1976-2006): assumes ***episodic*** non-stationarity

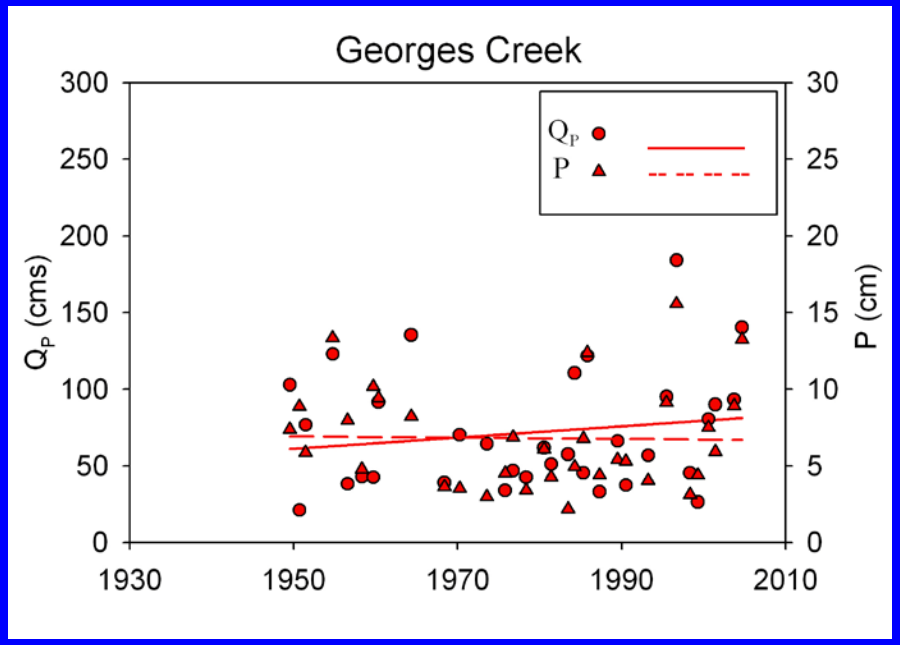
b) Differences in moments using a 21-year moving window: better for addressing a ***secular*** change

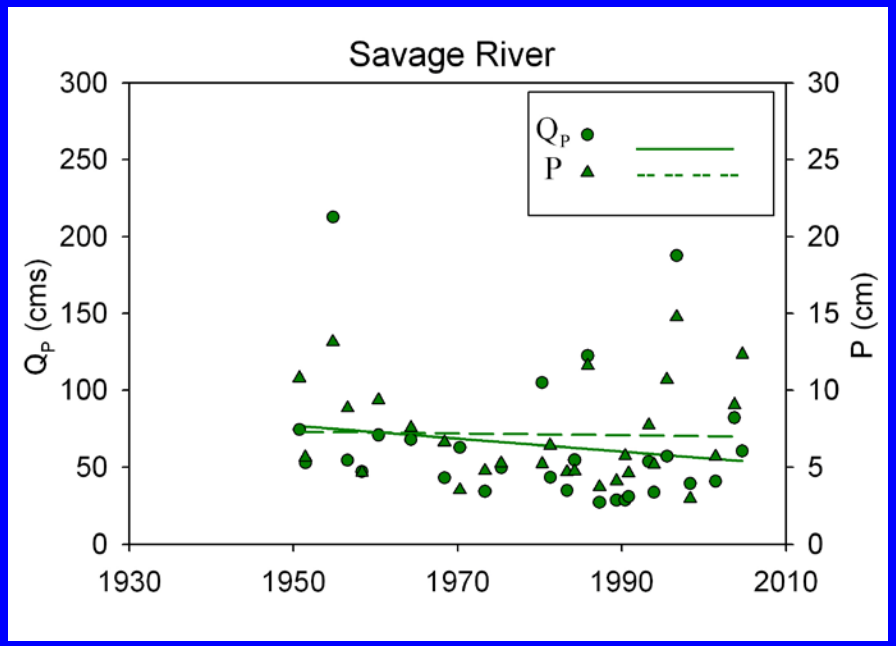




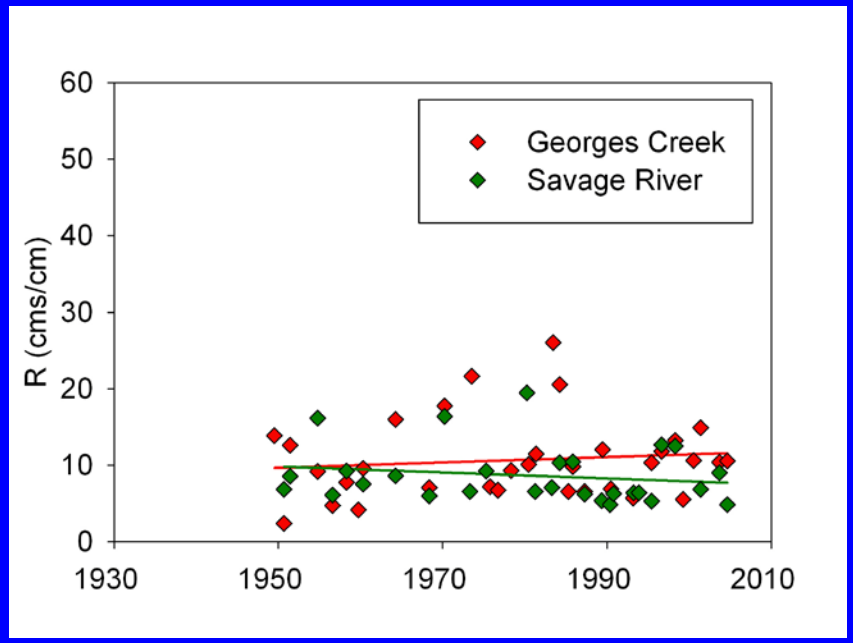
McCormick *et al.*, *WRR*, in revision

Q_P and P Trends*





R' Trends*



River Basins: Method #2

*regression lines shown

*no trends were statistically significant ($p \leq 0.05$) using 3 different tests

McCormick *et al.*, *WRR*, in revision

River Basins: Method #3

Paired rainfall-runoff analysis of 27 contemporary warm season storm events (1996-2006)

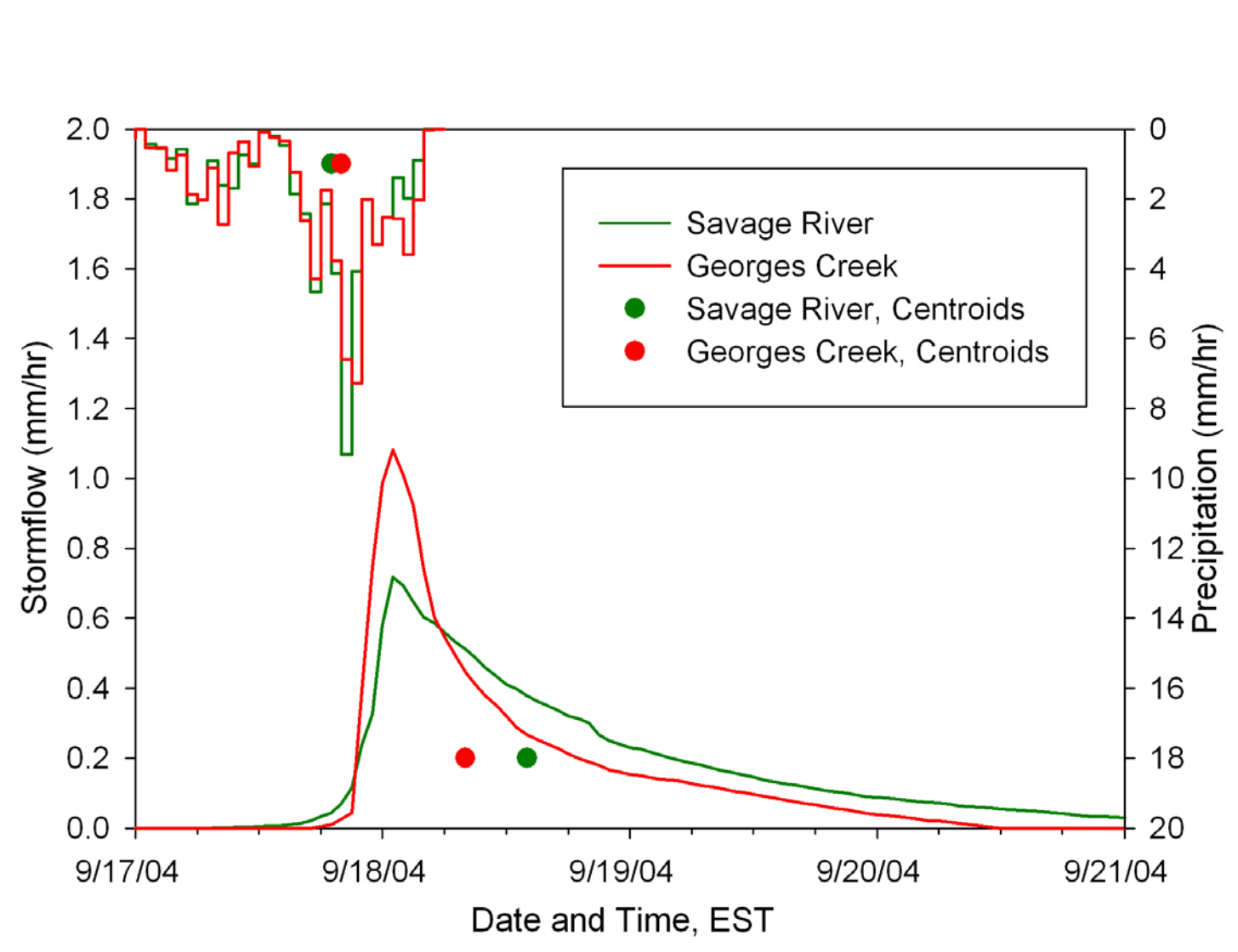
a) Classical hydrograph separation: computation of normalized runoff volume (R_V) and peak runoff (R_P)

b) Total event areal rainfall (P) and peak areal intensity (p_{max}) from the NWS WSR-88D (NEXRAD) "Stage III" operational radar rainfall product (archived)

c) Compare R_V:P, R_P:p_{max}, and centroidal lag (L_C)

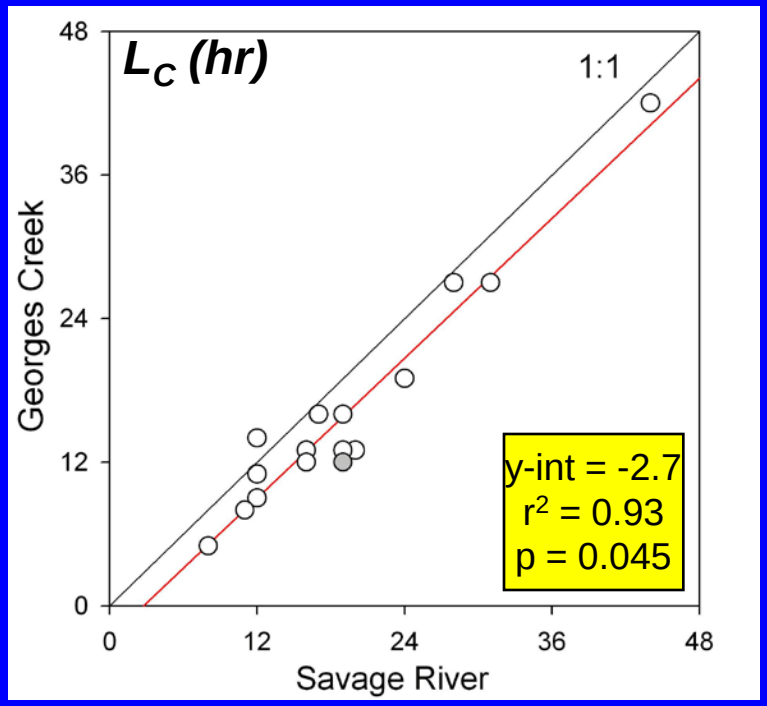
d) Eleven events culled *a priori* for violating pre-set conditions

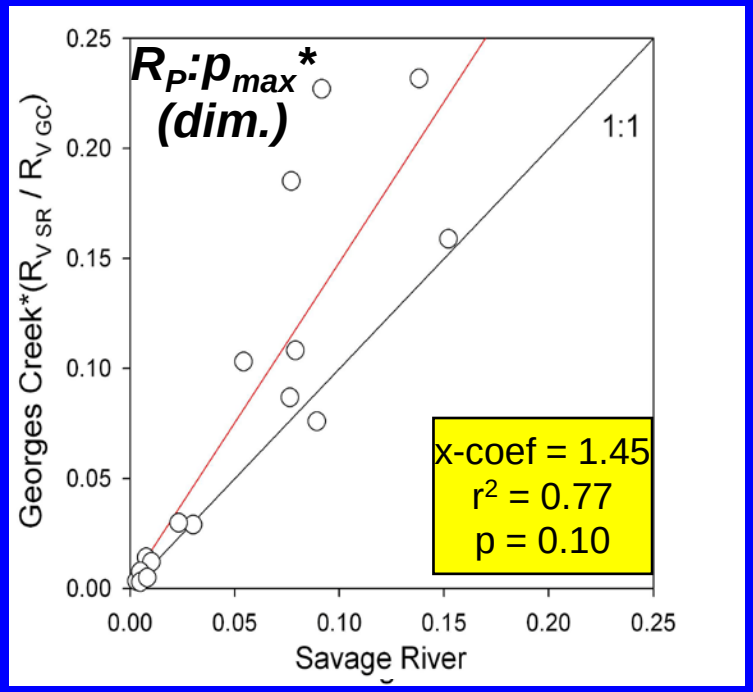
Remnants of Hurricane Ivan (September 2004)

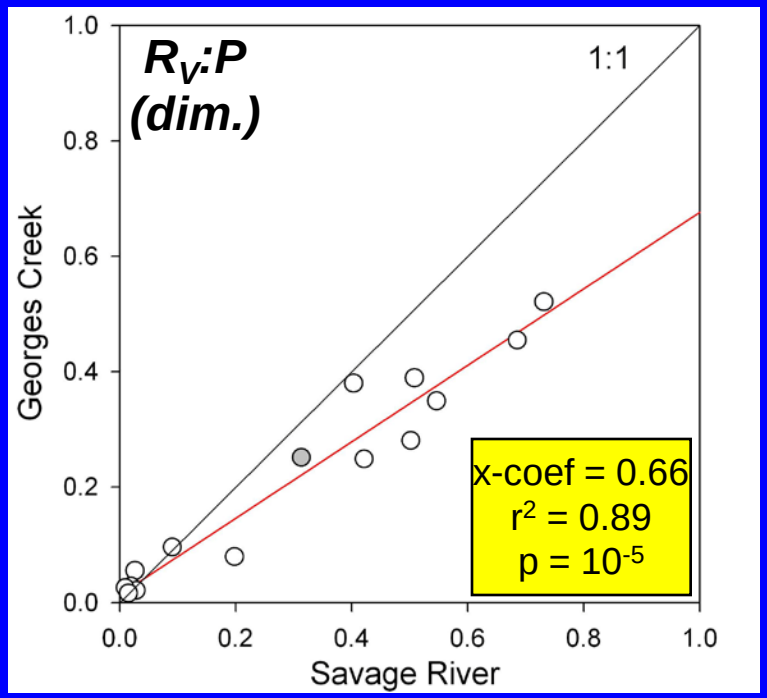


McCormick *et al.*, *WRR*, in revision

16 Runoff Events (1999-2006)







The Legacy of Deep Mining in Georges Creek

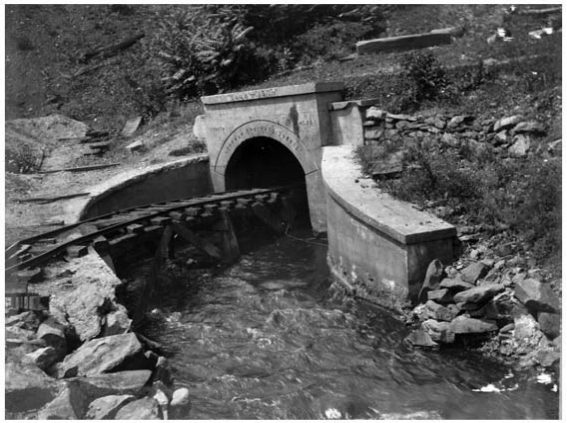
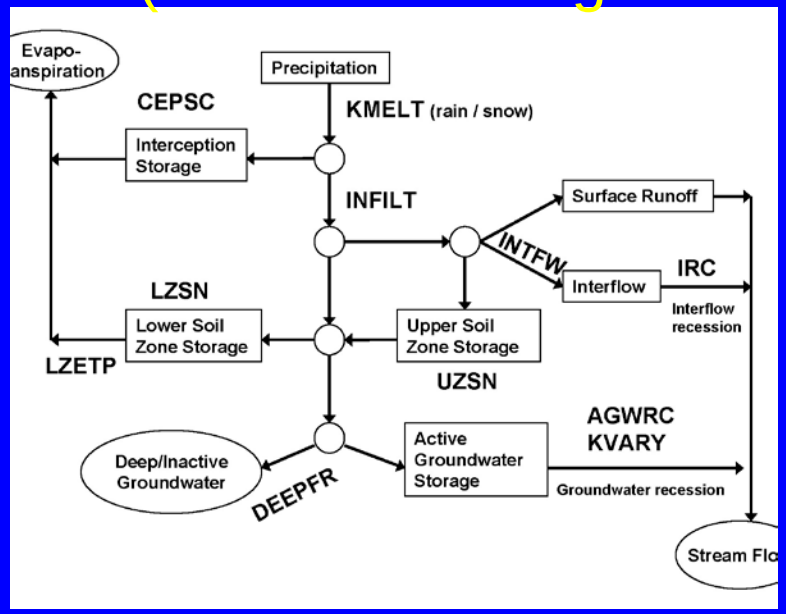


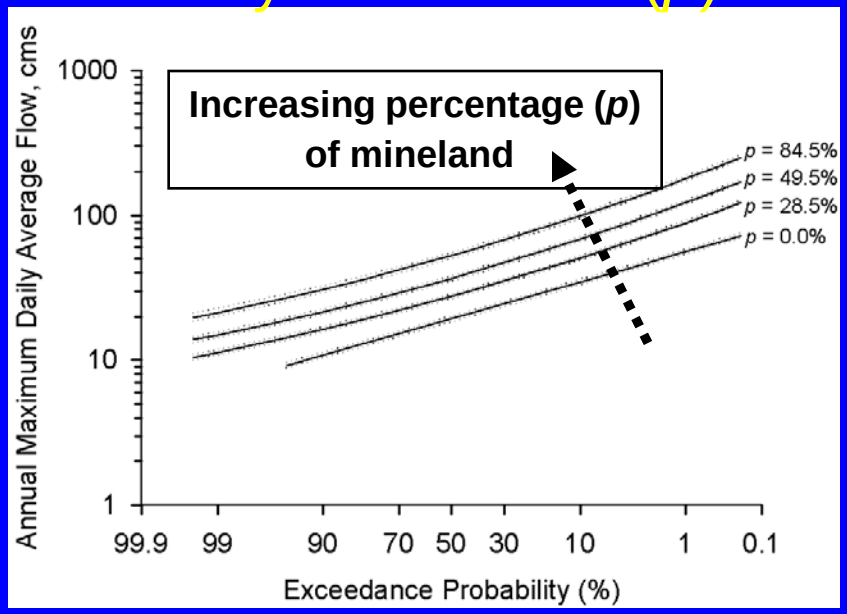
Photo Credit: USGS

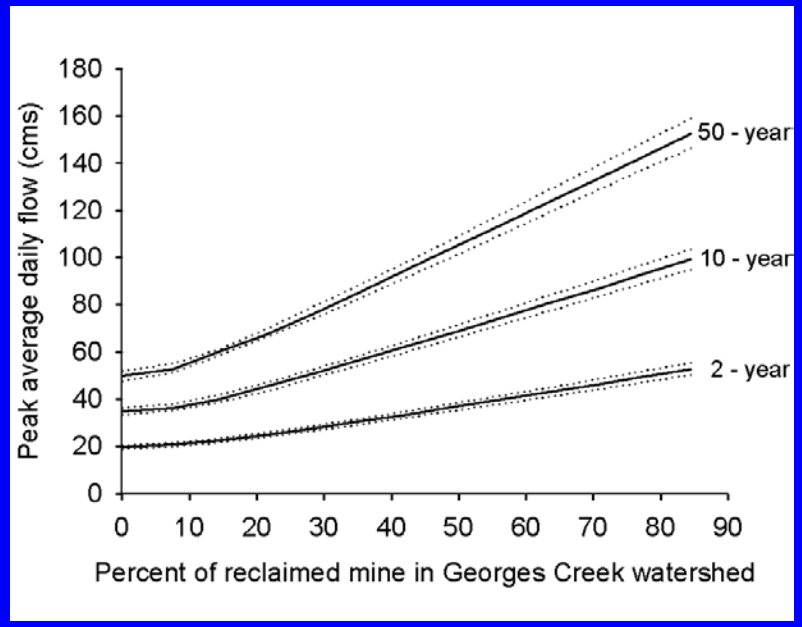
McCormick *et al.*, *WRR*, in revision

HSPF (calibrated using PEST)



"Family" of FFCs = f(*p*)





Stormflow peaks increase with increasing LCLUC: 25% mineland causes enhancement by a factor of about 40% at all frequencies

Ferrari *et al.*, *WRR*, in press

Conclusions

- Surface mining and land reclamation can *amplify* storm runoff responses of small catchments.
  - SCS-CN method often *underestimates* actual response
- Effects of mining were not *detectable* at the river basin scale using long gage records and conventional flood frequency methods.
- A *comparative paired analysis* produced significant results, in particular:
  - Comparable flood volumes (assumed)
  - Decreased centroidal lag (~ 3 hr)
  - Higher normalized peaks (~ 40%, across the board)
- Modeling suggests that increased mining and reclamation will further “enhance” flooding responses in Georges Creek.

Acknowledgments

Collaborators

P. Townsend, T. Lookingbill, L. Pitelka, W. Currie, M. Castro

Scientific Support at AL

J. Ferrari, C. Giffen, M. Ramsey, R. Richardson, G. Frech, M. Kline, J. Welch, D. Wiley, K. Kline, C. Kingdon

Data & Permissions

MDE - permits
MBOM - mining history
NRCS - aerial photography
USGS - historical streamflow data
NCDC-NOAA - historical precipitation data
Ian Littlewood - IHACRES
Paul Willison & Simon Mohr (deceased) - landowner permissions

Sponsors

A.W. Mellon Foundation
NASA LCLUC Program

Disturbed Land Reclamation Design and Construction Using Fluvial Geomorphic Techniques

Presented by: Melissa Robson, E.I.
Water and Earth Team
1225 Red Cedar Circle, Suite A
Fort Collins, CO, 80524

970-225-6080

Water & Earth Technologies, Inc.

The Water and Earth Team (WET)

This project was completed by:

Water & Earth Technologies, Inc.
Water Resources and Environmental Consulting
1225 Red Cedar Circle, Suite A Fort Collins, CO 80524 (970) 225-6080

Habitat Management, Inc.
14 Inverness Drive East, Suite G-228, Englewood, CO 80112

Chevron

Chevron Mining Inc.
McKINLEY MINE

WET Qualifications

- Professional expertise and experience in:
  - Sediment and erosion control
  - Surface water conveyance and runoff control systems
  - Regulatory permitting services
- Trained in disturbed-land reclamation models including SEDCAD, RUSLE and Natural Regrade

Project Location

The project area is located due North of Gallup NM

Overview of the McKinley Coal Mine

Water & Earth Technologies, Inc.

Reclamation challenges that are presented for a surface coal mine include:

- Areas of disturbance are very large (>100 ac.),
- An earth balance is desired to minimize haul away or import materials, and

- Haul and push distances should be minimized for economic purposes.

Disturbance is composed of overburden material cast into piles by draglines.

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Area 12C

Project Area at the McKinley Mine Site

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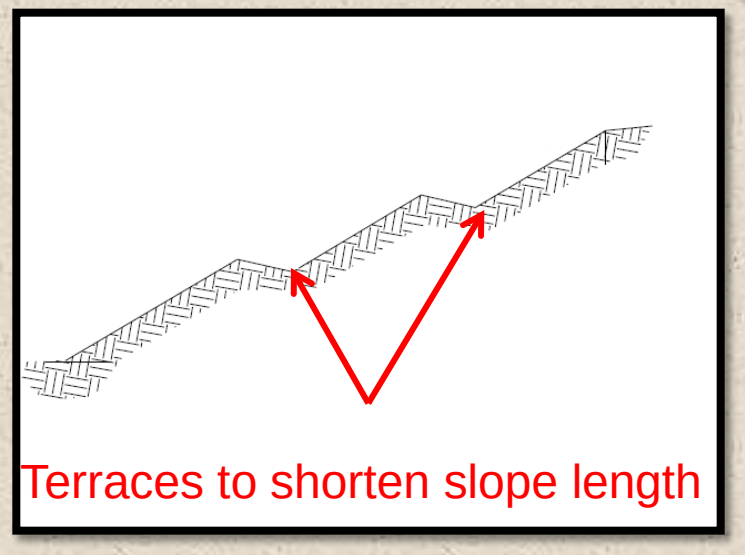
Site Specific Challenges

1. Long steep slopes (18%-35%)
2. Southwest facing aspect
3. Undisturbed rock outcropping
4. Operational need to limit bulldozer pushes
5. Balance cuts and fills

Image courtesy of Google Earth

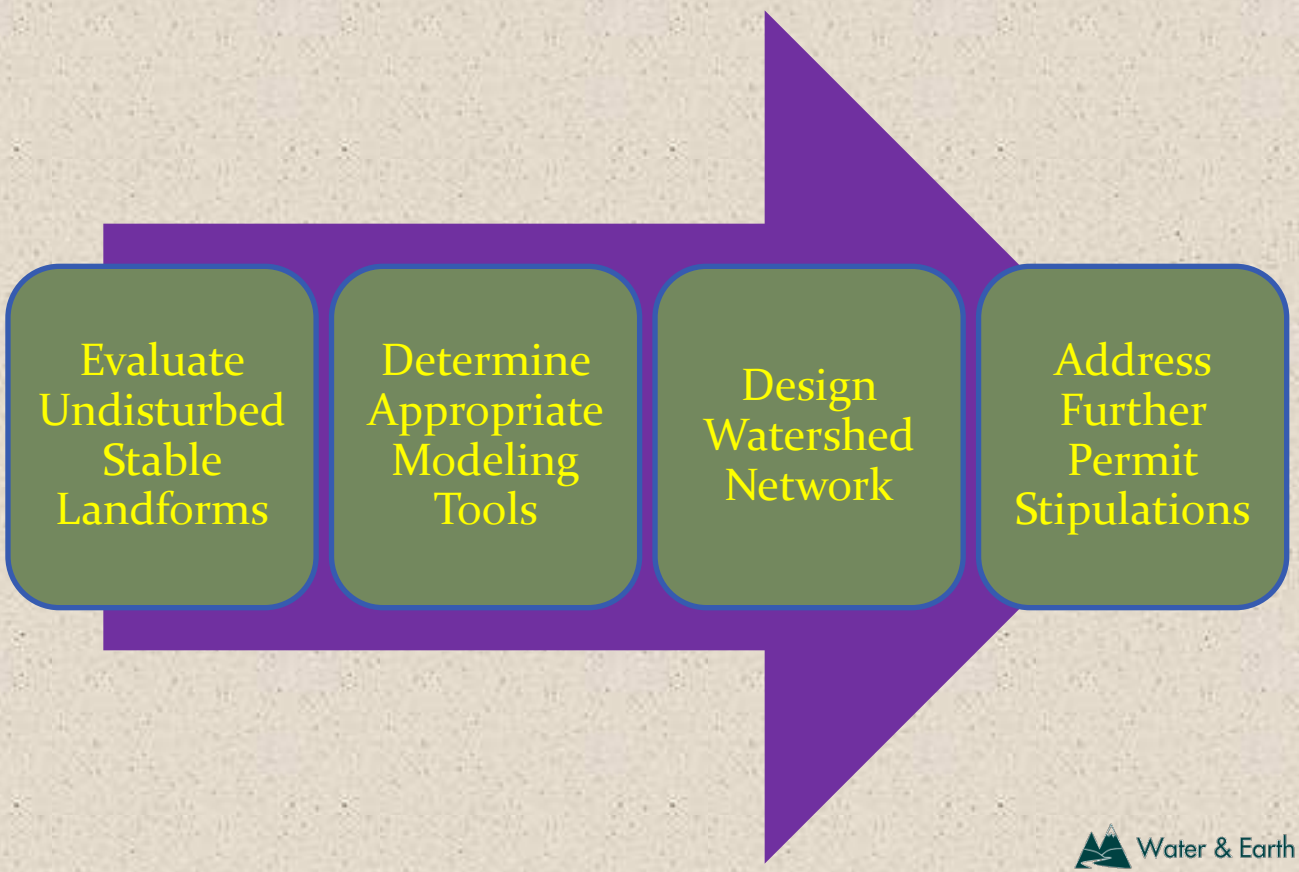
Traditional Solutions:

Draining terraces



Riprap downdrains

Geomorphic Approach



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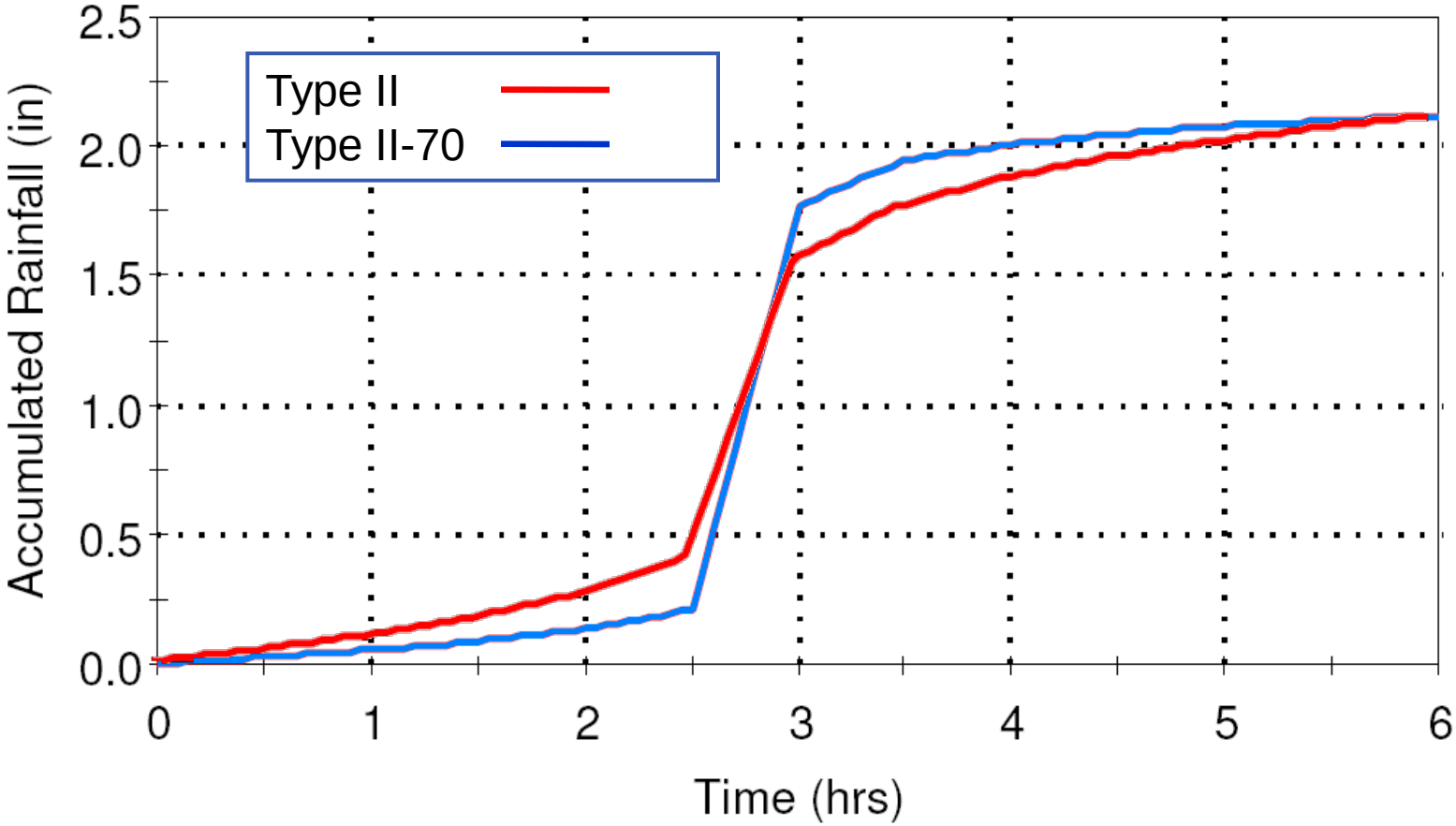
Rainfall Parameters

New NOAA Atlas 14 for New Mexico

- 2-yr, 1-hr (bankfull)
- 50-yr, 6-hr (floodprone)
- 100-yr, 24-hr (if required by permit)

Rainfall Distribution Curves

- Type II 70 distribution
- United States Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS)



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Complete Field Survey to Determine Input Parameters

A Geomorphic approach using Natural Regrade™ with GeoFluv requires input parameters including:

- -Drainage density
- -Ridge to head of channel

- -Sinuosity
- -Width to depth ratio
- - A-channel reach length

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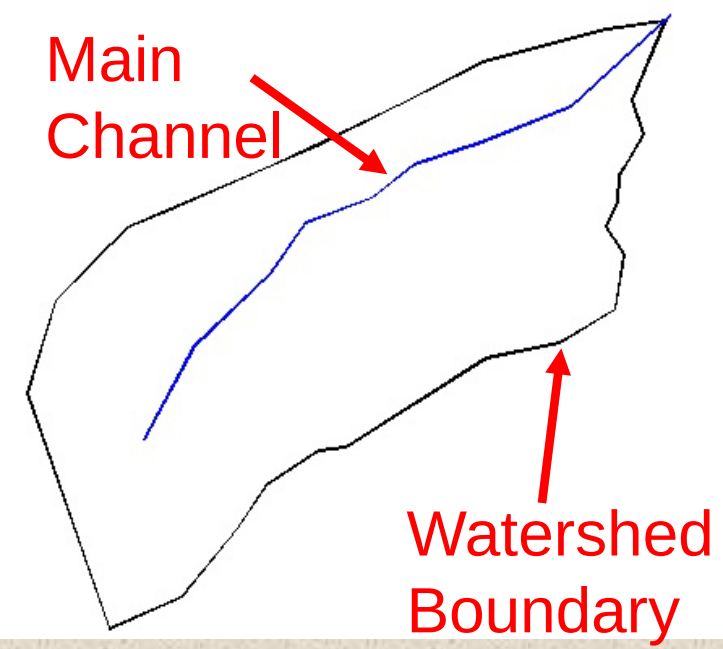
$$\text{Drainage Density} = \frac{Length_Of_Channel}{Watershed_Area}$$

Target Drainage Density = 154 ft/acre



Length = 420 ft

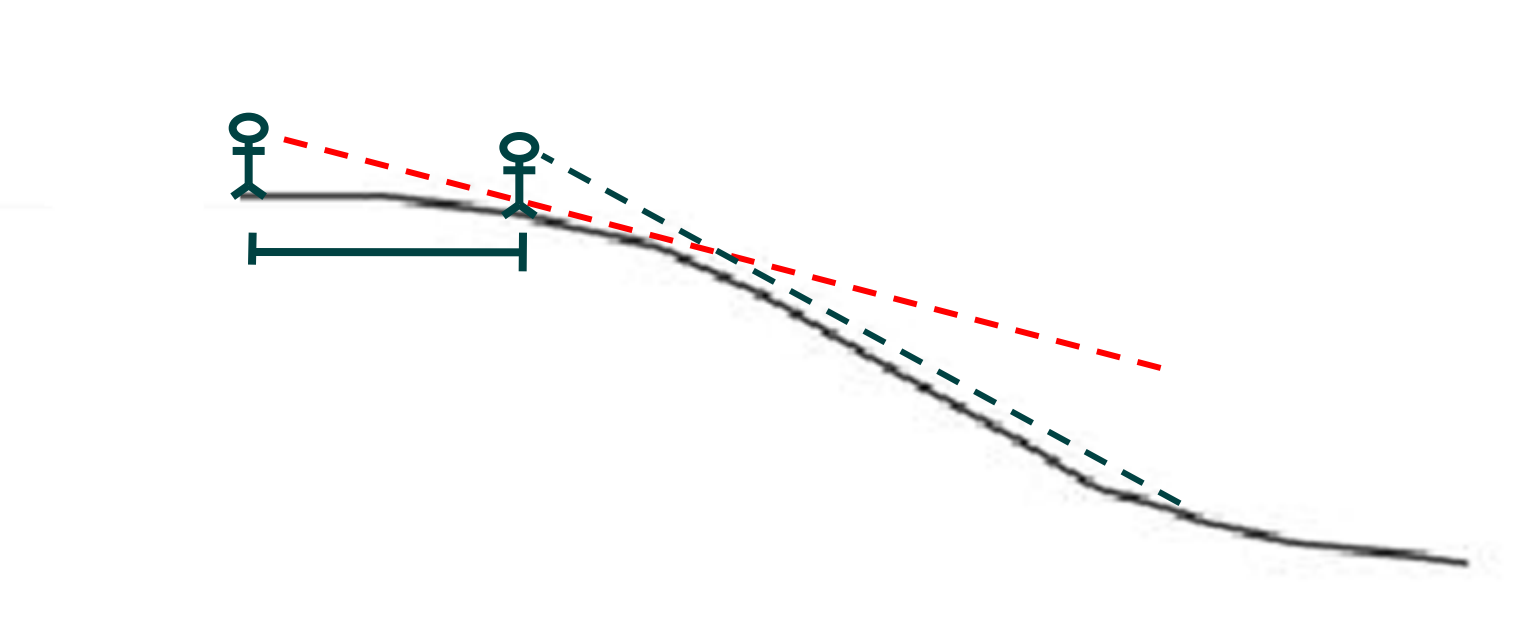
Watershed Area = 2.9 ac

Drainage Density = 145 ft/ac

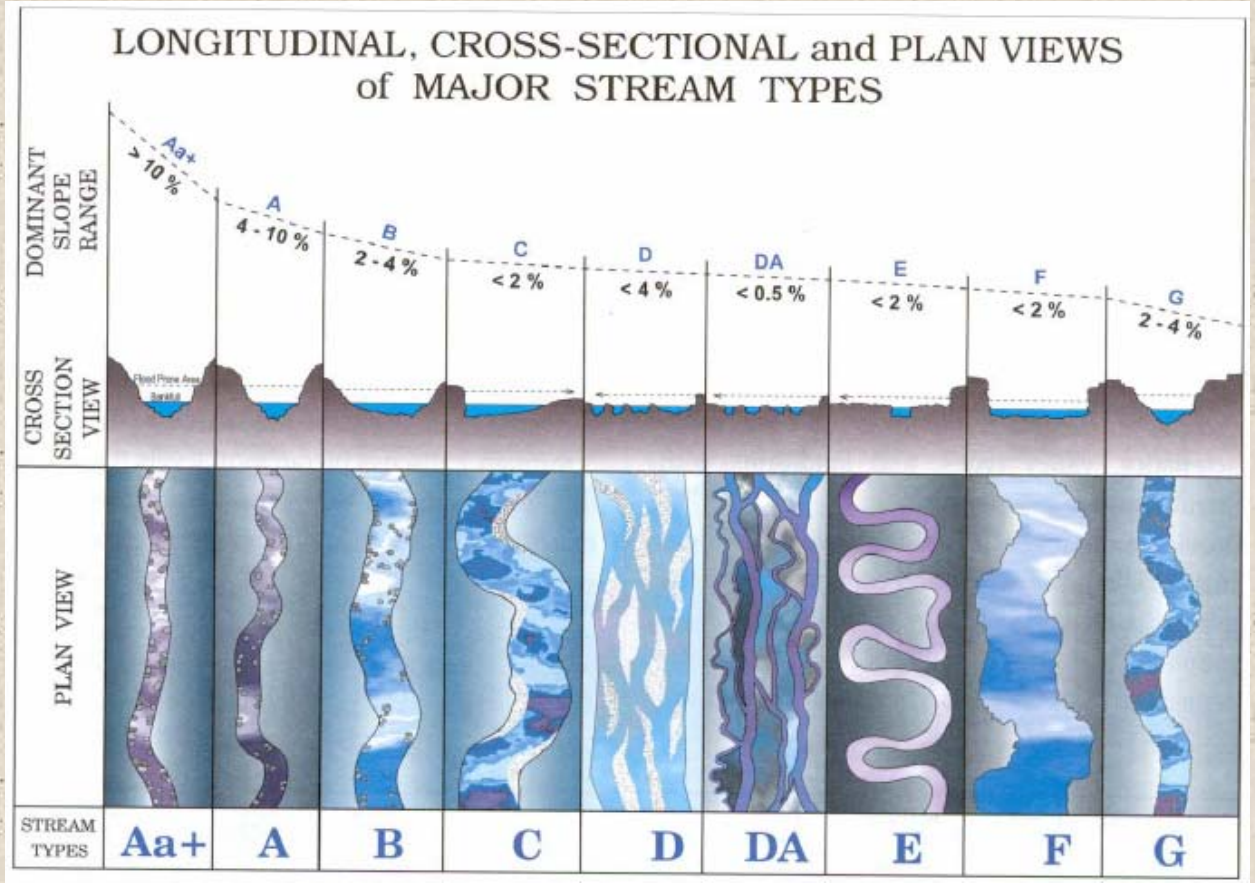
Ridge to Head of Channel Distance

Ridge

Head of Channel



What is an “A-Channel”?



Rosgen Stream Classification System

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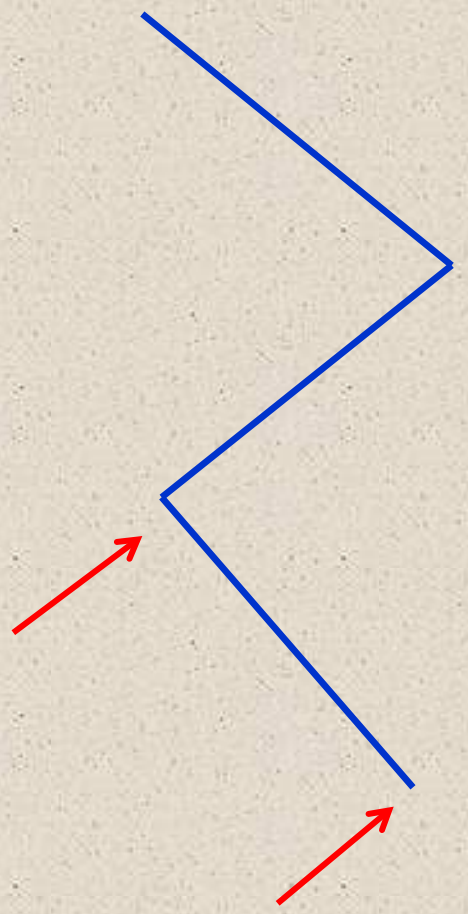
A-Channel Reach Length



Determine the Geofluv Configuration for a Functioning Watershed System

Watershed configuration for Area 12C

Seven subwatersheds to drain to existing arroyo

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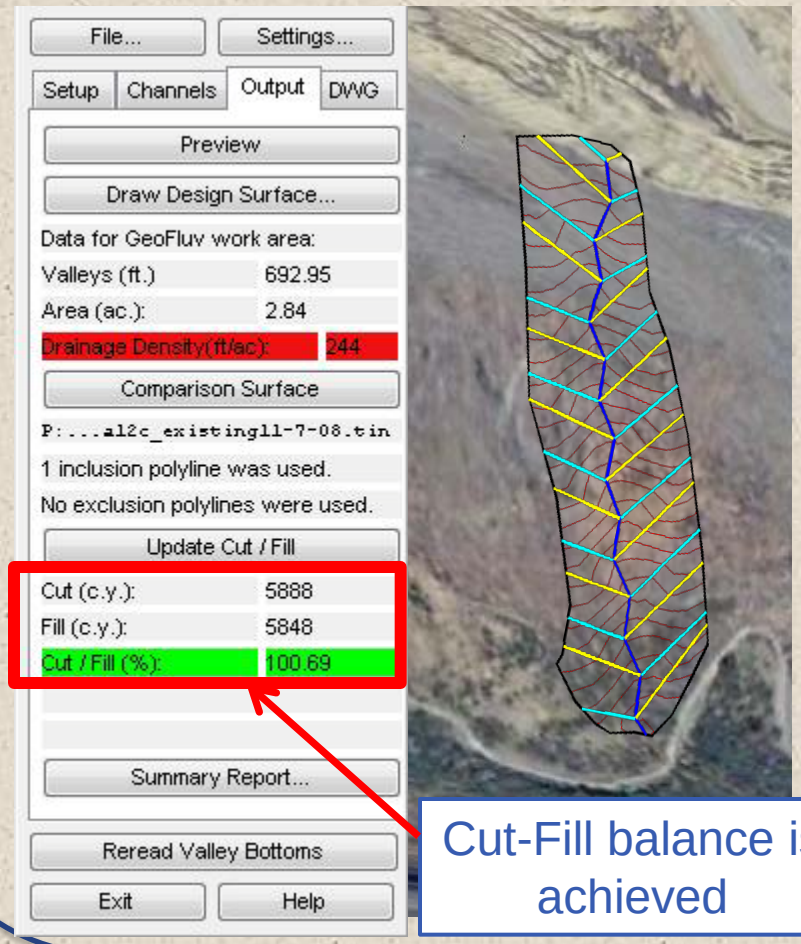
Complete a Geomorphic Design for Stable Landforms using Natural Regrade™



Cut-Fill balance is achieved

Subwatershed Boundary

Channel

Ridge

Valley

5' Contour

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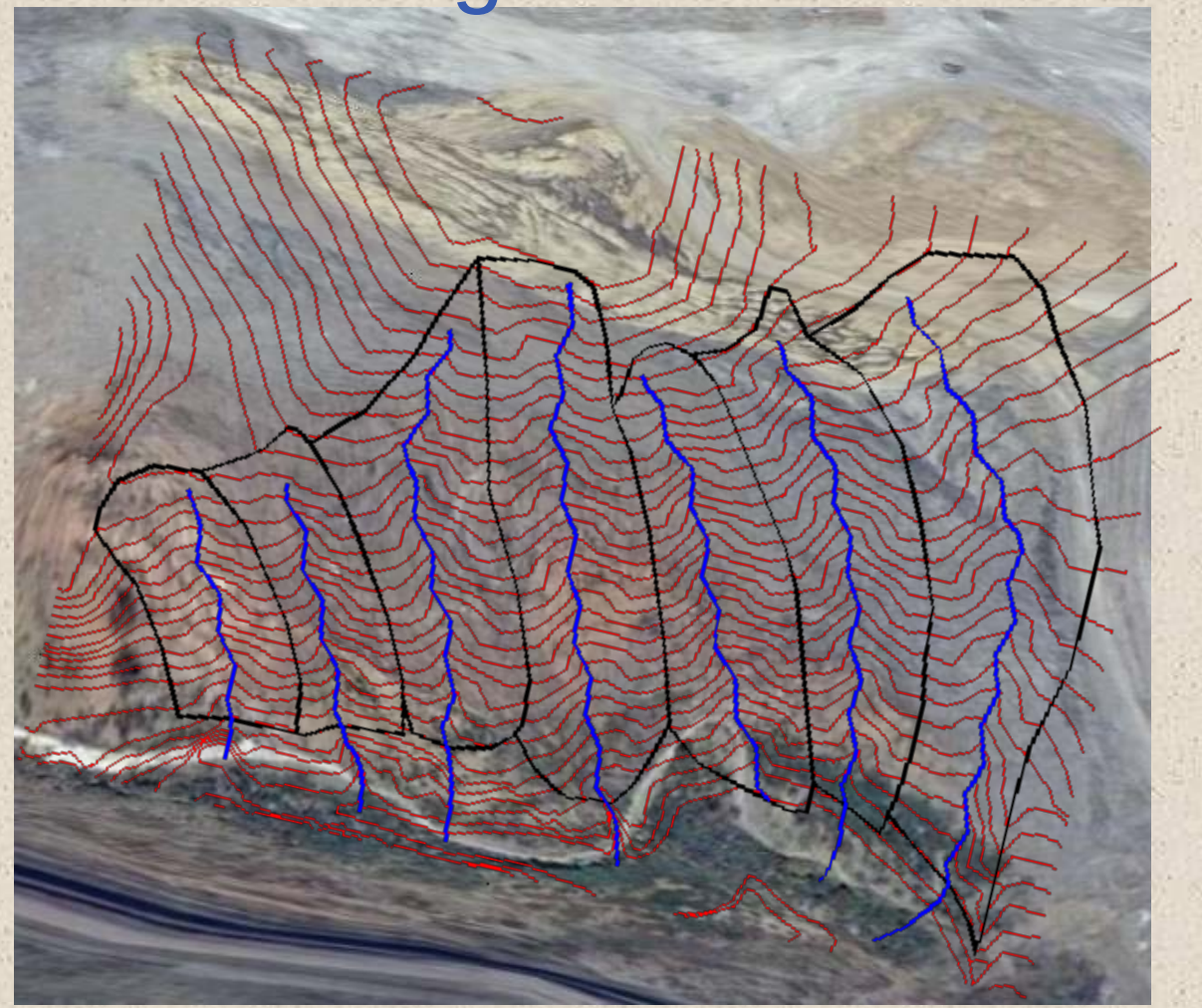
Final Design for Area 12C



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Erosion Considerations

Additional analysis on the geomorphic design surface was completed to show that erosion rates and specified design flows would meet the correct criteria.

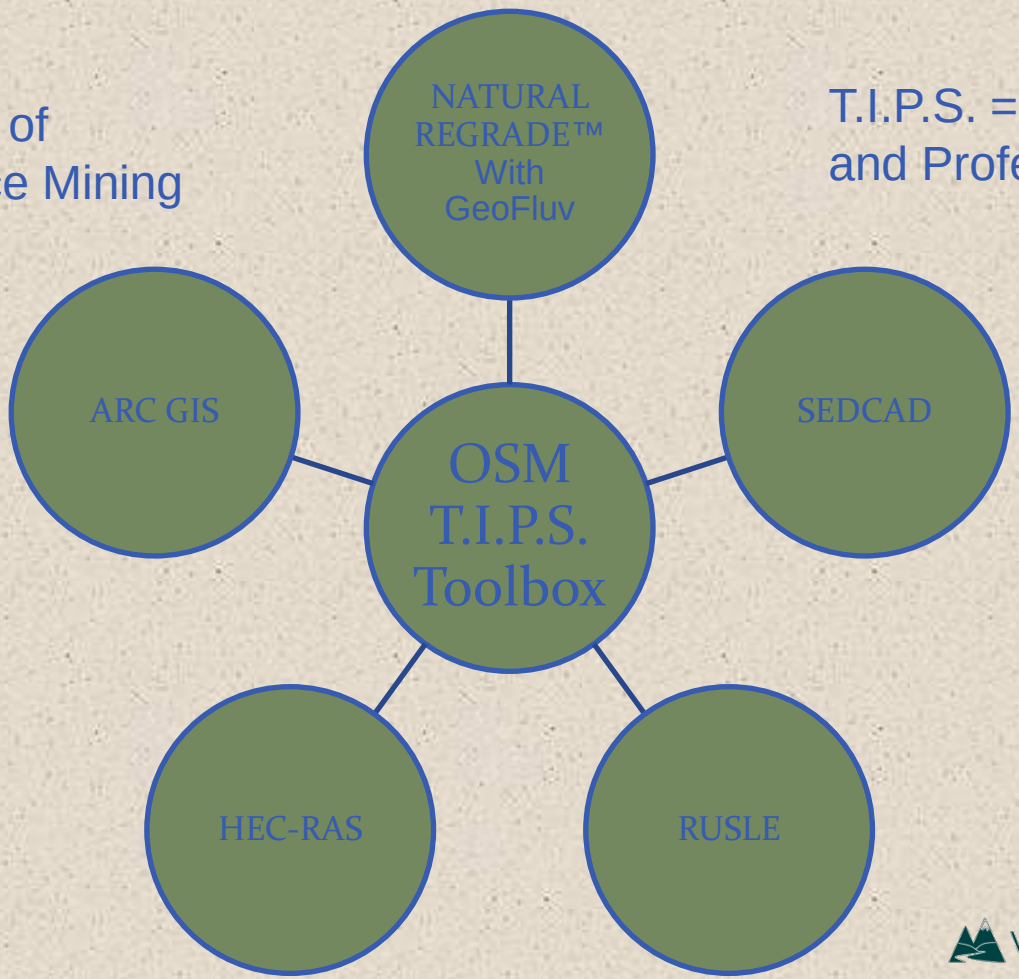
Additional Analysis Completed

- A 50-yr,6-hr peak flow analysis was completed for designed watersheds with contributing area less than 1 square mile.
- A soil loss analysis was completed on the worst case slope in each watershed. The condition needed to be better than or equal to soil loss for pre-mining conditions.
- A channel stability analysis was completed to determine if additional channel protection would be necessary.

Available Tools to Support Geomorphic Analysis

OSM = Office of Surface Mining

T.I.P.S. = Technical Innovation and Professional Services



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Tools Used for Analysis

The geomorphic design was analyzed using:

SEDCAD = Sediment, Erosion, Discharge by Computer Aided Design

RUSLE = Revised Universal Soil Loss Equation

RUSLE

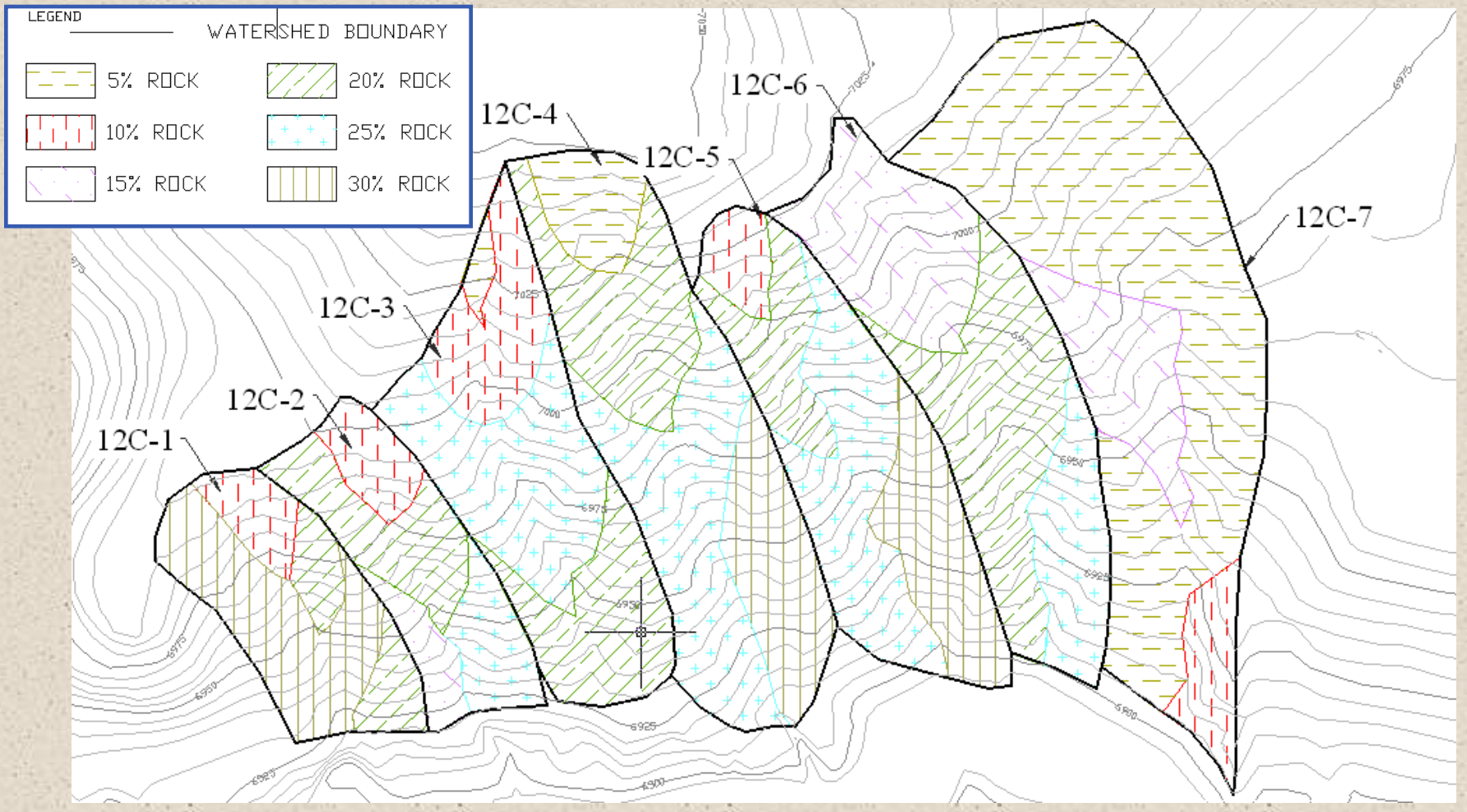
Predicting erosion by water

Sensitivity Analysis

Peak flow comparison between models:

Subwatershed	Peak Flow (cubic feet per second) Natural Regrade (50-yr, 6-hr = 2.12")	Peak Flow (cubic feet per second) SEDCAD (50-yr, 6-hr = 2.12")
12C-1	2.52	2.46
12C-2	2.33	2.28
12C-3	4.95	4.87
12C-4	6.1	5.99
12C-5	5.02	4.95
12C-6	6.11	6.03
12C-7	9.32	9.16

RUSLE Analysis



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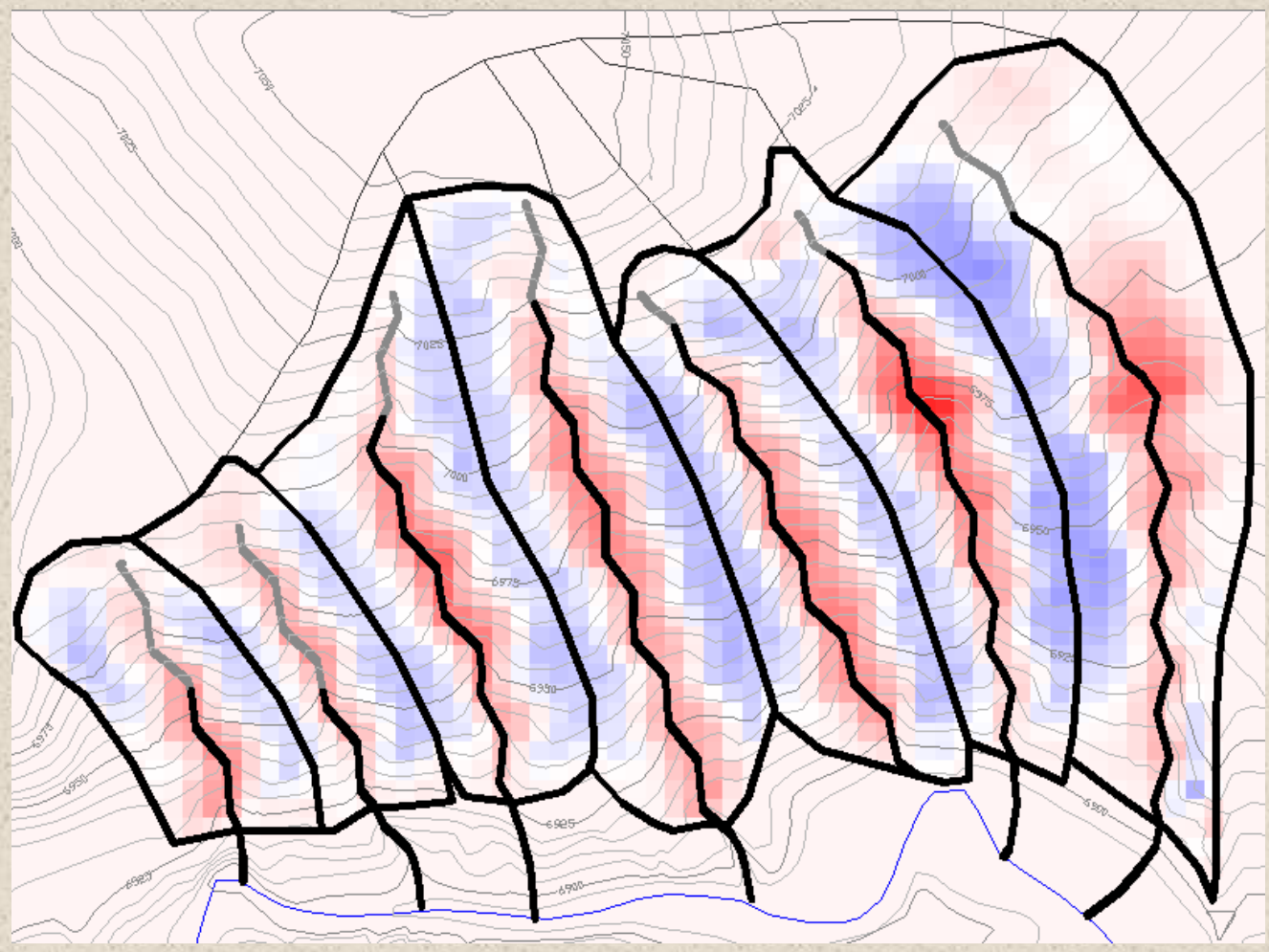
From Design to Construction



Area in Cut

Area in Fill

Cut-Fill Color Mapping

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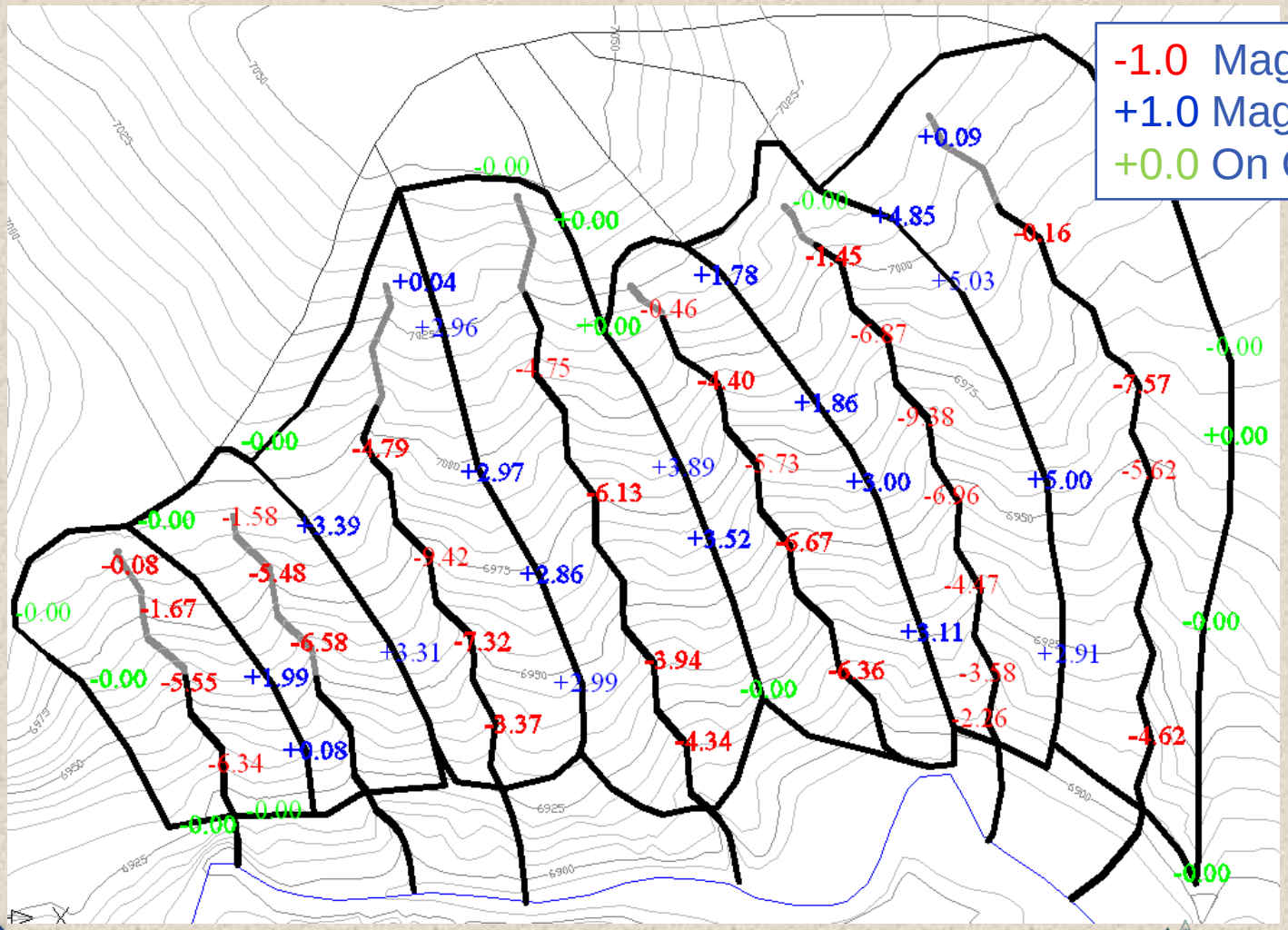
Construction Staking



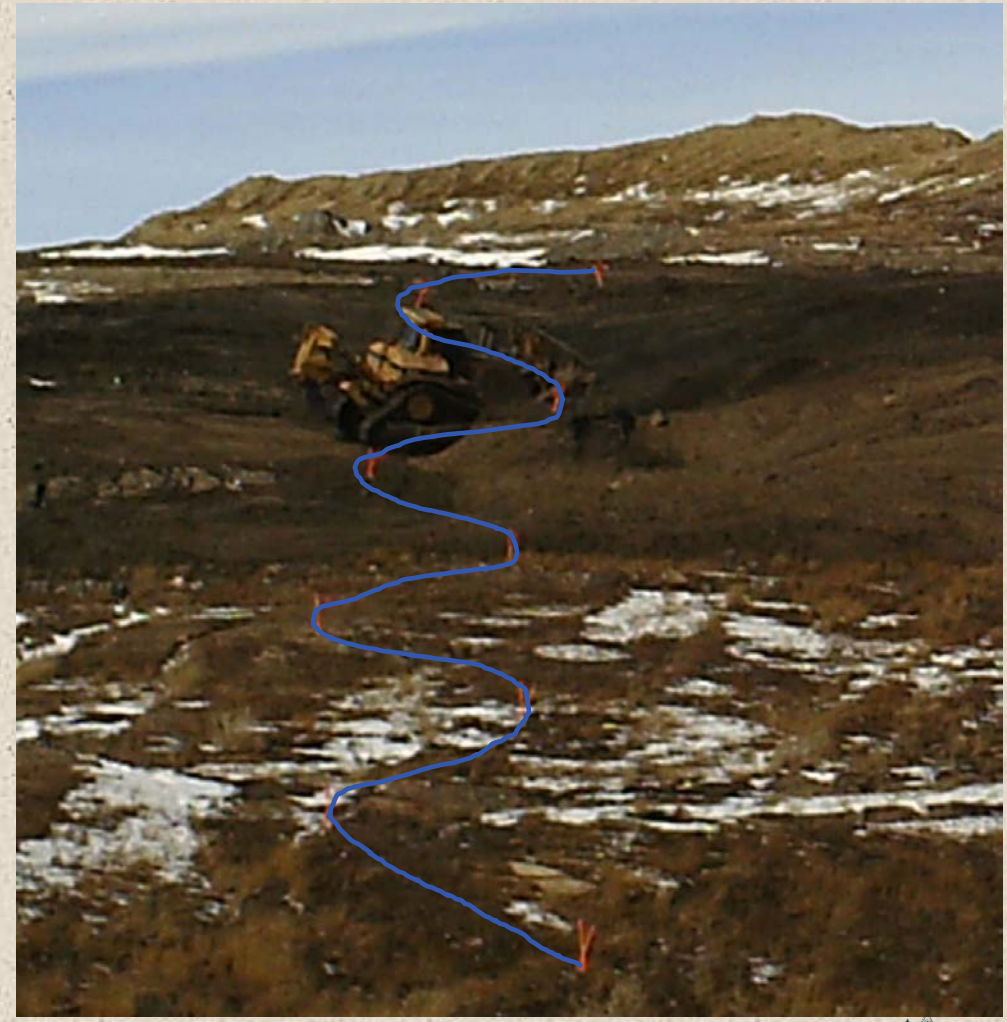
-1.0 Magnitude of Cut
+1.0 Magnitude of Fill
+0.0 On Grade

Water & Earth Technologies, Inc.

Construction

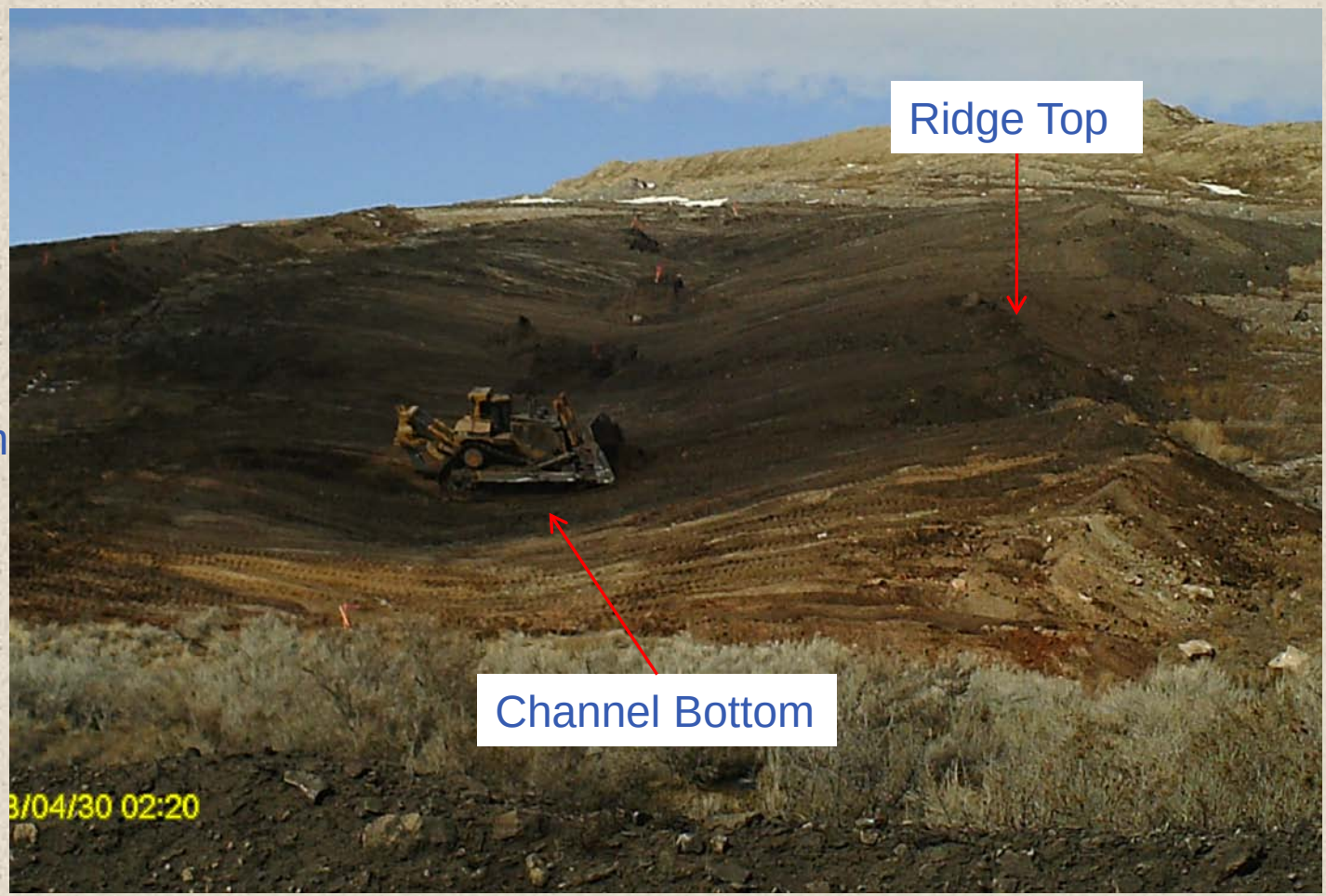
Red flagging in the field indicates the location and magnitude of channel cuts.

Channel sinuosity defined by stake locations.



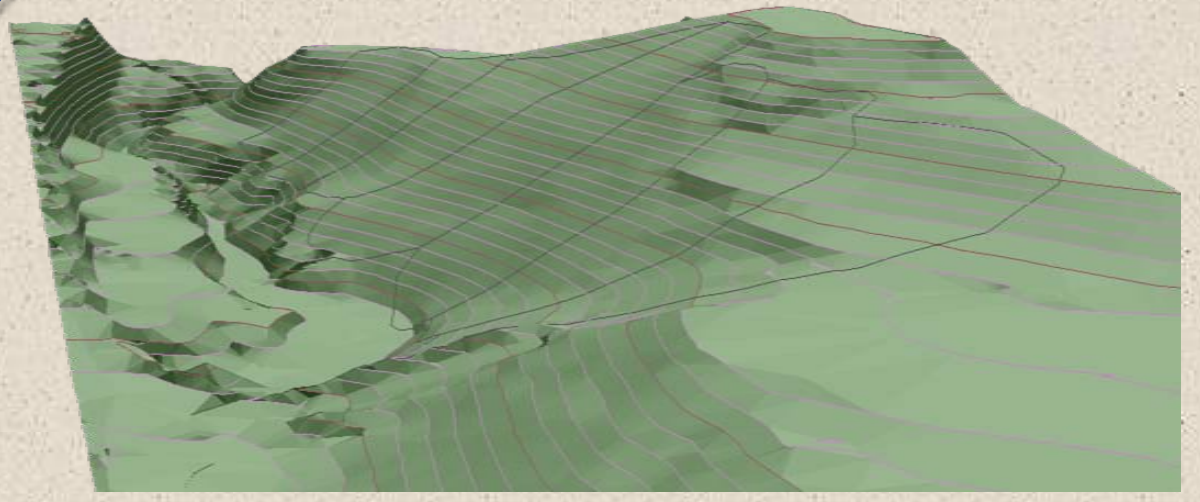
Construction

Bulldozer rough grades watershed geometry by pushing horizontally from the channel bottom to the ridge tops

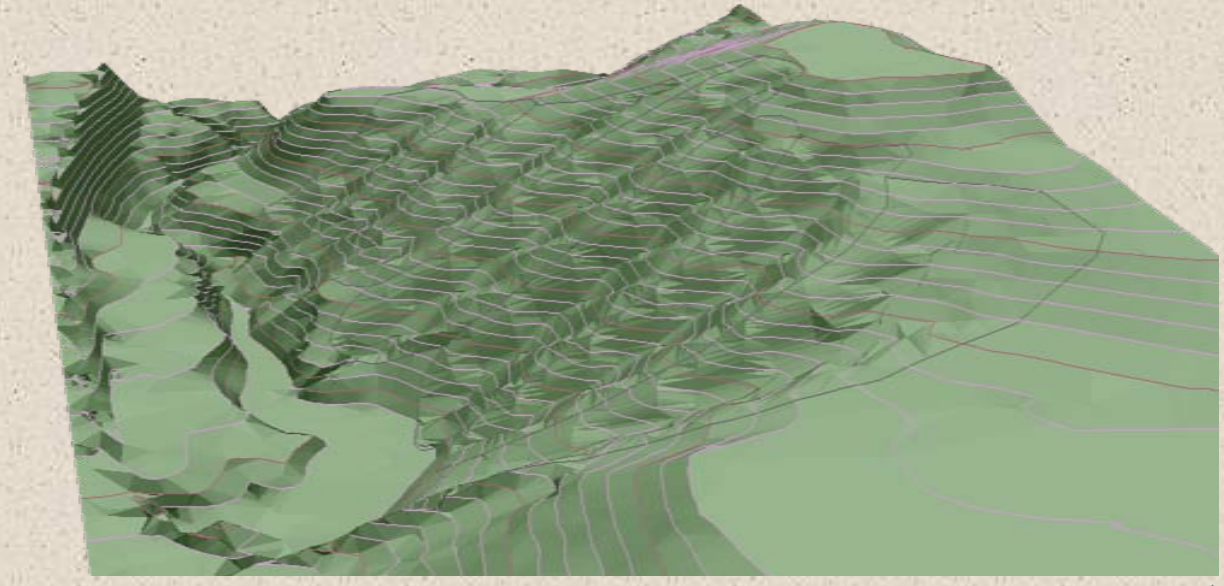


Construction

Regraded hill slope draining toward existing channel



Pre-Regraded Surface



Proposed Final Reclamation Surface

Water & Earth Technologies, Inc.

Compliance

Provisions agreed to by the Office of Surface Mining:

1. Final Post Mining Topography can deviate +/- 10 vertical feet.

2. Constructed watershed boundaries must be within 10% of designed area.

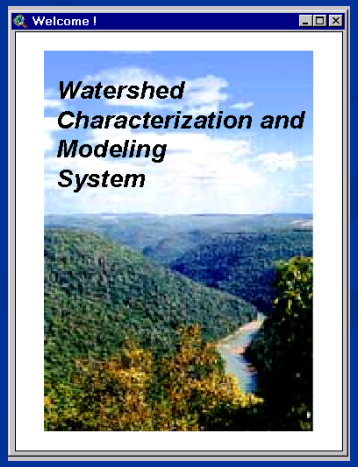
3. Drainage Density must be maintained.

4. Constructed channels designed with freeboard to meet or exceed minimum requirements.

Questions

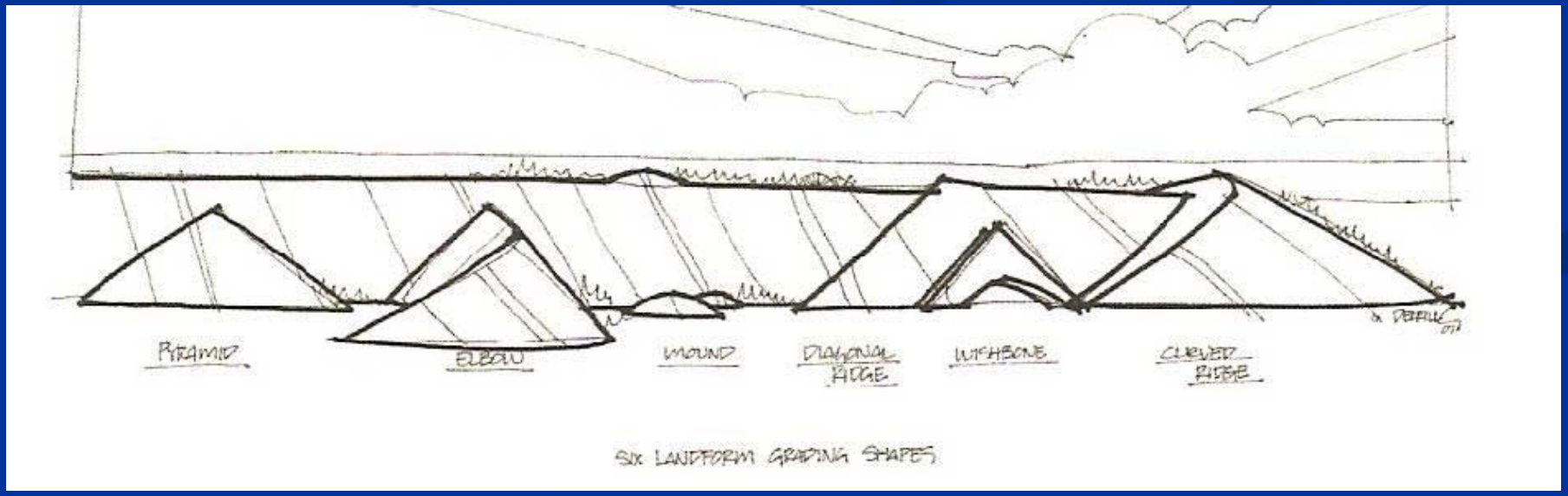
Integrating Visualization, Landform Shaping and Geomorphic Analysis for Eastern Surface Mine Reclamation

Charles Yuill
And Michael Hasenmyer
West Virginia University

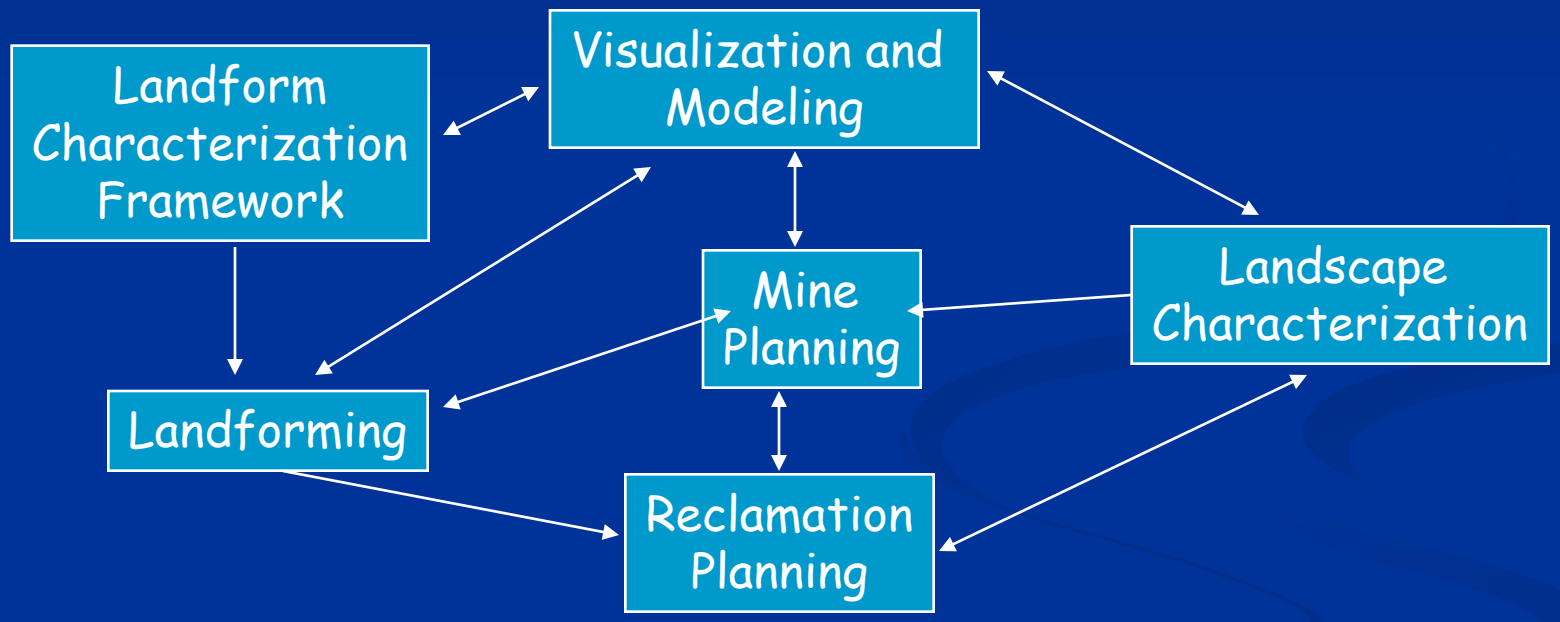


A working definition

- *Geomorphic landforming* – what is it?
  - Regrading disturbed or altered landscapes respecting and working with….
    - Natural terrain patterns - the idea of reference terrain
    - Natural geomorphic and hydrogeomorphic processes
    - Natural vegetative patterns
    - Natural processes are allowed to proceed at rates that would be typical for undisturbed landscapes of similar topography.
    - Differs from many other forms of regrading that are designed to optimize the lack of natural processes focusing on immediate stabilization at the expense of the above.



An applied research agenda

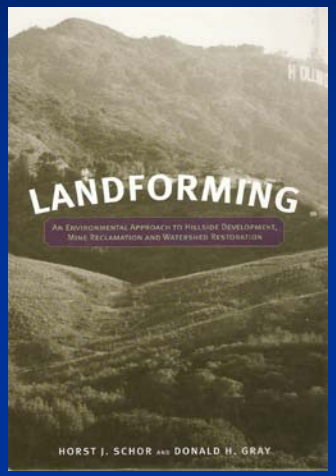


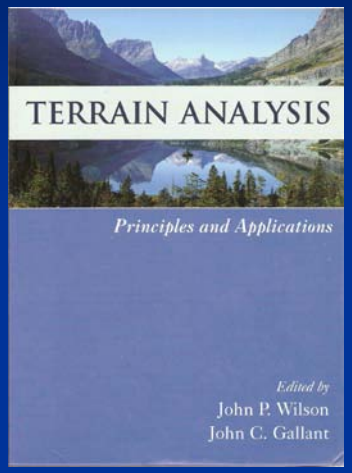
How we visualize the parts fitting together

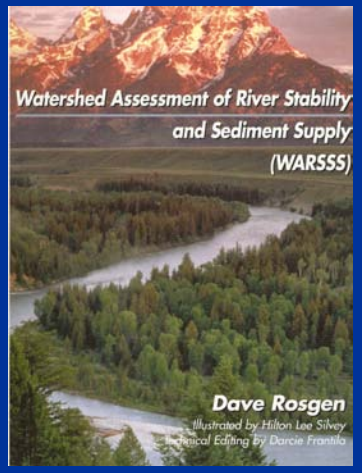
Why an applied research agenda in geomorphic and creative landforming for Eastern coal mines?

- The obvious applicability……and unrealized opportunities
- Active mining
  - Mountaintop mining
    - Emerging concern with land use – forestry, biofuels, energy parks. etc. – example – in southern WV slope / aspect can impact site productivity by + or – 20% independent of soils
    - Grading and land shaping for 0 order watersheds – better drainage area delineation in these areas
    - Grading for upper slopes including drainage course design
    - Where site context is potentially sensitive
    - Mountaintop operations in general
  - Contour mining
    - Regraded and natural slope transitions
    - Drainage channel and stream design

Before we go on… acknowledge some important supporting or parallel work

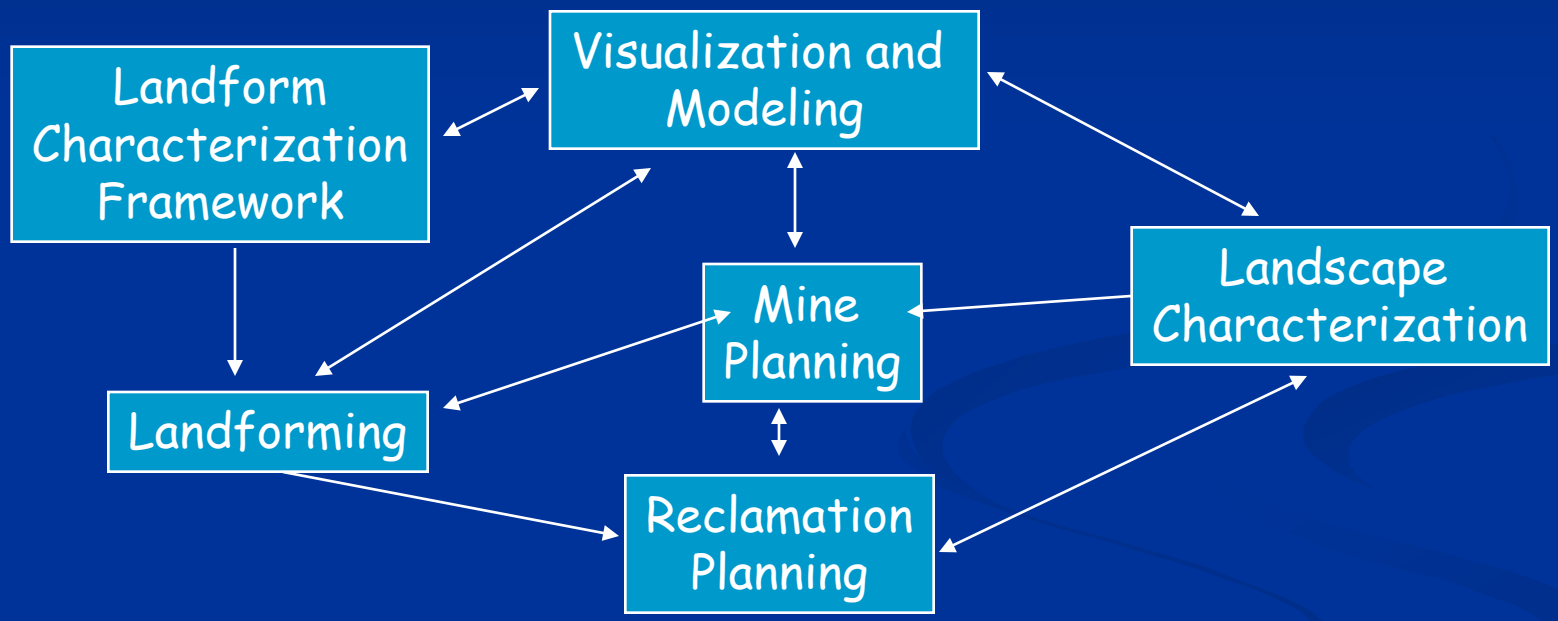






- Current (COTS) applications conceptual leaders are….
  - Geofluv
  - Rivermorph

So back to our framework



So why are visualization and modeling the unifiers in this framework?

Faro Mine

The Faro Mine Complex is located in south-central Yukon. It is 15 km north of the town of Faro and almost 200 km northeast of the City of Whitehorse. From Whitehorse, the mine is a 30-minute charter flight or a 4-hour drive away. The mine complex is located in the traditional territory of the Kaska Nation and upstream from the traditional territory of the Selkirk First Nation.

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Faro Mine Closure

The mine complex, has a total footprint of over 25 km^2 (9.65 mi^2) with mining pits over 335 m (1072 ft) deep and surrounded by approximately 500 million tons of waste rock, and 55 million tons of stored mine tailings.

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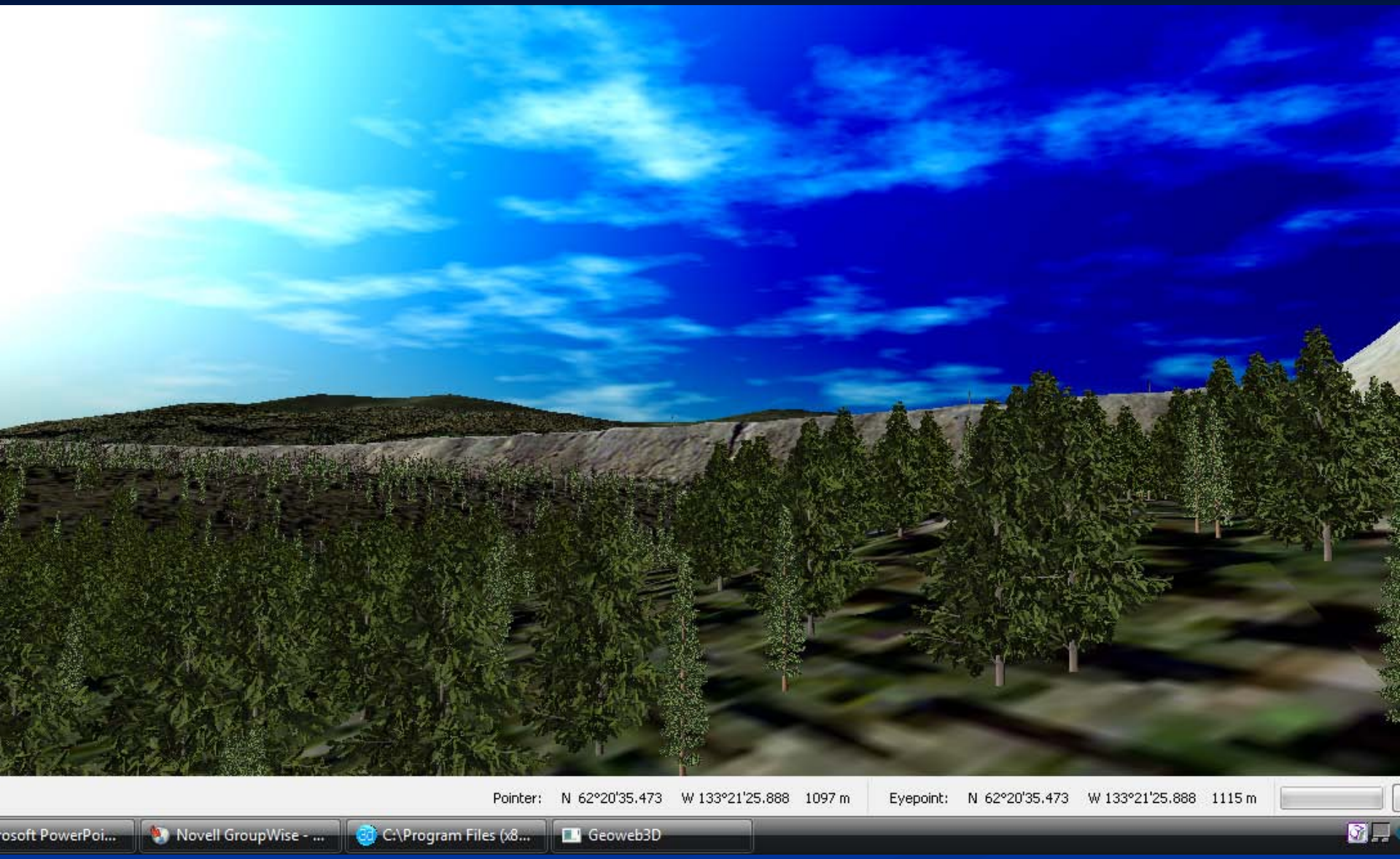
Eyepoint: N 62°20'36.562 W 133°21'54.069 1290 m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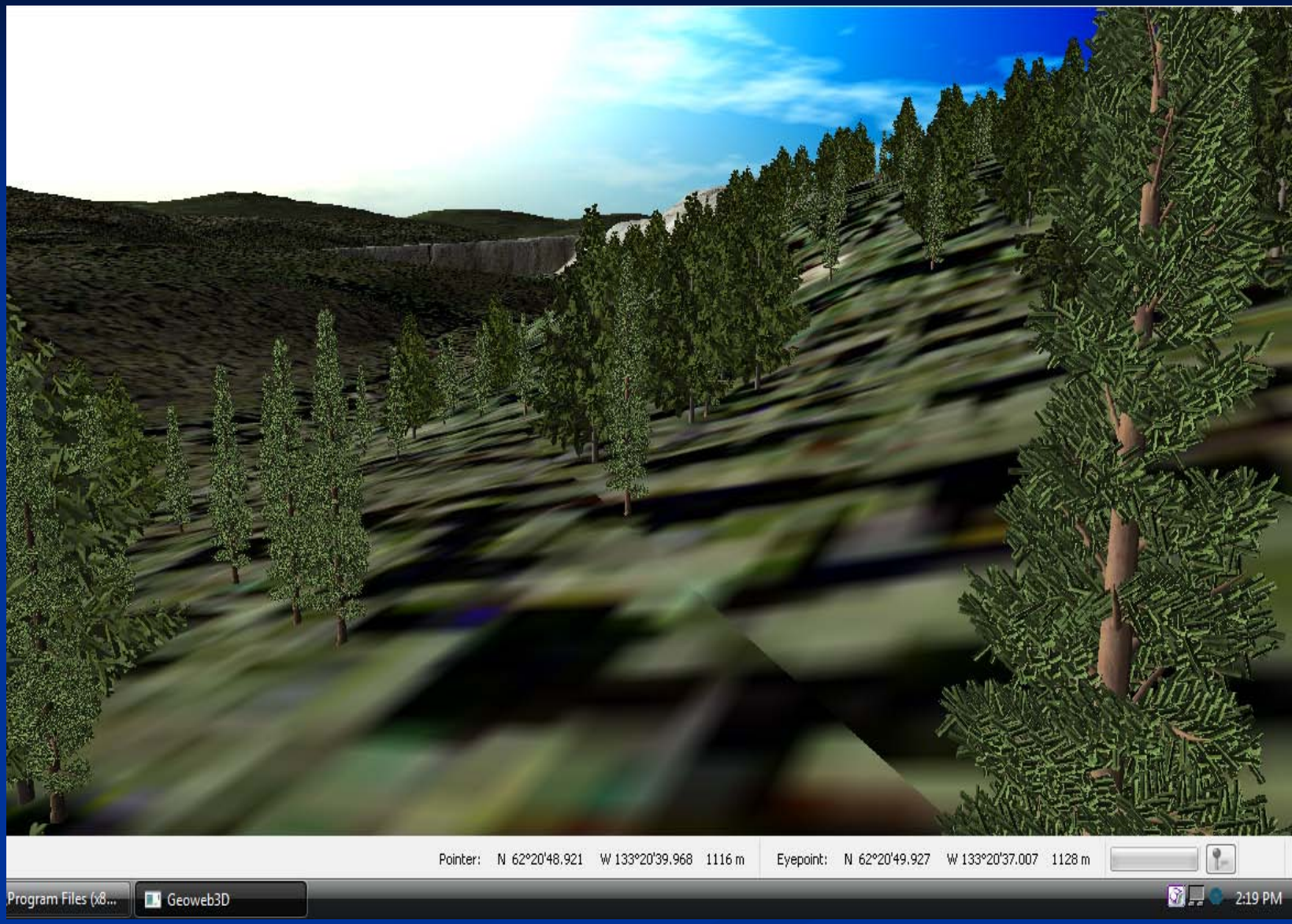
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Geoweb3D

Controls

Home | Add Data | 3D Bookmarks | Tools | 3D Settings

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Time
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Fog | Near | Far
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Virtual Earth | Define
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Performance

Exposure 1.29 | Focal Length 35 mm
Camera

Layers

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  - Imagery
- 90m_dem1.img
  - Elevation
- area image.ecw
  - Imagery
- Mine3m.tif
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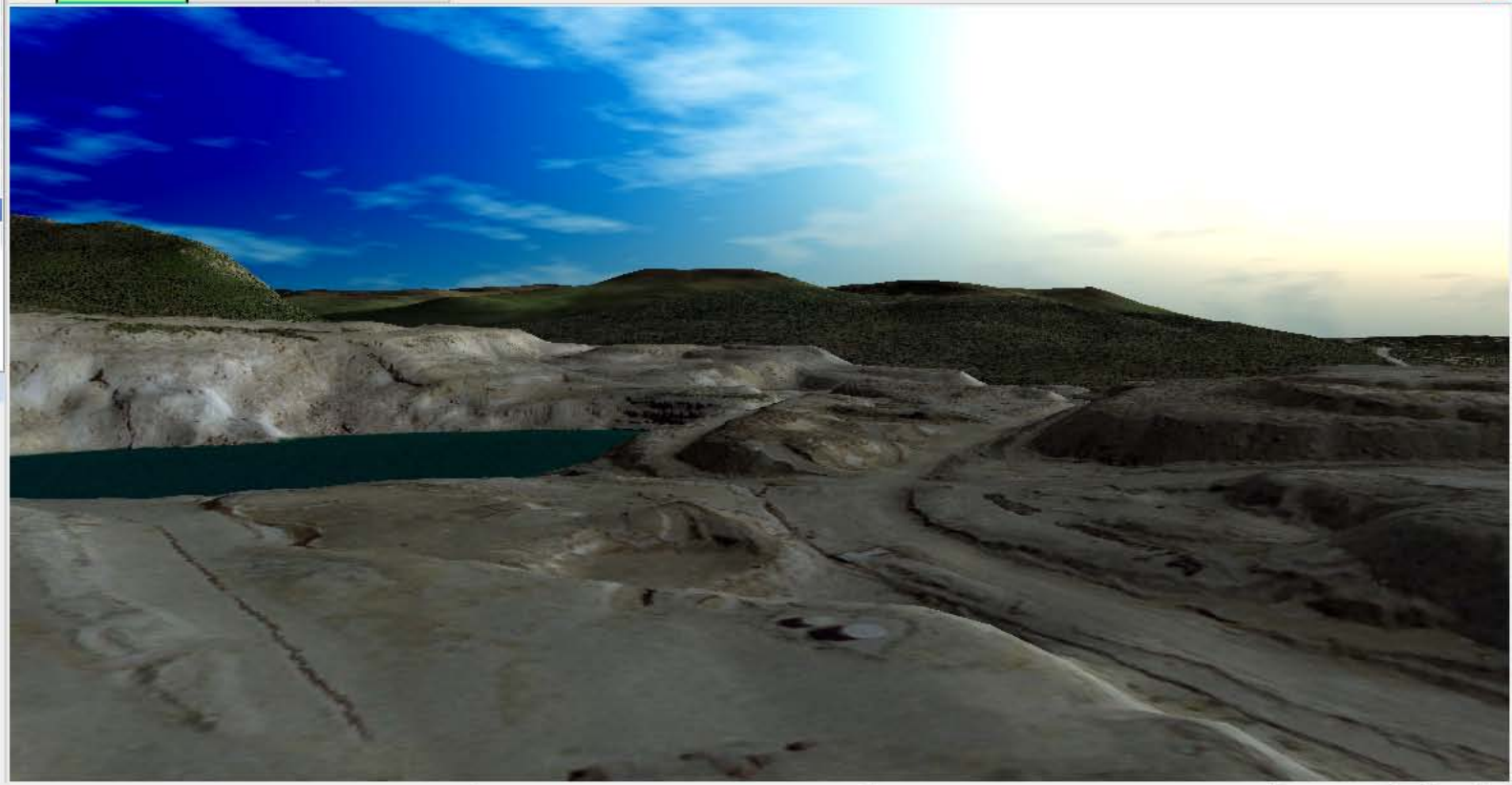
- Minesite_detail.ecw
  - Imagery

Attribute Mapping

1 Field | 2 Map | 3 Add

Geoweb3d | Google Maps | Projects



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Geoweb3D

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Navigation

Override | Auto Detect
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Exposure 1.29 | Focal Length 35 mm
Camera

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  - Elevation
- area image.ecw
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- Minesite_detail.ecw
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Attribute Mapping

1 Field | 2 Map | 3 Add

Geoweb3d | Google Maps | Projects

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Controls

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Copy | Save | Screenshot

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User's Guide | Forum | Help

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Attribute Mapping

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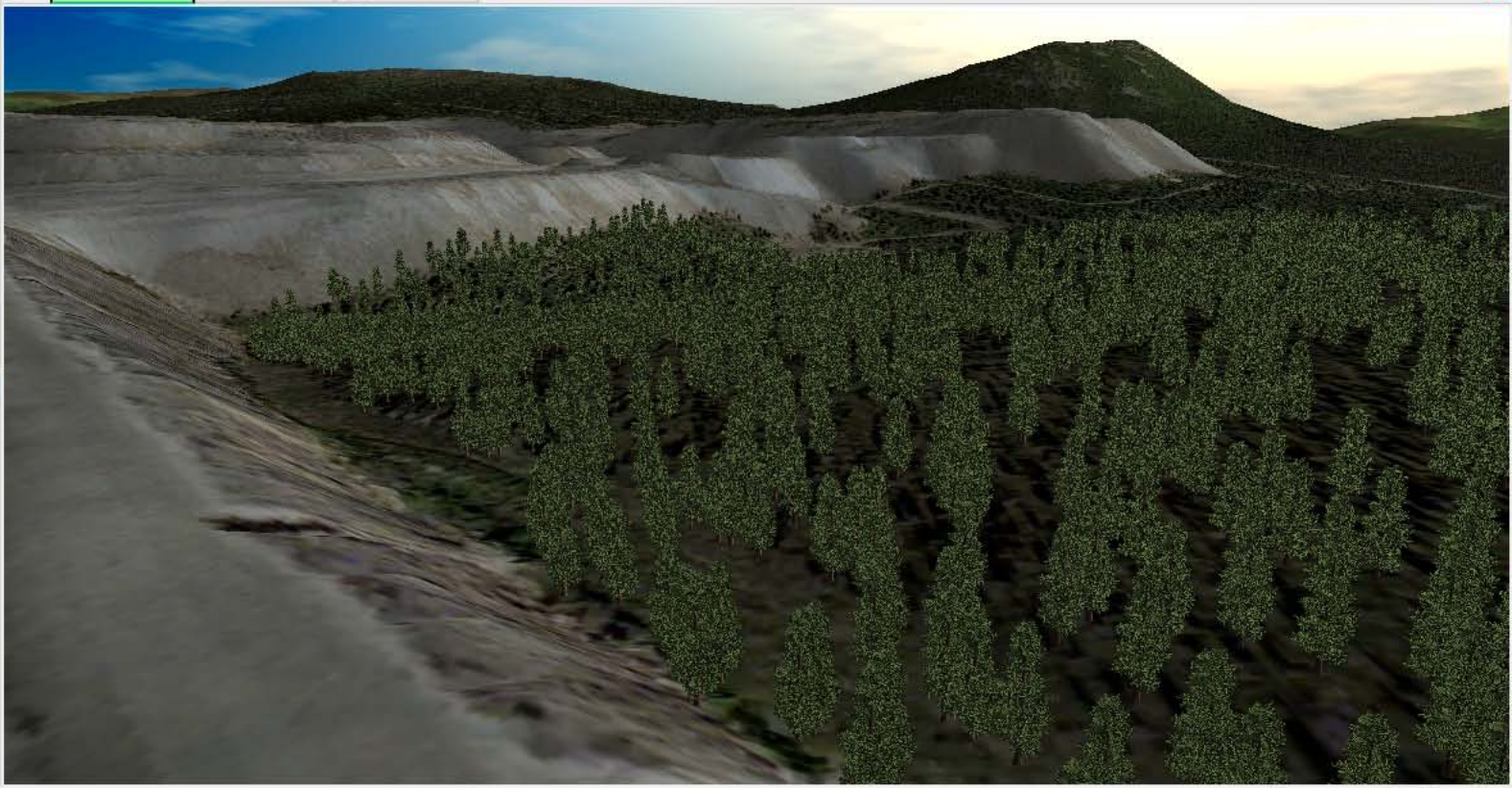
Geoweb3d | Google Maps | Projects



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Rotation

Axis: X
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  - Elevation
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Attribute Mapping

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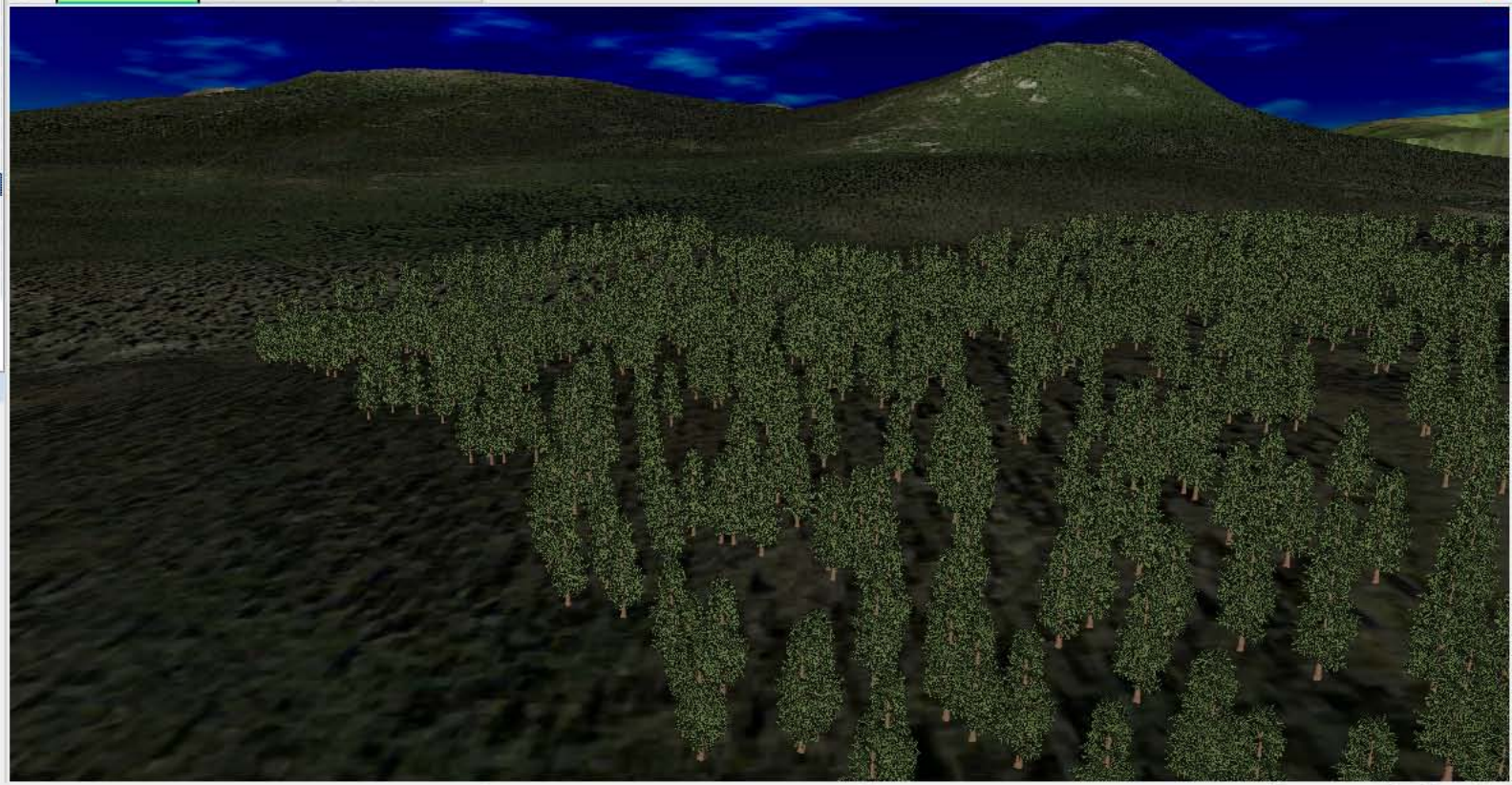

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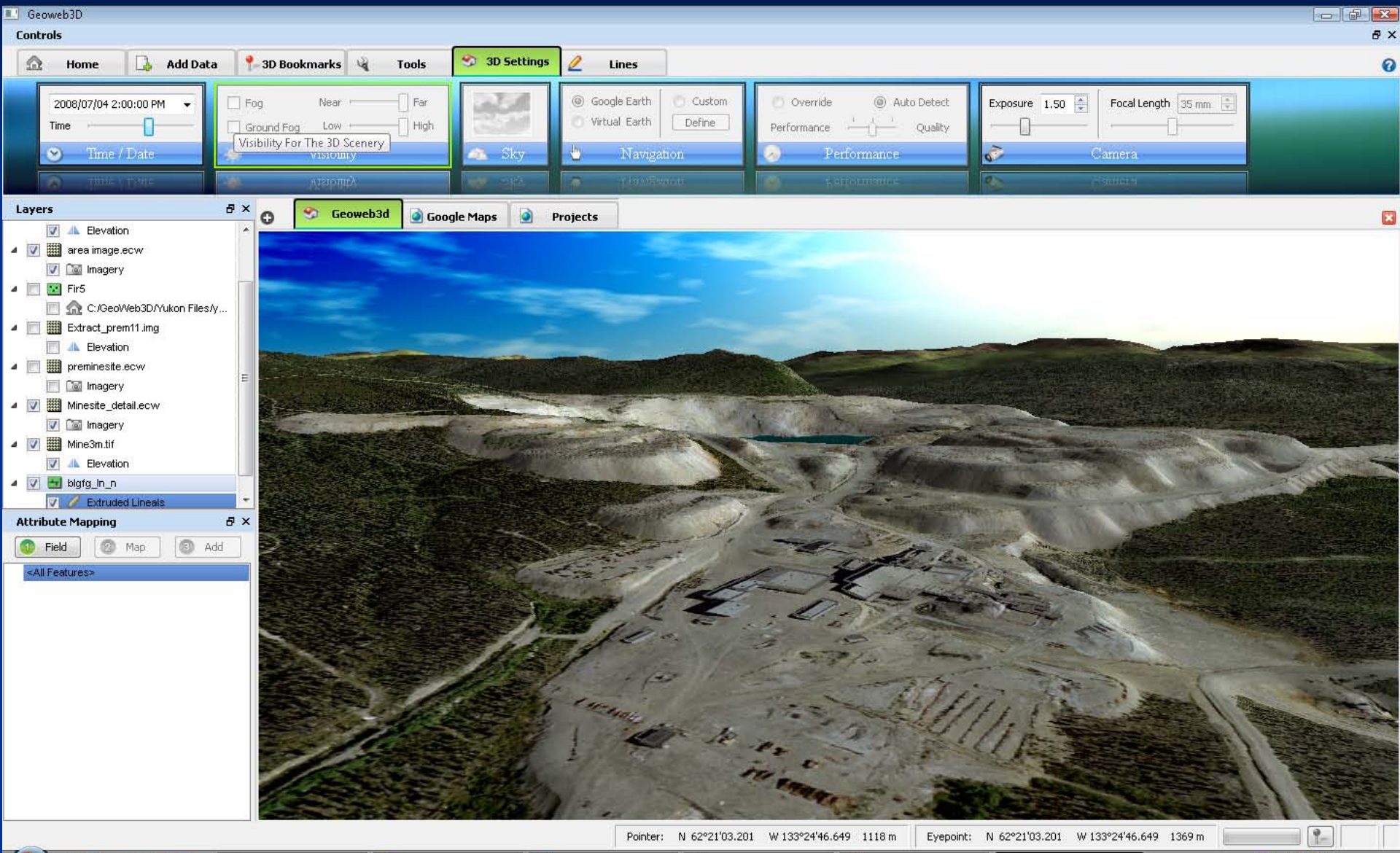
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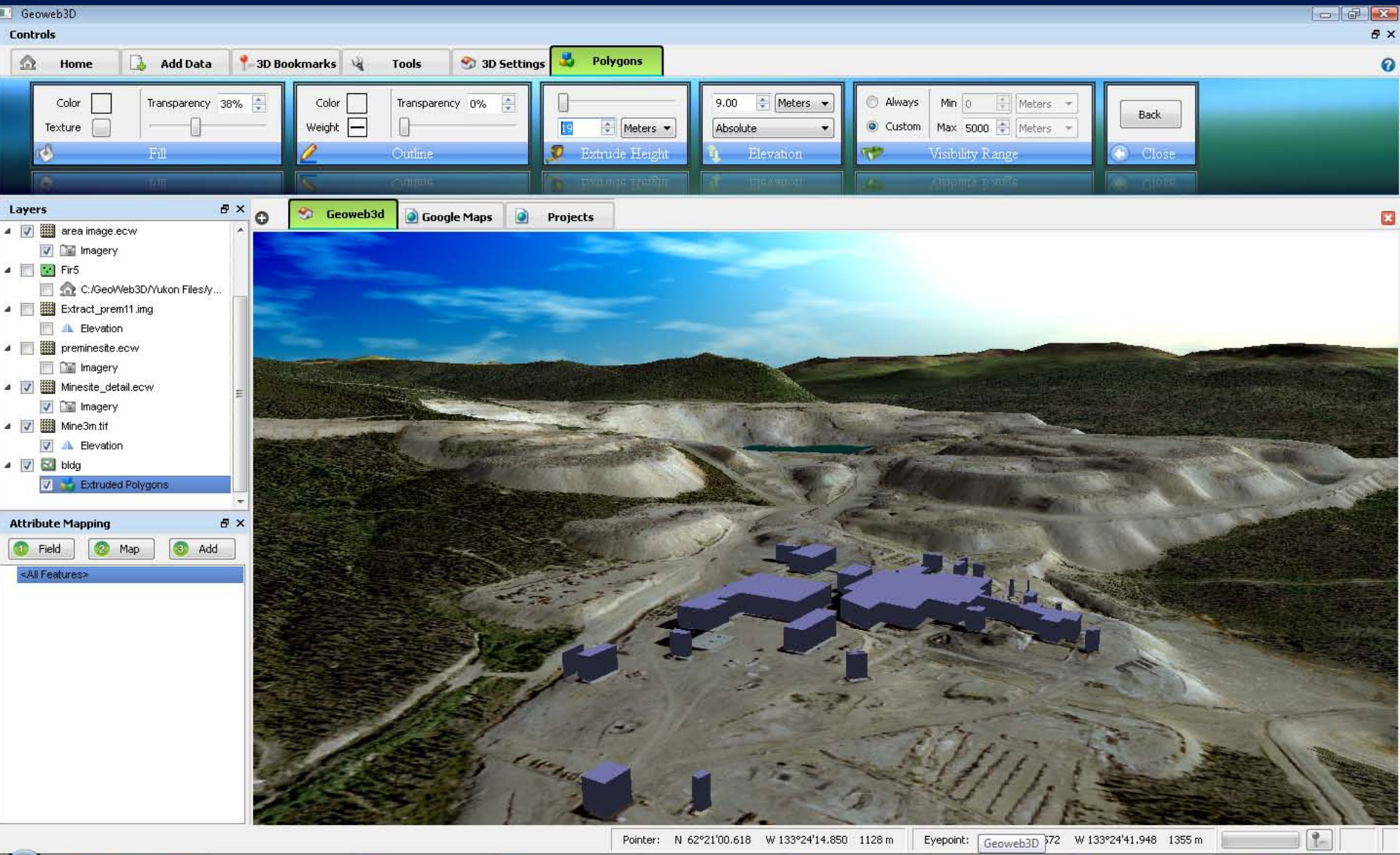
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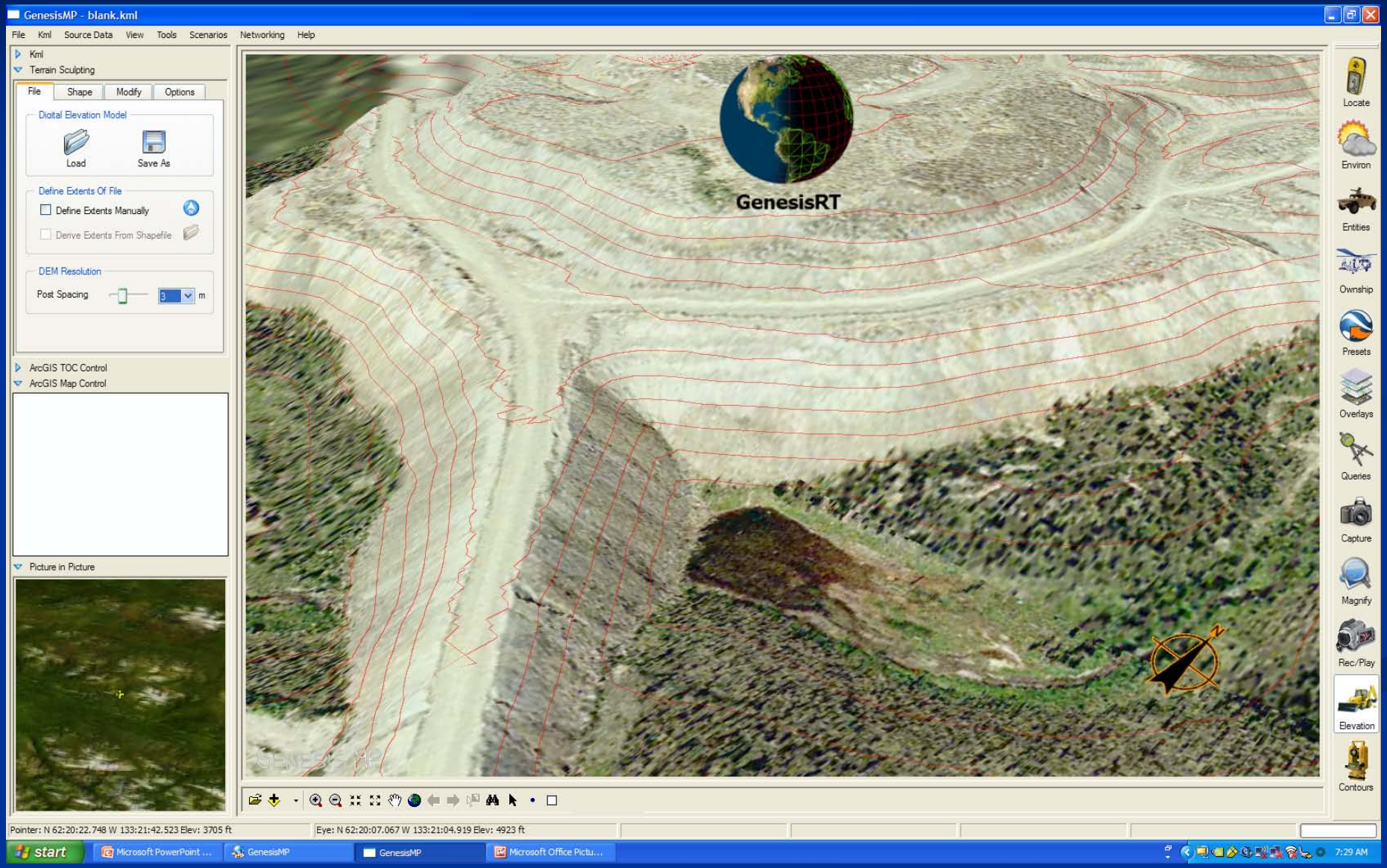
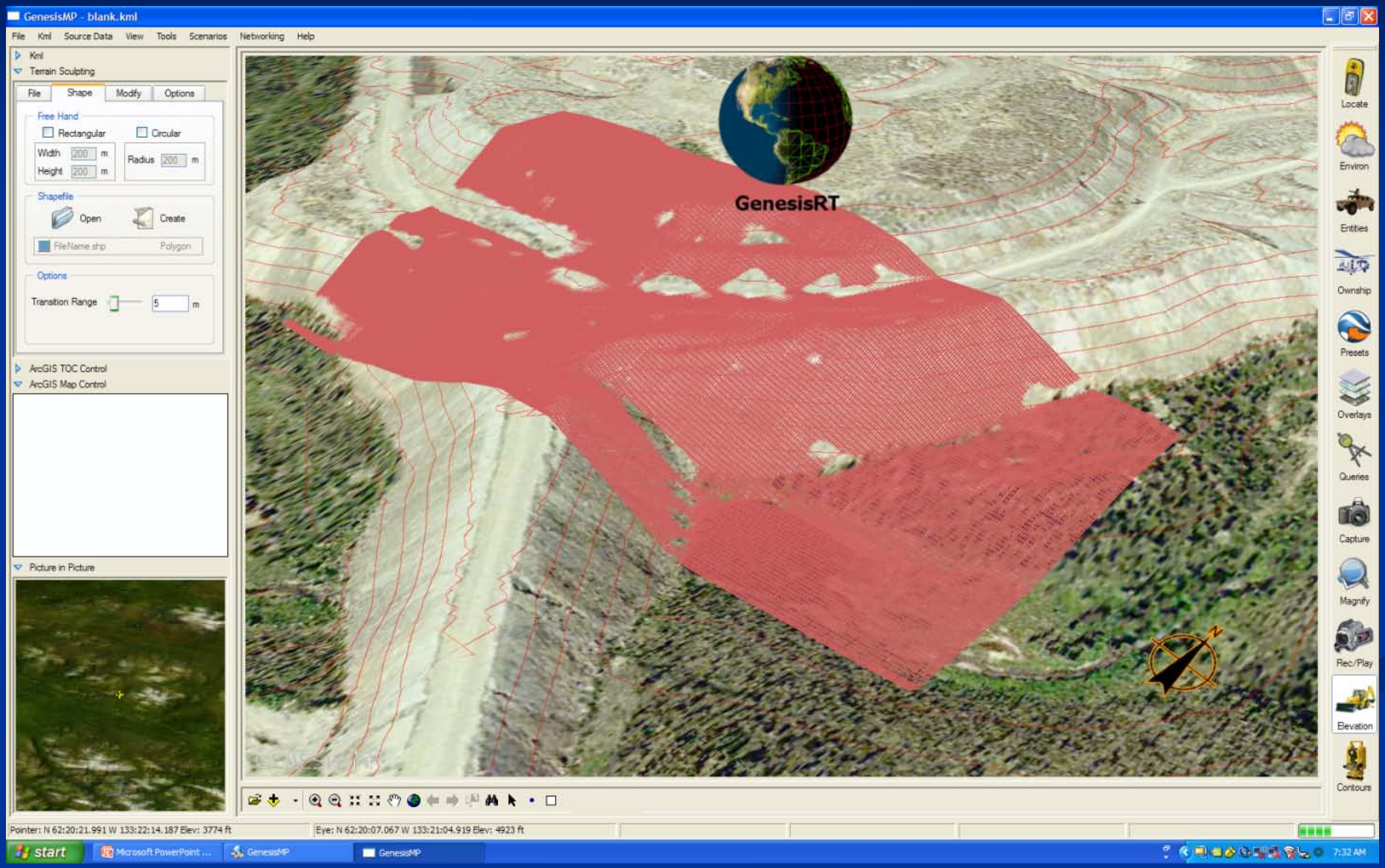
Linking landshaping with visualization

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We can then take the results of this landform manipulation to analysis software for evaluation on the fly.

Project status – initial plans have been developed for spoil regrading, tailings stabilization, the mill, and surface water – preparing to visualize those plans.

Leads us to… Methods for examining and hopefully integrating aspects of geomorphic reclamation into eastern active mining more fully

- Methods for understanding and engineering / designing landforms
- Methods for hydrologic system design
- Methods for detailed landform engineering

- Again visualizing such a process

For examining landform…we wanted an approach that

- Would be useful as a research tool and potentially be applicable in real situations
- Be implementable
- Would be useful for landform stability, erosion, land cover, and hydrologic assessments

So what evolved was a multi stage approach that considered….

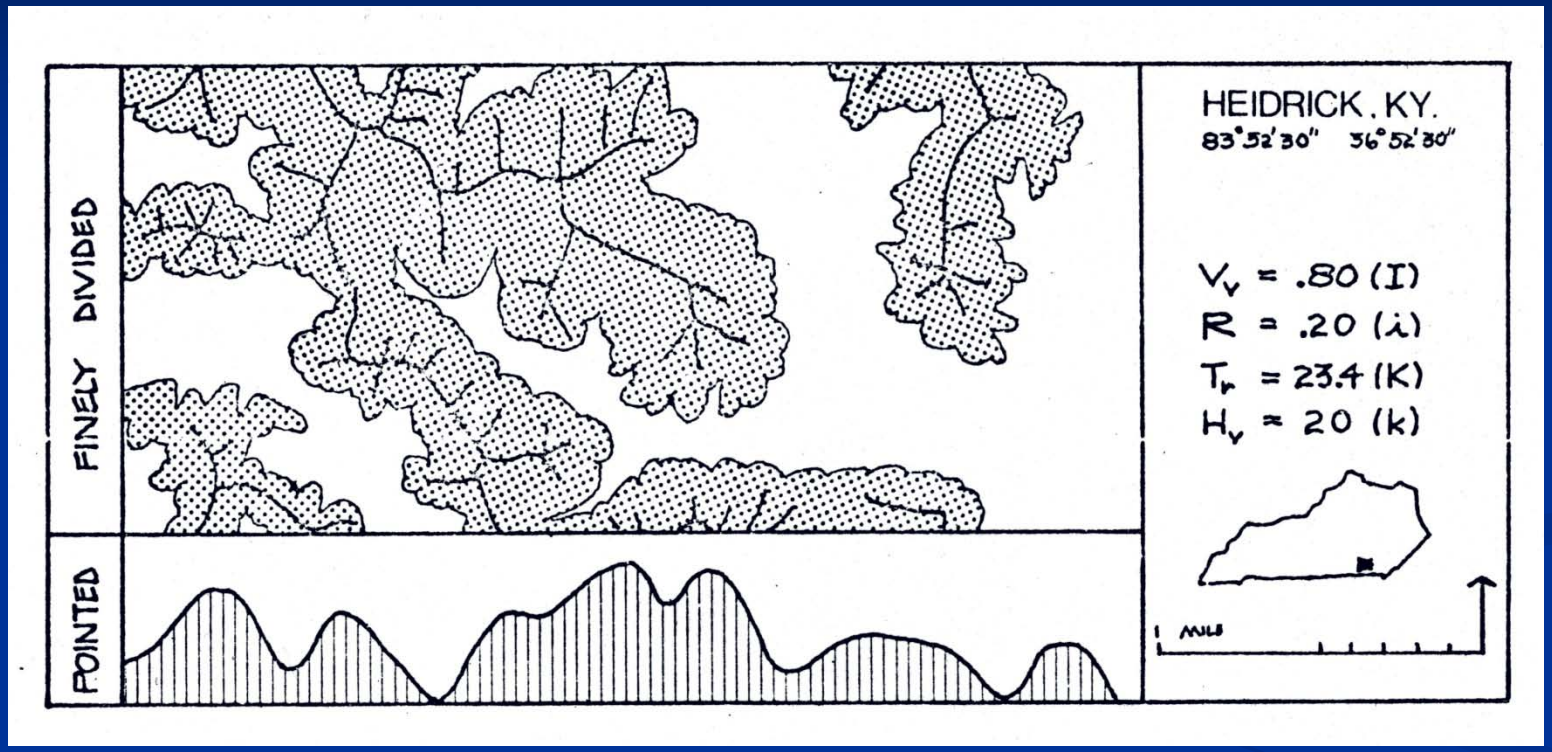
- Mine site within its context scale
  - Elevation, spacing and connectivity of landforms
  - Data, map and field surveys
  - Permit data – if available
- Parameters useful within a mine site
  - Survey and field data collection
  - Permit data – if available
- Detailed site parameters
  - Field survey
  - Historic data
  - Reference landforms
  - Reference reaches

Site context parameters – landform parameters

- Landform texture – e.g. ridgeline length per unit area
- Vertical variation – amplitude of elevation changes on upper slopes
- Reticulation – terrain net patterns
- Horizontal variation – distances to adjacent landscapes at roughly the same elevation

- Parameters measurable from data – DEM, LIDAR, imagery, etc.

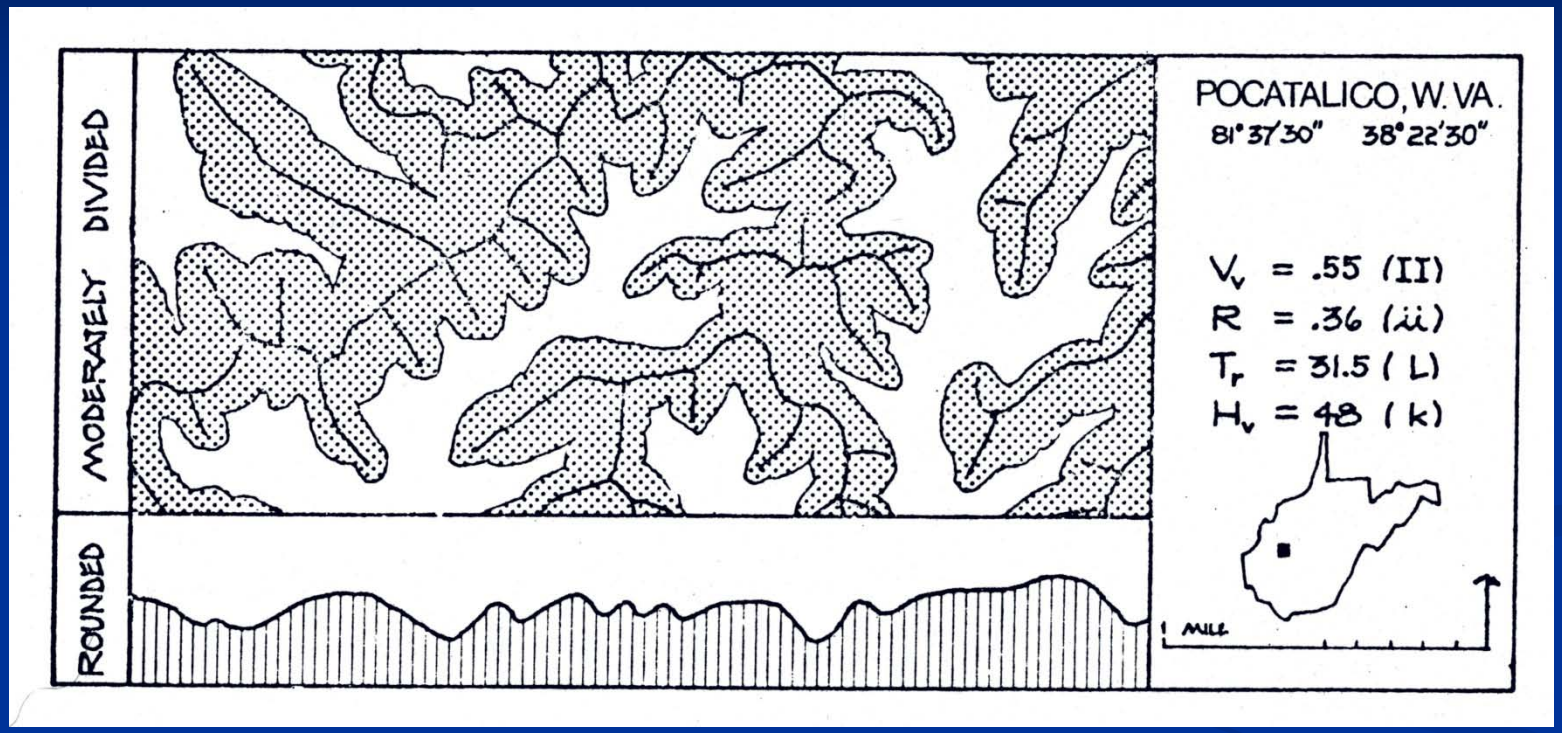
Some examples of the resulting landscapes from this level of classification with results for including landform parameters



Pointed-Finely Divided (Ii)

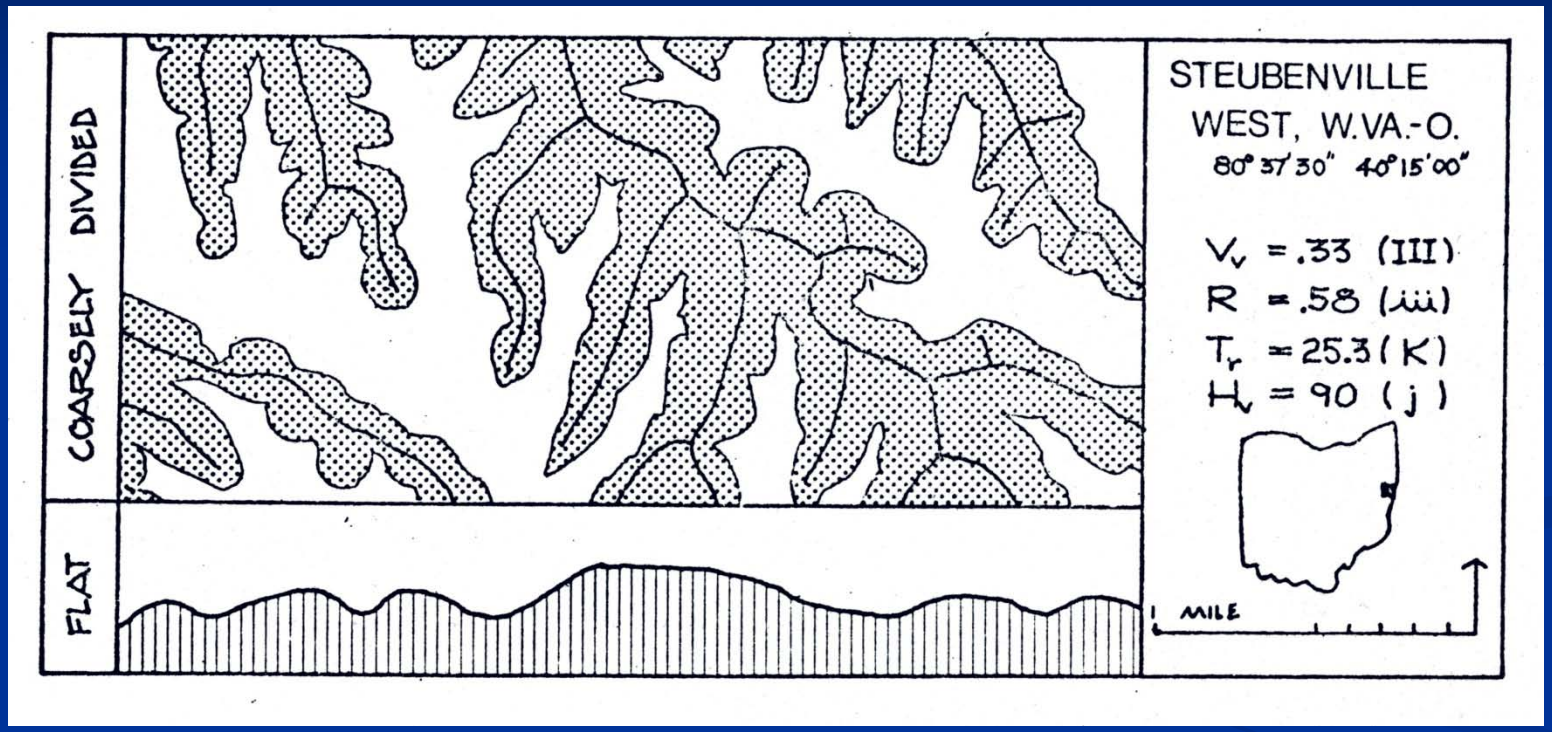
The parameters refer to landform texture, vertical variation, reticulation And horizontal variation

Another landscape within the western Appalachians of West Virginia



Rounded-Moderately Divided (Iiii)

And a third landscape where the Appalachians for flattening out



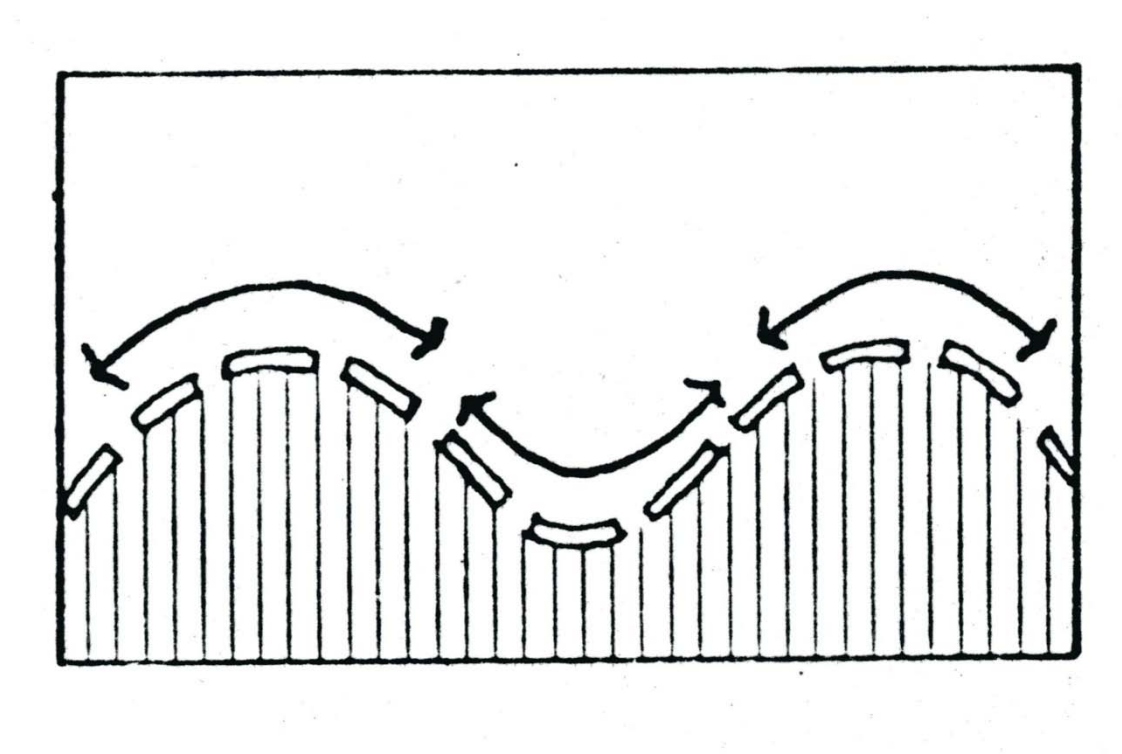
Flat-Coarsely Divided (IIIiii)

The site level – actual details for landforming parameters

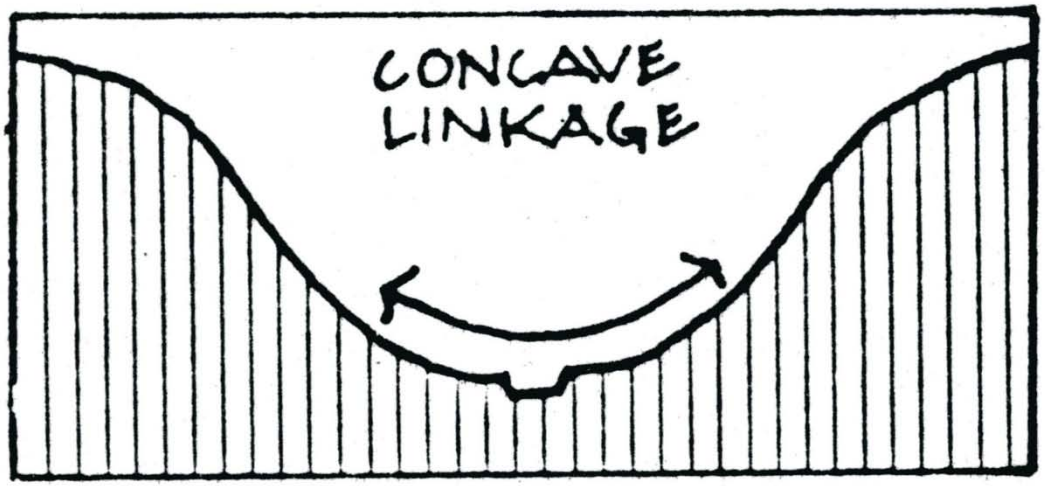
- Crest curvature
- Linkage angles
- Texture – drainage network
- Slope profiles

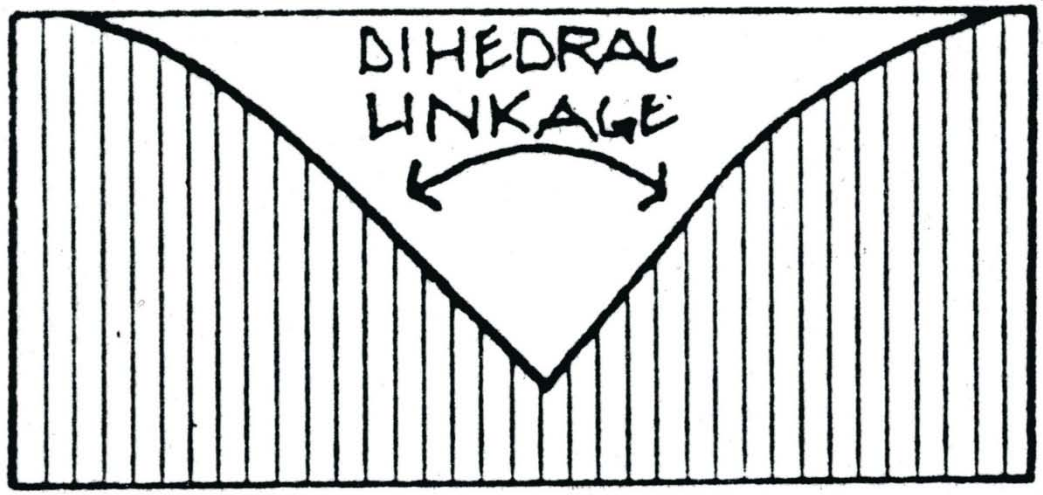
- Field investigations, historic data, reference data

Crest curvature

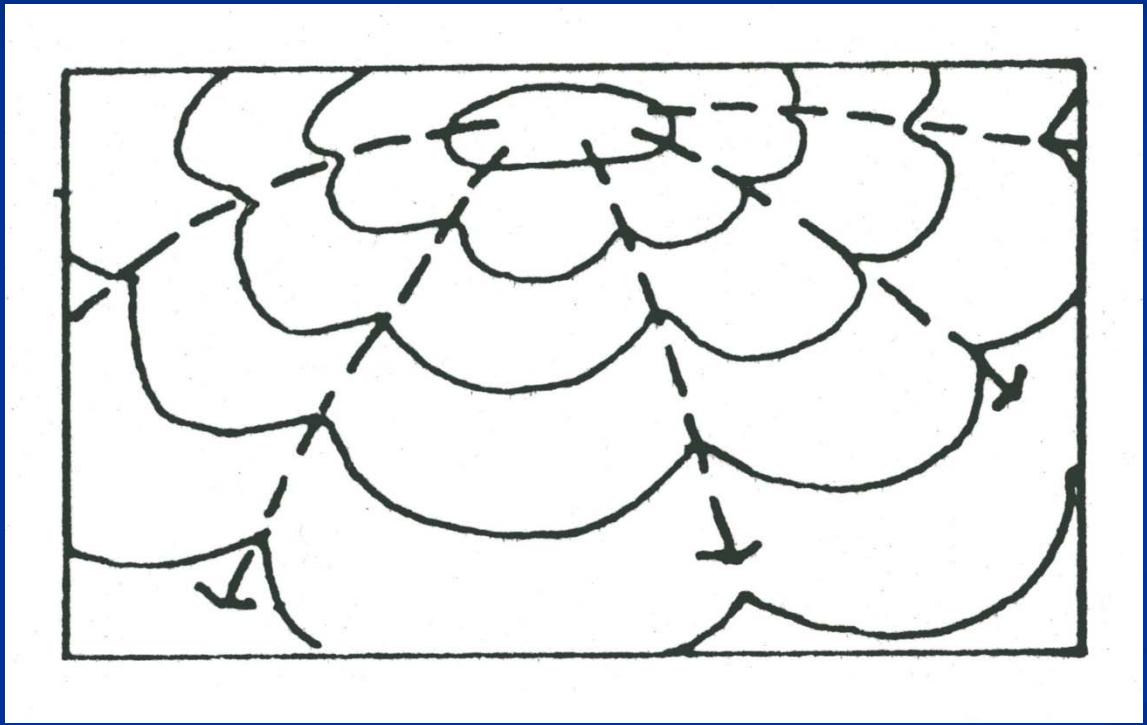


Linkage angle

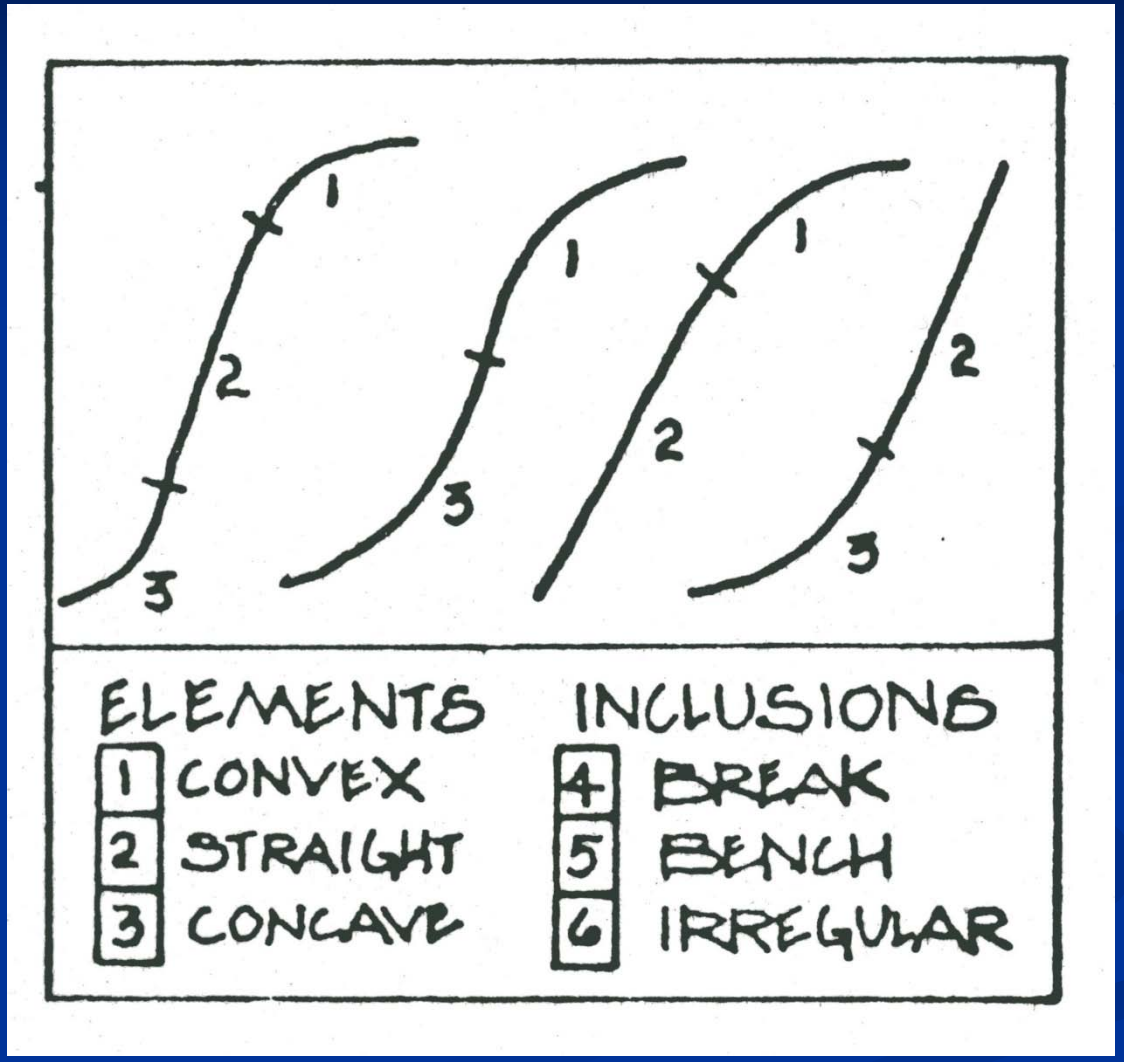




Micro texture / drainage density



Slope profile



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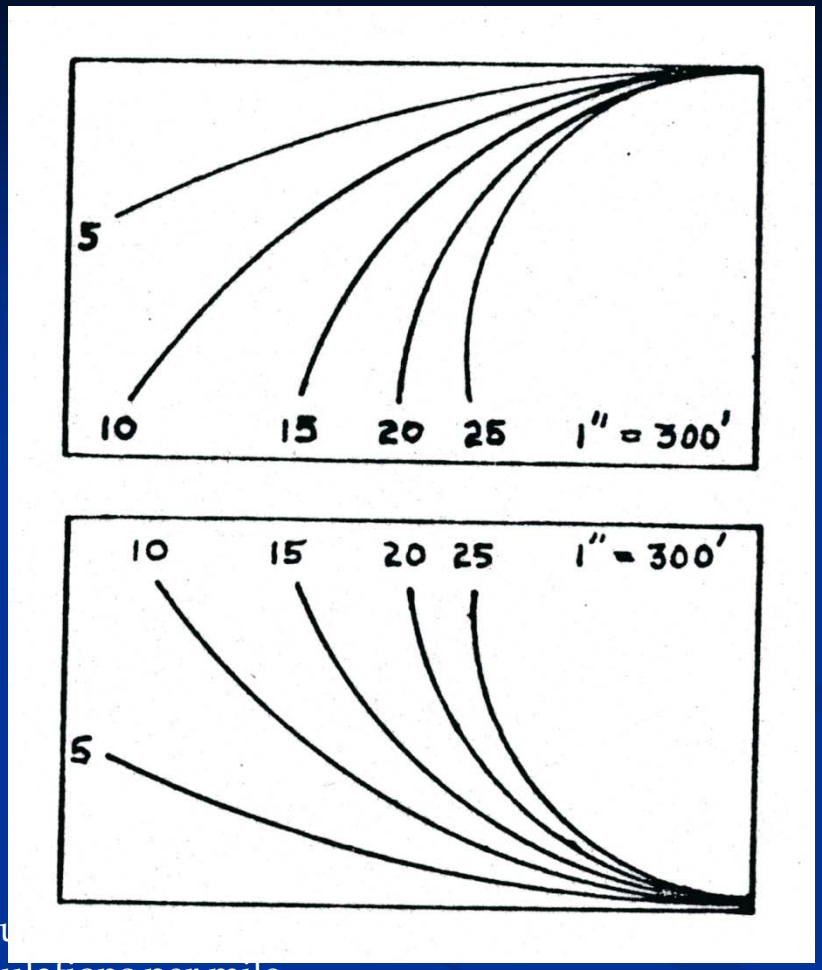
	c2	5° –10° per 100′
	c3	10° – 15° per 100′
	c4	15° – 20° per 100′
	c5	20° – 55° per 100′
	c6	Dihedral Angle
LINKAGE ANGLE	1	0° – 5° per 100′
	2	5° –10° per 100′
	3	10° – 15° per 100′
	4	15° – 20° per 100′
	5	20° – 55° per 100′
	6	Dihedral Angle
MICRO TEXTURE	x1	coarse 5 crenu
	x2	medium 5 - 8 crenulations per mile
	x3	fine 8-11 crenulations per mile
	x4	very fine 11+ crenulations per mile

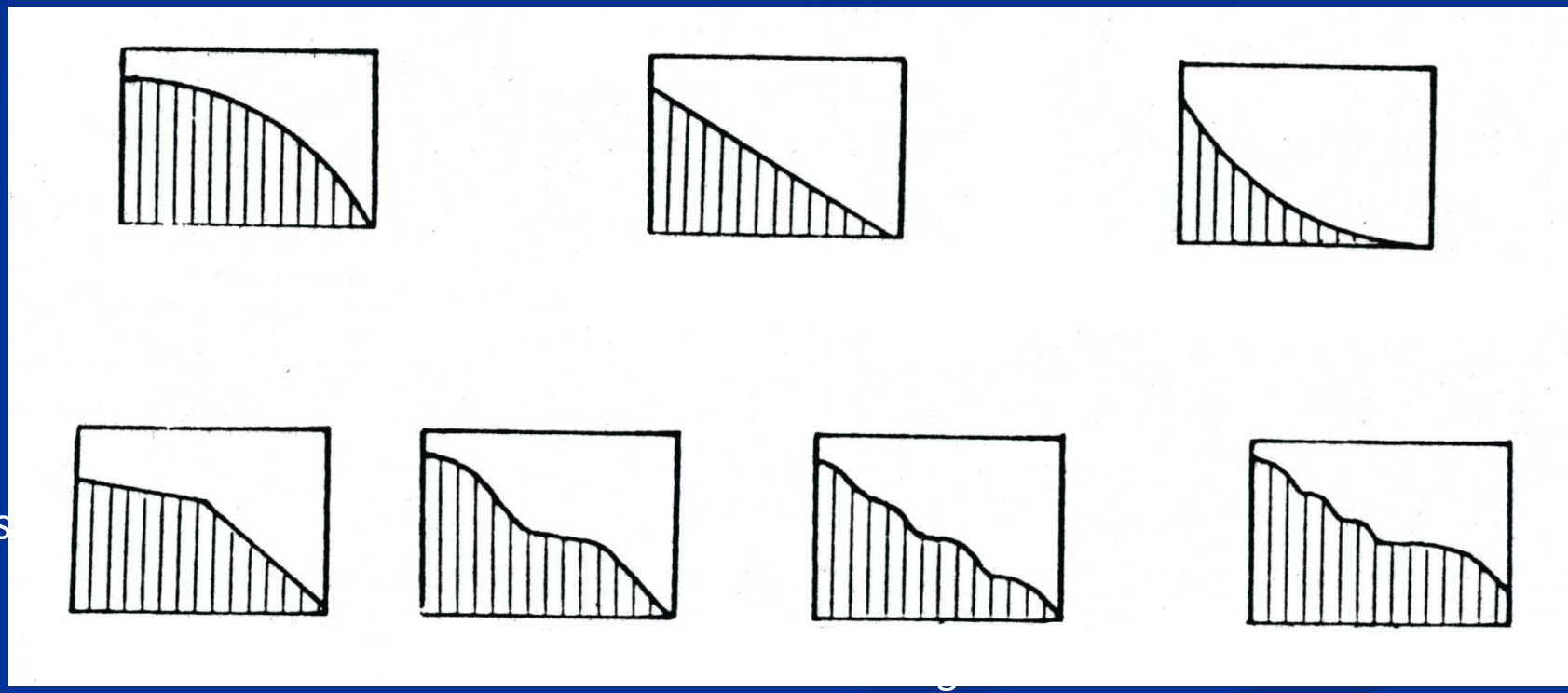


SLOPE PROFILE

Profile is classified by the sequence of curvature elements, codes 1, 2, 3 and by the presence of profile inclusions, codes 4, 5, 6 and 7.

Elements

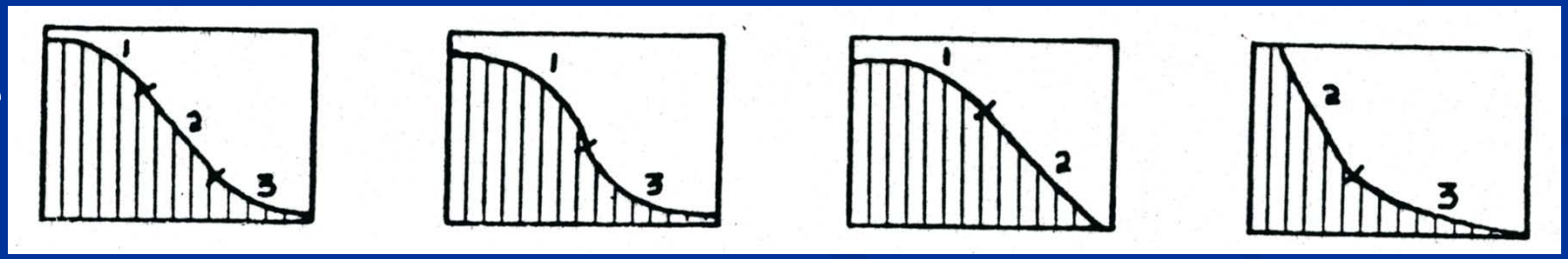
Inclusions



of 4, 5 & 6

Four sequence types, coded A, B, C, and D are designed and described below. By noting the presence of inclusions (e.g., A5, D6, etc.), a fairly sophisticated description and classification of slope profile is possible.

Sequence Types



Type A	Type B	Type C	Type D
1-2-3	1-3	1-2	2-3

Such a system….

- Opportunities for understanding terrain systems using measurable terrain parameters
- A design framework for post mining land shaping
- A system for evaluating alternative plans – qualitatively and quantitatively

- A system based in…
  - Geomorphic descriptions and processes
  - Helps place surface hydrology on the land
  - Language used by engineers, landscape architects and other landforming professionals
  - Uses historic patterns and reference data whenever possible

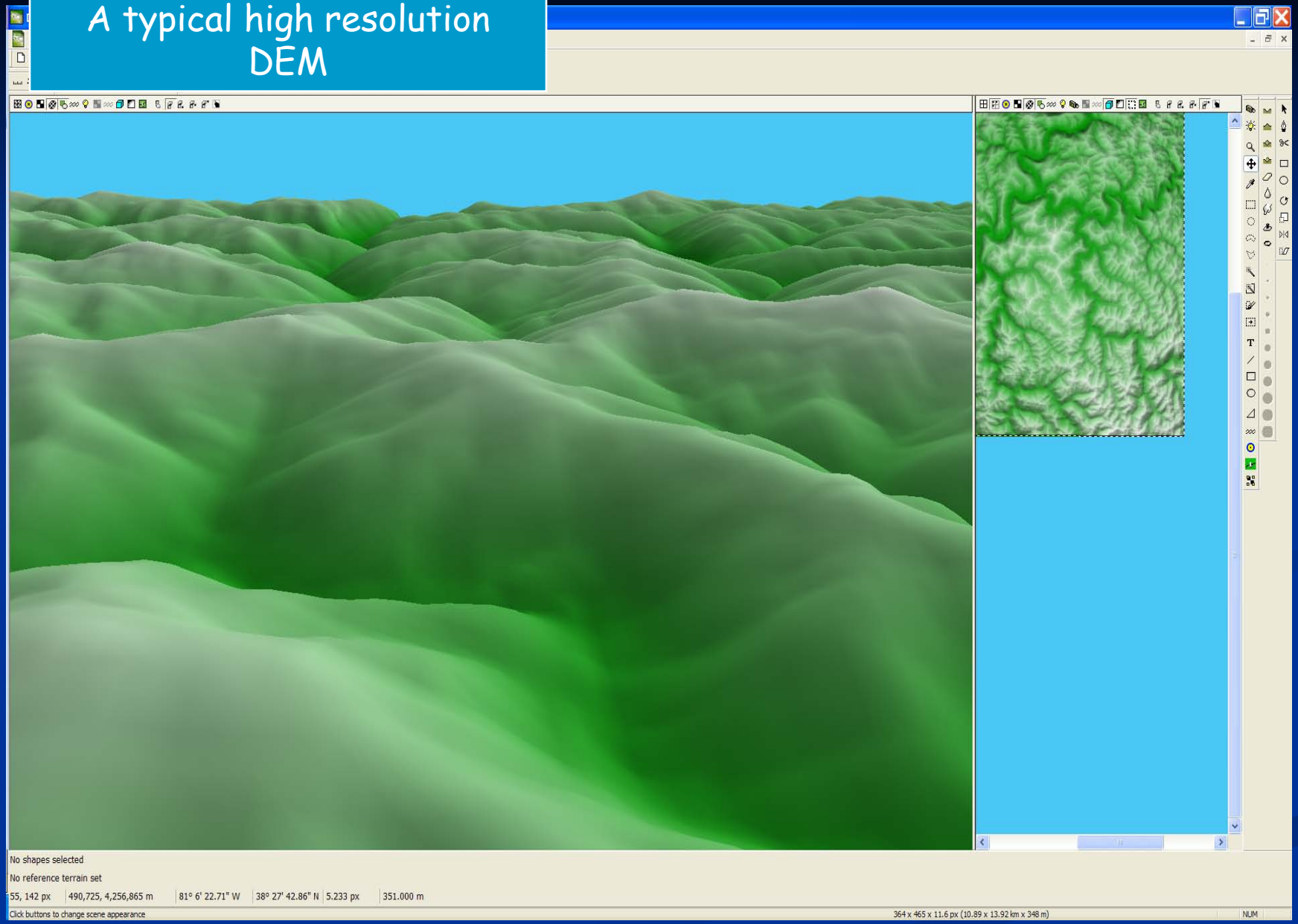
A second component we are interested in exploring

- Landforming – design and pre-engineering
- Basic methods derived from evidence that engineering and design that focuses in 2D plan view design is often difficult to visualize during plan development
- 3D methods may present us with pre-engineering opportunities for landforming
- 3D methods can feed traditional engineering documentation development

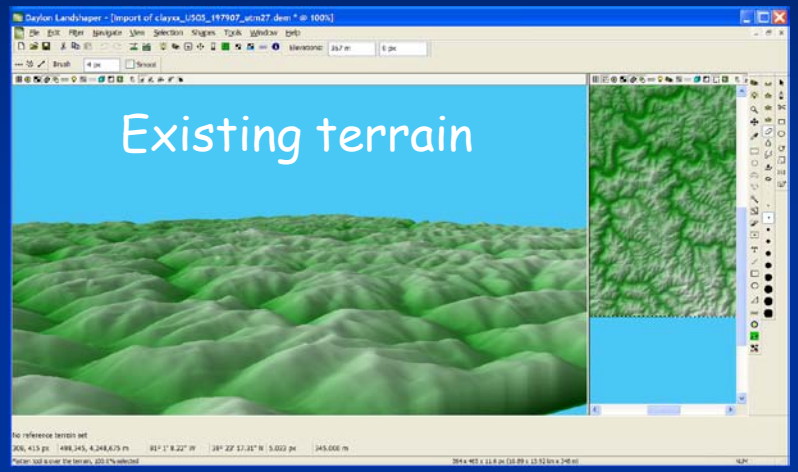
We are working with two approaches

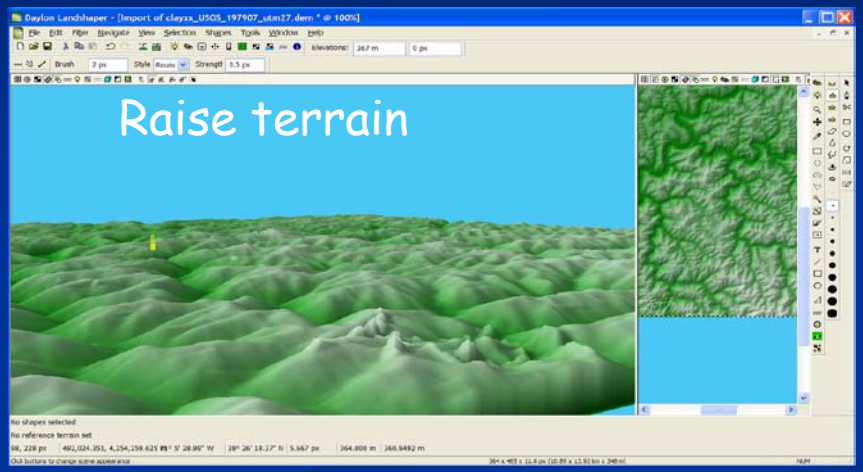
- The earlier on-the-fly landform manipulation tools
- A more controlled set of landform manipulation primitives
  - Currently prototyping a workable mining landforming system with of-the-shelf-software – landshaper sdk – can be standalone or embedded in other applications.

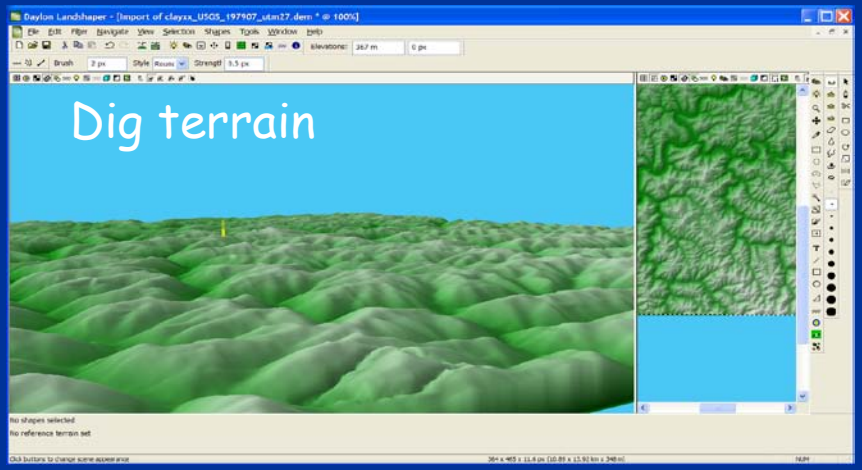
A typical high resolution DEM

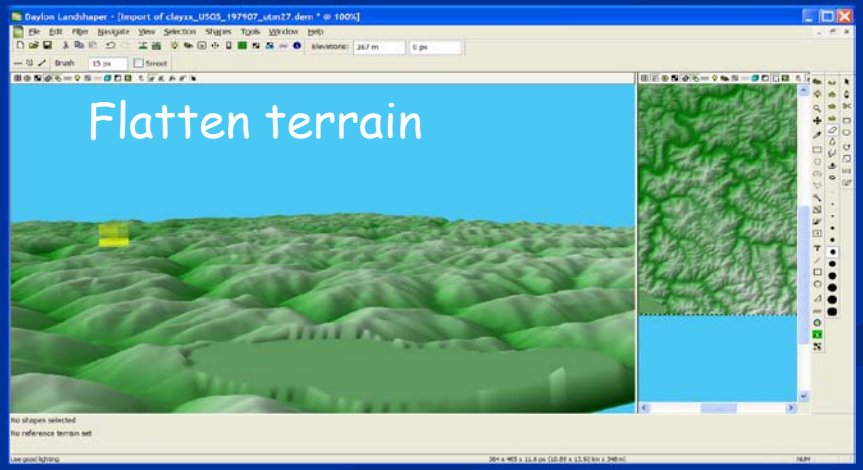


Some terrain modification tools – from a larger toolset



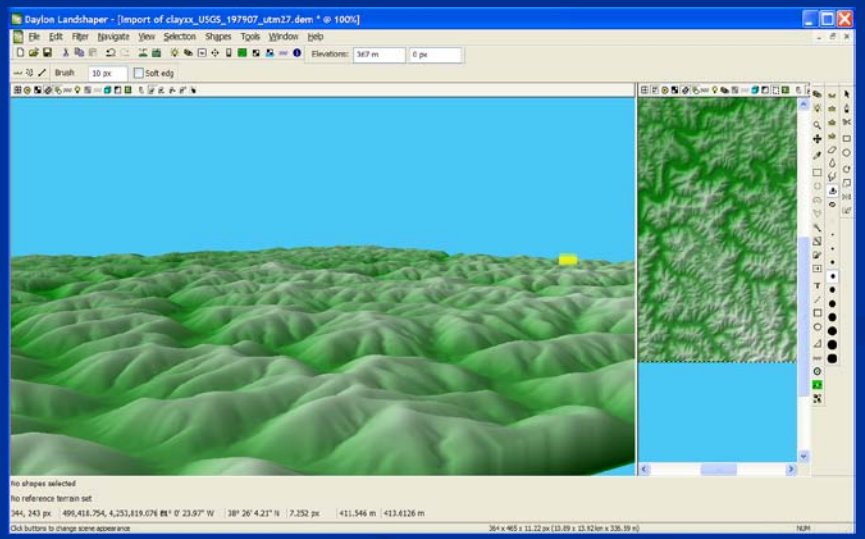






One more to mention…erosion

- This has been linked to the results obtained with the SIBERIA/EAMS erosion model which has utility to long term modeling of erosion potentials in disturbed landscapes.



Terrain / land shaping

- Can then subject all modified terrain to various assessments using GIS or other software
- Can kick alternative landforms back to our visualization functions

- There are over 30 such individual commands. Individual primitive commands can be chained together to form complex landforms such as
  - Fills
  - Backfill / backstack areas
  - Haul roads
  - Stream channels
  - Highwall backfills

A project initiated in the Central Appalachians

- Initial planning for 16,000 acres of a total 45,000 acre area
- Various mining methods over the site over a proposed project period of 20 years
- Intensive land uses are proposed or visualized as a part of the project
- A proposed 20 mile scenic and economic byway is proposed for the area
- Development is emerging as a private / public partnership

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Project Introduction

Mission Statement

Create a visual management plan and improve roadway alignment on a 16.5 mile section of the Clay-Nicholas Economic Corridor. Suggest basic alignment of the roadway to make the drive more desirable and visually pleasing in an extensively mined area of Clay County. Utilize reclamation techniques to buffer and naturalize areas of mining. Implement low impact design practices to encourage long term sustainability and improve water quality within the corridor.

Goals/Objectives

Goal 1:
Enhance the transportation network by producing a faster, safer route between Clay and Summersville that can accommodate the traffic of heavy industry. Yet, emphasizes the area's natural beauty in the overall design scheme to create a scenic, desirable drive.

- Suggest an improved roadway alignment for the Clay Corridor supplemented by an arc and tangent layout.
- Implement sweeping horizontal curves into the roadway for a safe commute.
- Maintain grades of less than 15% for industrial traffic.
- Design roadway layout to optimize the full spectrum of intrinsic qualities.
- Buffer undesirable visual features along the corridor.
- Enhance desirable naturalistic features.
- Utilize points of topographical prominence for possible visual opportunities.
- Preserve the adjacent streams near the corridor when design the road layout.
- Capture natural terrain features to convey scenic drive.

Goal 2:
Site educational, commercial, industrial, and residential facilities while preserving the scenic view for a wide range of residents along the corridor.

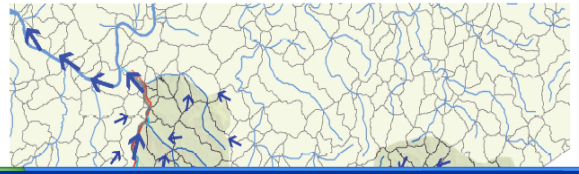
- Propose three land-use plans using variations of educational, commercial, housing, and industrial space.
- Clay County High School and vocational building will be included in the educational area.
- Preserve non-mine areas for future development.
- Preserve the land in the corridor view shed for a naturalistic experience.
- Current valley fill permitted areas will be preserve

Goal 3:
Reduce environmental impact within the corridor by proposing development only on mine permitted areas. Incorporate the area's natural aesthetic features to convey a more naturalistic and visually pleasing drive to residents and other users of the corridor.

- Re-grade surface area affected by mining for a more natural landscape.
- Re-vegetate area with native plants to complement existing vegetation.
- Utilize Landform Grading Principals where applicable
- Implement wildlife corridors along the Clay Corridor.
- Use grass swales where needed.

Area History

Clay County was formed in 1858 from parts of Braxton, Kanawha, and Nicholas Counties and was named in honor of Henry Clay, a Kentucky statesman. We declared our statehood in 1863. Clay County has around 10,120 residents, all of which are located in rural areas. This brings the population density to only thirty people per square mile. In actuality the population has declined from the 1960's and 1970's in Clay. Clay County is made up of about 3,200 county owner-occupied homes and about 900 renter occupied apartments, make about 21% of renters. Clay averages about 2.5 people per household. This figure should be considered when designing housing units. The average rent in Clay in about $250 a month. With an average income of around $27,000 Clay is under the state average at $37,000. Estimated averages of condos in Clay are around $75,000 while detached homes average around $125,000. Clay is predominantly made up of Caucasian Americans (98%) while gender numbers are even at 50% for men and women. The mean annual temperature is 55 degrees and the mean annual snowfall ranges from 22 to 40 inches. The county area is 346.1 square miles, while two thirds of the county lies at elevations of 1000 feet above sea level.



Program Elements

Education
Housing
Business
Recreation
Low Impact Design
Roadway

Program Relationships

Education

- Clay County High School
- Clay County Technical Center
- Arboretum
- Football Field
- Baseball Field
- Fitness Center
- Archery Range
- Driving Range
- Golf Facility

Housing

- Single Family Homes
- Multi-Family Attached Units
- Apartments
- Business
- Business Incubator

Commercial Park

- Industrial Space
- Medical Facility
- Private Practice Physician Space
- Restaurant

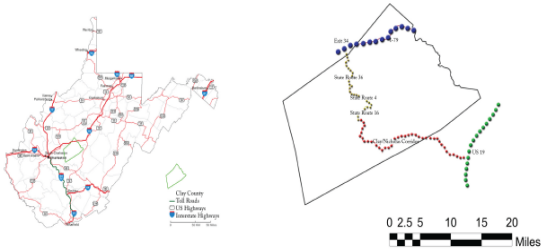
Low Impact Design

- Bioretention areas
- Bio Swales
- Vegetation Buffers
- Native Plants
- Mine Reclamation

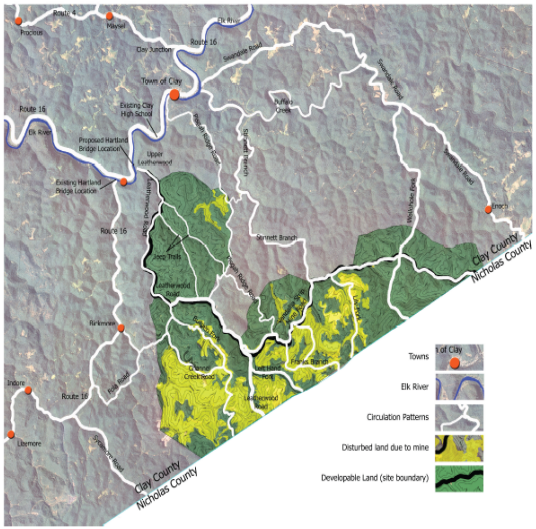
Sheet Flow
Channel Flow
Perennial Stream (Leatherwood Creek)
Sub Watersheds
Proposed Corridor

Location, Climate, and Hydrology

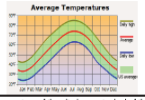
Site Location Maps



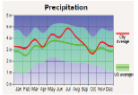
Site Context Map



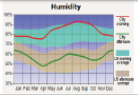
Climate Information



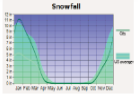
The temperature of the site is very typical of the northeastern part of the country, and enjoys all four seasons evenly throughout the year. In winter months the temperatures can stretch from 20 F to 45 F, while summer averages from around 60 F to 85 F giving the area a balanced seasonal weather pattern.



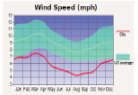
The region's precipitation levels are slightly higher than the rest of the nation. The rainfall is the highest in July, right under five inches. February is the lowest month for precipitation, right about three inches. Due to the average levels of precipitation and slopes within the area the site will need increased stormwater management implementations.



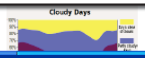
Humidity patterns in this region usually are within the normal range of the rest of the nation. Morning humidity levels are at their highest in September, around 90%, while the lowest humidity level is in April, about 50%. The largest stretch of humidity takes place from May to September.



The past snowfall patterns indicate that the site receives more snow then our nation's average. Average snowfall can reach of eleven inches in January, with the nation's average being just above five inches. Snowfall will be a factor when designing on ridge tops within the site.



The region's average wind speed is below the nation's average throughout the year. Overall wind should not be a major concern for the corridor location; however possible ridge top development locations may provide excessive wind which will need to be accounted for.



Circulation Analysis

The route of the proposed corridor is made up for three main roads. The first road, located nearest to the Elk River, is Leatherwood Road. Leatherwood Road runs along the proposed corridor route until mile seven when the Vandellia Strip Mine Road continues the proposed route. The two roads are separated by a stream. Vandellia Strip Mine runs along the corridor until about mile sixteen, into Nicholas County, when it

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Clay Corridor Mine Site

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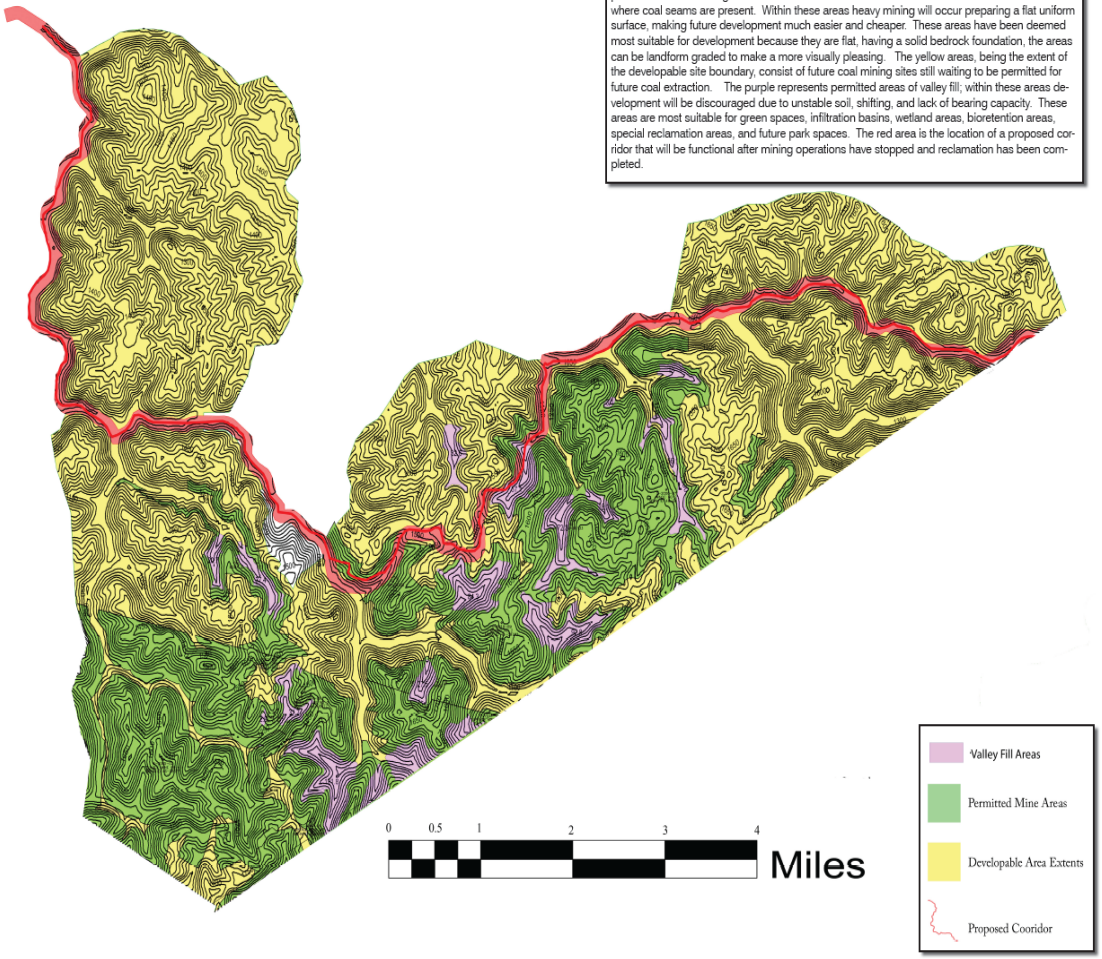
The composite analysis was completed by studying mining permits, contour mining areas, strip mining areas, site boundaries, and permitted valley fill areas. The green areas within the site are permitted surface mining areas that are focused on the 1200 foot and the 1400 foot contour areas where coal seams are present. Within these areas heavy mining will occur preparing a flat uniform surface, making future development much easier and cheaper. These areas have been deemed most suitable for development because they are flat, having a solid bedrock foundation, the areas can be landform graded to make a more visually pleasing. The yellow areas, being the extent of the developable site boundary, consist of future coal mining sites still waiting to be permitted for future coal extraction. The purple represents permitted areas of valley fill; within these areas development will be discouraged due to unstable soil, shifting, and lack of bearing capacity. These areas are most suitable for green spaces, infiltration basins, wetland areas, bioretention areas, special reclamation areas, and future park spaces. The red area is the location of a proposed corridor that will be functional after mining operations have stopped and reclamation has been completed.



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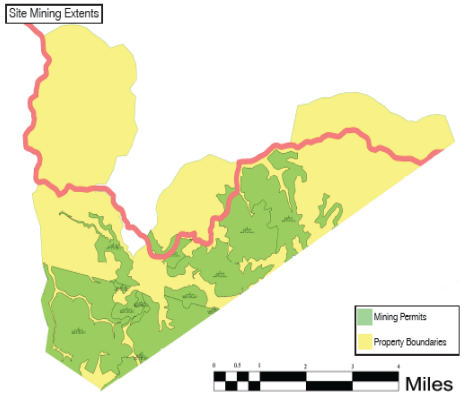
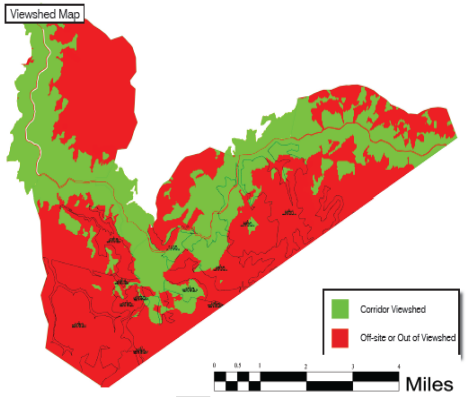
Design Development

Site Mining Extents

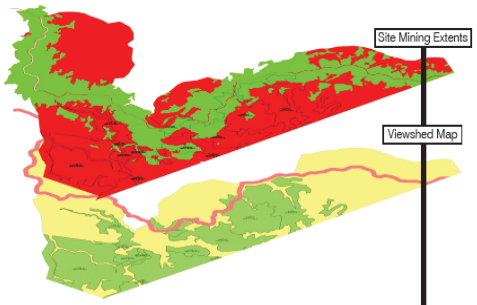


This site map shows the extends and boundaries of the mining permits that are current within the site. When identifying areas that were critical for reclamation, many factors were taken into consideration. Proximity of the mining permit areas to the site development areas, and the corridor had to be understood to begin formulating methods for identifying the key areas for reclamation.

Viewshed Map

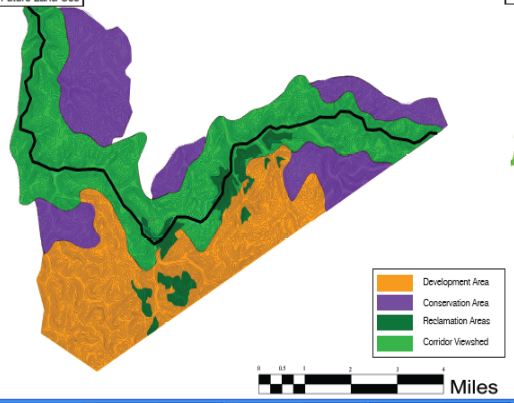


After understanding the mining permit extents and locations, a viewshed analysis was done to give a better understanding of what a passer by driving on the corridor could actually see. From this analysis we were able to conceptually formulate a plan based on viewshed areas and permit areas.

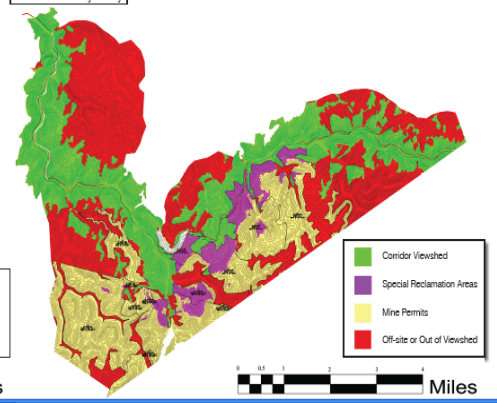


After doing a map over lay of the mining extents map and the viewshed map, the conceptual viewshed map was made to give a general representation of where potential visual impact areas would be. These areas were outlined in purple, and gave a quick representation of where these areas were.

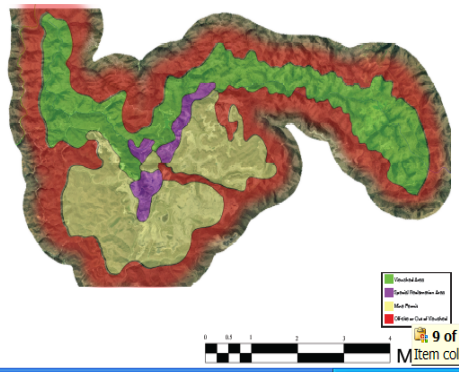
Future Land Use



Visual Sensitivity Study



Conceptual Viewshed Map



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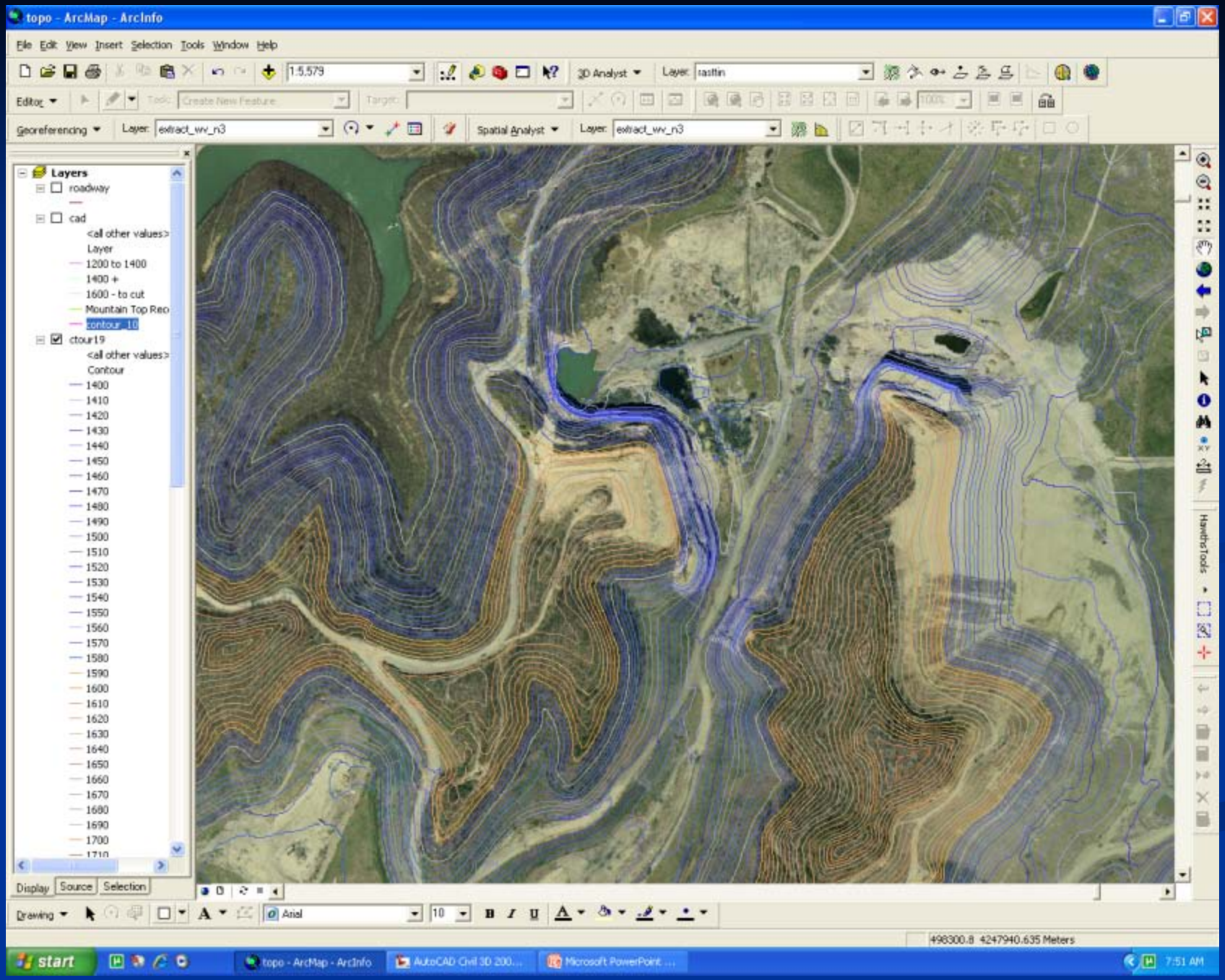
So the project

- Large mine and re-mining areas
- All new mining is being evaluated for some degree of geomorphic reclamation
- Critical areas are being planned with close attention to landforming details

Basic project methods

- Work from past reclamation, current permits and proposed future mining
- Use land use planning and viewshed analysis to establish general landforming goals
- Complete landform analysis using site context and site parameters to quantify current conditions
- Develop preliminary landforming strategies using landforming tools
- Review and finalize preliminary landforming strategies using analysis functions from WCMS and EAMS

- MAJOR ISSUES – integrating new reclamation with recent reclamation and with land use goals.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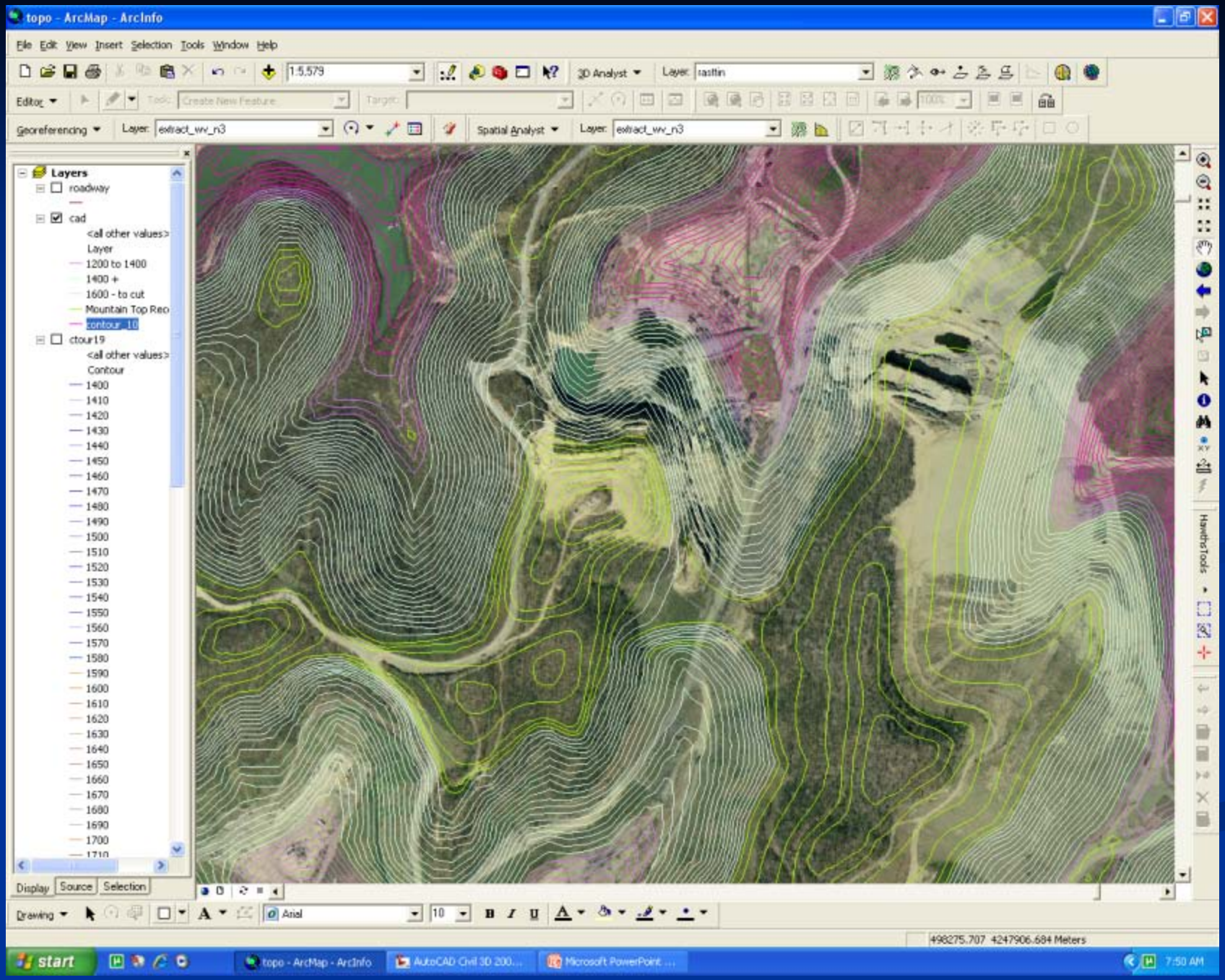
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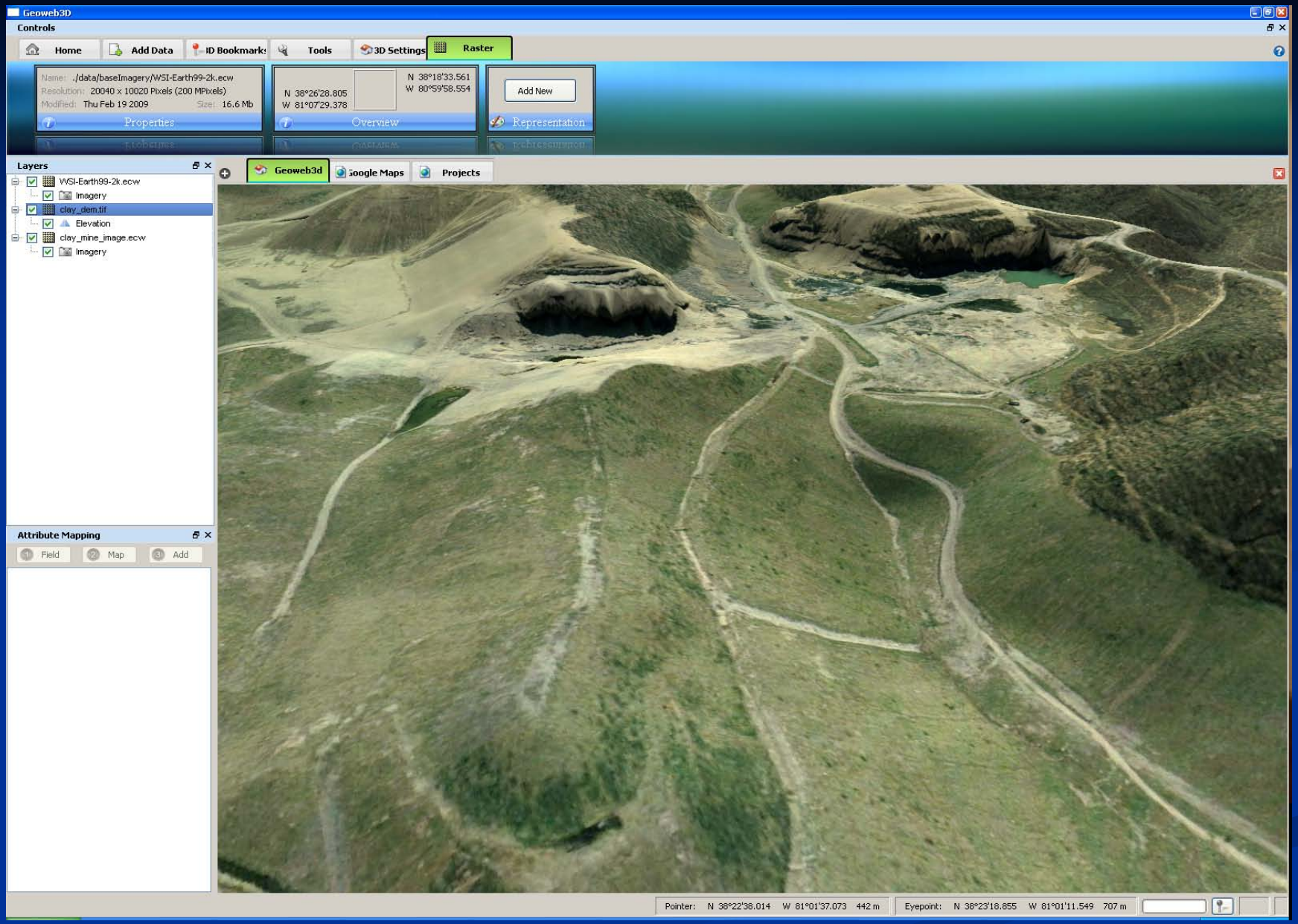
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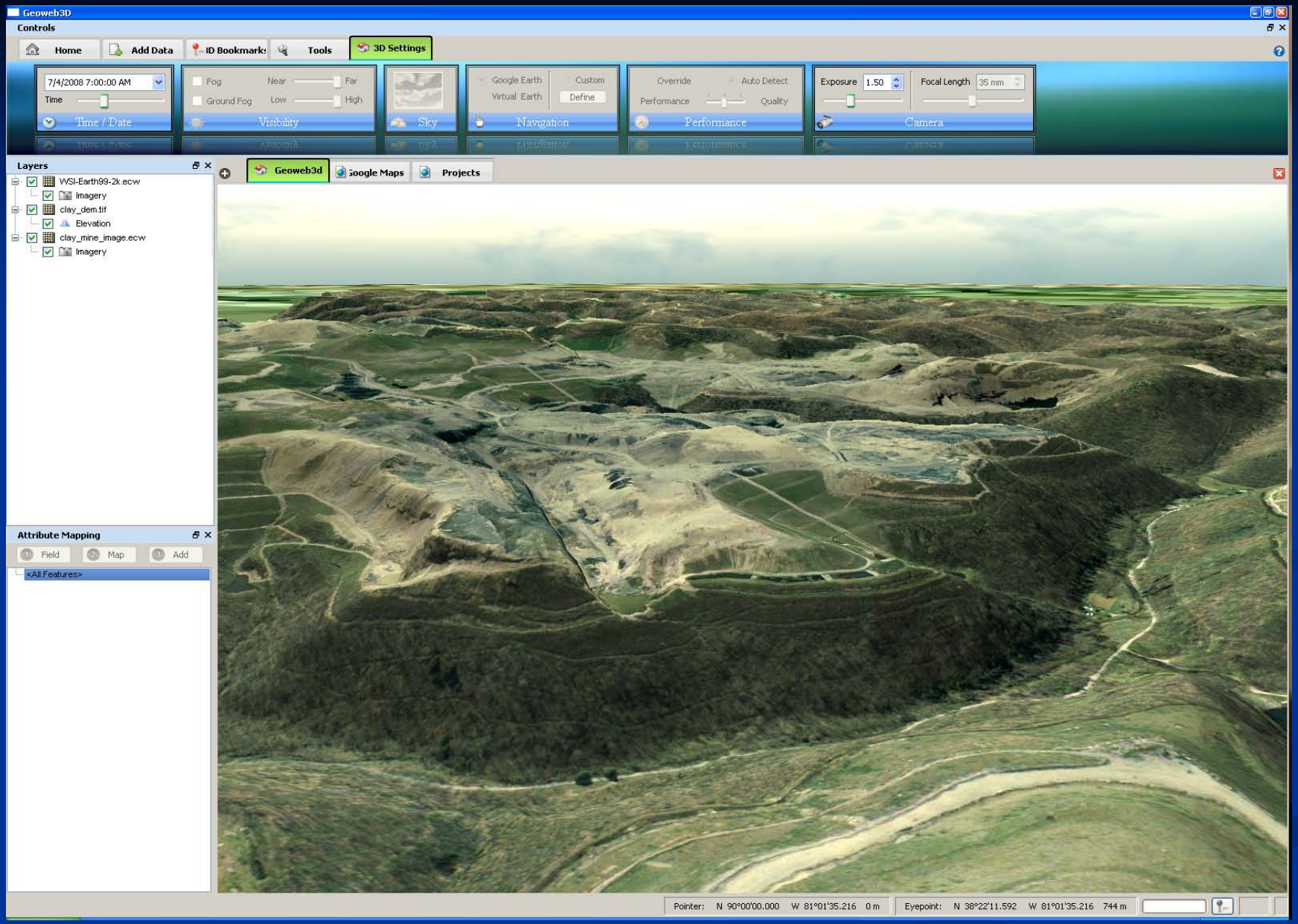
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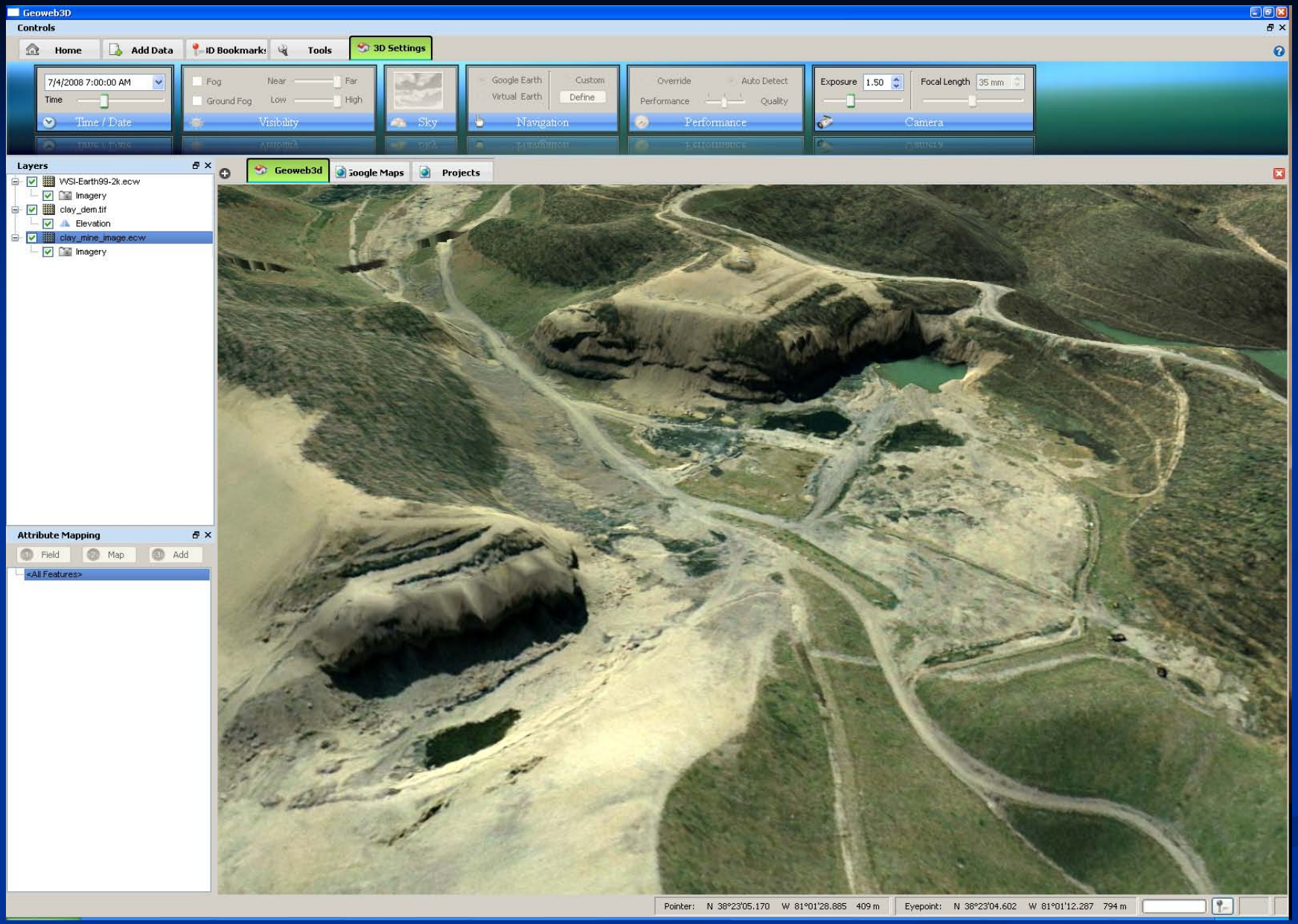
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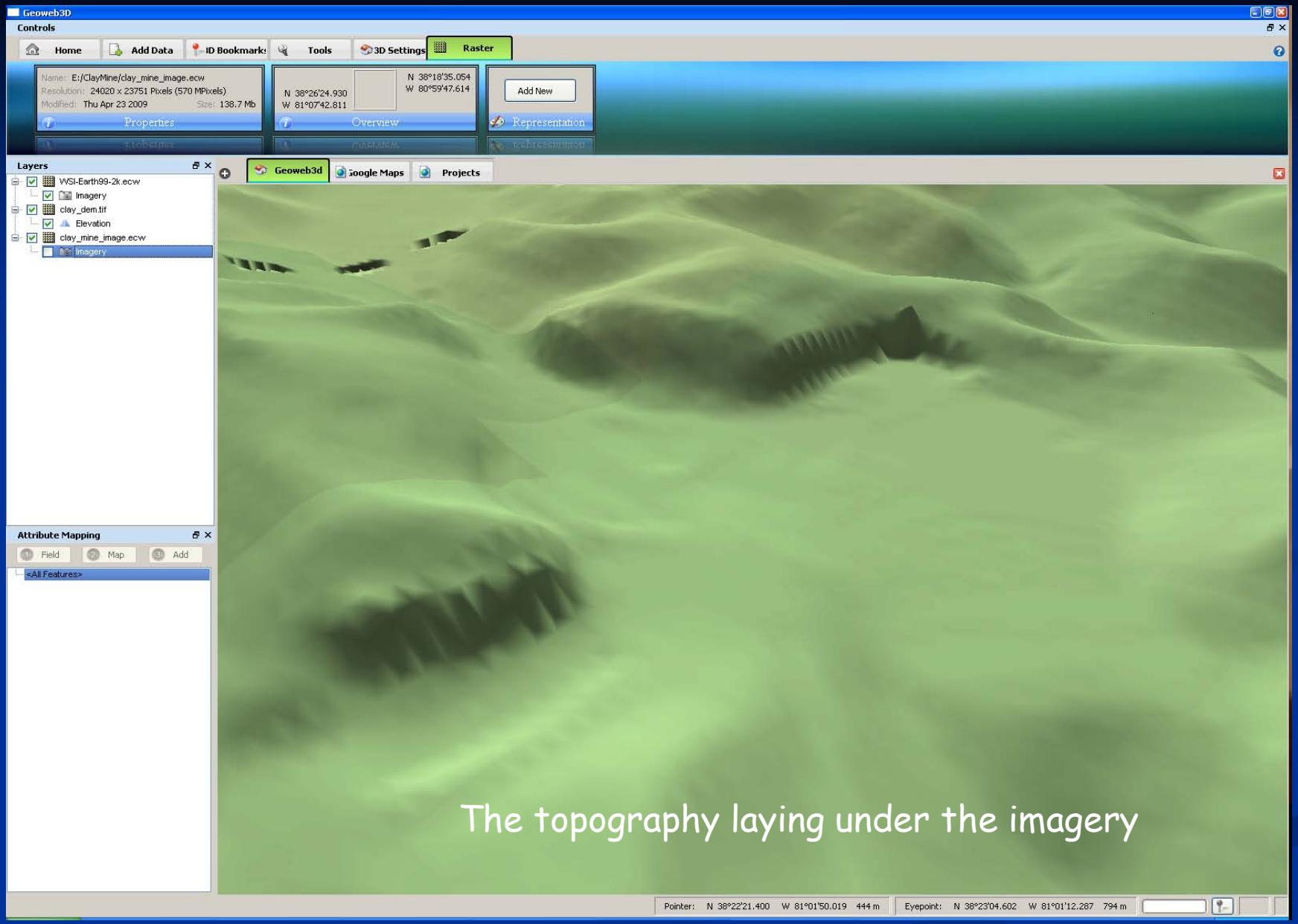
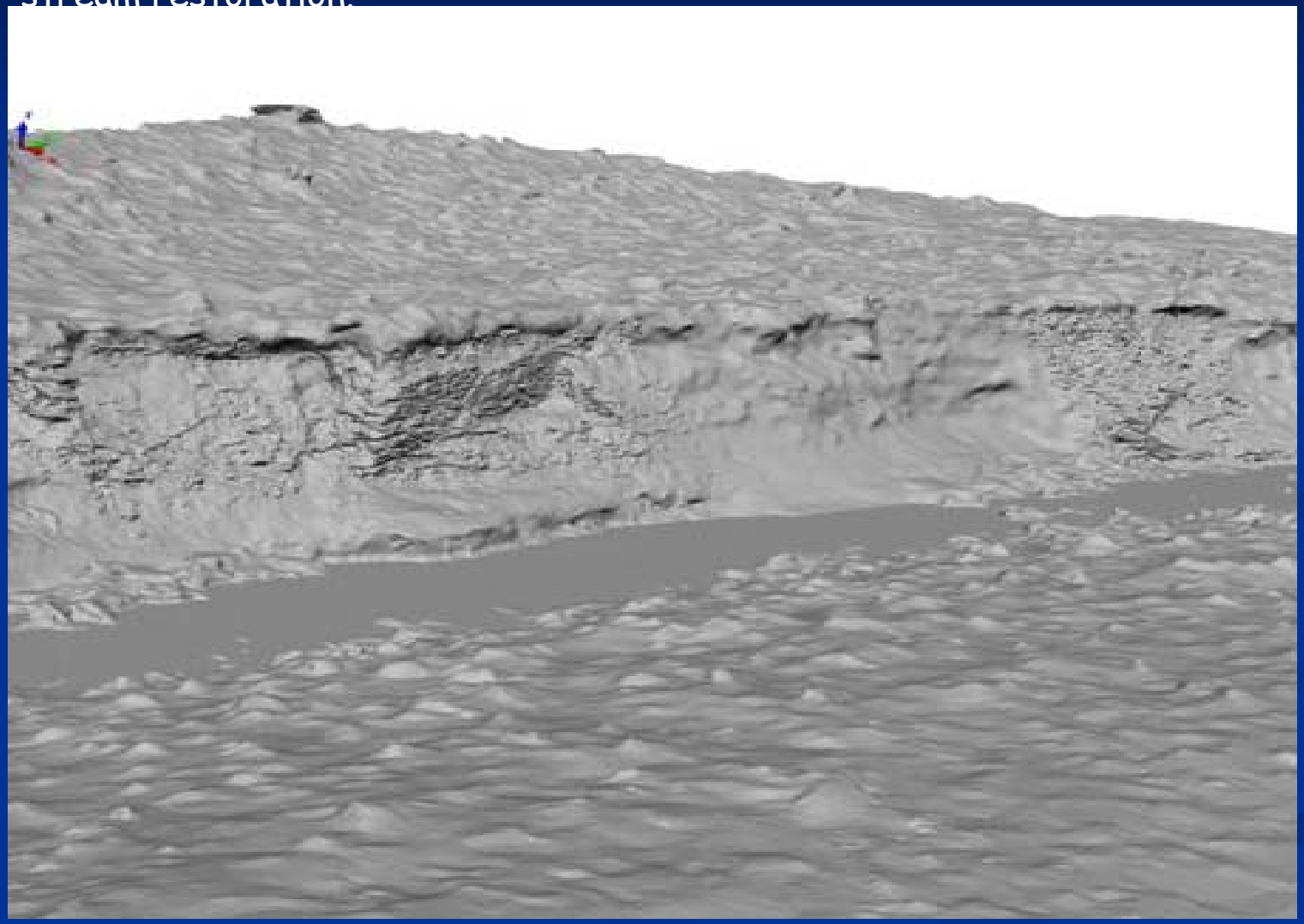
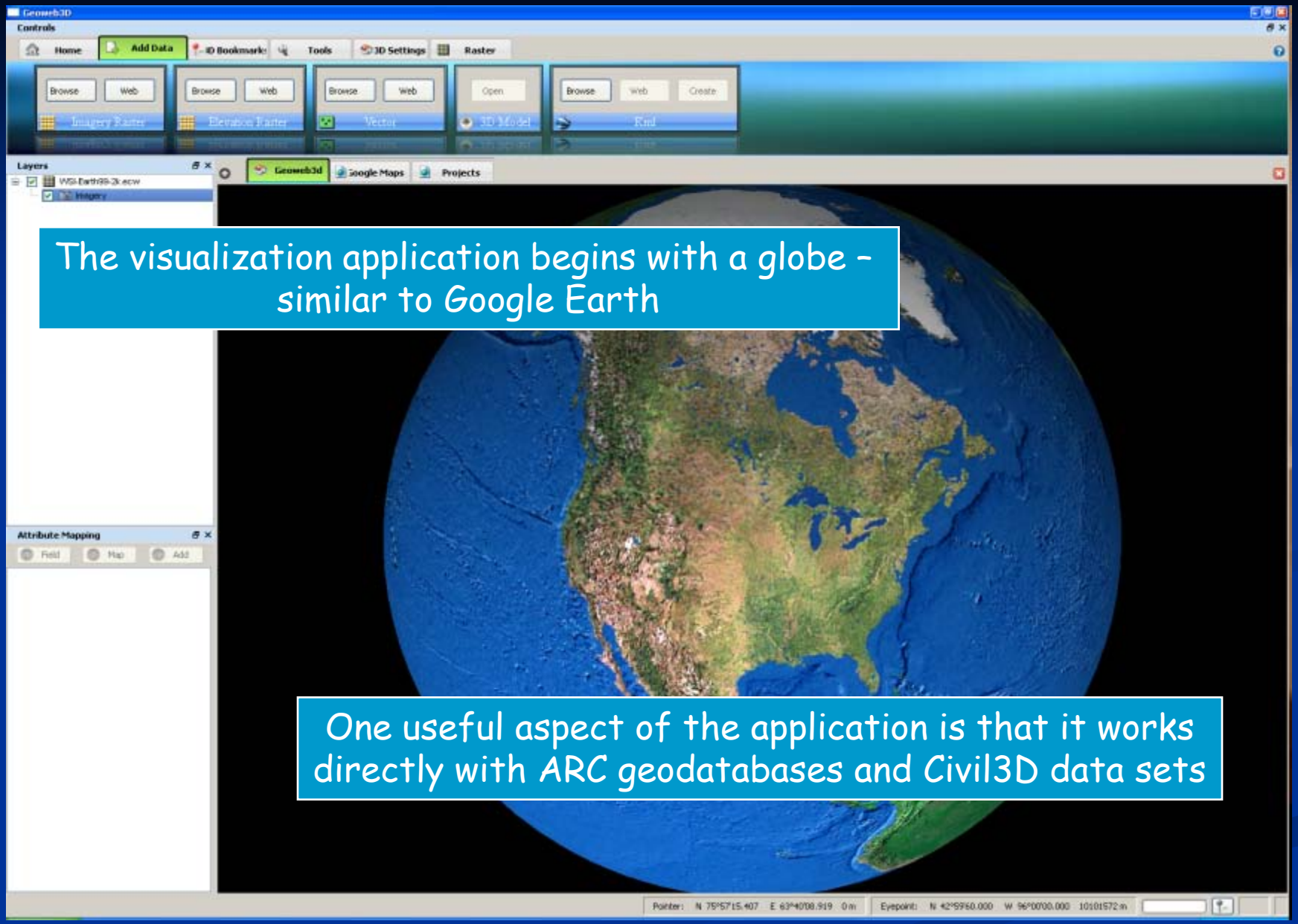
Google Earth
Custom
Virtual Earth
Define
Navigation
Override
Auto Detect
Performance
Quality
Performance
Exposure
1.50
Focal Length
35 mm
Camera
Layers
WSI-Earth99-2k.ecw
Imagery
clay_dem.tif
Elevation
clay_mine_image.ecw
Imagery
Attribute Mapping
Field
Map
Add
<All Features>
Geoweb3d
Google Maps
Projects
Pointer: N 38°23'05.170 W 81°01'28.885 409 m
Eyepoint: N 38°23'04.602 W 81°01'12.287 794 m



The topography laying under the imagery

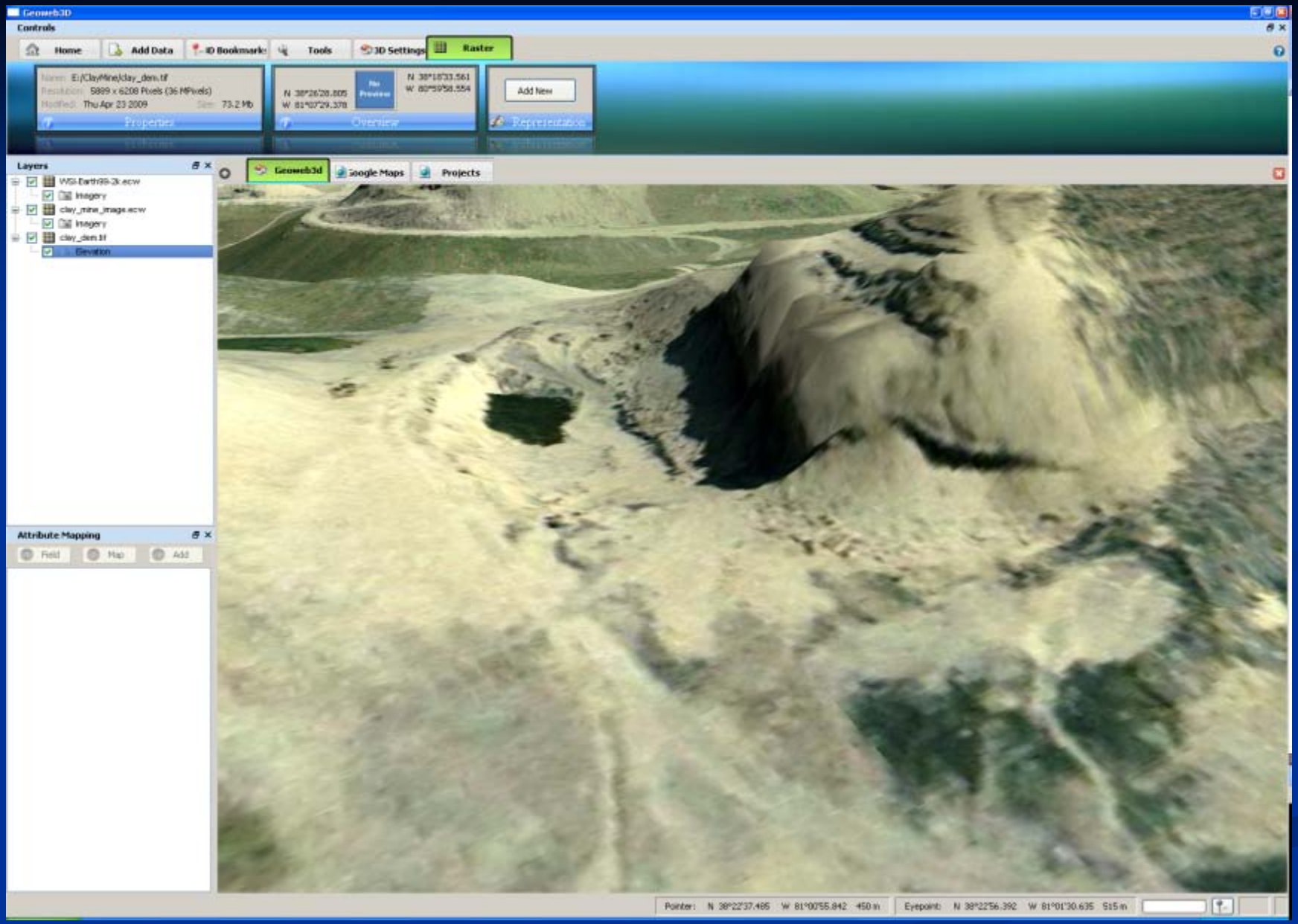
One tool that shows promise for capturing terrain is ground based LIDAR - in particularly critical portions of the sites – for both landforming and stream restoration.



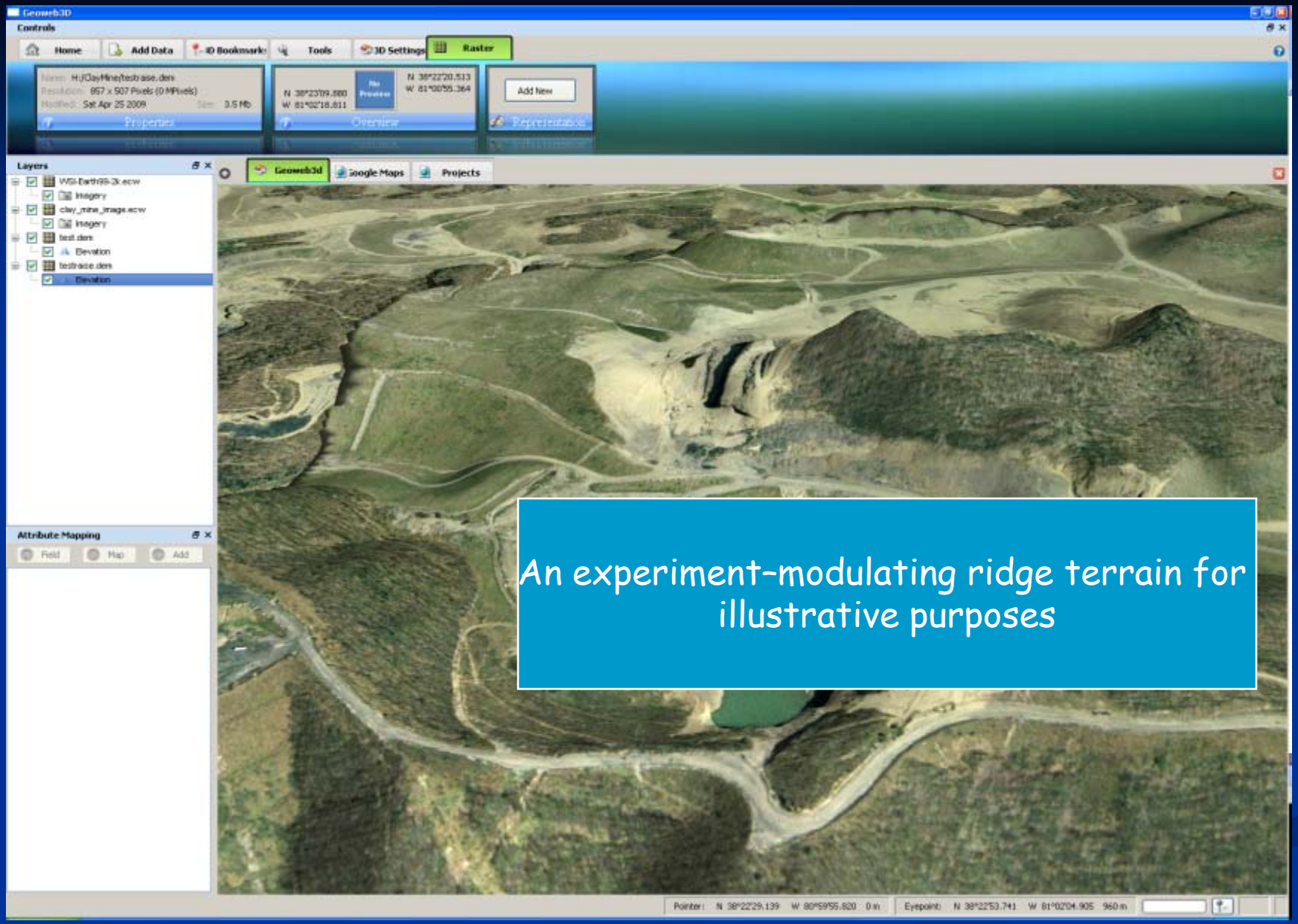


The visualization application begins with a globe – similar to Google Earth

One useful aspect of the application is that it works directly with ARC geodatabases and Civil3D data sets

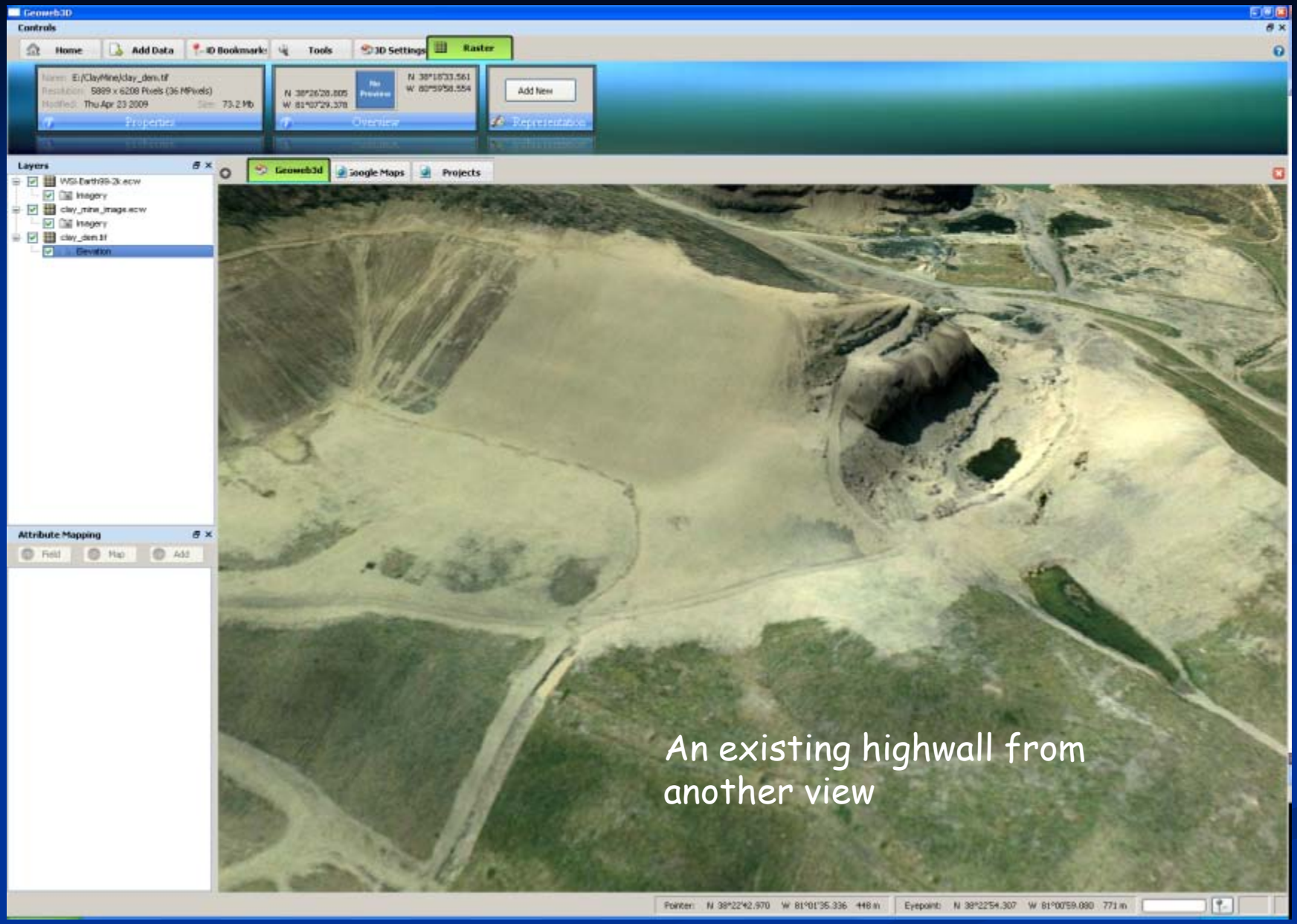

Geoweb3D
Controls
Home
Add Data
3D Bookmarks
Tools
3D Settings
Raster
Name: E:/ClayMine/clay_dem.tif
Resolution: 5889 x 6208 Pixels (36 MPixels)
Modified: Thu Apr 23 2009
Size: 73.2 Mb
Properties
No Preview
N 38°26'28.805
W 81°03'29.378
N 38°18'33.561
W 80°59'58.554
Overview
Add New
Representation
Layers
WSI-Earth98-2k.ecw
Imagery
clay_mine_image.ecw
Imagery
clay_dem.tif
Elevation
Attribute Mapping
Field
Map
Add
Geoweb3d
Google Maps
Projects
Pointer: N 38°22'37.485 W 81°00'55.842 450 m
Eyepoint: N 38°22'56.392 W 81°01'30.635 515 m

Here is the resulting edge of the ridge landform merging with previously mined areas and areas planned for future development



An experiment–modulating ridge terrain for illustrative purposes

Or a sharper less modulating ridge to define the viewshed from the proposed road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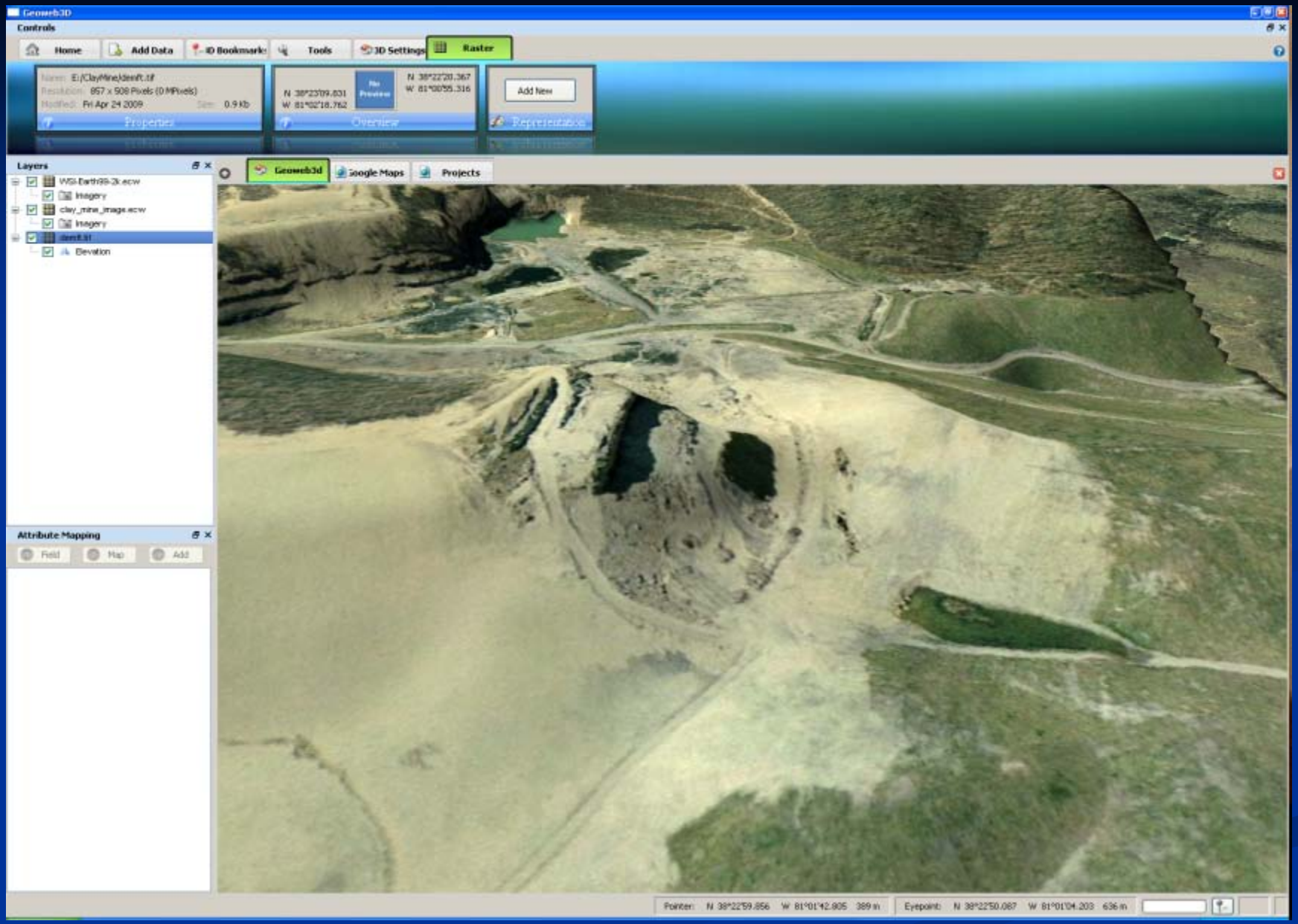
Add
An existing highwall from another view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Projects
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Imagery
Elevation
Attribute Mapping
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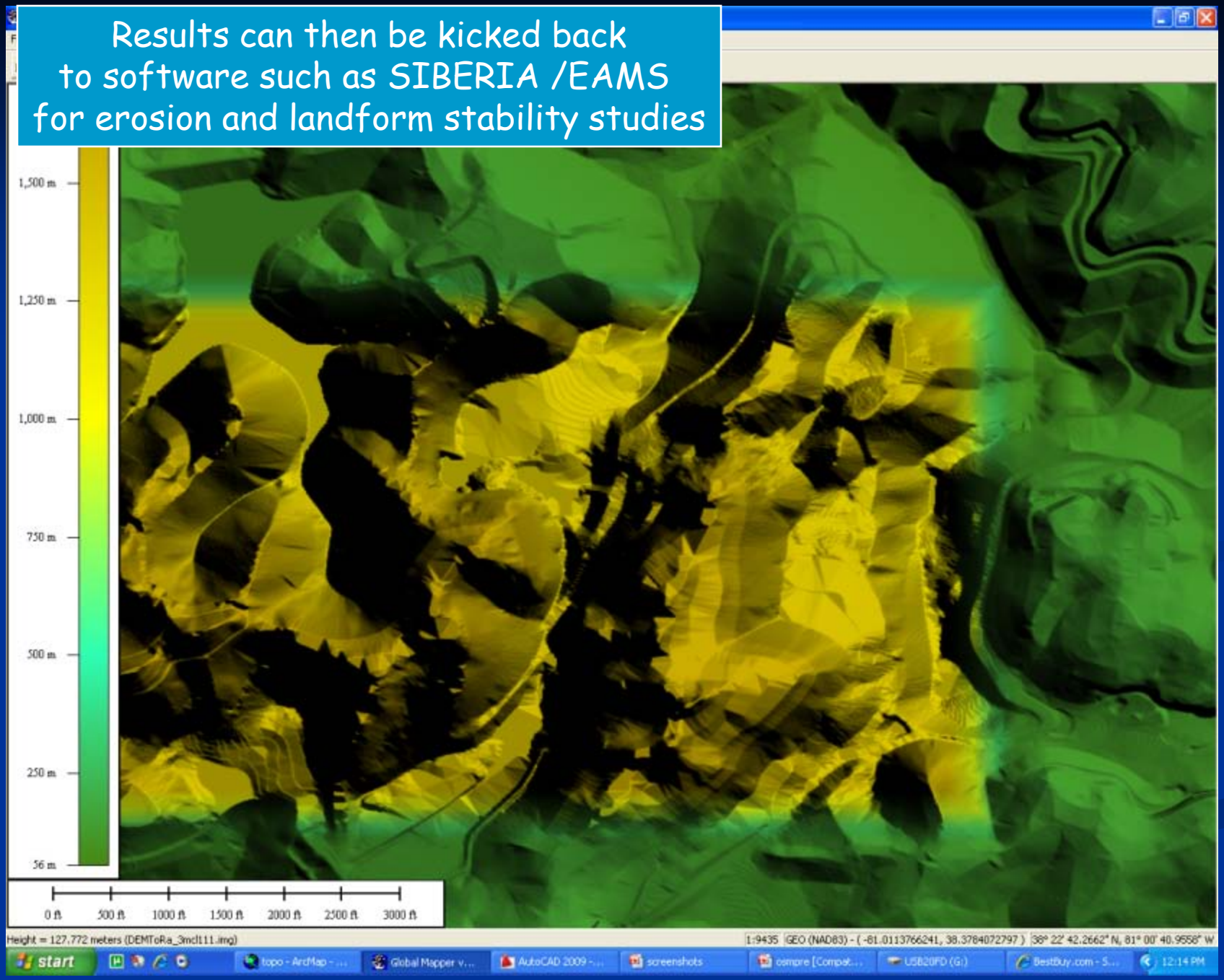
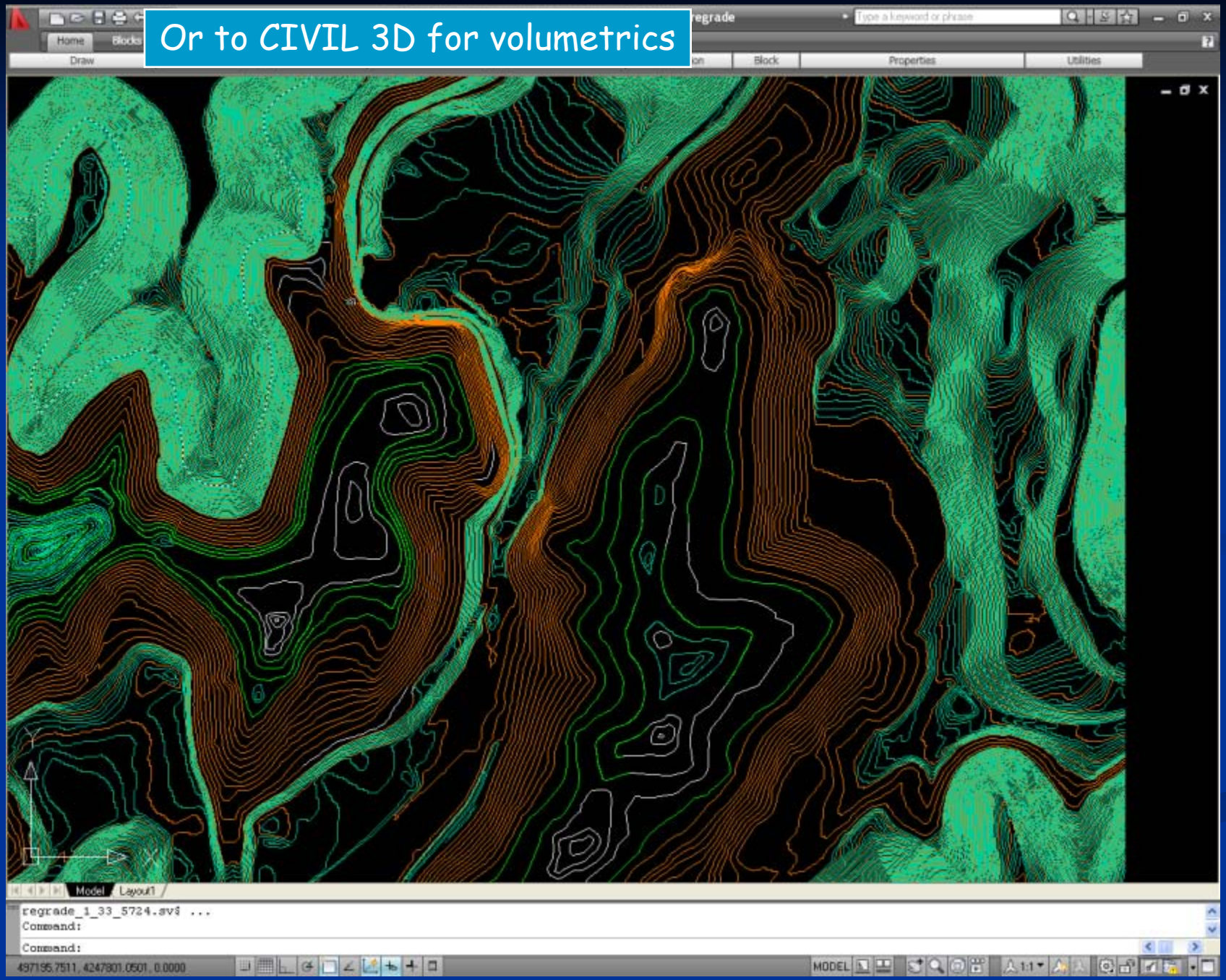
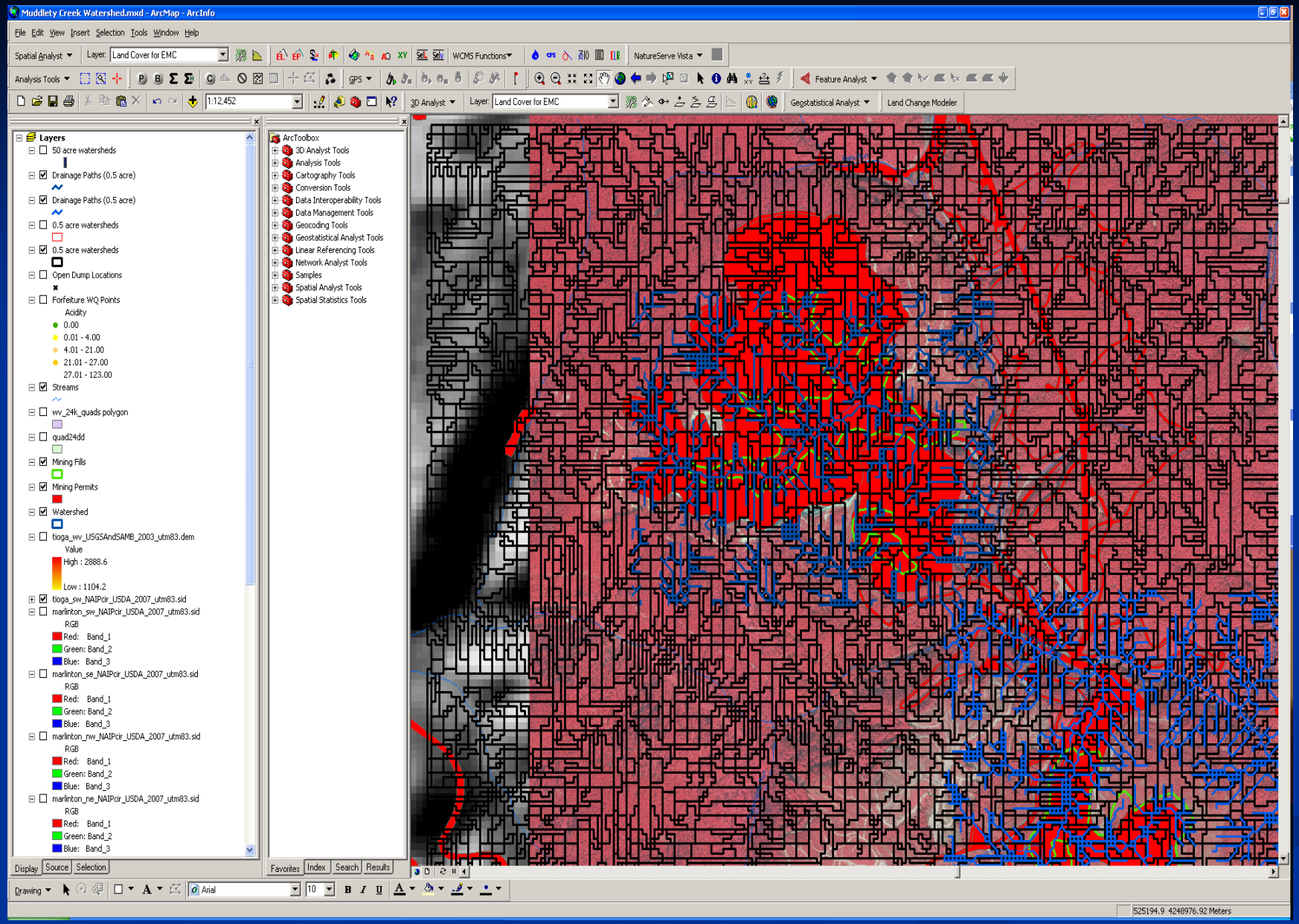
Map
Add
Pointer: N 38°22'59.856 W 81°01'42.805 389 m
Eyepoint: N 38°22'50.087 W 81°01'04.203 636 m

Results can then be kicked back
to software such as SIBERIA /EAMS
for erosion and landform stability studies



Or to CIVIL 3D for volumetrics





Or to WCMS in ARC-GIS. Average watershed size – pre-mining conditions and proposed reclamation conditions

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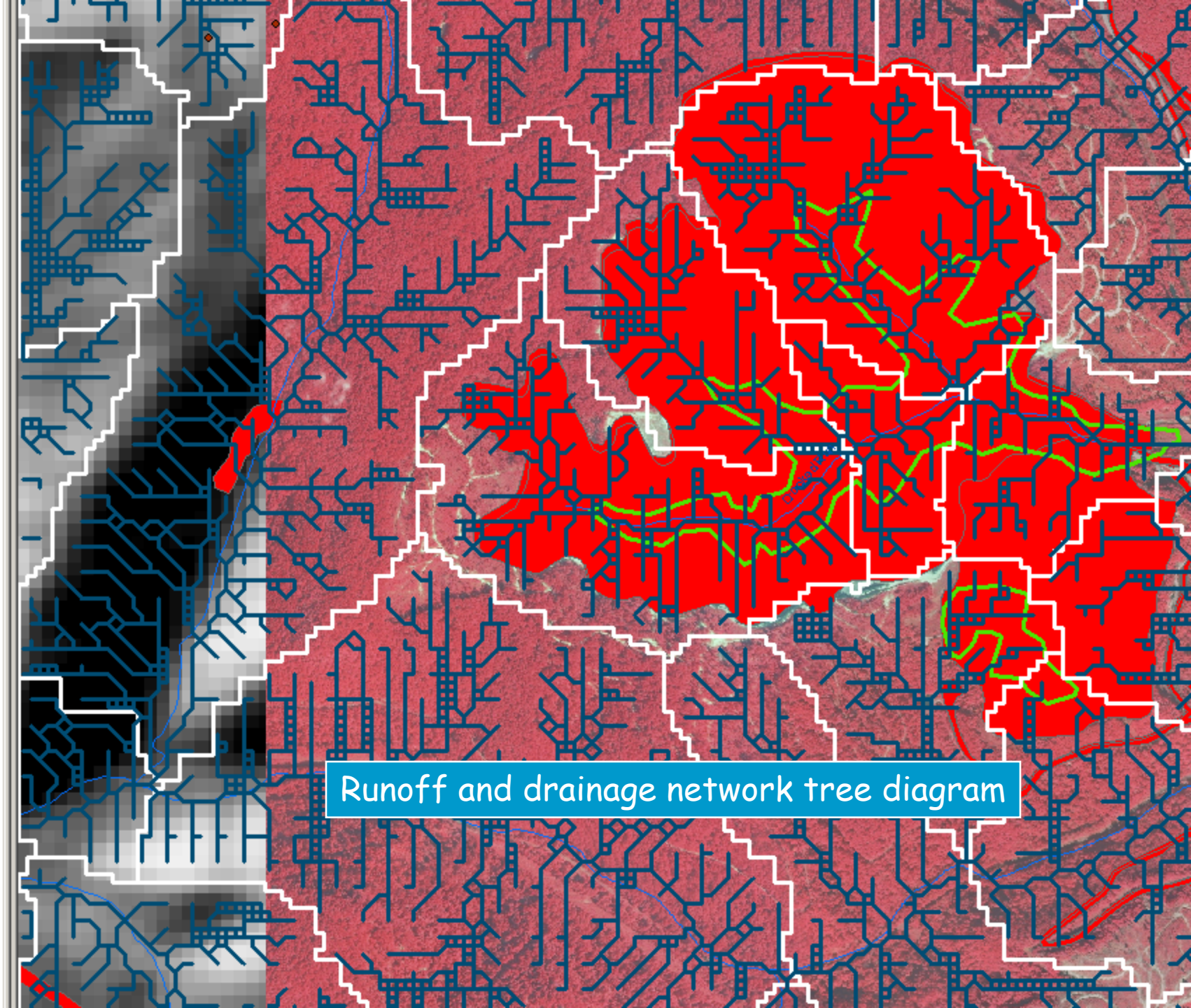
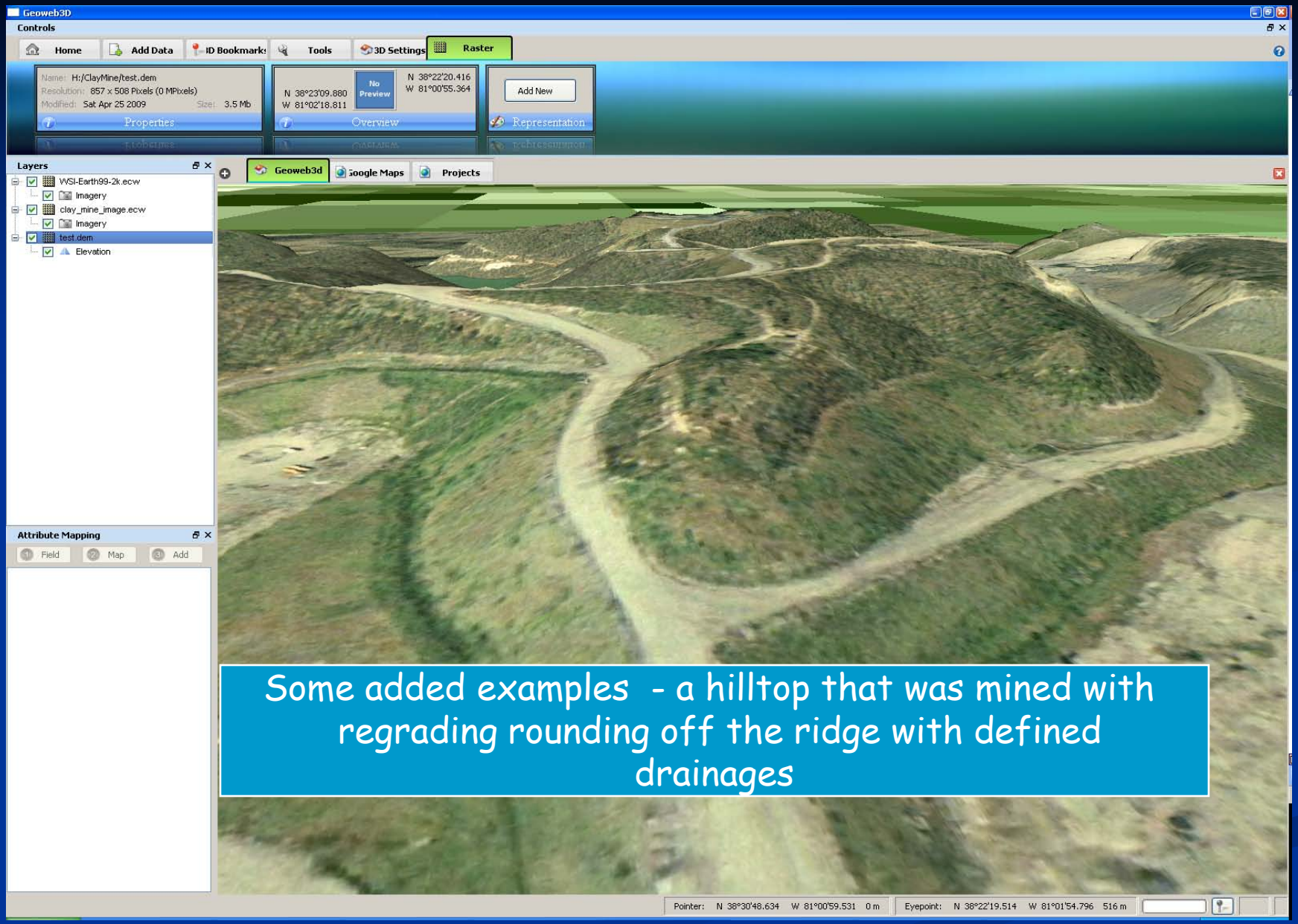
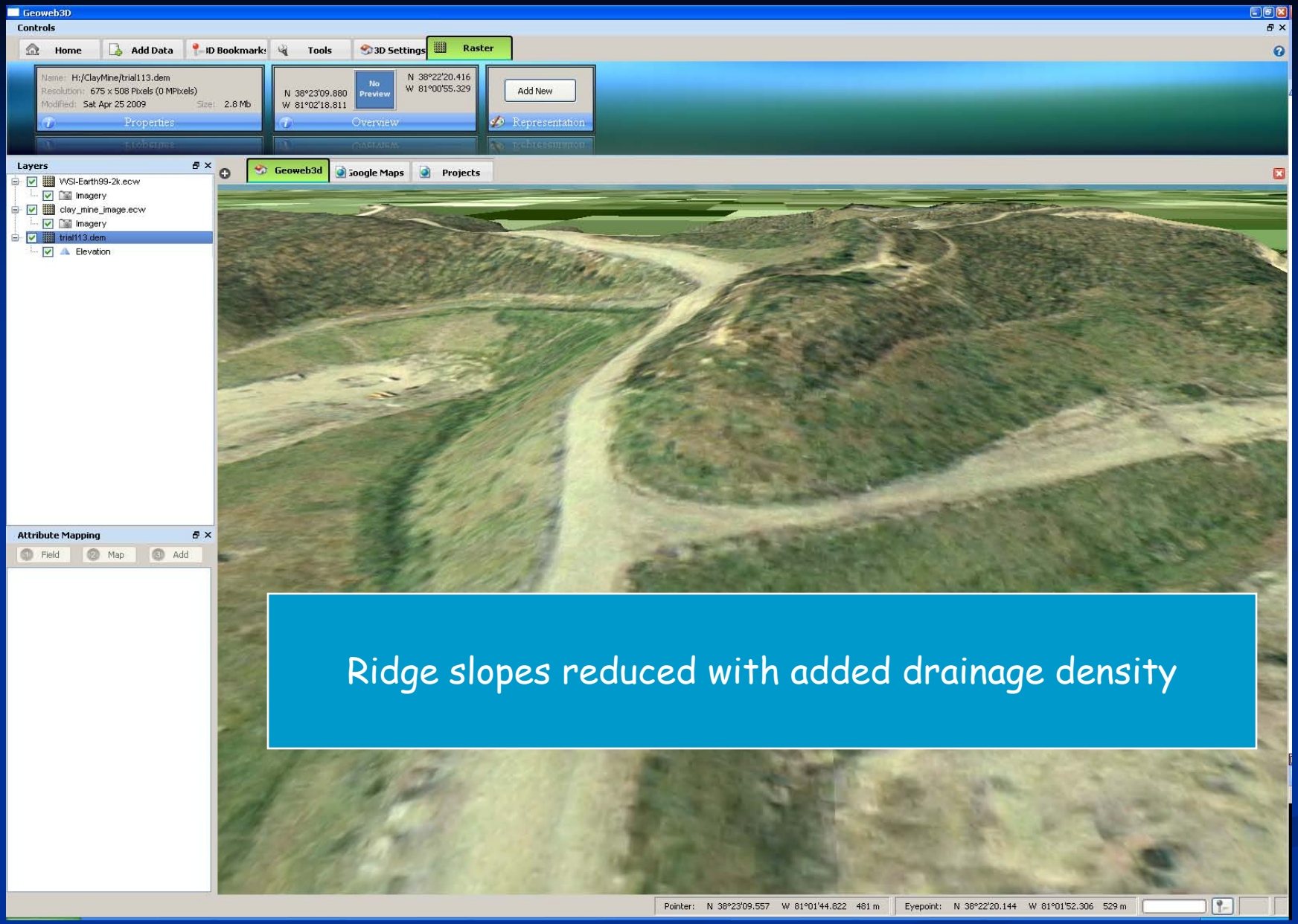
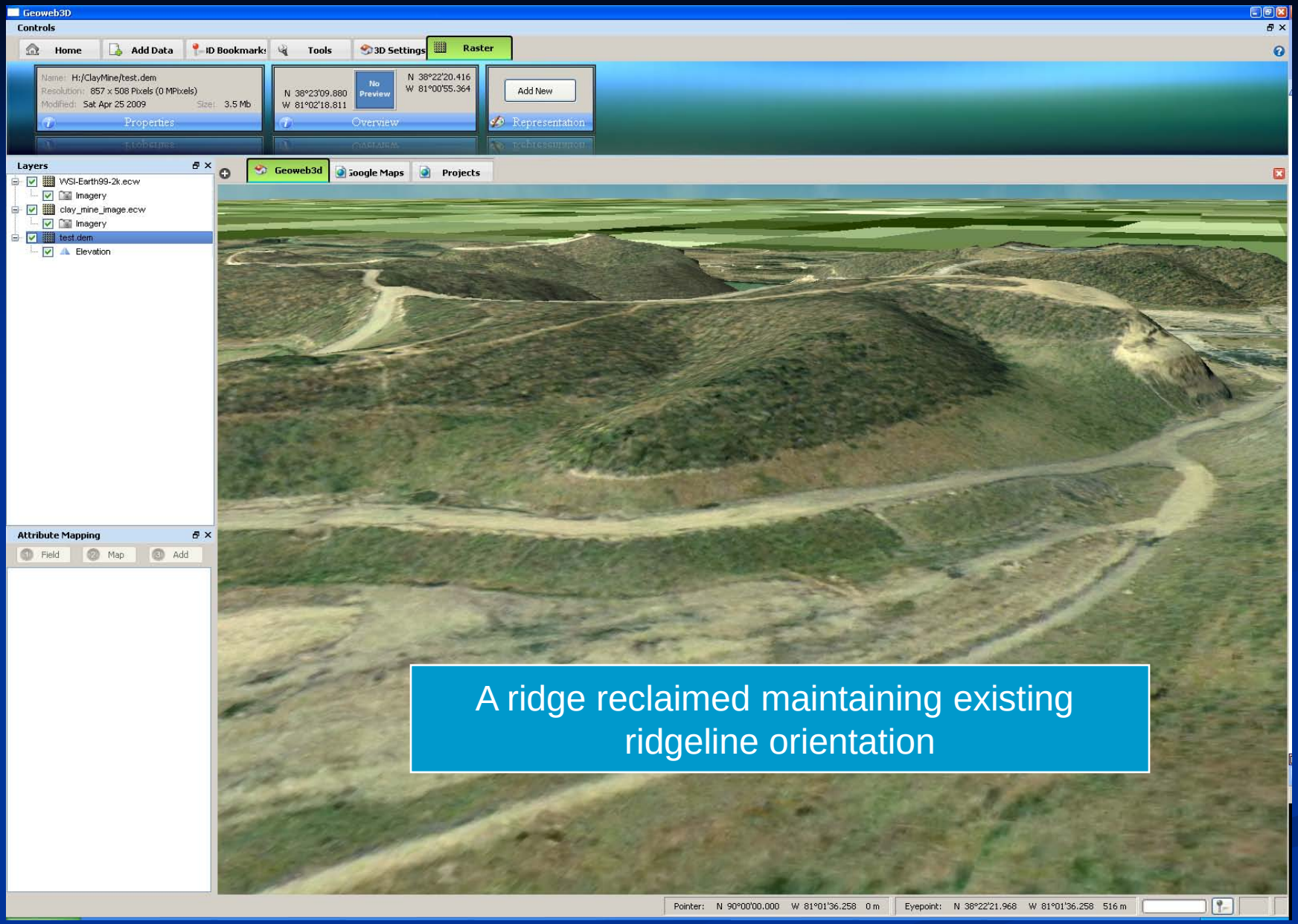




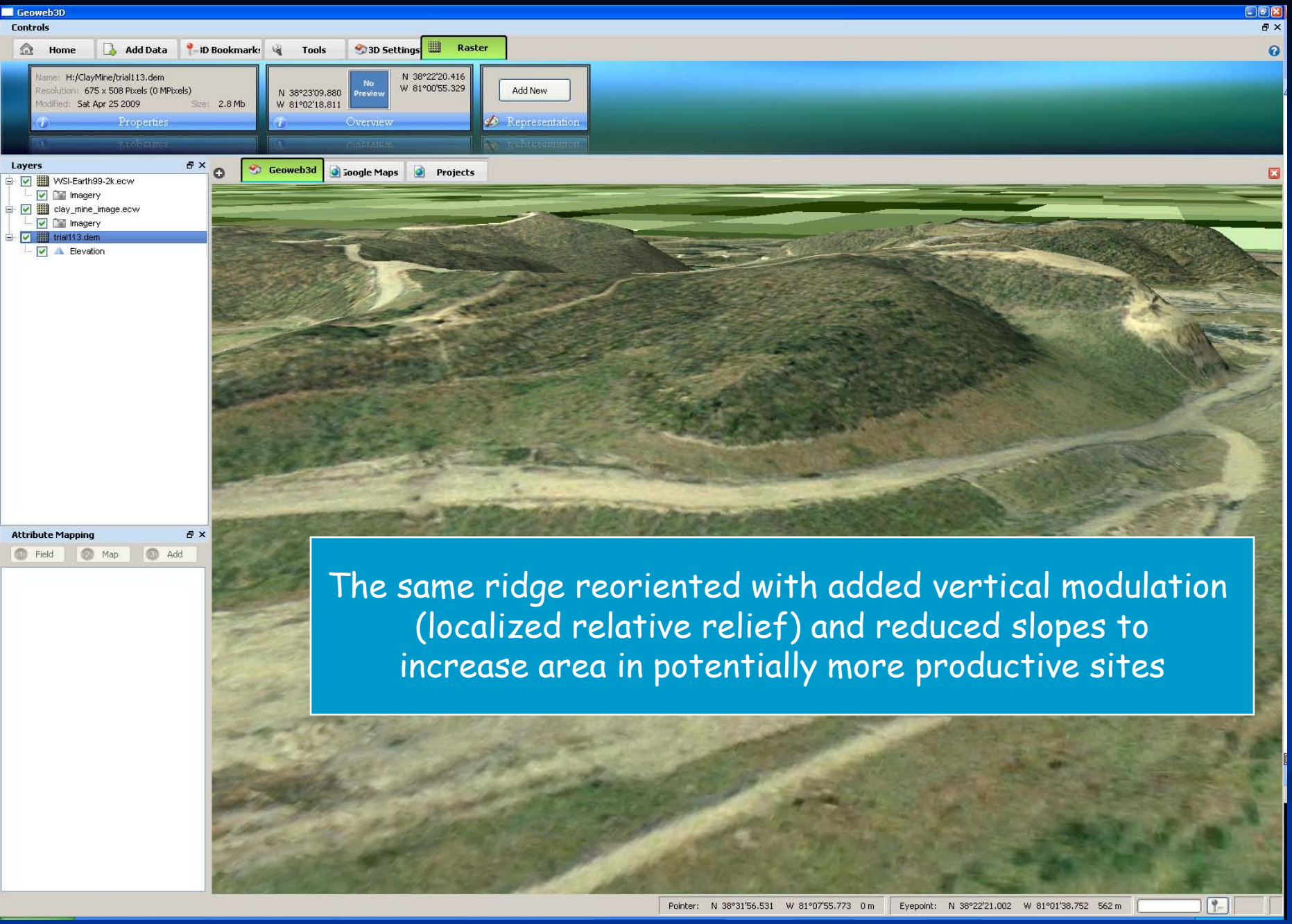
Some added examples - a hilltop that was mined with regrading rounding off the ridge with defined drainages



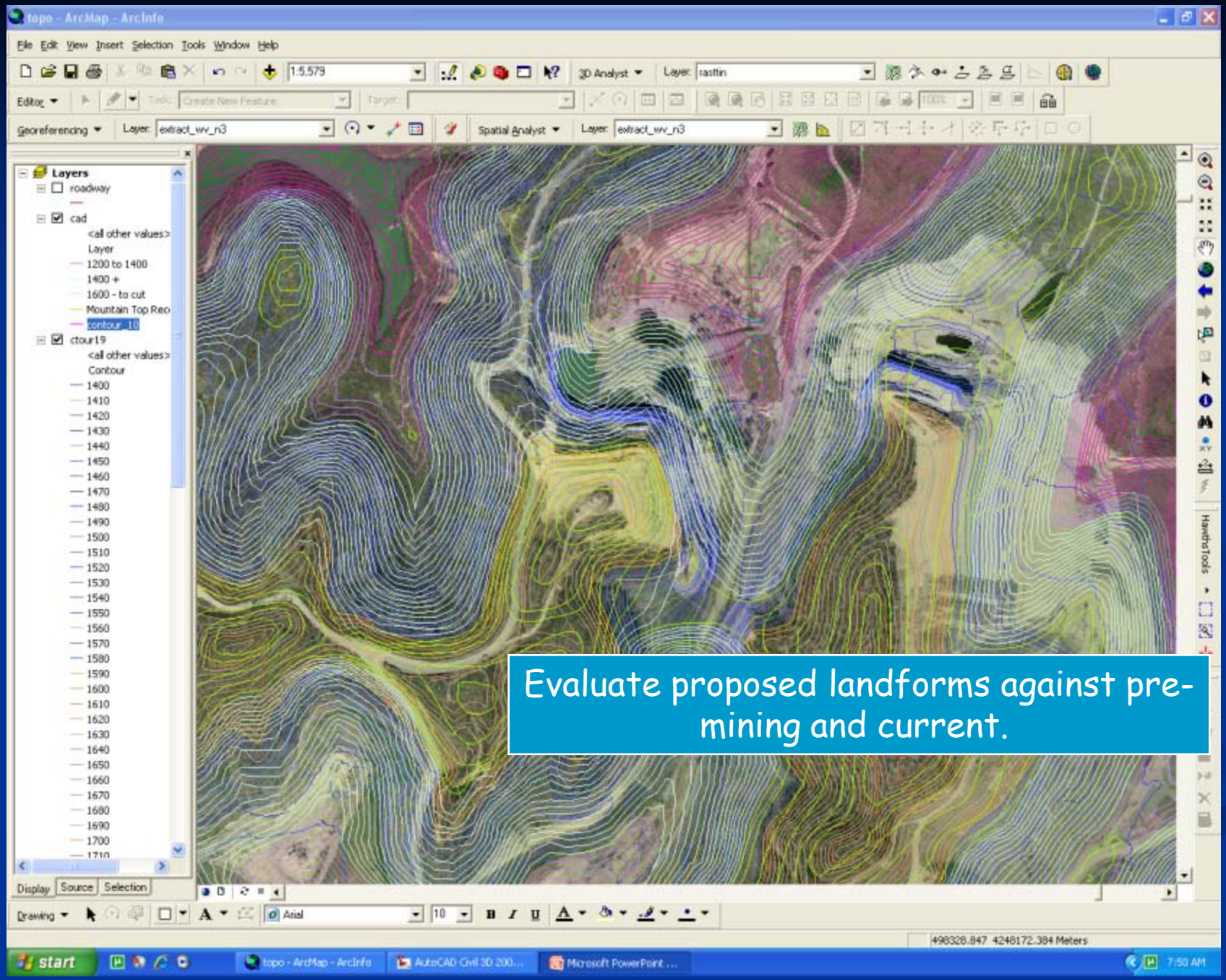
Ridge slopes reduced with added drainage density



A ridge reclaimed maintaining existing ridgeline orientation



The same ridge reoriented with added vertical modulation (localized relative relief) and reduced slopes to increase area in potentially more productive sites



Evaluate proposed landforms against pre-mining and current.

So what we tried to do was…

- Illustrate landforming methods to evaluate and redesign the landforming tools
- Develop a planning approach that..
  - Increases stability and drainage definition in 0 order and adjacent areas by redesigning up-slope drainage networks
  - Increases future site utility
  - Reduces slopes while maintaining natural appearance
    - Increasing areas in more productive slope orientations
    - Minimizes level areas
    - Slightly decreasing slopes in those areas to increase management and planting options but mixing with appropriate steeper areas for……
      - Forest management
      - Managed timberlands – forest / slope protection for critical slopes
      - Sites for potential biofuels production

thanks