Integrating Natural Form and Process

with Drainage Reclamation in Montana

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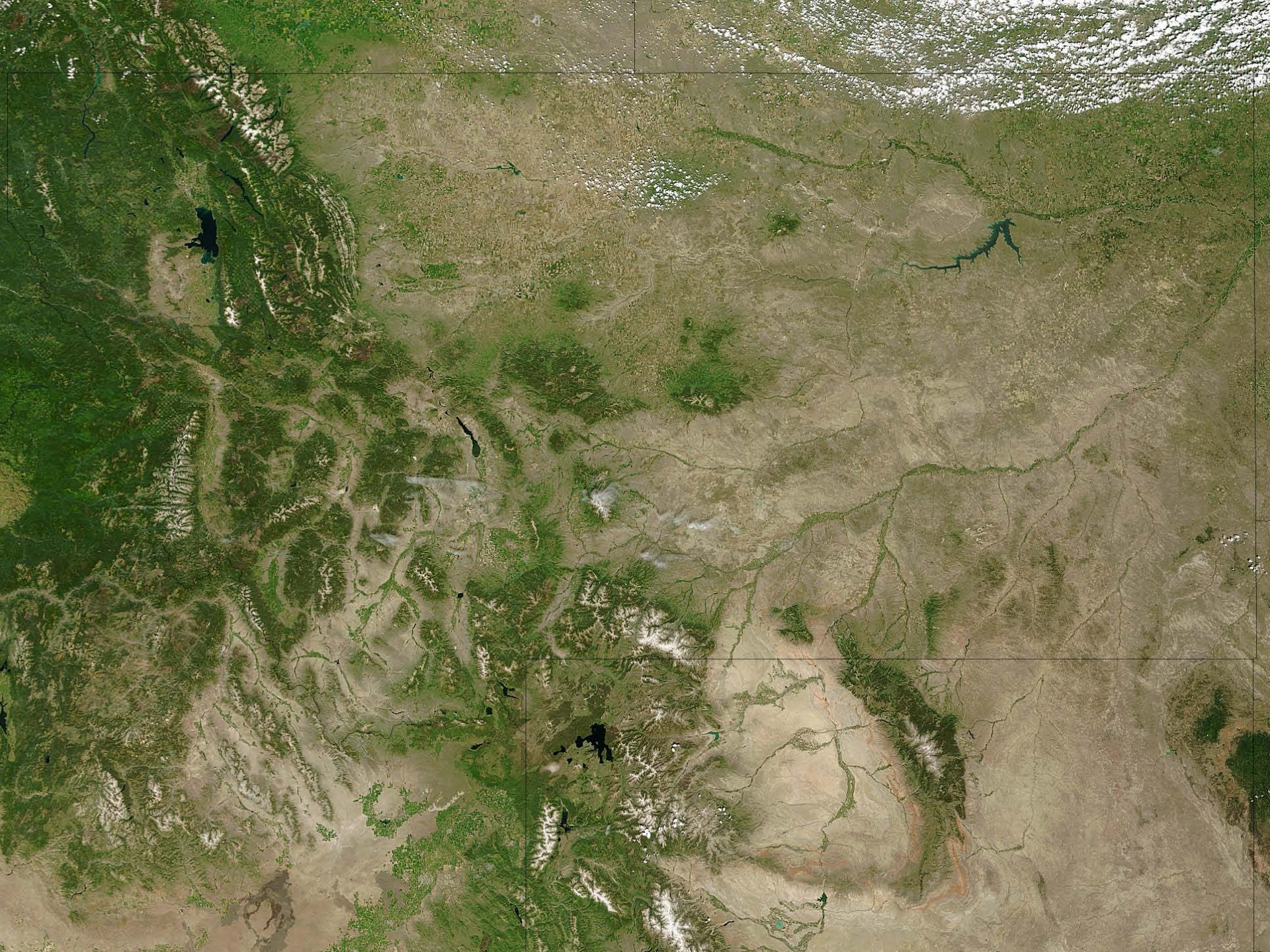
Montana Department of Environmental Quality - Coal Program

Geomorphic Reclamation and Natural Stream Design at Coal Mines
OSM National Technical Forum

April 28-30, 2009 Bristol, Virginia



Drainage Basin Reclamation - Requirements

Approximate Original Contour (AOC)

- closely resembles the general surface configuration of the land prior to disturbance
- blends into and complements the drainage pattern of the surrounding terrain

Approximate Premine Drainage Basin Topography & Geomorphology

- Drainage Basin Area, Dimensions, Shape
- Drainage Density, Profiles
- Topography – Slope Profiles, Aspect, Relief
- Valley Bottom & Floodplain Morphology, Channel Shape

Approximate Premine Hydrologic & Ecologic Processes & Land Use

- Runoff Characteristics, Infiltration, Ponding
- Soil, Vegetation & Wildlife Habitat

Drainage Reclamation Plan – Application Requirements

Description of postmining drainage basin reclamation that ensures protection of the hydrologic balance, achievement of postmining land use performance standards, and prevention of material damage to the hydrologic balance in adjacent areas, including:

- comparison of premining and postmining drainage basin size, drainage density, and drainage profiles to identify characteristics not apparent on premining and postmining topographic maps;
- explanation of how, within drainage basins the plan will:
  - meet Drainage Basin Reclamation performance standards (ARM 17.24.634); and
  - protect the hydrologic balance where postmining topography differs from AOC

Drainage channel designs appropriate to prevent material damage to the hydrologic balance in the adjacent area, and to meet drainage reclamation performance standards, including:

- detailed drainage designs, including fluvial and geomorphic characteristics - for channels that contain critical hydrologic, ecologic or land use functions, and
- typical designs and discussions of general fluvial and geomorphic habit, pattern, and other relevant functional characteristics - for all other channels.

Drainage Basin Reclamation – Performance Standards

Drainage basins, valleys, channels and floodplains must be constructed to:

- approximate original contour
- an appropriate geomorphic habit or characteristic pattern
- an overall concave longitudinal channel profile
- dimensions and characteristics blending with undisturbed drainages above & below
- provide for long-term relative stability of the landscape
- safely pass runoff from a 100-year, 6-hour preciptiation event
- remain in dynamic equilibrium with the drainage basin system
- establish a diversity of habitats consistent with the postmining land use, and restore, enhance or maintain natural riparian vegetation

Drainage Basin Design & Evaluation - Resources

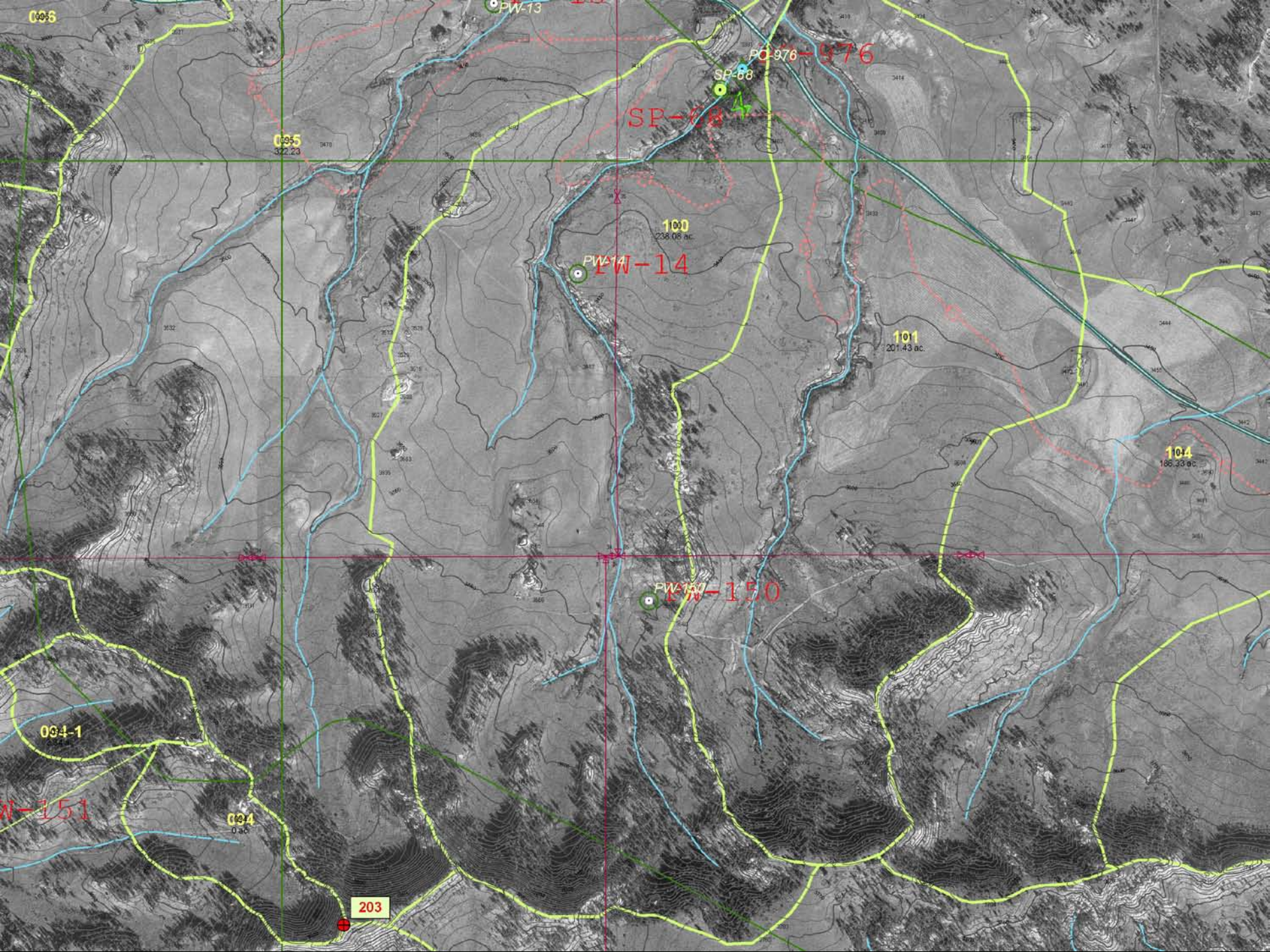
Maps, Data, other Resources (*Premine and Postmine*)

- Mine Area / Drainage Basin Maps, Aerial Photographs
  (Topography, Drainage Basins, Channel Networks)

- Drainage Channel & Valley Bottom Maps & Surveys
  (Longitudinal Profiles & Cross Sections, Plan View)

- Photographs of valley & drainage features

- Other Maps & Related Data
  (Soil, Vegetation, Wildlife, Land Use)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PW-14
PW-14
101
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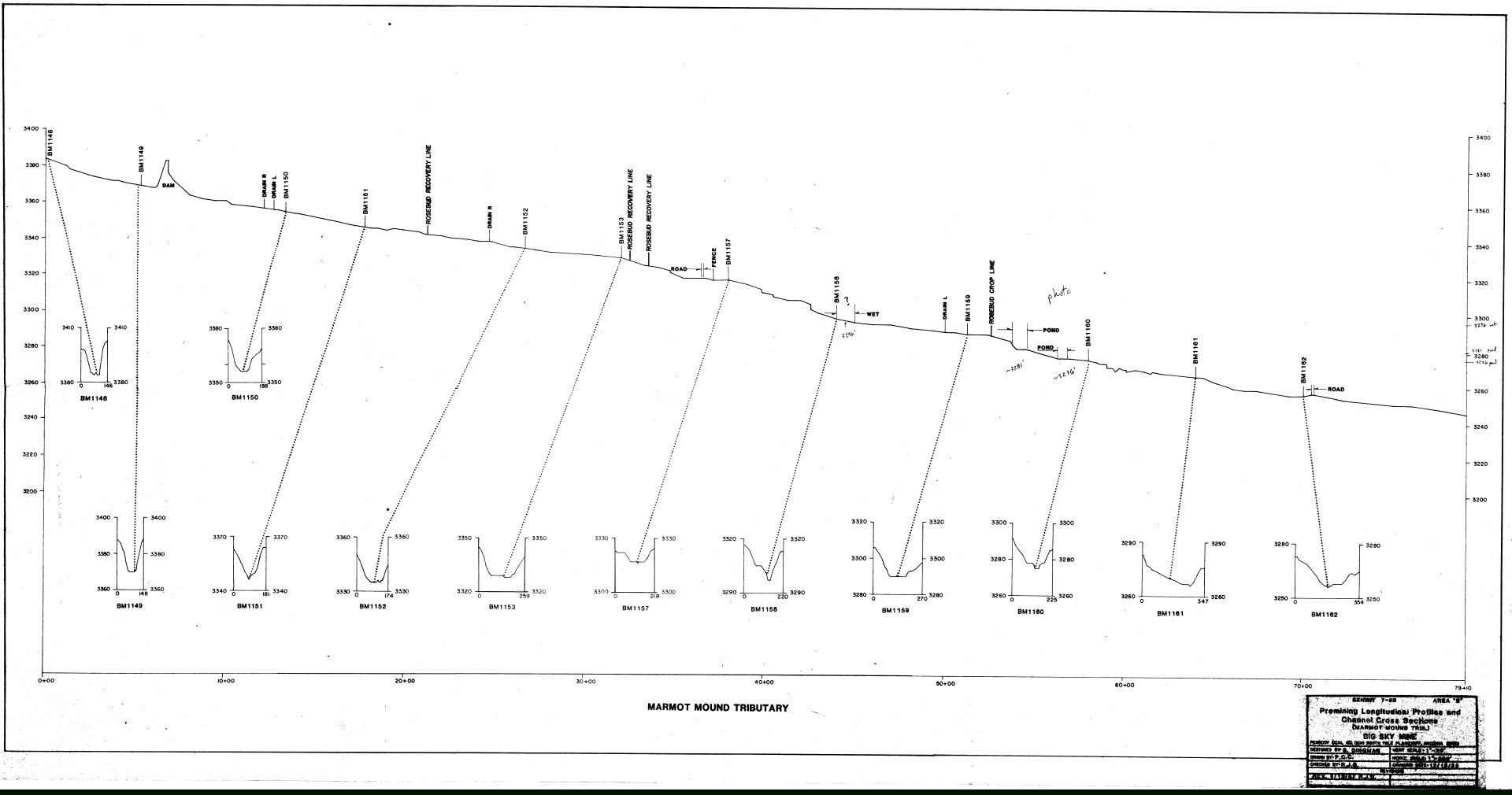
104
186.33 ac.
PW-150
PW-150
094-1
094
0 ac
W-151
203

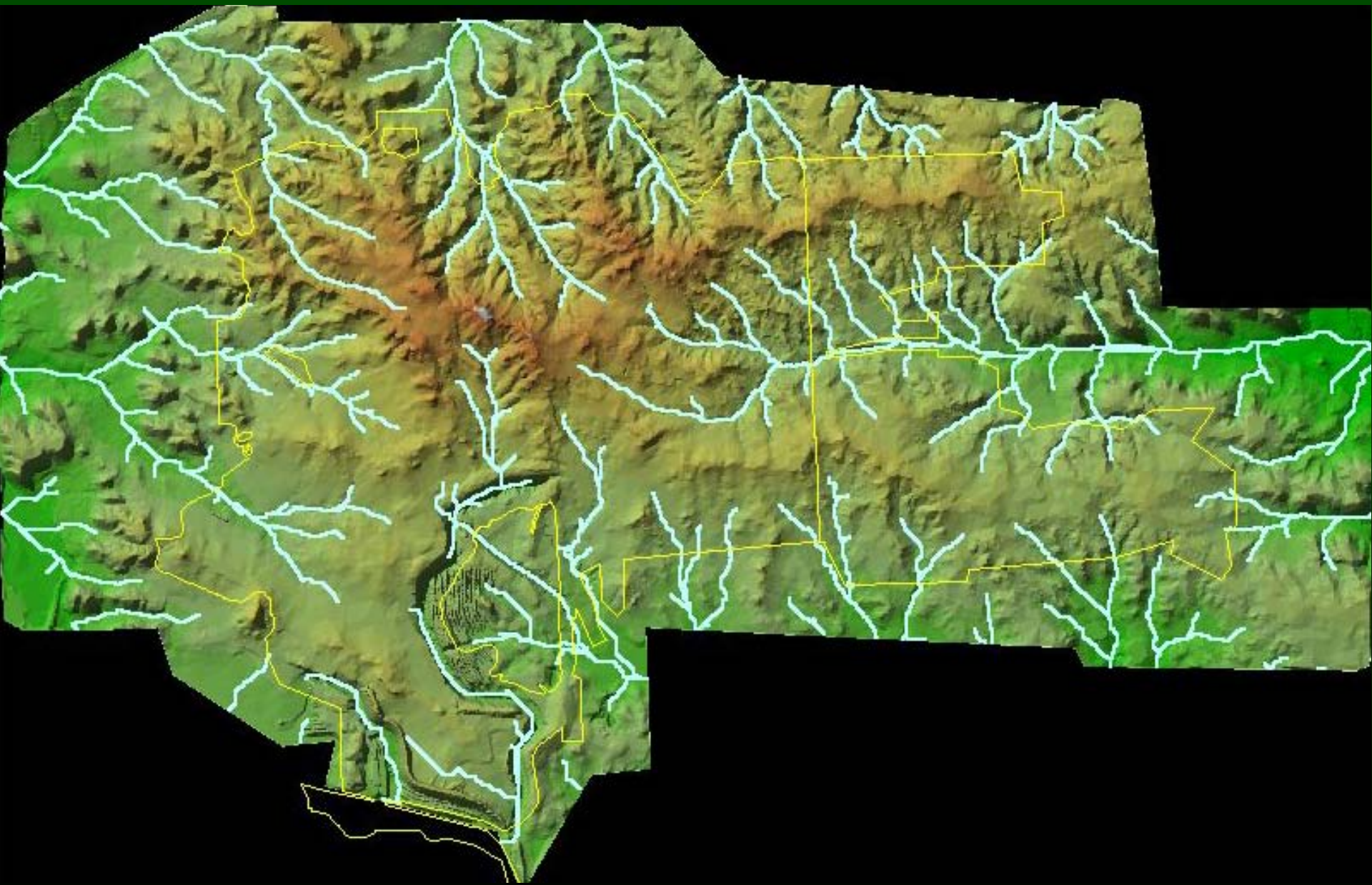
Premine Drainage Surveys – Profiles & Cross Sections



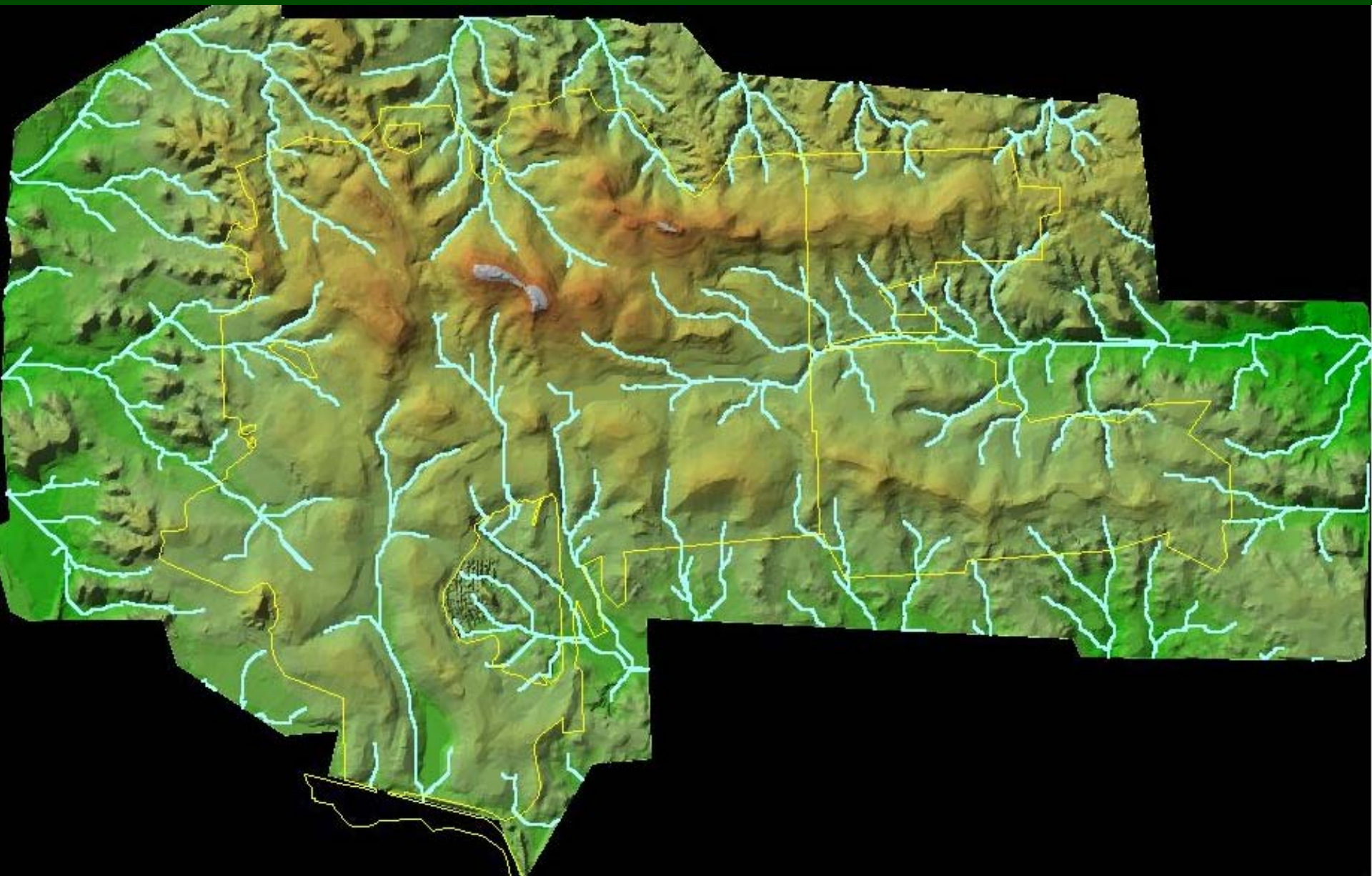
Drainage Basin Design & Reclamation - Process

- Design Plans & Review
  - Approximate PMT & Drainage Reclamation Plans in Permit
  - Final Reclamation Plan Adjustments (including field adjustments)
- Construction/Reclamation
  - Prep Work Staking/Surveying
  - Regrading & Resoiling
  - Reseeding, Tree & Shrub Planting
- Monitoring
  - As-built Survey
  - Follow-up Inspections, Surveys, Hydrologic & Other monitoring
- Maintenance ?
  - Case-by-Case Evaluations (problems, potential development, need for intervention)
  - Initial Design/Reclamation Quality, Reclamation Surveys & Monitoring critical
- Bond Release

Premine Topography & Drainages



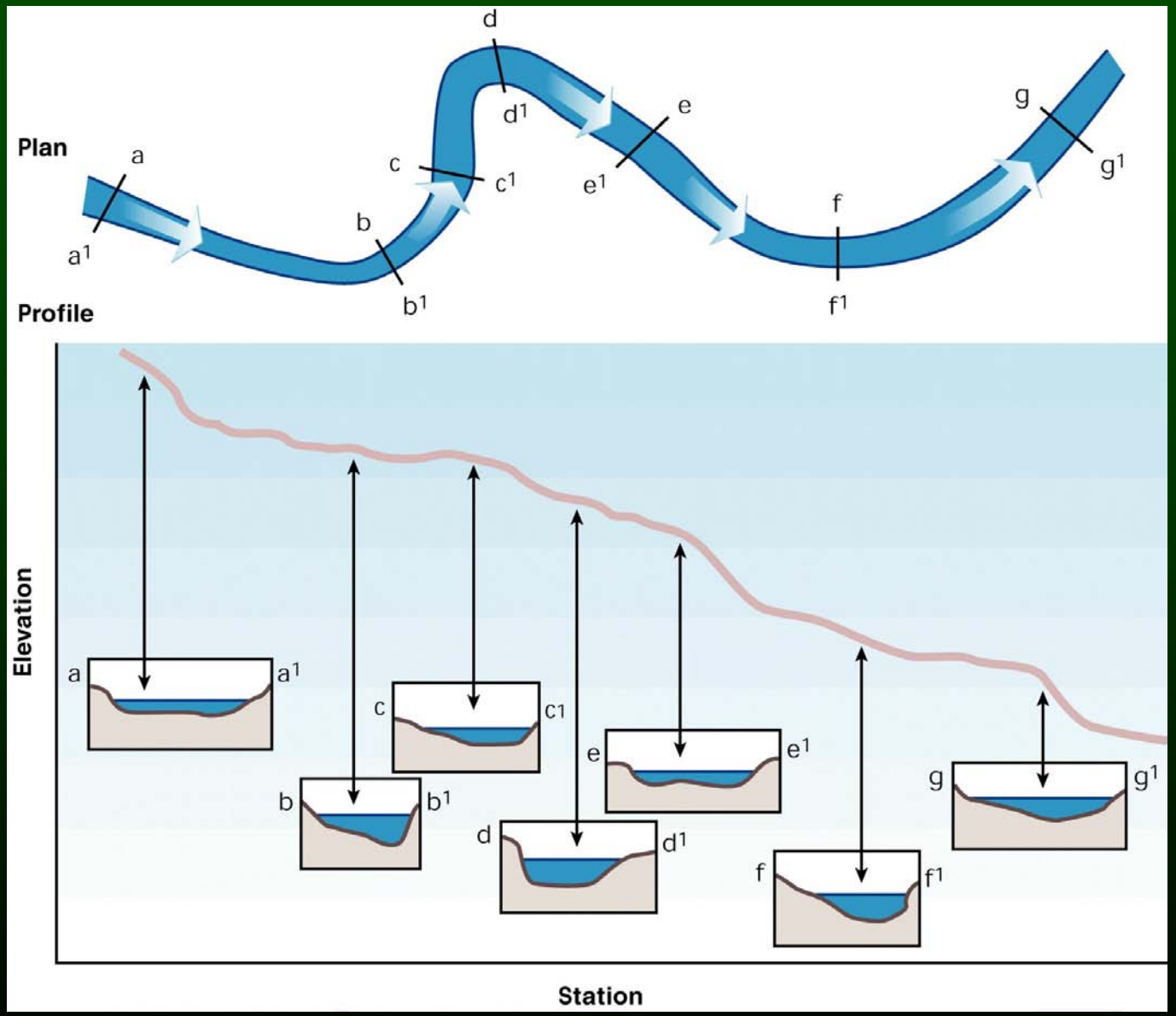
Postmine Topography & Drainages



Basic Channel Morphology

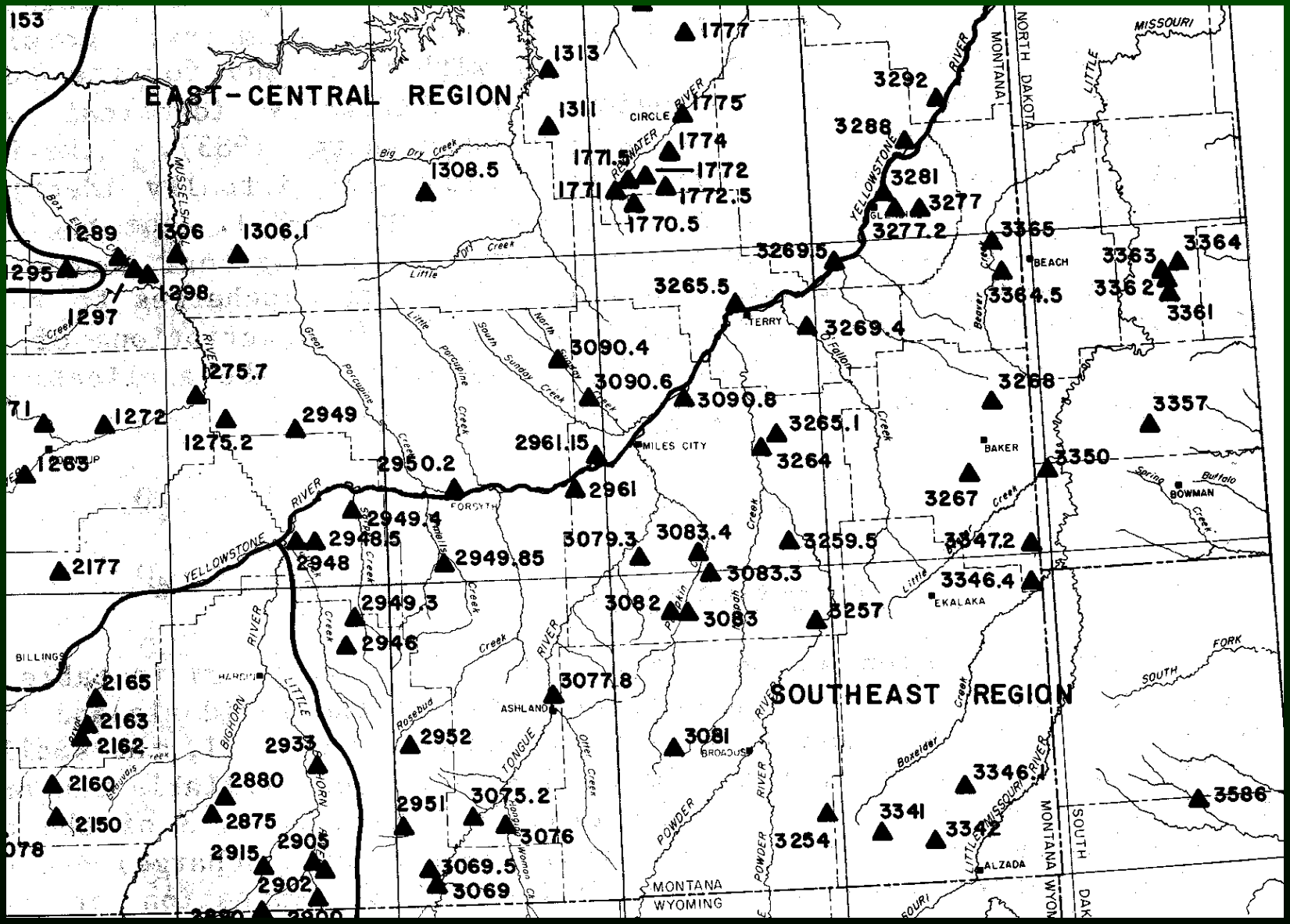
- **Longitudinal profile**
  - Valley Slope, Channel Slope , Sinuosity
  - Average, Concave Longitudinal Profile
- **Cross section**
  - Width, Depth, W/D Ratio, Entrenchment
  - Bed & Bank Materials, Roughness, Flow Velocity
- **Plan view**
  - Channel & Floodplain Patterns, Dimensions
  - Meander Wavelength, Belt width

Channels - Plan View, Long Profile & Cross Sections



Federal Interagency Stream Restoration Working Group (1998) http://www.usda.gov/stream_restoration

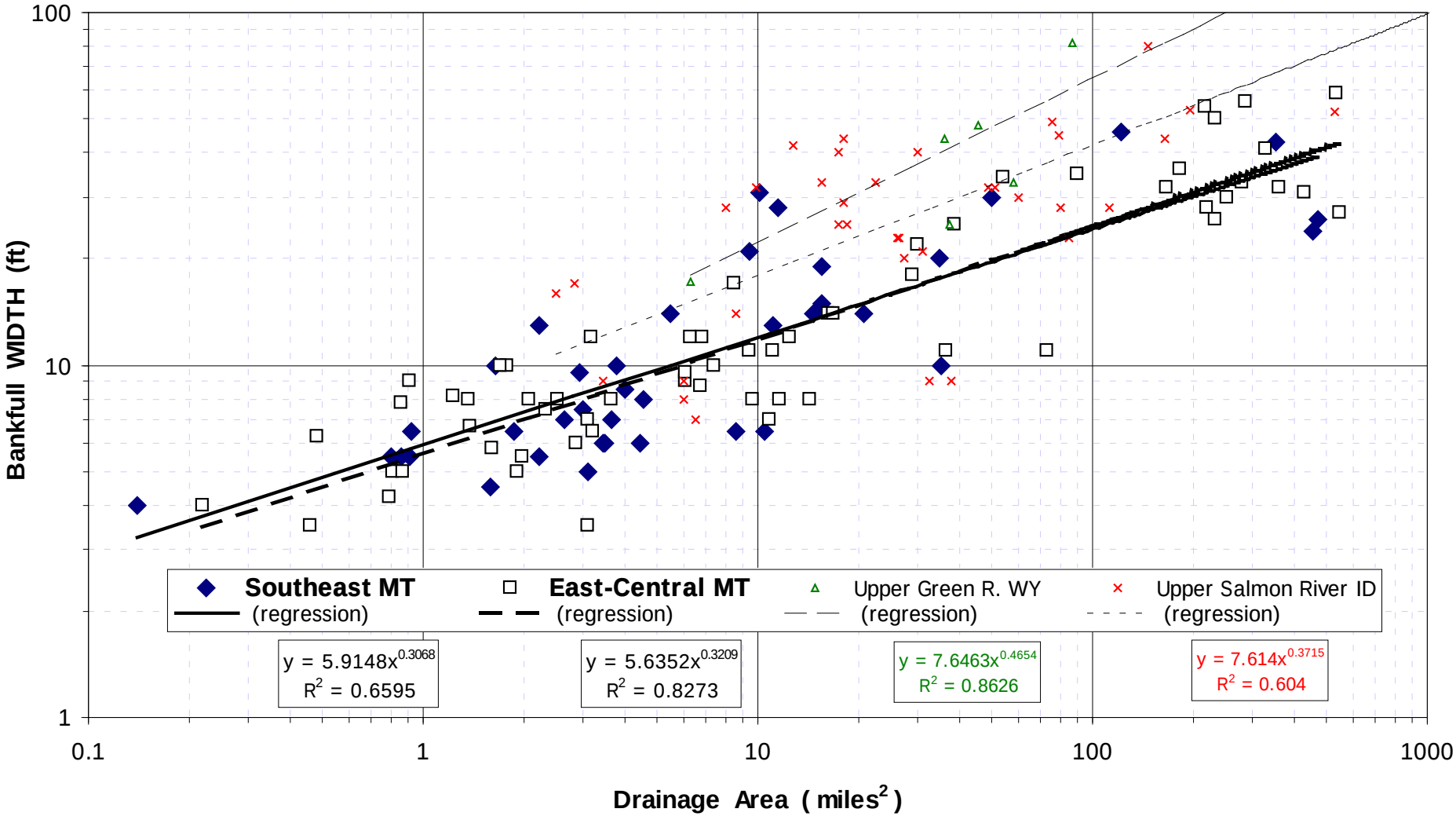
Regional Relationships - USGS Peakflow Gaging Stations (Southeast Montana)



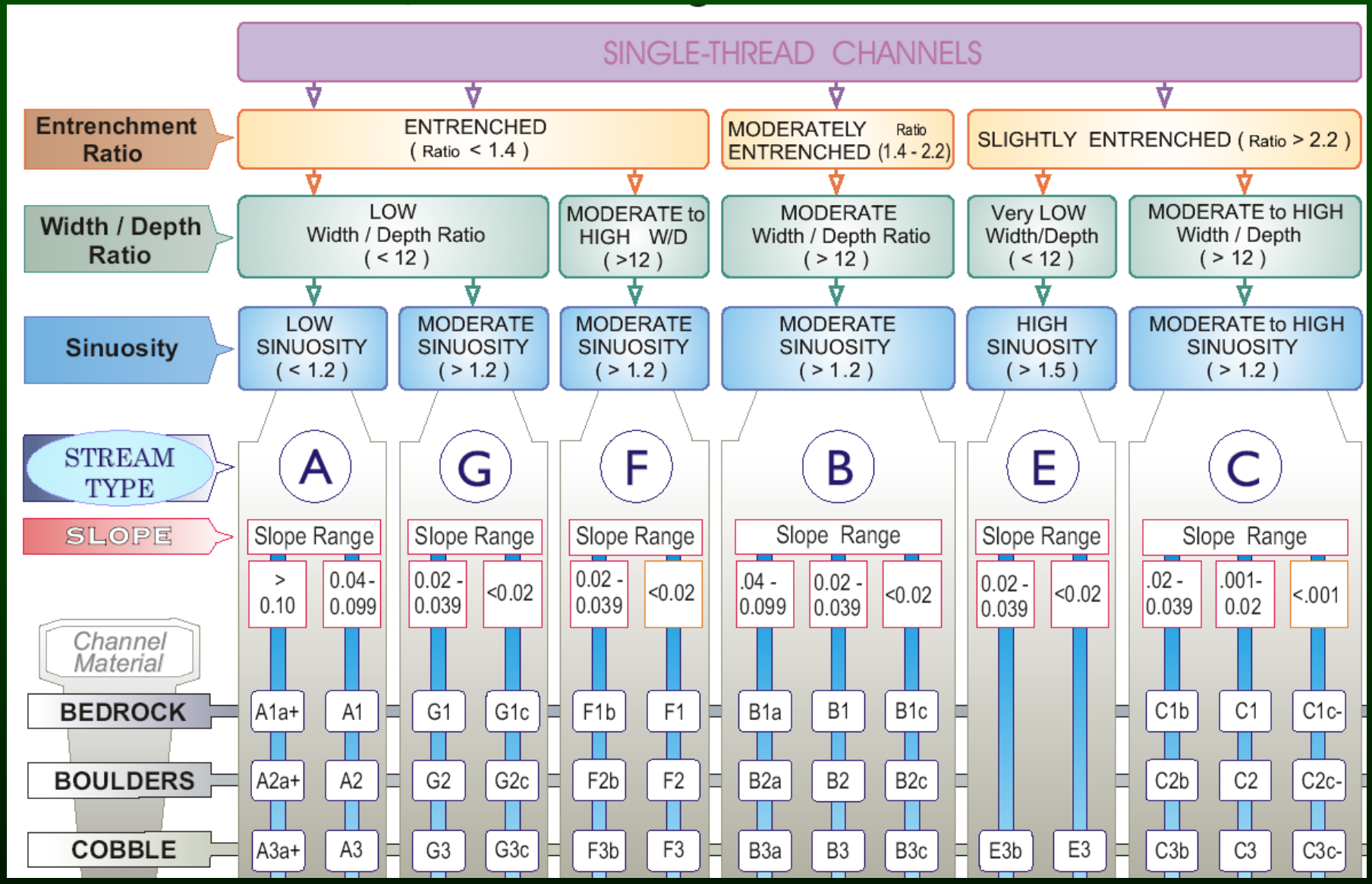
From: Parrett et al. (1987)

Regional Relationships - Channel Width vs. Drainage Area

Southeast & East-Central MT (with regional comparisons)



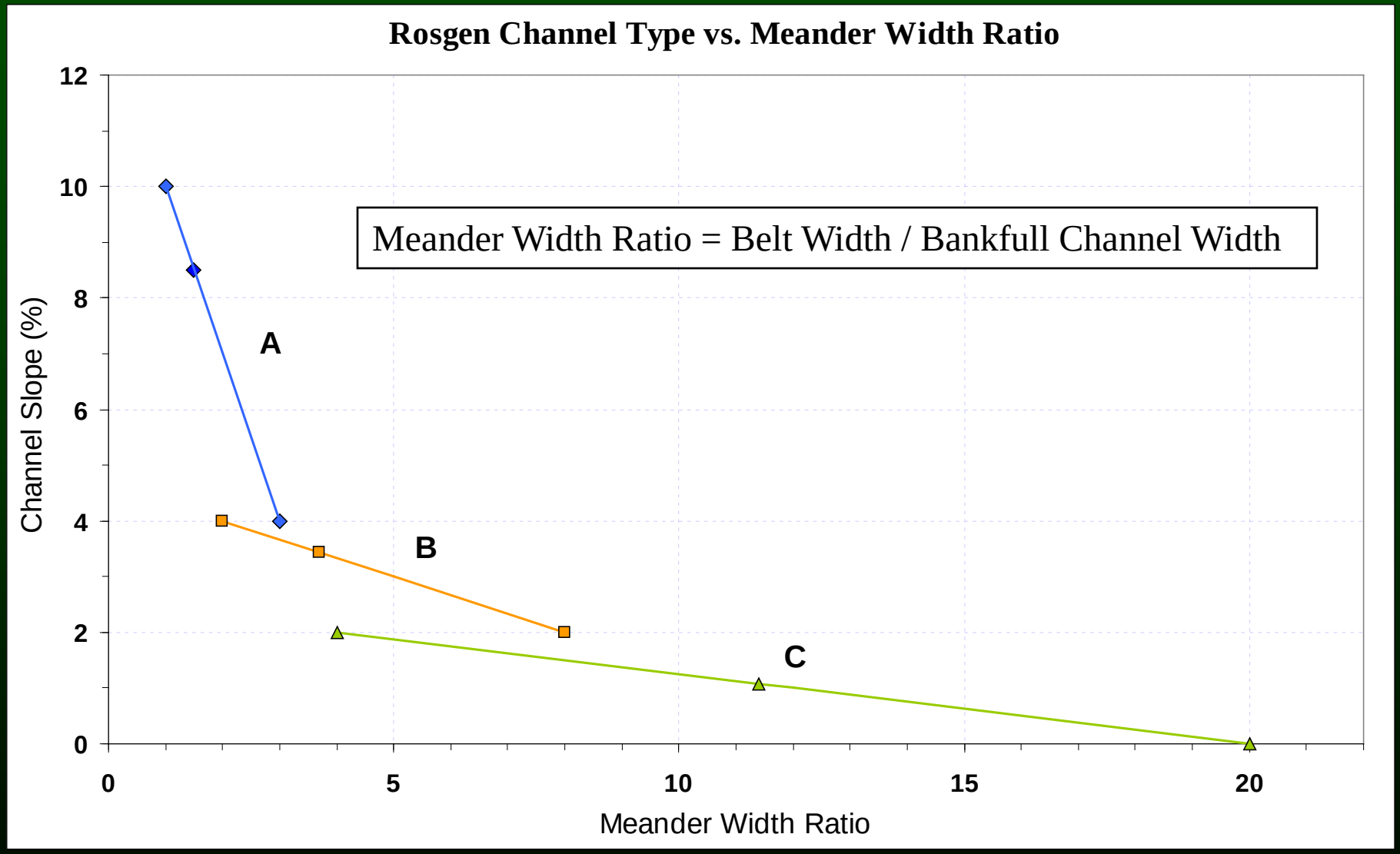
Montana data from Parrett et al. (1987) and Omang (1992), with updates from Parrett (pers. comm., 5/2001); Upper Green River, WY and Upper Salmon River, ID data from Dunne & Leopold (1978); and Emmett (1975).



KEY to the ROSGEN CLASSIFICATION of NATURAL RIVERS. As a function of the "*continuum of physical variables*" within stream reaches, values of ***Entrenchment*** and ***Sinuosity*** ratios can vary by +/- 0.2 units; while values for ***Width / Depth*** ratios can vary by +/- 2.0 units.

excerpted from: Rosgen Geomorphic Channel Design by David L. Rosgen (2007). Chapter 11 In J. Bernard, J.F. Fripp & K.R. Robinson (Eds.), Part 654 Stream Restoration Design National Engineering Handbook (210-VI-NEH). Washington, D.C.: USDA Natural Resources Conservation Service (see also http://www.wildlandhydrology.com).

Approximating Floodplain Width



data from : Rosgen, D.L. 1994. A classification of natural rivers. Catena 22: pp. 169-199. see: http://www.wildlandhydrology.com

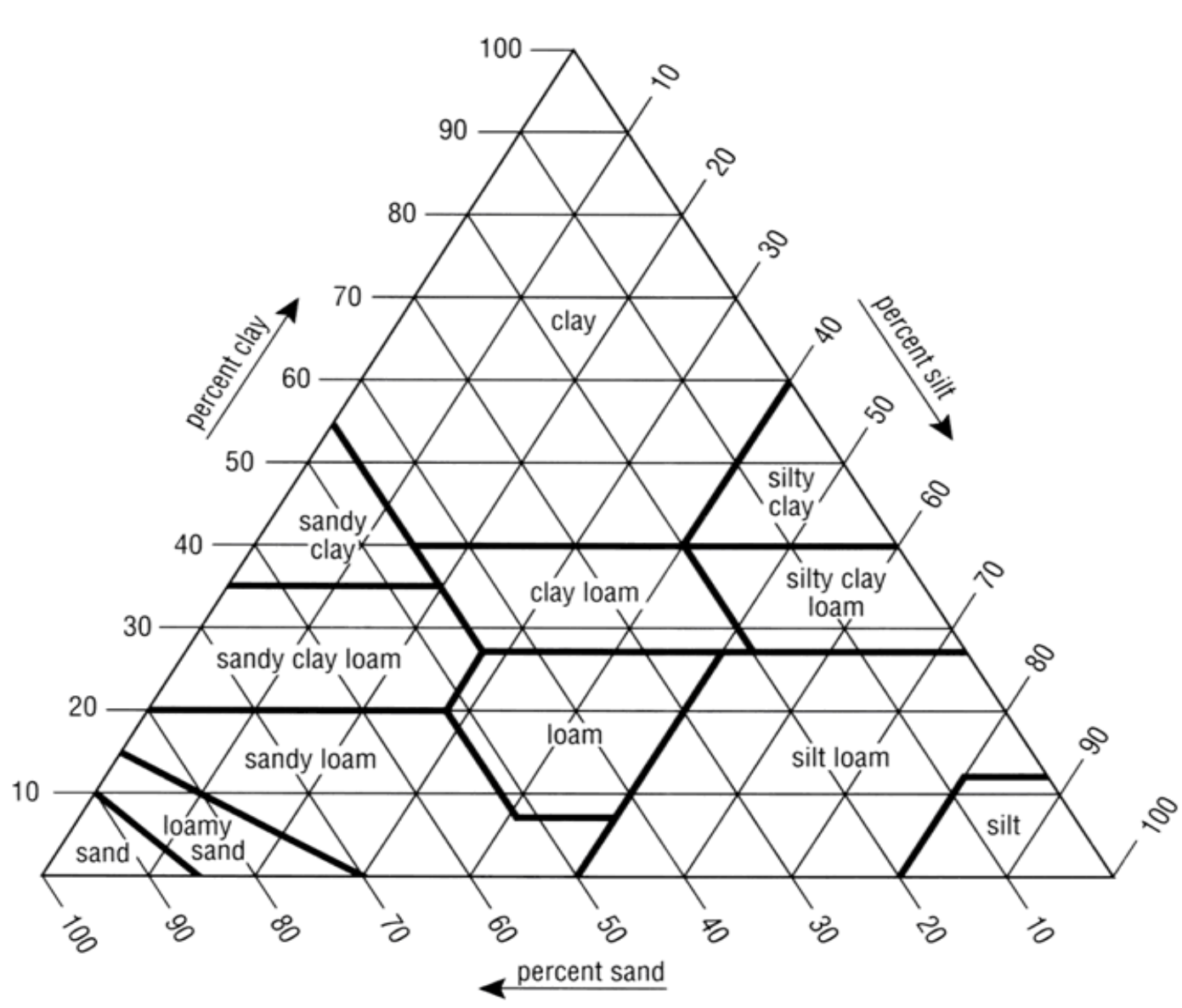
Reconnection – Upland Slopes & Tributaries

Final Regrading – Communicating with Bulldozers

Final Regrading Adjustments – Staking Tributaries

Final Regrading Adjustments – Tributaries In

Soils ?


percent clay
percent silt
percent sand
clay
silty clay
sandy clay
clay loam
silty clay loam
sandy clay loam
loam
sandy loam
silt loam
silt
loamy sand
sand

2008/ 5/30

2007/05/23

Vegetation

The Application of Geomorphic Reclamation Methods in Wyoming

Marcelo Calle

Jonathan Stauffer

Wyoming Department of Environmental Quality

Geomorphic Reclamation and Natural Stream Design at Coal Mines, A Technical Interactive Forum

April 28-30 Bristol, Virginia

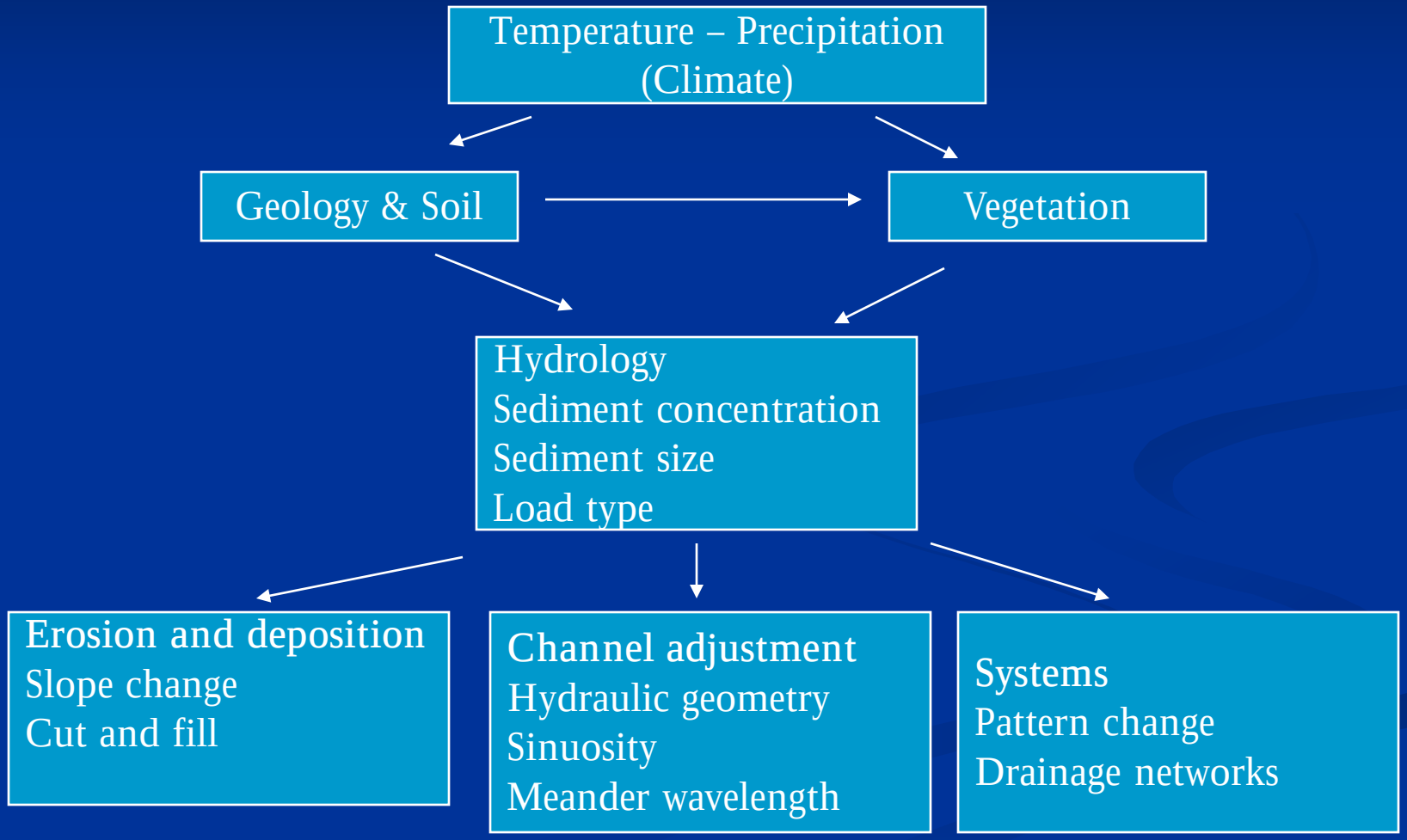
Agenda

- Process Geomorphology
  - Basic Theory
  - Semi-arid Landforms and Processes
- Wyoming General Setting
  - Location
  - Climate
  - Geology
- Geomorphic Reclamation Approaches
  - Watershed Measurement and Reconstruction
  - Empirical Relationships
- Reclamation Examples
  - Permitted Examples
  - Abandoned Mine Lands

Process Geomorphology

- A delicate balance or equilibrium exists between landforms and process.
- This balance is created by the interaction of energy, force and resistance.
- Changes in force and/ or resistance may push the system beyond the limits (threshold) of stability.
- Temporary disequilibrium and major response towards establishing a new equilibrium.

Process Geomorphology

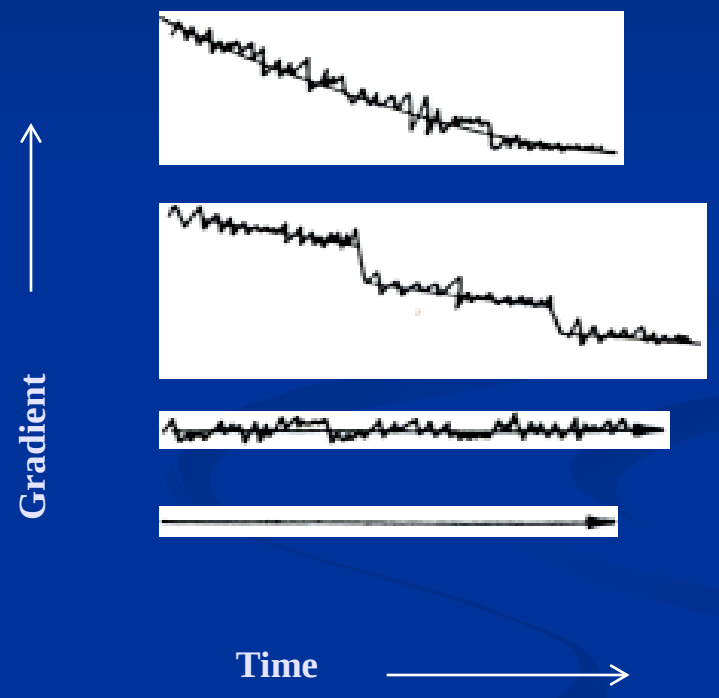


(From Ritter et al., 1995)

Process Geomorphology (cont.)

Geomorphic time

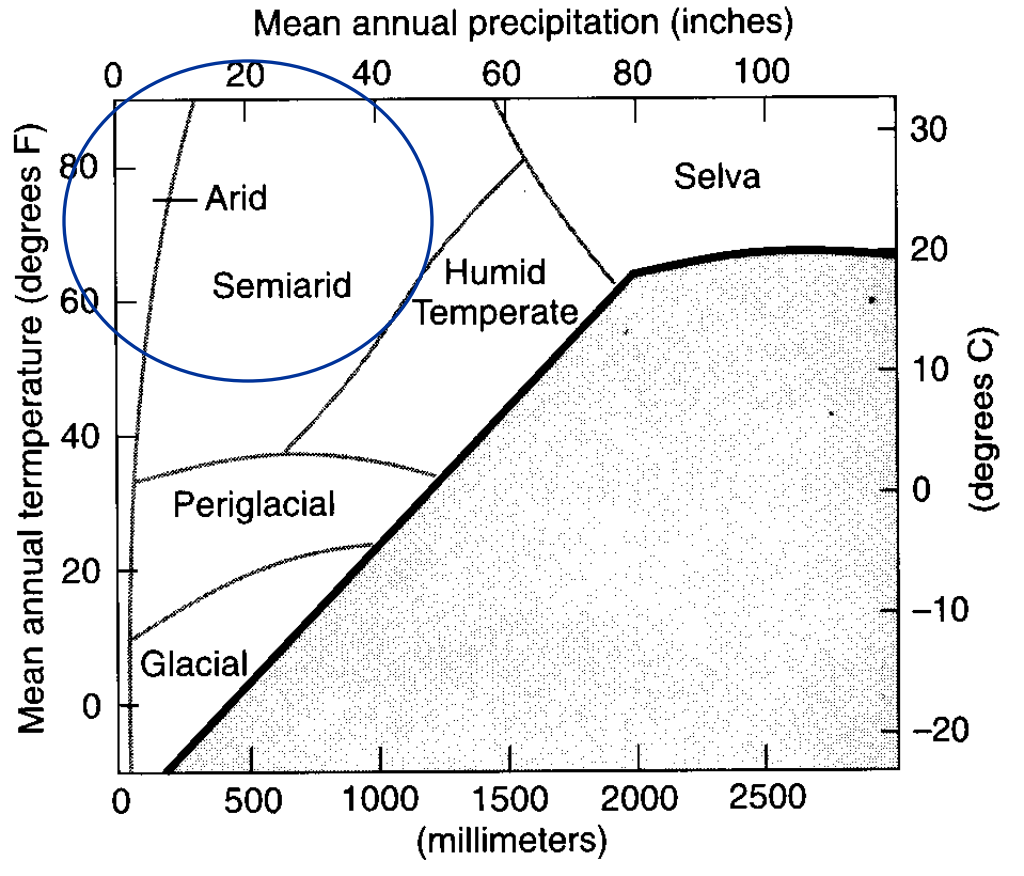
- Cyclic
- Graded
- Steady



Perception of ‘Stability’

Schumm and Lichty, (1965)

Climate Processes and Landforms



Wilson (1968)

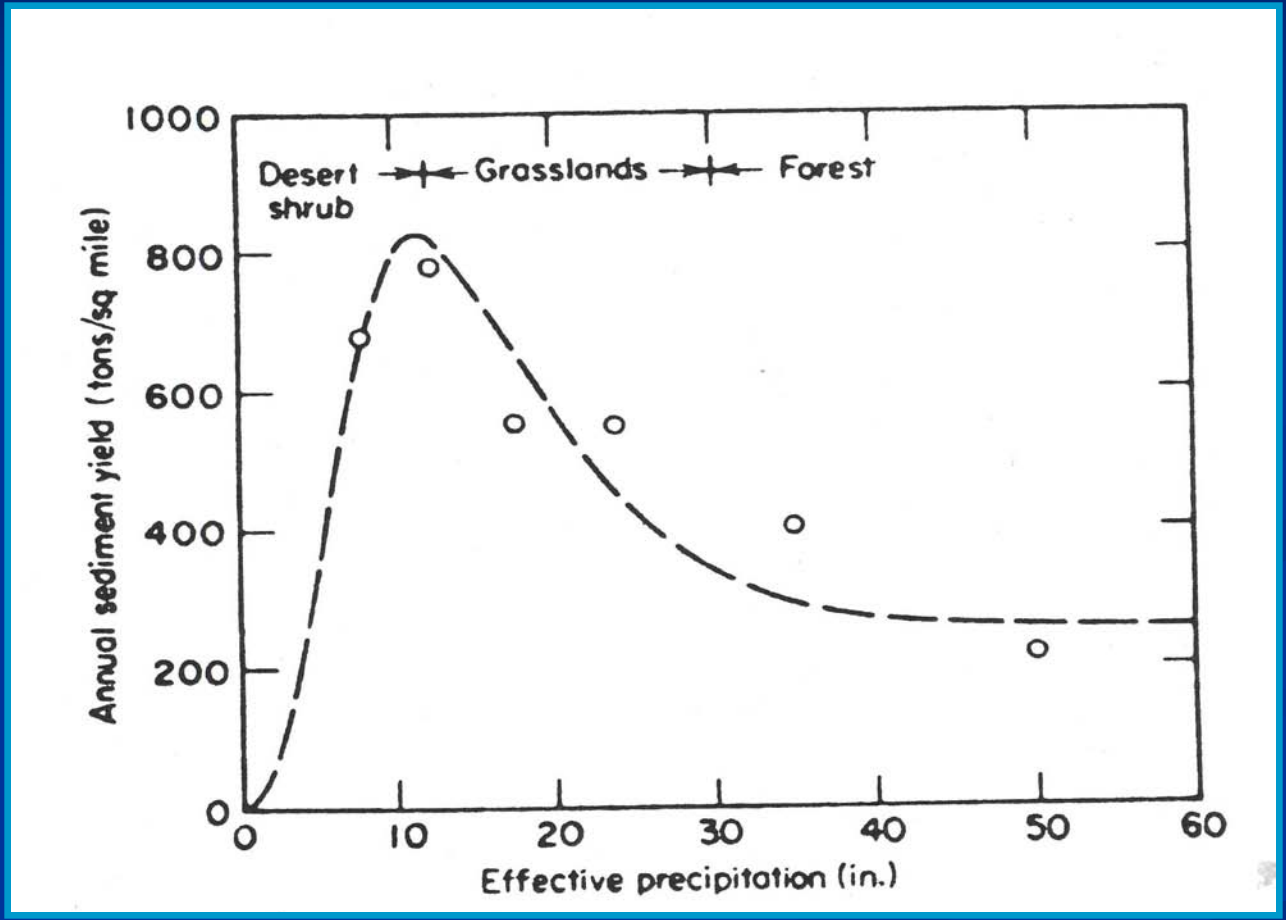
Climate Processes and Landforms (cont.)

Semiarid (10-20 in. annual precipitation)

- Dominant Geomorphic Processes
  - Running water
  - Weathering (especially mechanical)
  - Rapid mass movements
- Landscape characteristics
  - Pediments
  - Fans
  - Angular slopes with coarse debris
  - badlands

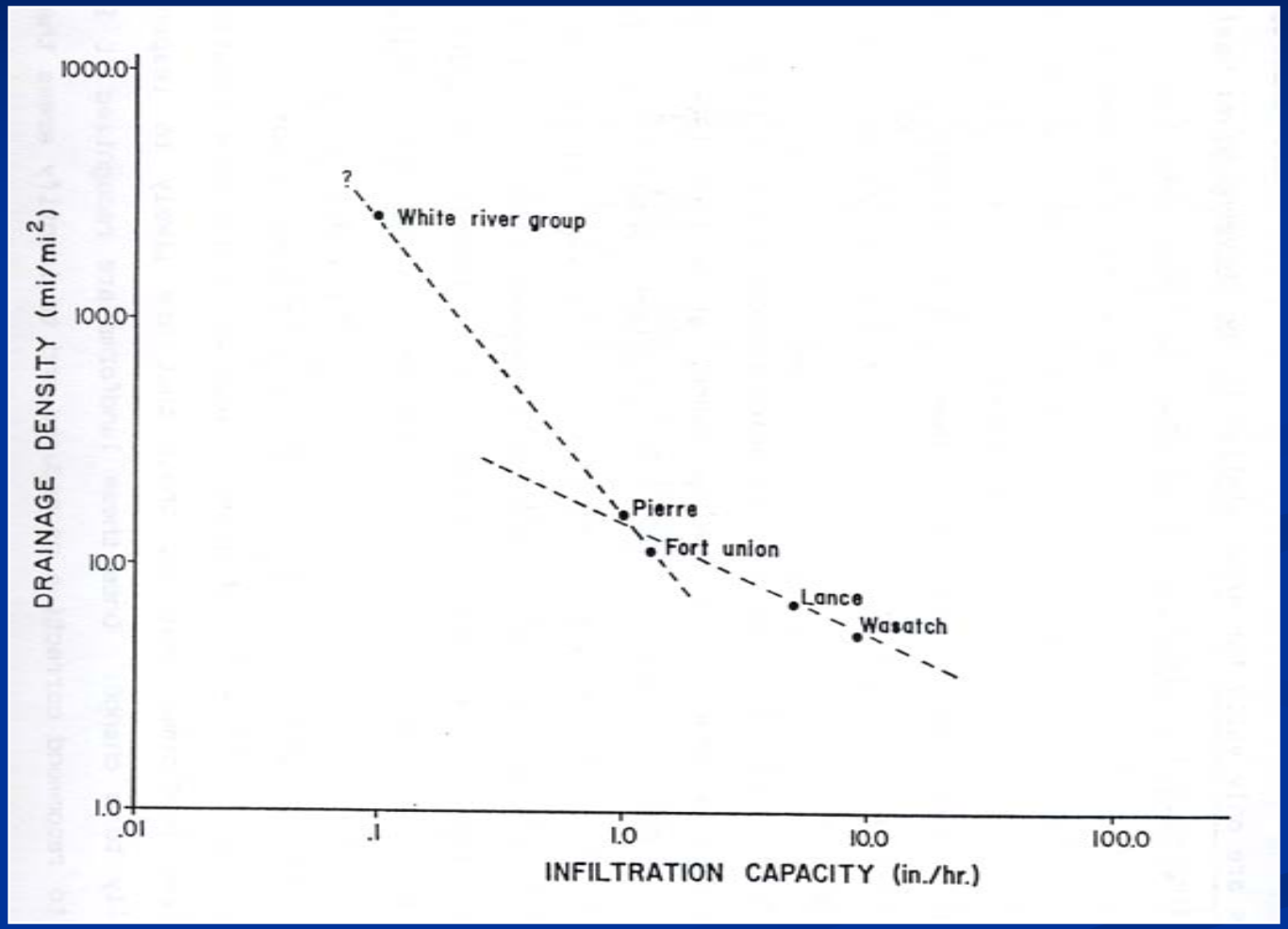
(Wilson, 1968)

Climate Processes and Landforms (cont.)



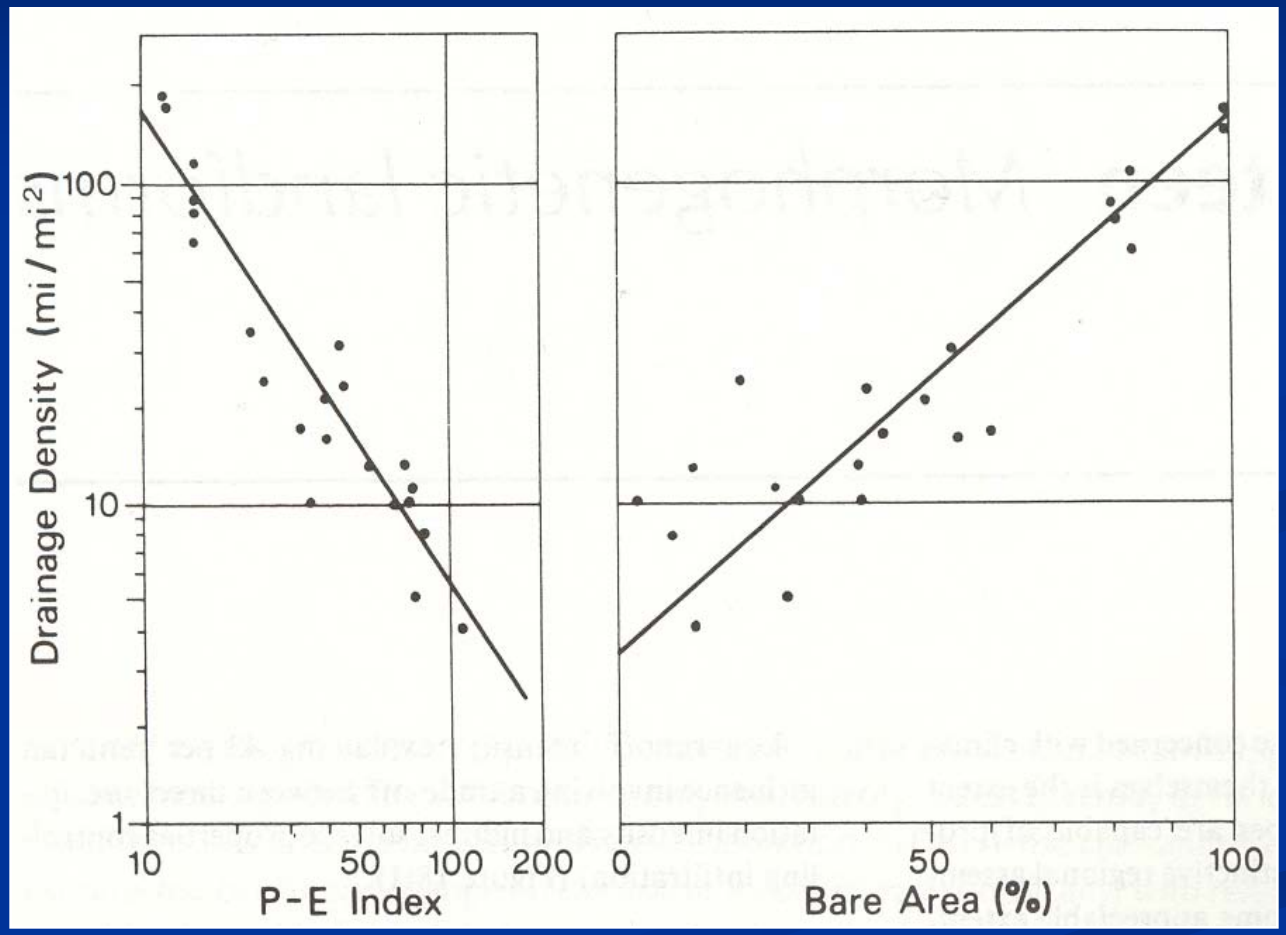
Variation of sediment yield with climate as based on data in the United States (Langbien and Schumm, 1958)

Landform as Function Geology & Soil



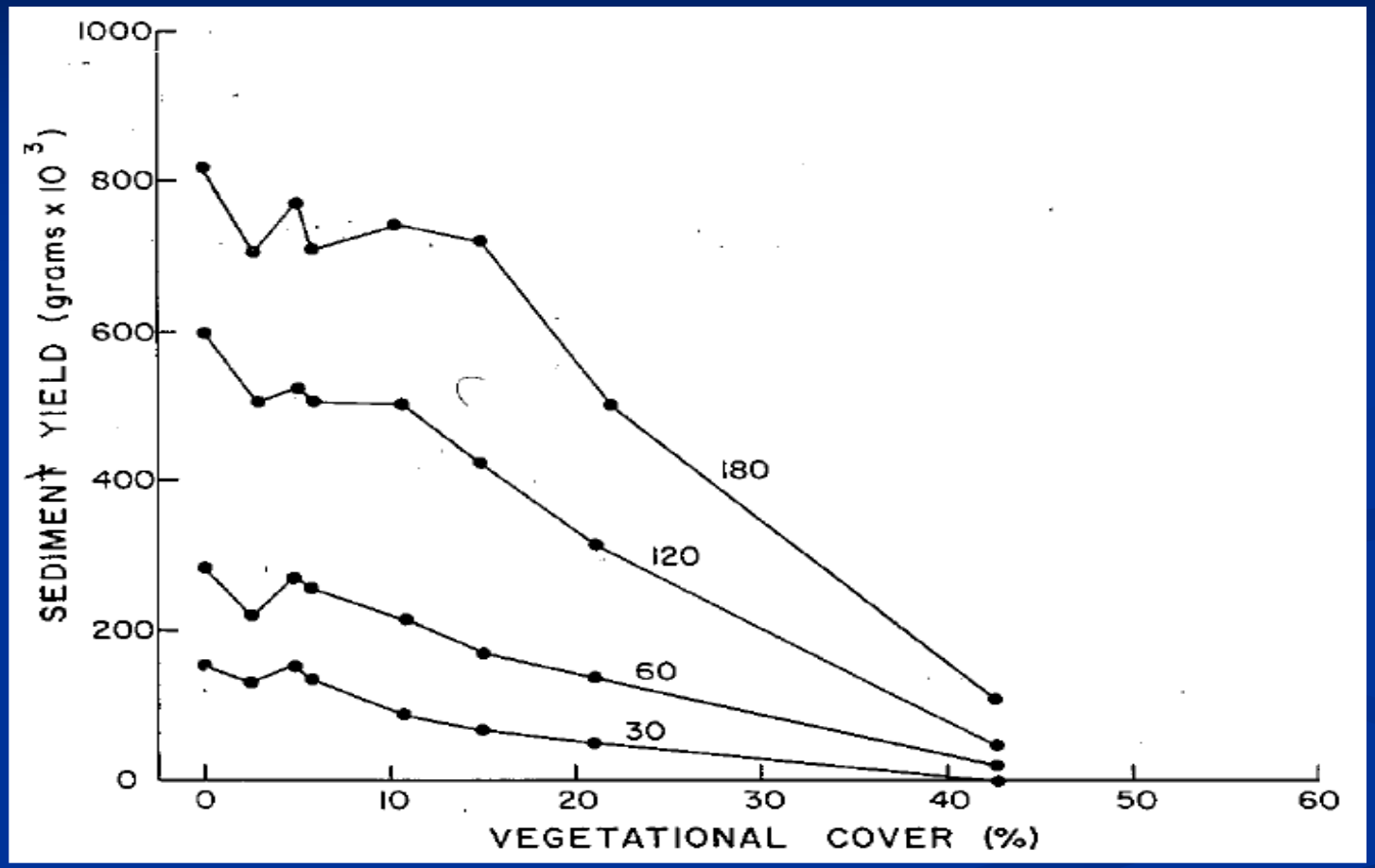
Hadley and Schumm (1961)

Landform as Function Vegetation



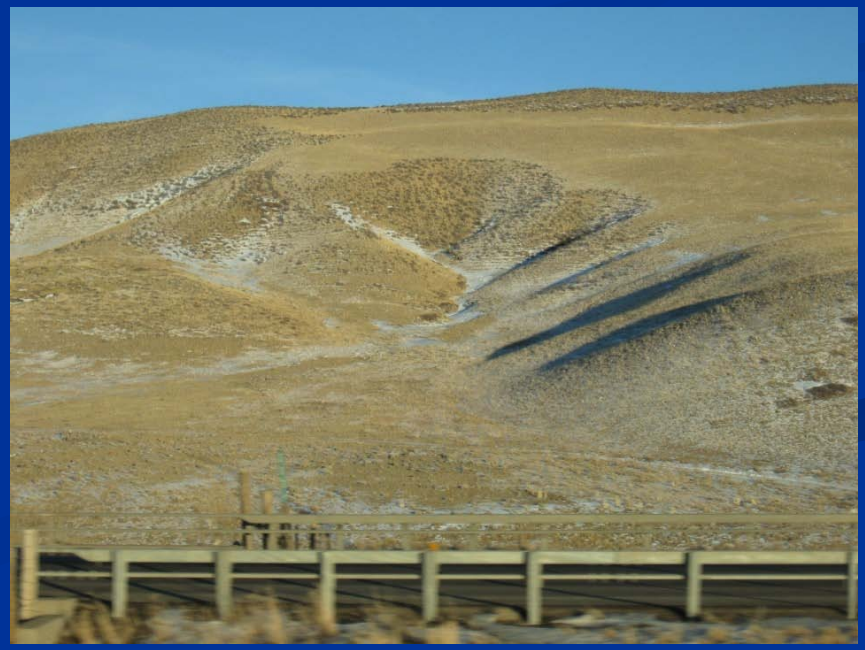
From Chorley, Schumm and Sugden (1984)

Landform Process as Function Vegetation

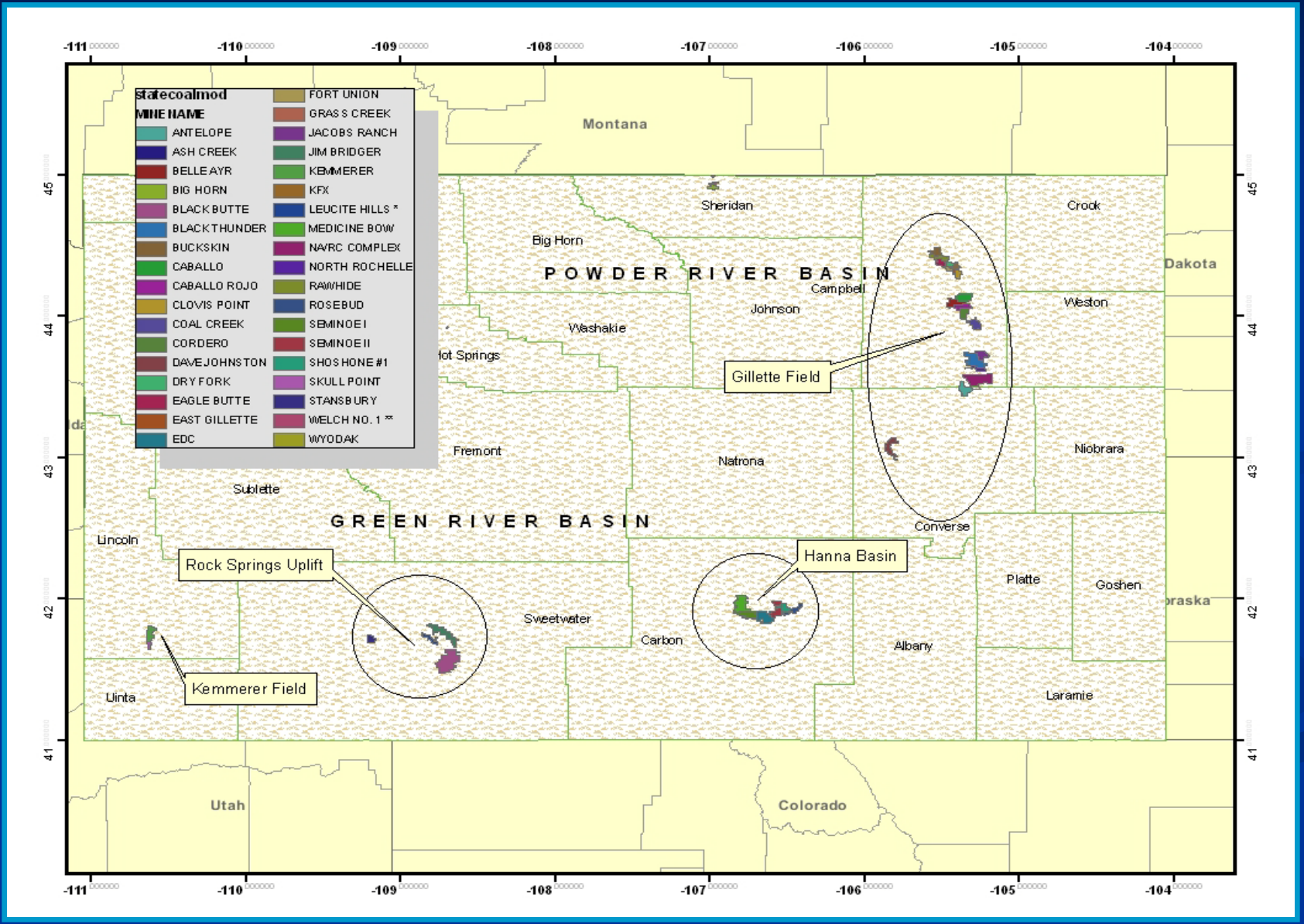


Cumulative sediment yields vs. percent vegetation cover on an experimental 9 X 15 meter watershed having a 10 percent gradient, at 30, 60, 120 and 180 minutes (from Rogers and Schumm, 1991)

MILE
212
33
AH
MILE
212
27
BK



Wyoming Coal Mines



Geology & Soils

Late Tertiary sedimentary

- Wasatch Formation
- Fort Union Formation

Cretaceous sedimentary

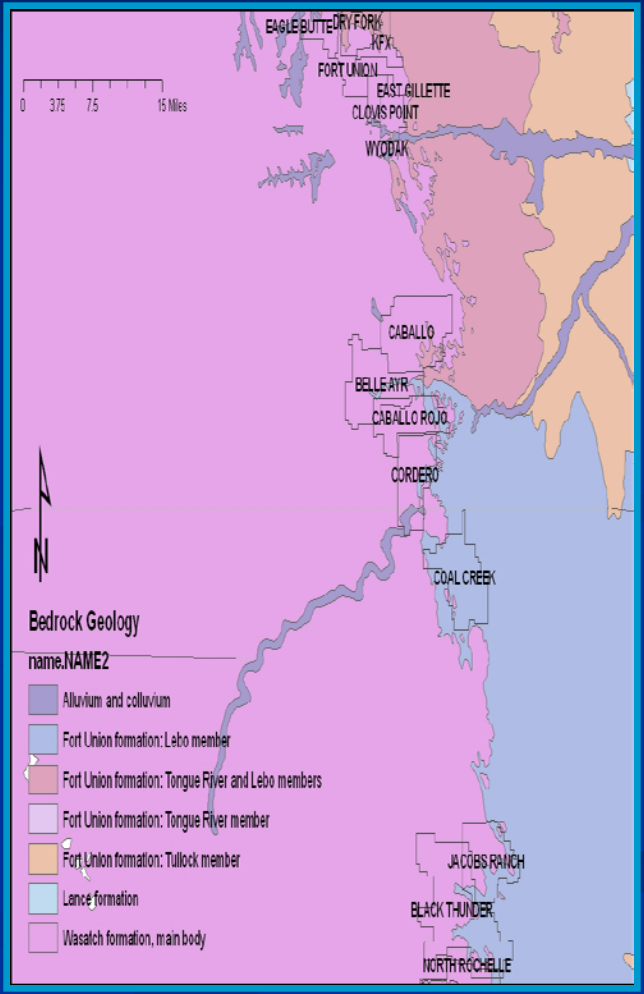
- Lance Formation

Sandstones, siltstones and shale

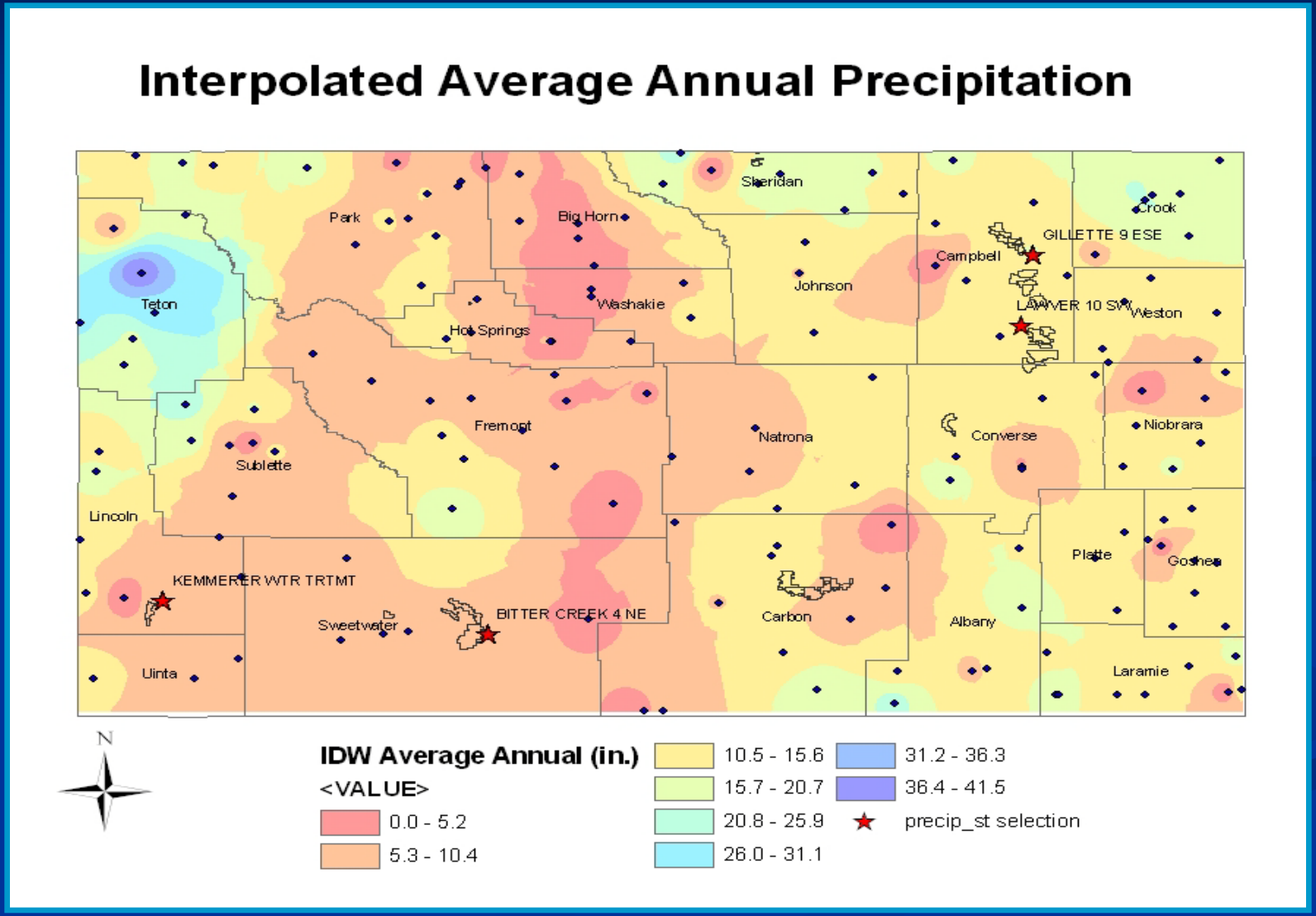
Residuum and alluvium from parent material

Poorly developed soils

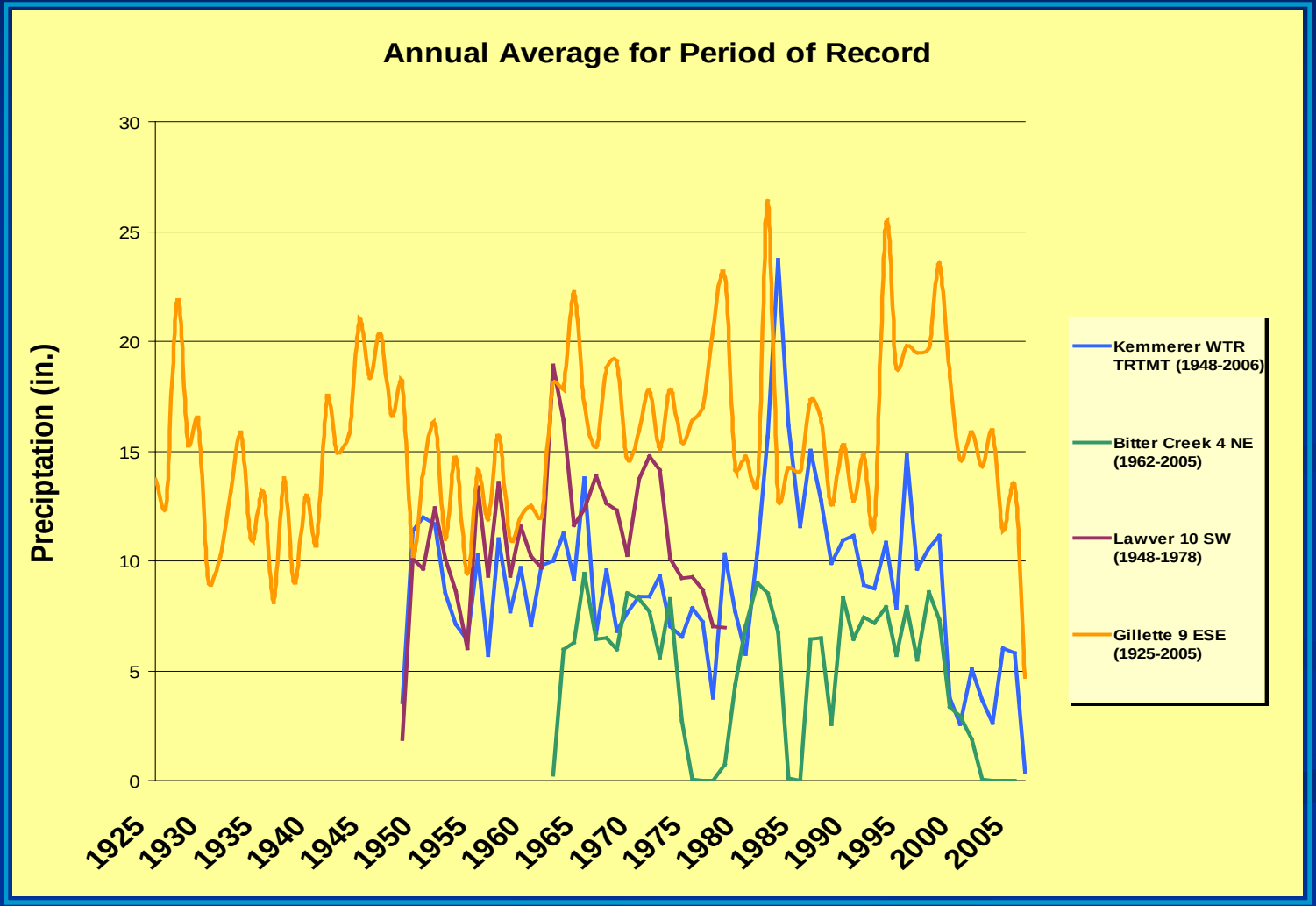
- Aridisols
- Entisols



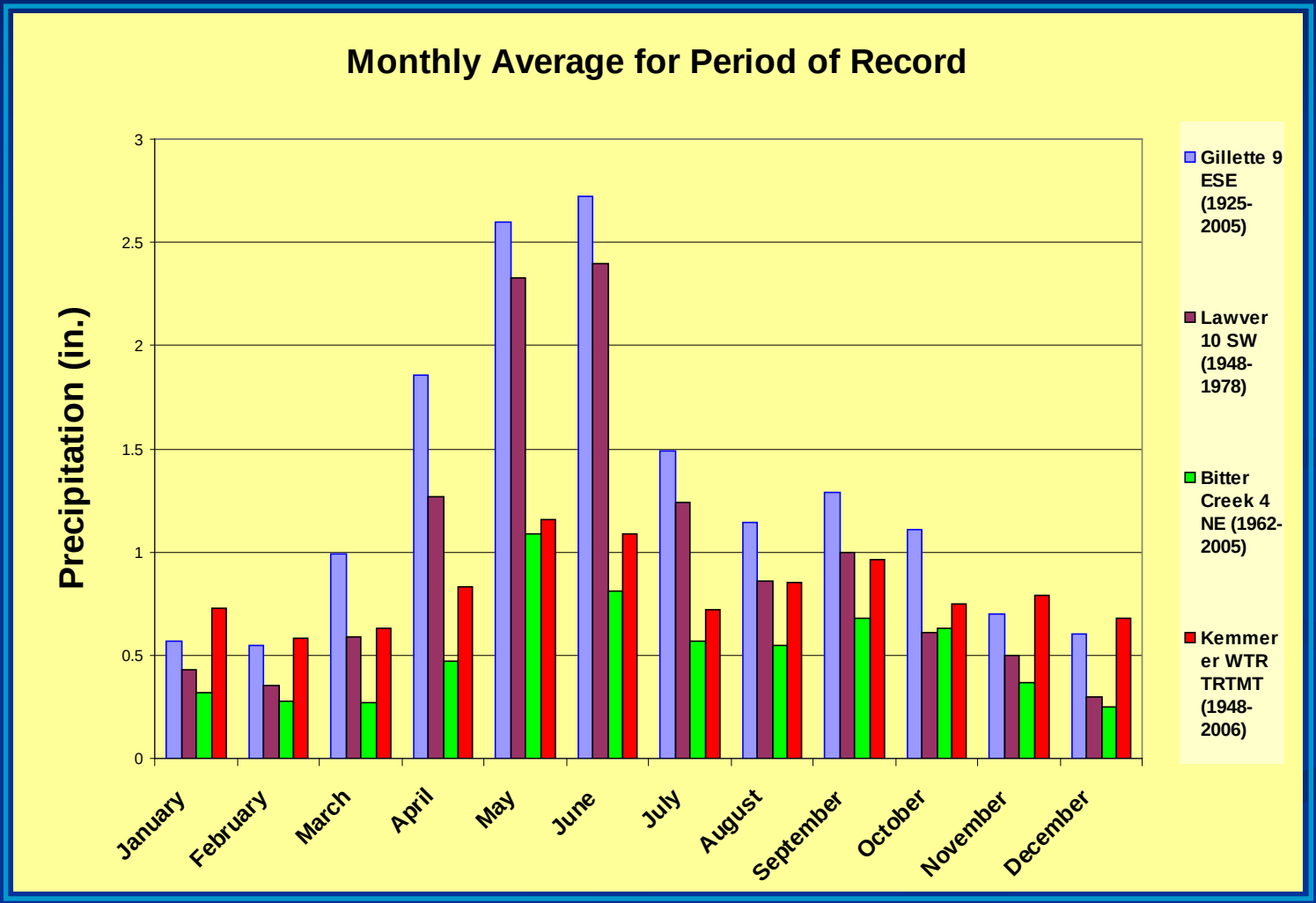
Precipitation



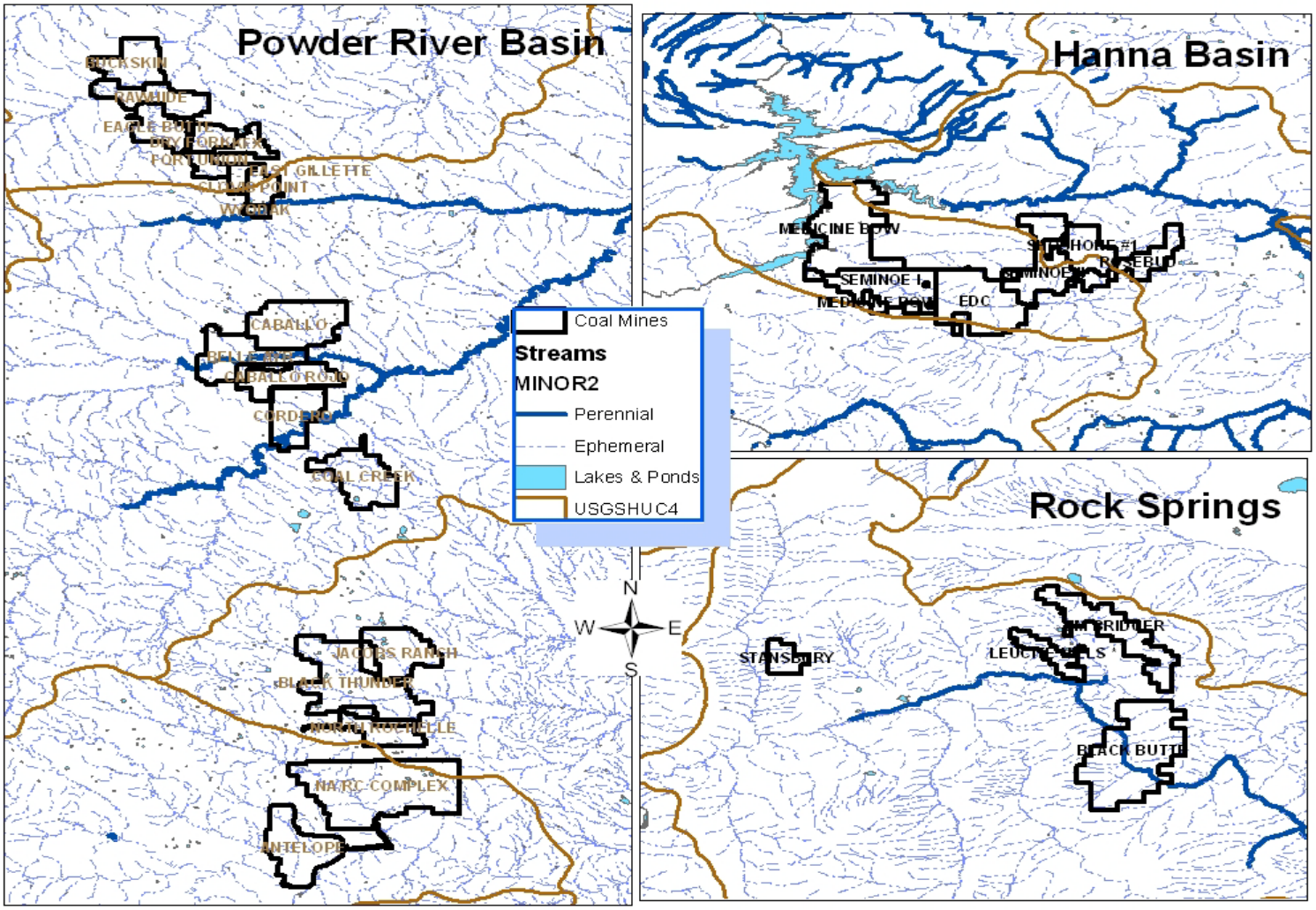
Precipitation (cont.)



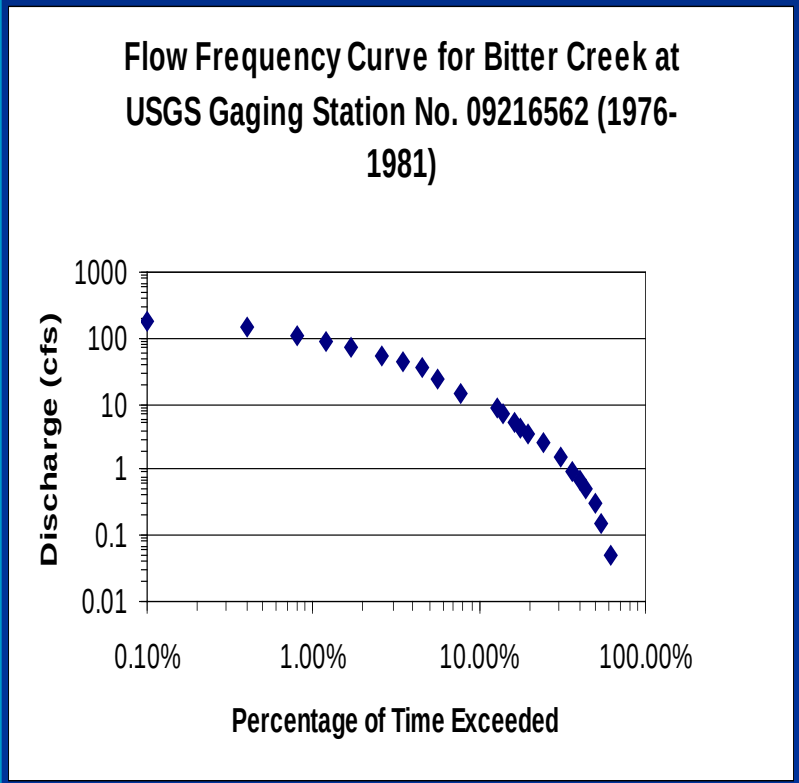
Precipitation (cont.)

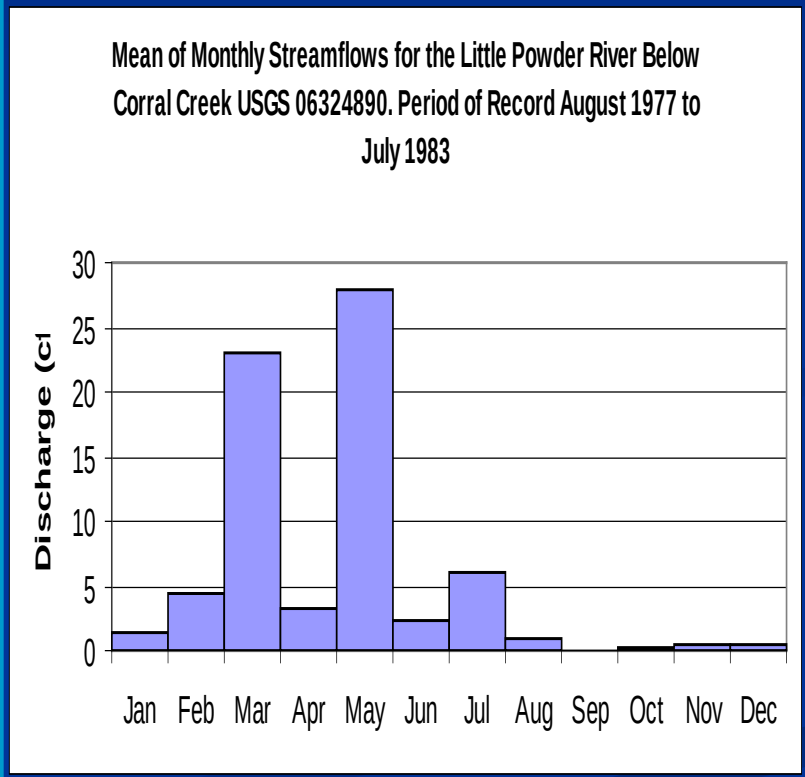


Surface Water Systems



Surface Water Systems (cont.)





Watershed Measurement & Reconstruction

- Drainage Basin Morphometry
  - Areal
  - Relief
  - Linear
- Hillslopes
  - Gradient
  - Aspect
  - Profile
- Channel Characterization

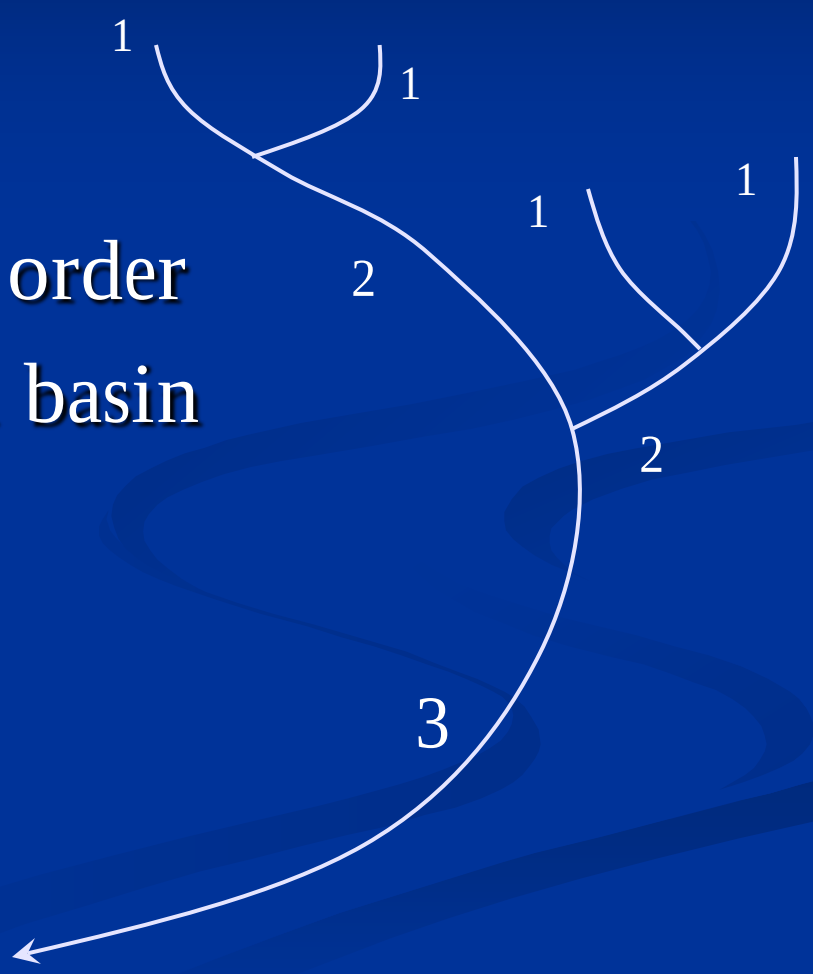
Drainage Basin Morphometry

- Measurements that describe a landform
- Individual measurements can be used to create relationships
- Quantifiable in numeric units or dimensionless values (ratios)
- Classified as:
  - Areal relationships
  - Linear relationships
  - Relief relationships

Drainage Basin Morphometry (cont.)

Linear Relationships

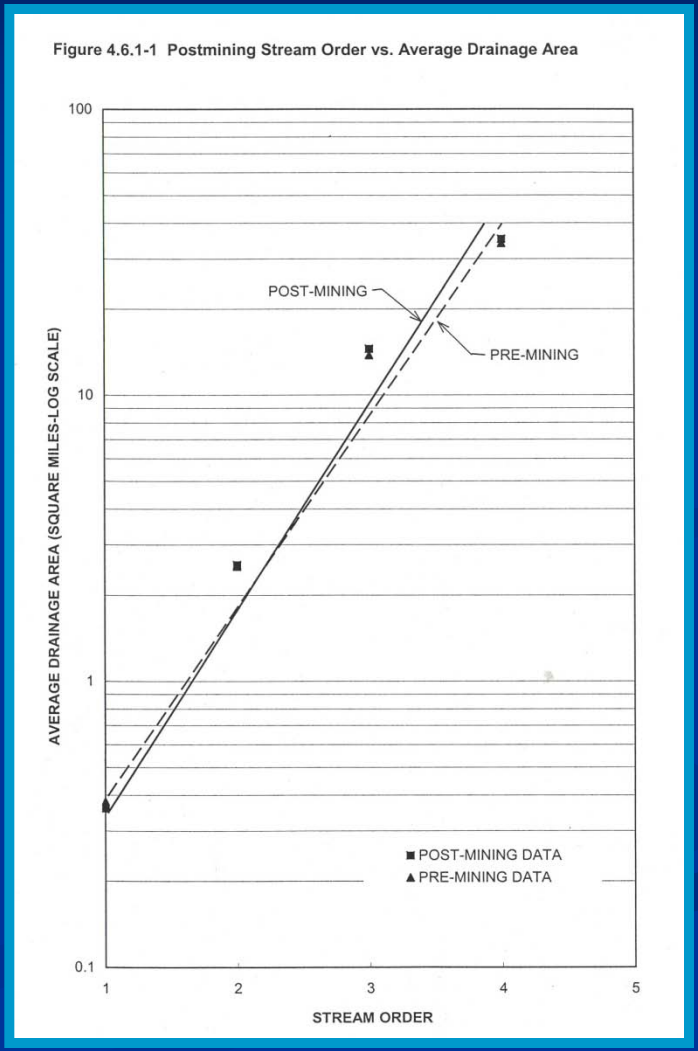
- Horton Analysis
- Stream number in each order
- Total stream number in basin
- Average Stream length
- Total Stream length
- Bifurcation ratio



Drainage Basin Morphometry (cont.)

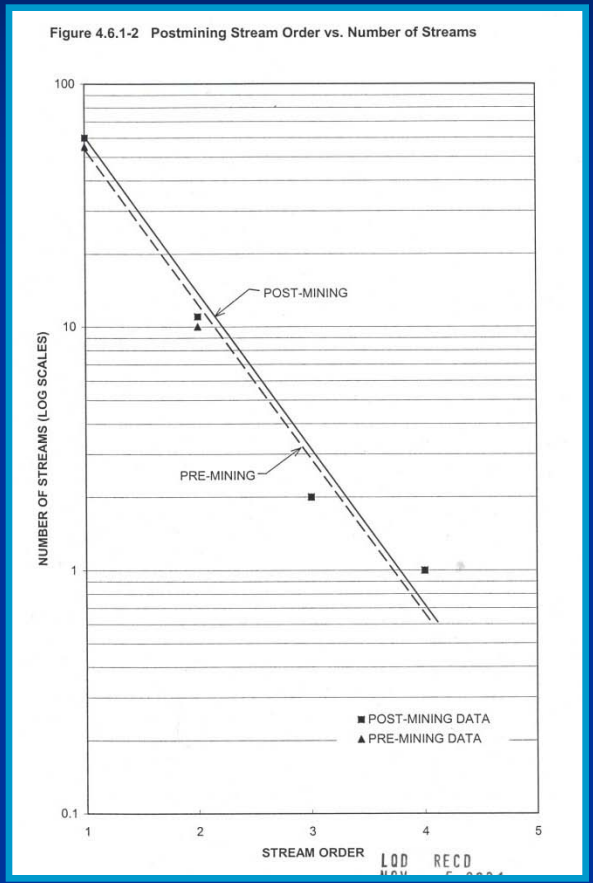
Areal Relationships

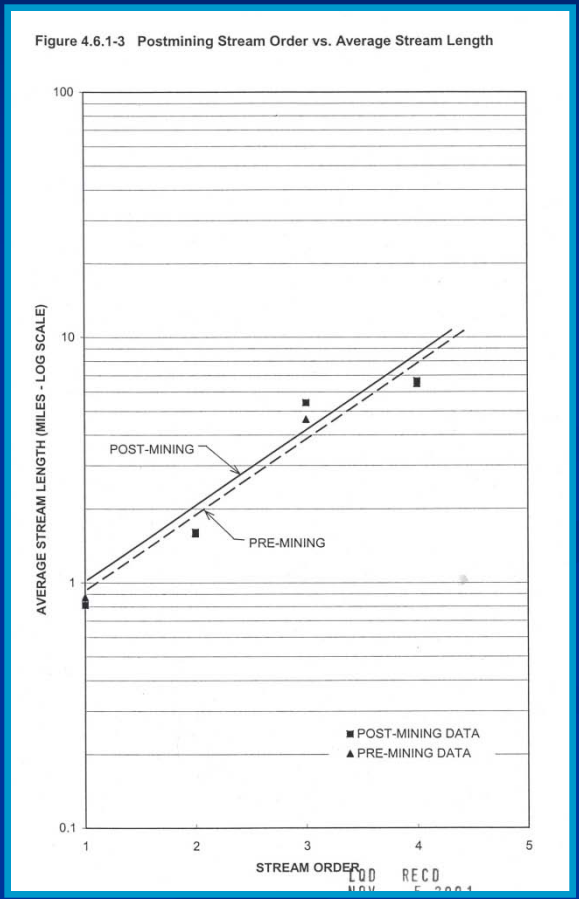
- Drainage area for each stream order
- Drainage density (D)
- Constant of channel maintenance (inverse of D)



(Eagle Butte Mine Permit #420, 2006)

Drainage Basin Morphometry (cont.)





(Eagle Butte Mine Permit #420, 2006)

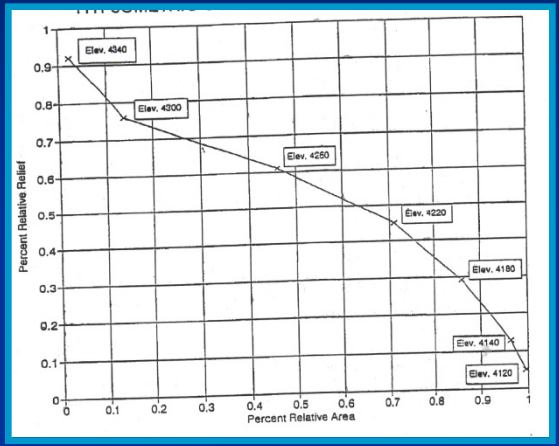
Drainage Basin Morphometry (cont.)

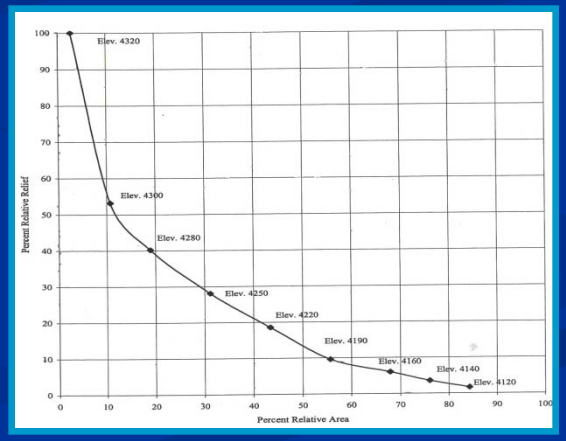
Relief Relationships

Hypsometric Curve

- Basin area and elevation
- Describes the distribution of mass above the vertical datum
- Can be used to compare drainage basins
- Indicates relative maturity of the landform
- Hypsometric Integral – area under curve; indicator of erosion potential

% Relative Relief





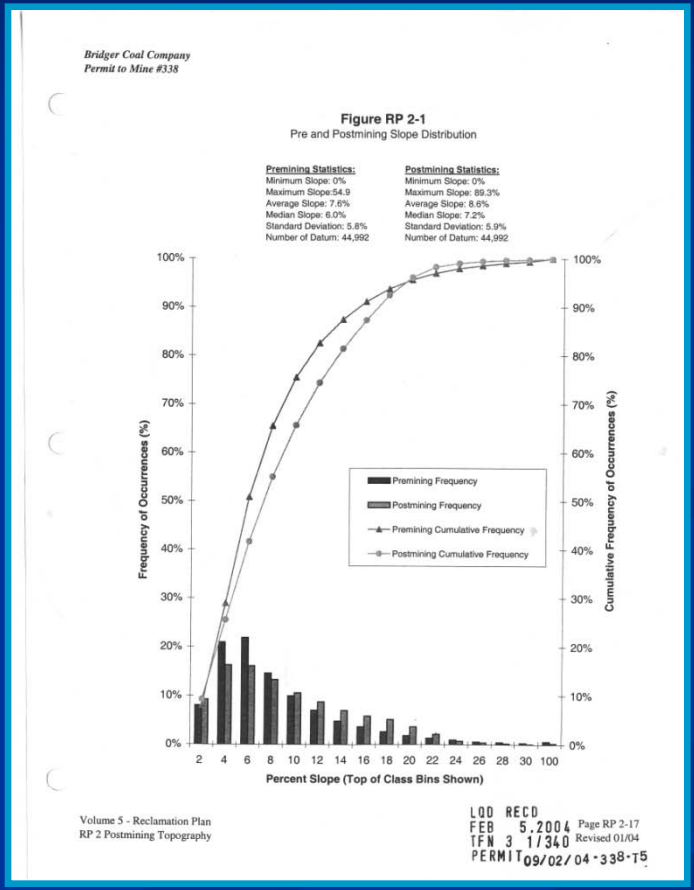
% Relative Area

Pre and post-mining hypsometric curves (Buckskin Permit #500, 2006)

Hillslope

Gradient

- Mass movement increases with hill slope angle
- Decrease in infiltration and soil moisture on steeper slopes
- Optimum vegetation establishment requires slopes < 25% (4:1) (EPA, 1972)
- Adopted as regulatory maximum

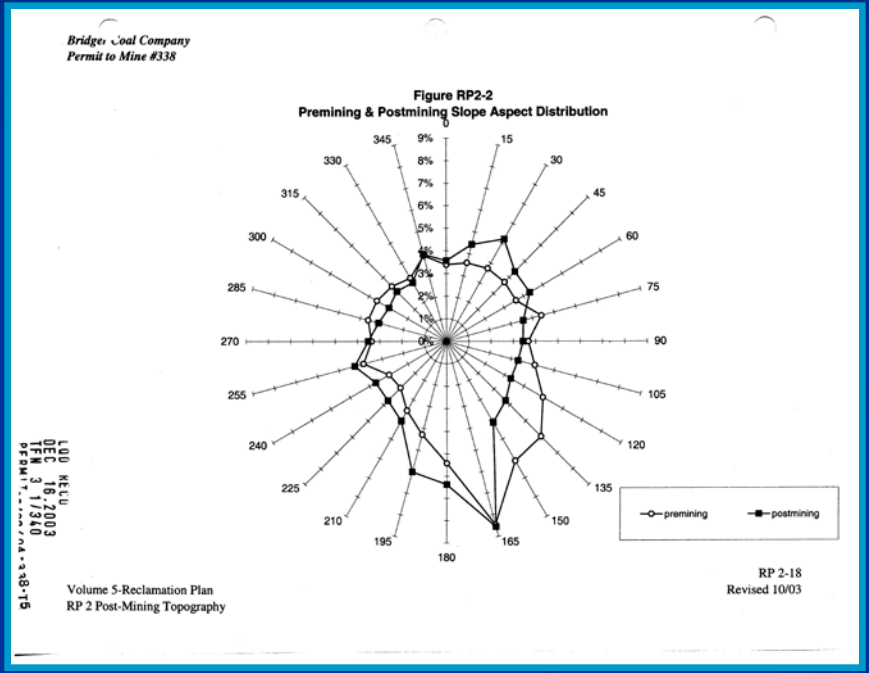


Slope distribution from Bridger Coal Mine Permit #338, 2006

Hillslopes (cont)

Aspect

- South facing slopes are more susceptible to erosion
- More solar radiation
- Less soil moisture and less vegetation
- Drainage density averages 11.3 mi/mi^2 for southern slopes and 5.2 mi/mi^2 for north facing slopes (Hadley, 1962)



Slope aspect distribution (Bridger Coal Mine Permit #338, 2006)

Hillslopes (cont)

Profile

- Convex
  - Rapid increase of soil loss with increasing gradient progressing down slope
- Uniform
  - Gradual increase of soil loss as move down the slope
- Concave
  - Soil loss greatest near the top of hillslope decreasing towards the toe
- Complex
  - Soil loss greatest in midslope inflection and decreasing downslope towards the toe

Hillslopes (cont.)

Graded slope at North Antelope Rochelle Mine (Anna Waitkus, 2004)

Hillslopes (cont)

Reclaimed slopes at Rosebud Mine (Pam Rothwell, 2003)

Reclaimed slopes at Seminoe II Mine (Pam Ross, 2003)

Channel Characterization

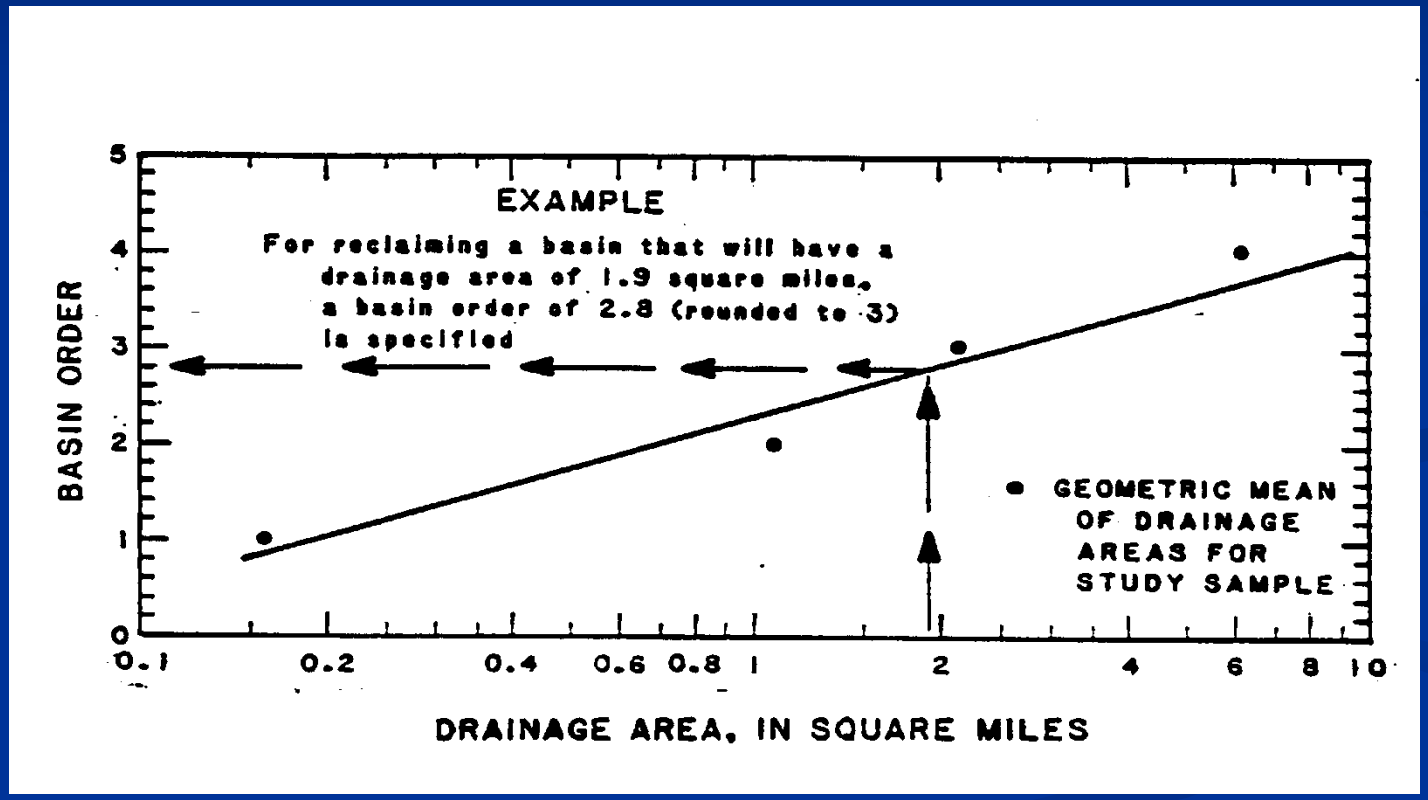
Baseline inventory

- Longitudinal profiles
  - gradient
  - shape
- Cross sections
  - area
  - depth
  - top width
  - wetted perimeter
  - hydraulic radius
- Channel pattern
  - wavelength (λ)
  - amplitude (A)
  - radius of curvature (r)

Empirical Relationships

- Based solely on observation rather than theory. An empirical relationship requires only confirmatory data irrespective of theoretical basis.
- Historically the discovery of empirical relationships has been important as a stepping stone to the discovery of true theoretical relationships.
- An **empirical equation** is simply a mathematical statement of one or more empirical relationships in the form of an equation.

Empirical Relationships (cont.)



Regression analysis for basin order as function of drainage area in eastern Powder River Basin (Lowham, 1993)

Empirical Relationships (cont.)

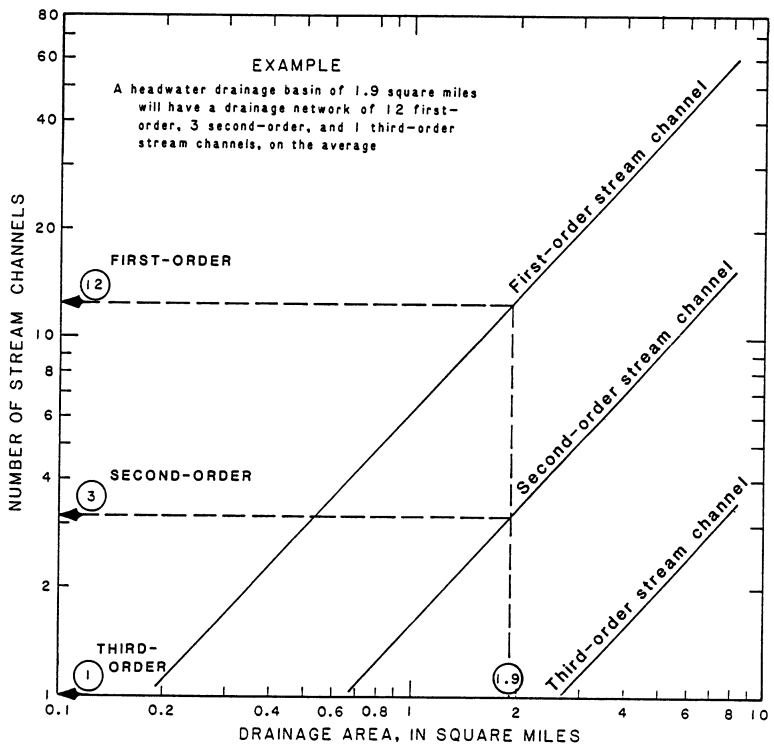


Figure 44.--Relation of number of stream channels to drainage area.

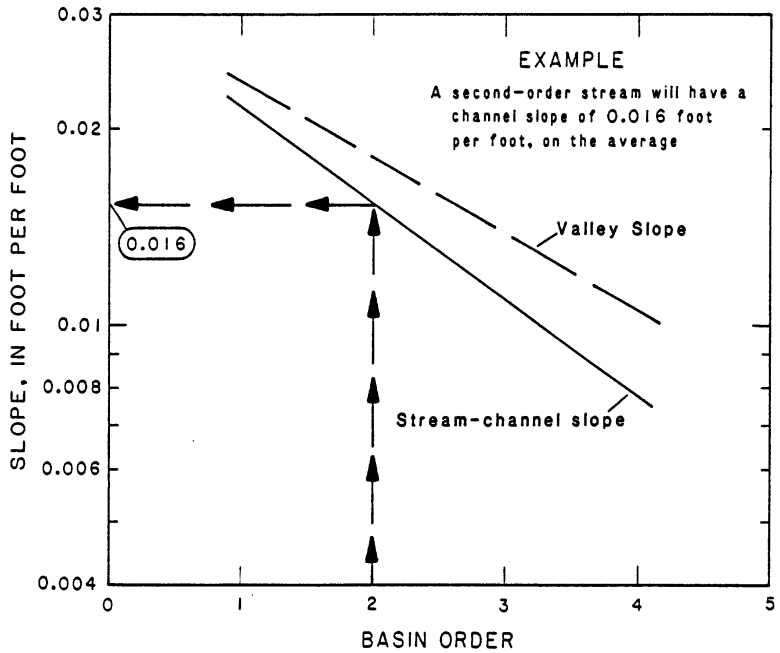


Figure 45.--Relations of stream-channel and valley slopes to drainage-basin order.

Regression analysis for various natural drainage basin variables in eastern Powder River Basin (Lowham, 1993)

Empirical Relationships (cont.)

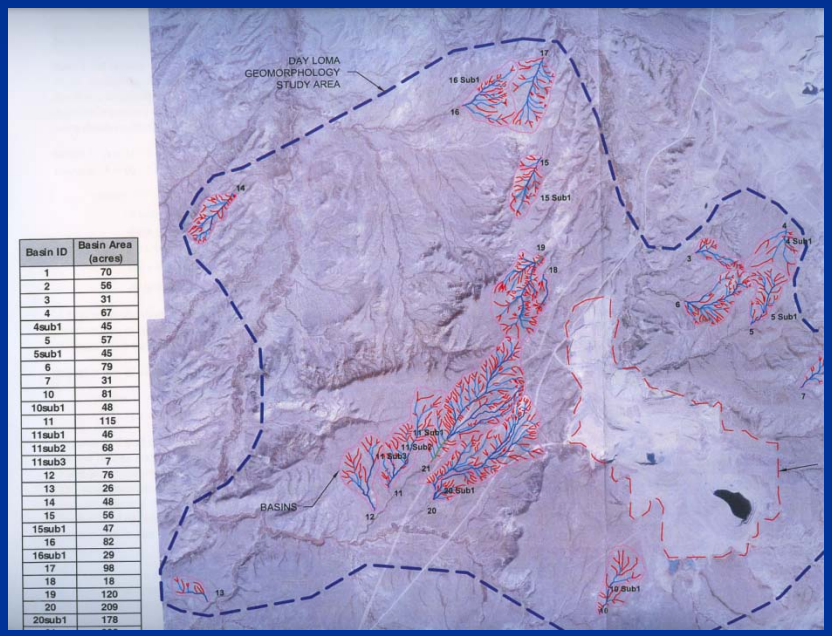
Regression analysis for various natural drainage basin variables in eastern Powder River Basin (Lowham, 1993)

Regression equation	Correlation Coefficient
Basin length (BL) = 1.85 Area (A) $^{0.51}$	0.96
Basin relief (R) = 227 A $^{0.28}$	0.71
R = 163 BL $^{0.52}$	0.72
Used Relief (UR) = 2.56 R $^{0.69}$	0.73
Channel length = 0.92 BL $^{1.16}$	0.98
Channel slope = 0.00036 BL $^{-0.89}$ UR $^{.90}$	0.96
Total channel length = 3.22 A $^{0.86}$	0.96

Empirical Relationships (cont.)

Day Loma Uranium Project

Lidstone & Associates -Fort Collins, Colorado



Basin ID	Basin Area (acres)
1	70
2	56
3	31
4	67
4sub1	45
5	57
5sub1	45
6	79
7	31
10	81
10sub1	48
11	115
11sub1	46
11sub2	68
11sub3	7
12	76
13	26
14	48
15	56
15sub1	47
16	82
16sub1	29
17	98
18	18
19	120
20	209
20sub1	178

1. Determine the design criteria

A
Between 30 and 150 acres

L_1
$L_1 = \frac{16 - A}{-0.006}$

→

Dd
$Dd = \frac{51 - A + .0065L_1}{1.44}$

→

L_2
$L_2 = \frac{1.4Dd - 56 + A}{0.012}$

N_1
$N_1 = \frac{99 - A - 3.4Dd}{-1.9}$

↓

F_1
$F_1 = A/N_1$

N_2
$N_2 = \frac{100 - A - 3.1Dd}{-5.82}$

↓

F_2
$F_2 = A/N_2$

↓

2. Compare results with geomorphic study of natural basins

↓

3. Use criteria to design basins

A_b	Drainage basin area	acres
L_1	Total length of first order streams	feet
L_2	Total length of second order streams	feet
Dd	Drainage density	mi/mi^2
N_1	Total number of first order streams	
N_2	Total number of second order streams	
F_1	Stream frequency for first order streams	acres/stream
F_2	Stream frequency for second order streams	acres/stream

(Lidstone, 2008)

Empirical Relationships (cont.)

Regression equations for estimating channel hydraulic characteristics in Wyoming plains and high desert (Lowham, 1993)

$P_2 = 41.3\ A^{0.60}\ A^{\wedge -0.05}\ Gf$ Plains

$P_2 = 6.66\ A^{0.59}\ A^{\wedge -0.03}\ PR^{0.60}\ Gf$ High Desert

$W = 0.98\ P_2^{0.54}$

$A_C = 0.173\ P_2^{1.02}$

P_2 = Predicted bankfull discharge

A = Drainage area

PR = Average annual precipitation

Gf = Dimensionless geographic factor

W = Bankful channel width

A_C= Cross sectional area

Empirical Relationships (cont.)

Regression equations used to predict fundamental channel form characteristics for ephemeral streams in northeast Wyoming.

$R_C = 65.5\ A^{0.35}$

$L_M = 317\ A^{0.28}$

Rechard, 1980

$\lambda = 30.6\ A^{0.52}\ H^{0.09}\ S_C^{0.41}$

Divis and Tarquin, 1981

Reclamation Examples

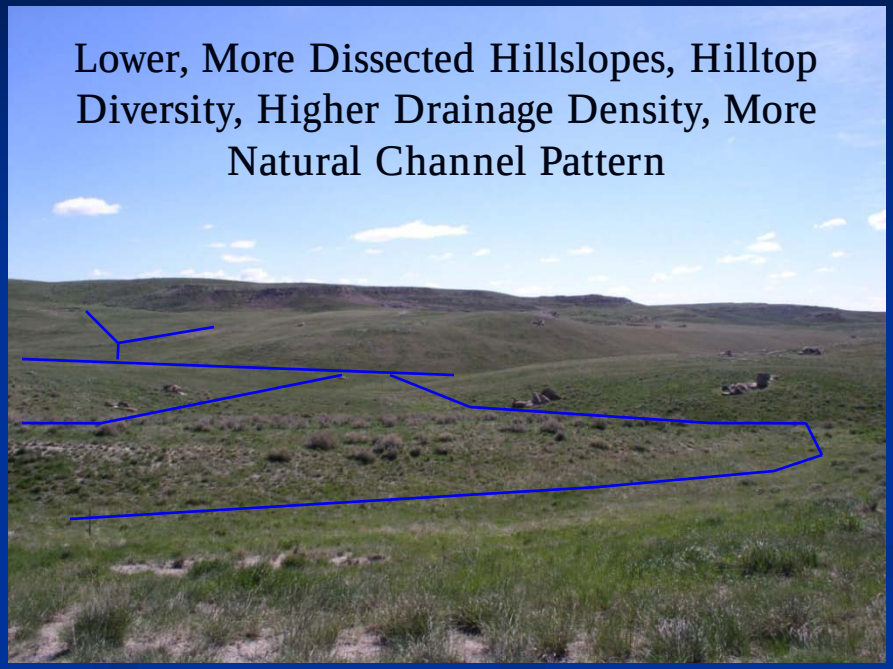
Rosebud Coal Mine: Hanna, Wyoming
7000’ Above MSL

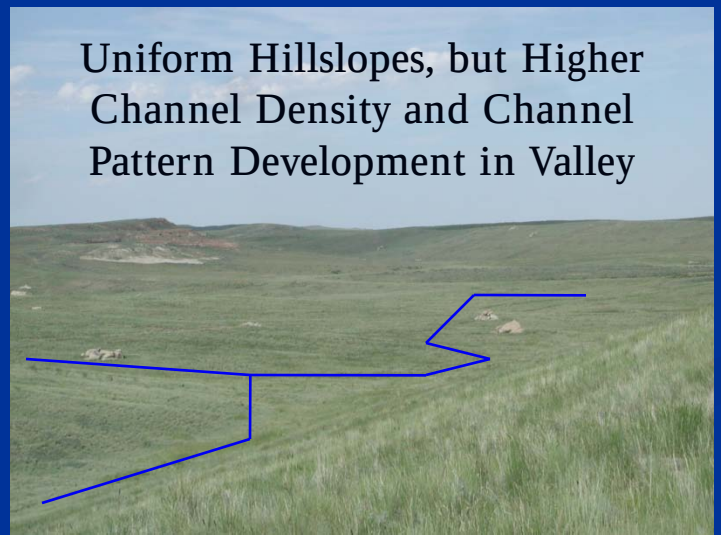
Mid-Term Reclamation With Uniform Sideslopes, Contour Ditches and Spacing, Rectangular Valleys, and Subdued Relief

Dissected Native In Background

Poor Vegetation Success:
Due to Rilling on Uniform Slope and Hilltop with Contour Ditches and Wind Loss

Rosebud Coal Mine : Contour Ditch Failure, and Later Reclamation





Dave Johnston Coal Mine : Glenrock, Wyoming 4500’ Above MSL

Dragline Pit and Spoil at Dave Johnston

Dave Johnston Coal Mine : Final Landform

Final Reclaimed Landform in the Lower, Main Valley Portions of the Watershed Include Higher Channel Density, Relatively Natural Channel Pattern, Elevational Diversity, Subdued Landform, Flatter Slopes, and Concave Channel Profiles

Dave Johnston Coal Mine : Final Landform

Final Reclaimed Landform in the Upper Portions of the Watershed Include Ridgetop Diversity, Relatively Natural Channel Pattern, Increased Hillslope Dissection/Higher Drainage Density, Lower Ridgetops, Flatter Slopes, and Complex and Concave Hillslope Profiles (and a Wind Energy Project in 2009)

Little Medicine Bow River: Main-Stem, Perennial Stream

AML Project: Uranium Mining District – Perennial Stream Restoration in a Regional Valley. Sinusoidal Channel Pattern, Pre-Mining Relationships Used in an Analog-Based Design . This Methodology is the Typical Approach to Perennial and Intermittent Stream Restoration in Wyoming Mine Reclamation.

AML Project 16N

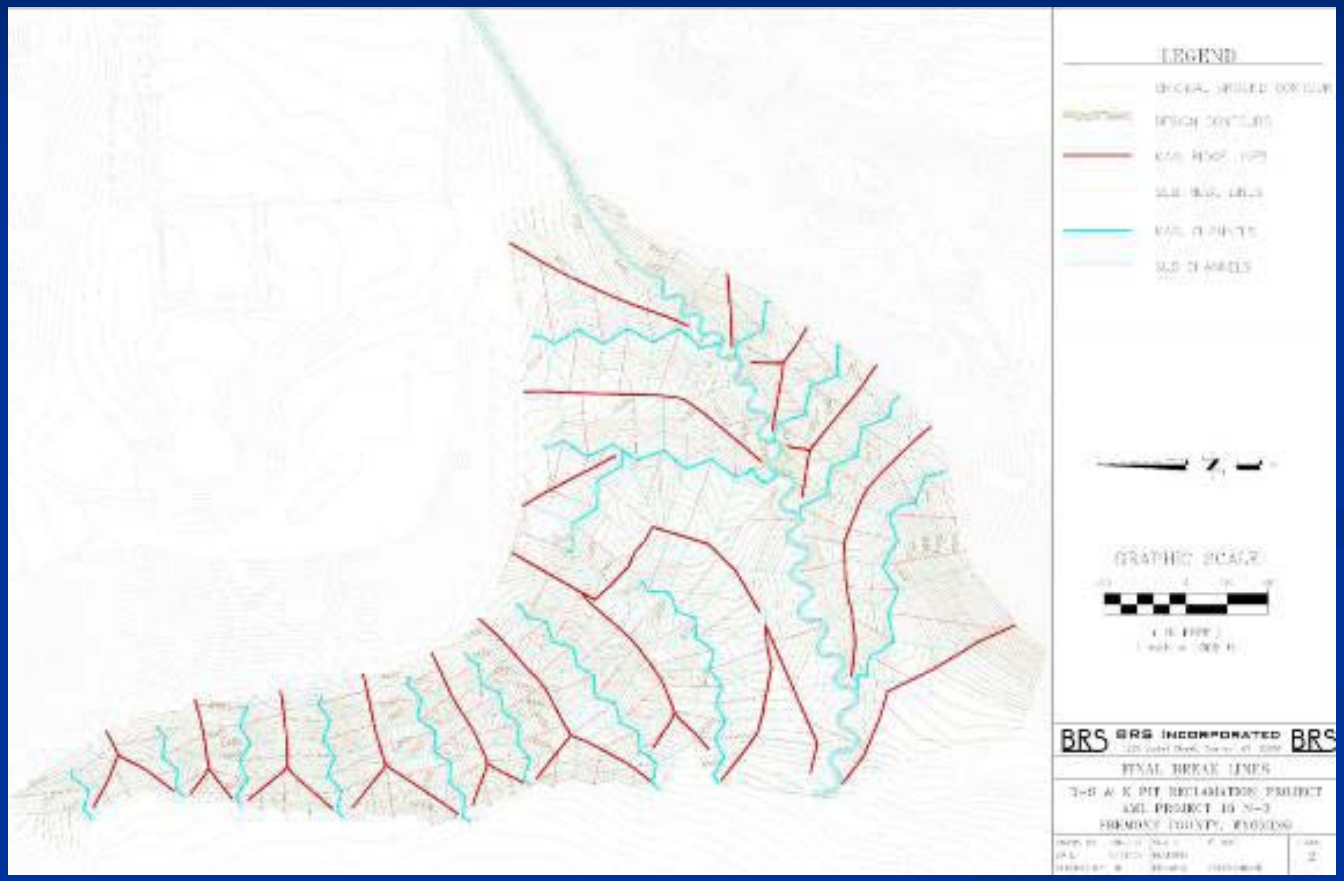
West Gas Hills, Fremont County, Wyoming

BRS Engineering - Riverton Wyoming

AML Project 16N (cont.)

Central spoils with poorly vegetated, long uniform slopes demonstrating significant rilling.

AML Project 16N (cont.)



Natural Regrade terrain model with sub-ridges (red) and designed flow paths and channels (blue).

AML Project 16N (cont.)

Haulage of central spoils material to fill the D-9 pit.

AML Project 16N (cont.)

GPS control dozers contouring valleys and divides and applying suitable cover material.

AML Project 16N (cont.)

Natural Regrade landform demonstrating characteristic terrain dissection through the use of sub-channels and sub-ridges.

AML Project 16N (cont.)

New landform that enhanced the topographic diversity and opened the viewshed.

AML Project 16N

West Gas Hills, Fremont County, Wyoming

Final reclamation landform; note traditional reclamation slopes utilizing contour ditches in background.

Closing Remarks

Moving Forward

- Based on our current understanding of the reclamation design process and the broad knowledge developed during the last 30 years of mine reclamation implementation, should the use of pre-mine analogs still be considered the most appropriate comparative tool, or target, for the development of the post-mining topography? Or, should stronger consideration be placed upon fluvial and watershed process-based methodologies? Simply put, should we reconstruct the pre-mine landform, or develop a new landform based on changes in the system?
- Are regulatory expectations that "any erosion is too much erosion" unrealistic, especially in the arid and semi-arid western region?
- If the erosion issue is reconsidered, and erosion flexibility policies are considered, will permitting and inspection personnel be retrained, and will guidelines be developed to assist in the understanding of "how much erosion is too much erosion"?
- As new guidance, methodologies, and technologies emerge, how will they be reviewed for technical adequacy, and incorporated into the current regulatory framework? Should operators be included in the development of these emerging techniques to ensure their feasibility?
- How will operators be provided assurance that flexibility in the allowance of progressive geomorphic designs and inspection criteria will be consistently applied? How can regulators be assured that the pursuit of these emerging reclamation approaches will not penalize the operators?
- Will these types of changes, if determined to be desirable, require extensive rule changes, or are can they be fit into the existing regulatory framework?

Questions?

References

1. Divis, A. a. (1981). The geohydrologic regime of the Powder River Basin. Wheatridge, Colorado: Environmental Science Associates.
2. Dury, G.H.. 1964. Theoretical implications of underfit streams. U.S.Geol. Survey Prof. Paper 452-C
3. Hadley, R.F., 1962, Some effects of microclimate on slope morphology and drainage basin development: U.S. Geological Survey Research, 1961, pp. B-32 to B-33.
4. Langbiem, W.B., and Schumm, S.A., 1958, Yield of Sediment in relation to mean annual precipitation: Transactions of American Geophysical Union, v. 39, pp. 1076-1084.
5. Leopold, L.B., and Wolman, M.G.1957. Riverchannel patterns; braided, meandering and staight. U.S.Geol. Survey Prof. Paper 282-B
6. Lidstone & Associates. (2008). Geomorphic and Hydraulic Analysis of the Day Loma Area. Fort Collins, CO.
7. Lowham, H. a. (1993). Characteristics of fluvial systems in the plains and deserts of Wyoming. U.S. Geological Survey Water-Resources Investigations Report 91-4153.
8. Martin, L.J., D.L. Naftz, Lowham, and J.G. Rankl, 1988. Cumulative Potential Hydrologic Impacts of Surface Coal Mining in the Eastern Powder River Structural Basin, Northeastern Wyoming. U.S. Geological Survey Water-Resources Investigations Report 88-4046
9. Peltier, L., 1950, The Geographical cycle in periglacial regions as it is related to climatic geomorphology: Annals, Association of American Geographers, v.40, pp. 214-236.
10. Rechard, R. (1980). Suggested stream pattern restoration for the eastern Powder River Basin. Second Wyoming Mining Hydrology Symposium (pp. 214-248). Water Resources Research Institute.
11. Ritter, Dale F., Kochel, R. Craig, Miller, Jerry R., Process Geomophology
12. Schumm, S. (1956). Evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersey. Geol. Soc. America Bull. , 67:597-646.
13. U.S. Environmental Protection Agency, 1972, Guidelines for erosion and sediment control planning and implementation: Environmental Protection Series, EPA R2-72-015.
14. Wilson, L., “Morphogenetic Classification” in Encyclopedia of Geomorphology, ed. by R.W. Fairbridge, copyright 1969 Dowden, Hutchinson & Ross, Inc.

Geomorphic Reclamation in New Mexico: A Regulator's Perspective

Dave Clark

NM Mining and Minerals Division

New Mexico’s coal fields can be very dry …

…or suddenly,
very wet

Soils and overburden are often of poor quality

Natural vegetation cover can be sparse

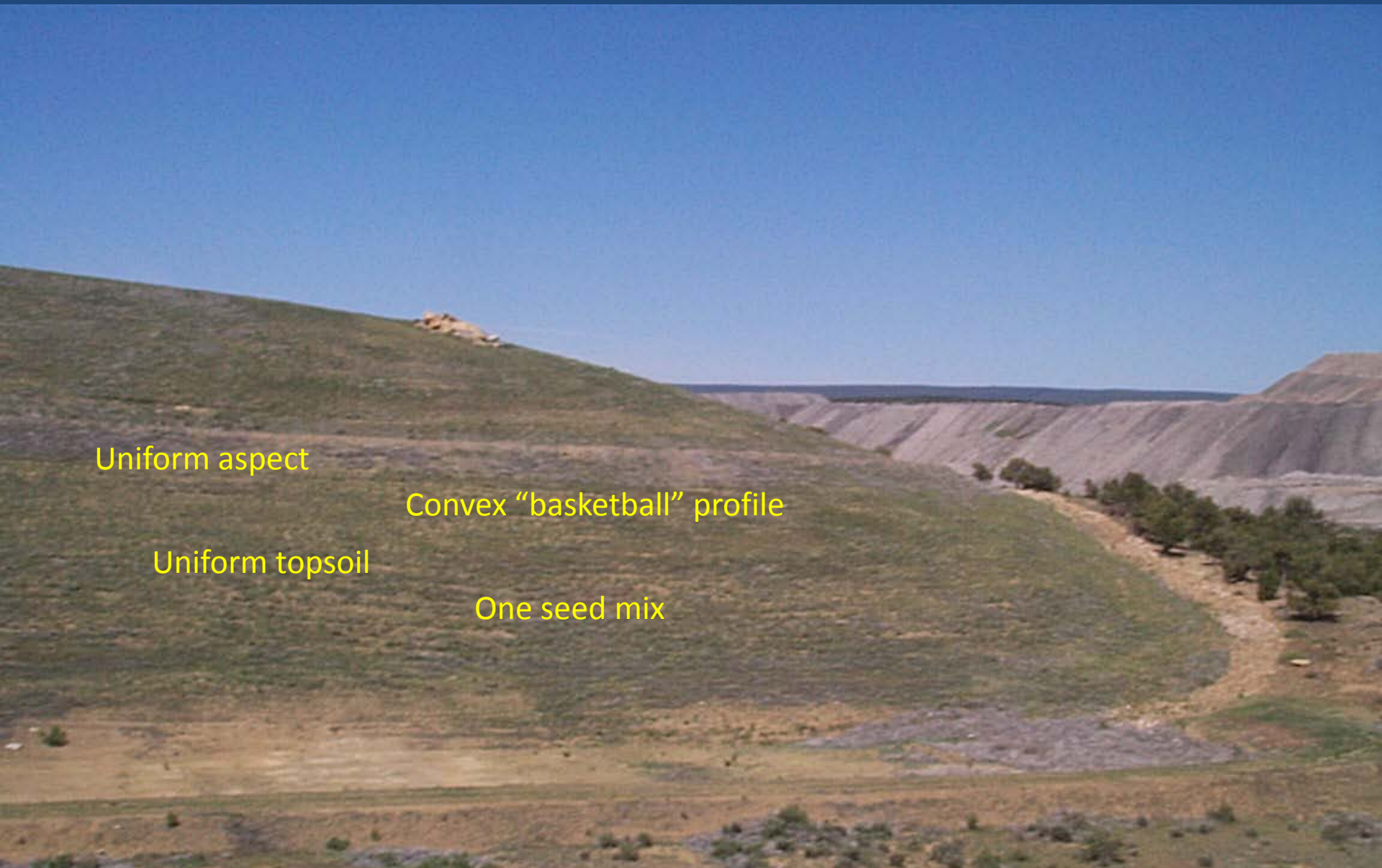
Community diversity requires substrate diversity

Conventional steep slope construction is typified by low gradient terraces that convey runoff across a slope to a rock-armored drop structure that has been designed to pass a specific event. On coal mines, this is typically the local 10-year / 24-hour precipitation event.

Storms that are smaller or larger than the design event cause problems, either by sediment deposition or erosion.

Differential settling may also be a problem.

Traditional slope design, with a gradient terrace, a rock down drain, and a boulder pile



Geomorphic Grading Goals

- Provide long-term drainage stabilization
- Meet runoff water quality criteria
- Reduce long-term maintenance
- Provide topographic diversity to enhance vegetation community development and wildlife habitat
- Promote timely liability bond release

Challenges

- Spoil suitability and mitigation
- Topsoil lay-down and seeding; extremely difficult in rough terrain
- Implement the new 434 NPDES regulation
- Tie in with natural drainages and previous reclamation—need an extremely good survey
- Dozer intensive; overly large mining equipment
- Enhanced operator skills; better communication and feedback; Machine Control
- Rock placement in channels and on slopes; if poorly done can create problems
- Management acceptance
- Regulatory acceptance

McDermott Dump 52-ac “proving ground”

- Geomorphic drainages
- Scallop slope
- Talus slope
- Rock rims
- Suitable spoil
- Rock mulch
- Multiple seed mixtures
- Wildlife pond

Best quality San Juan Mine revegetation prior to geomorphic grading

Failed stands may not have much more than annual wheatgrass cover

Topsoil re-spread underway at Cottonwood Pit

Cottonwood Pit end wall regrade

Highwall reclamation prior to seeding

Highwall reduction in 2008

Irrigating for seedling establishment

Reclaimed drainage channels and tie-in with older reclamation at SJM

Tie-in to a native arroyo

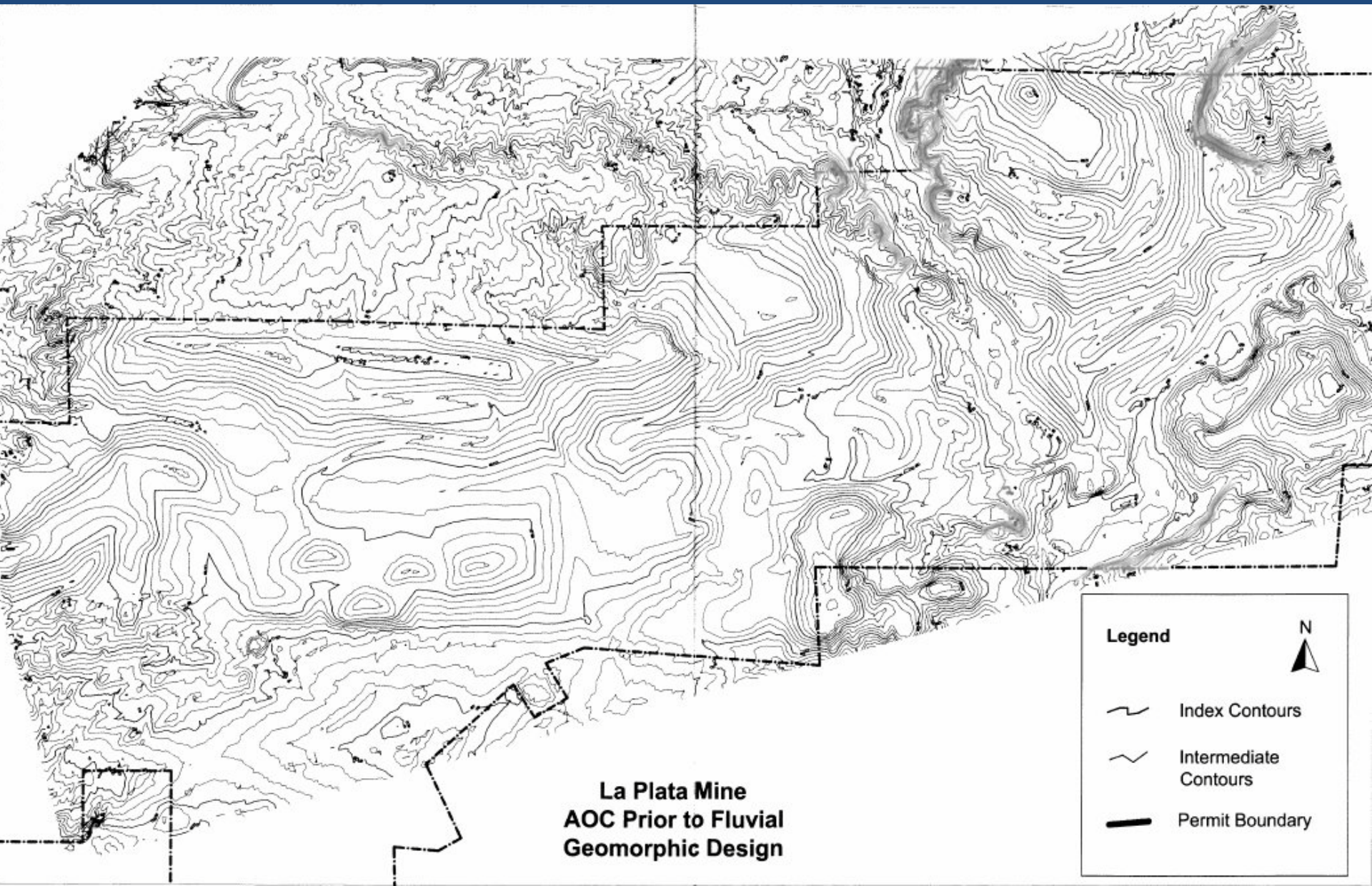
Close up of transition from reclaim to native

Two years after seeding Cottonwood Pit reclamation

Looking west over La Plata Mine in 2001

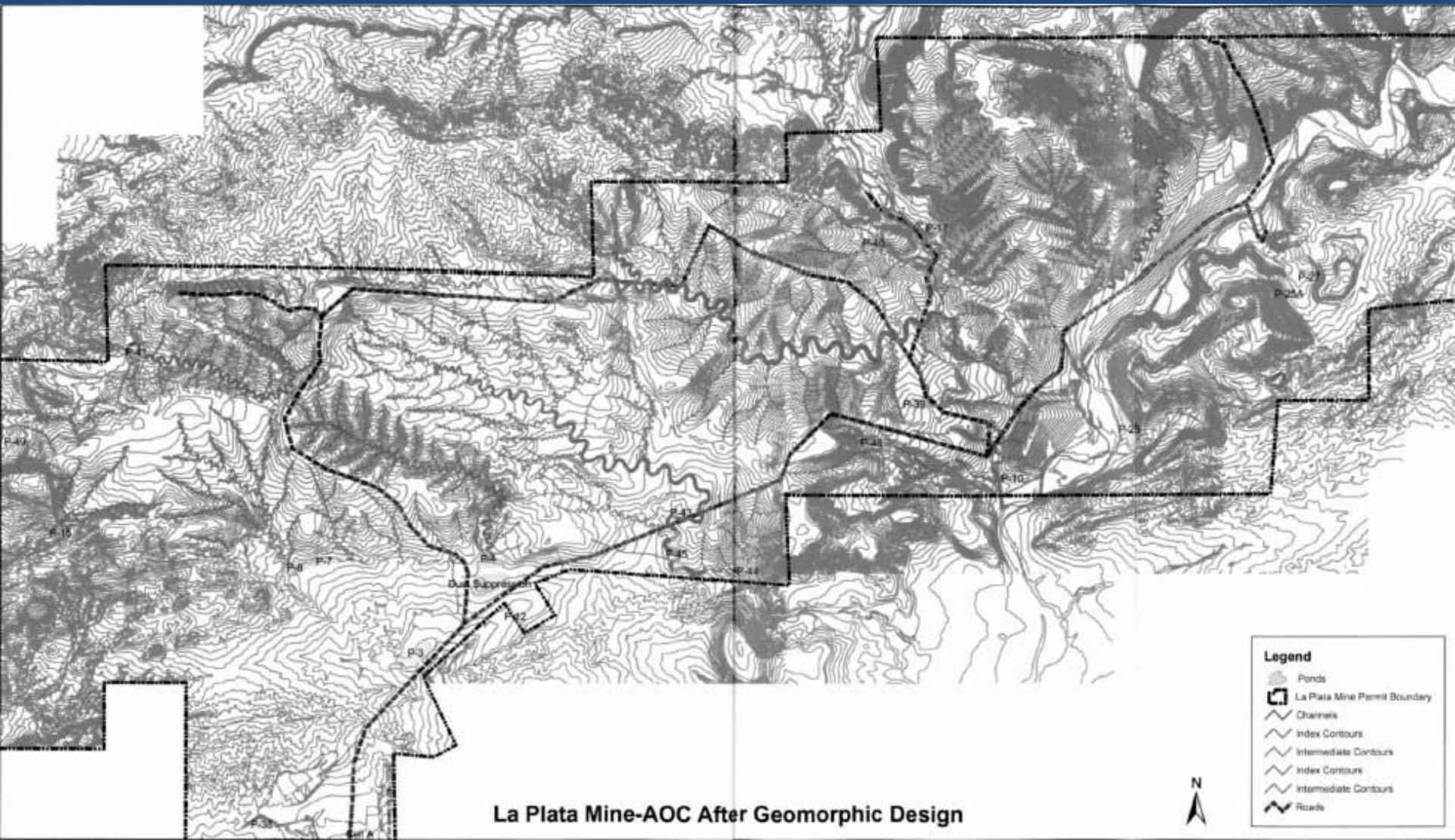
LPM pre-disturbance type topography with cuestas

LPM regrade plan prior to geomorphic design



York Canyon Mine, 1996 reclamation

LPM regrade plan after Natural Regrade was used



La Plata Mine, 2006 reclamation

Artificial outcrops

MMD inspection after a 200-yr/2-hr storm

Wildlife trail down to a permanent pond

Clarity of water in that pond

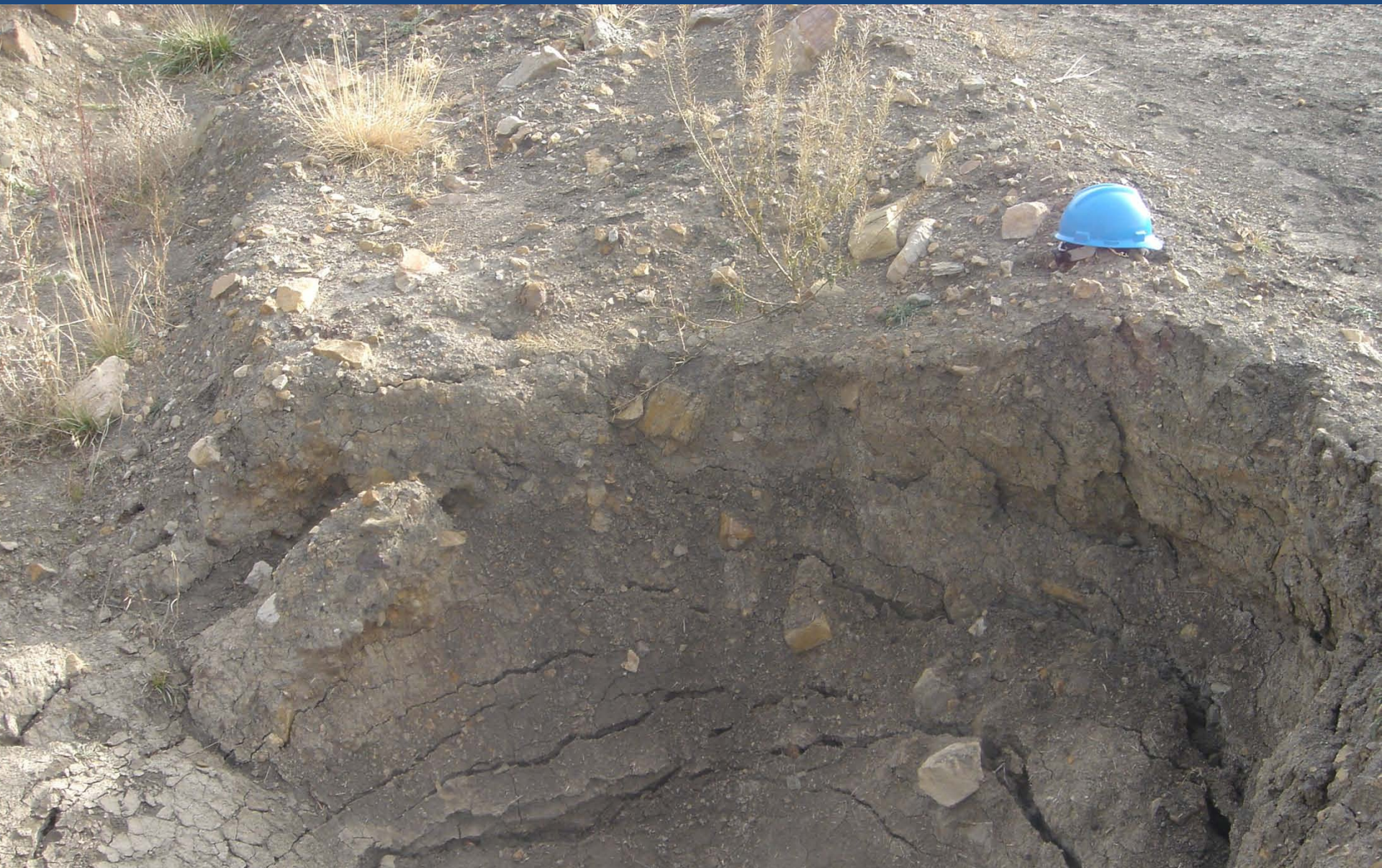
Wildlife watering hole within a permanent pond

McKinley Mine
Subsidence piping features on terraced reclamation

Piping hole

Differential settling on a terrace

Major feature requiring costly repair and creating liability concerns



Area 9 terrace, over-steepened cut slope

Erosion, flow blockage, differential settling, breach

Recently removed terraces

Cattle on a removed terrace

Complex topography, Pit 10 highwall reclamation

Ridges built by dumping excess spoil in windrows

Area 10 pit approaching final grade

Drainage channel constructed in a pit ramp

Swales and soil substitute material on slopes

Revegetation becoming established on Area 11 pit reclamation

2004 National Award recipients

2008 NM EMNRD
Excellence in Reclamation Award recipients

Questions?

Photo by Mickey Ginn, SJCC

Geomorphic Reclamation at BHP Billiton's New Mexico Coal - Successes, Challenges & Future

Daphne Place
Environmental Engineer, Navajo Mine Extension Project
April 29, 2009

bhpbilliton
resourcing the future

New Mexico Coal

Pride in our Heritage, *energizing* the future

Nearly half a century ago, the Navajo Mine, and later San Juan and La Plata mines, were constructed to supply energy to a growing and developing population in the Southwest. Three generations of our coal miners have since created value for our workforce, our shareholders, our customers, and to the community in which we operate.

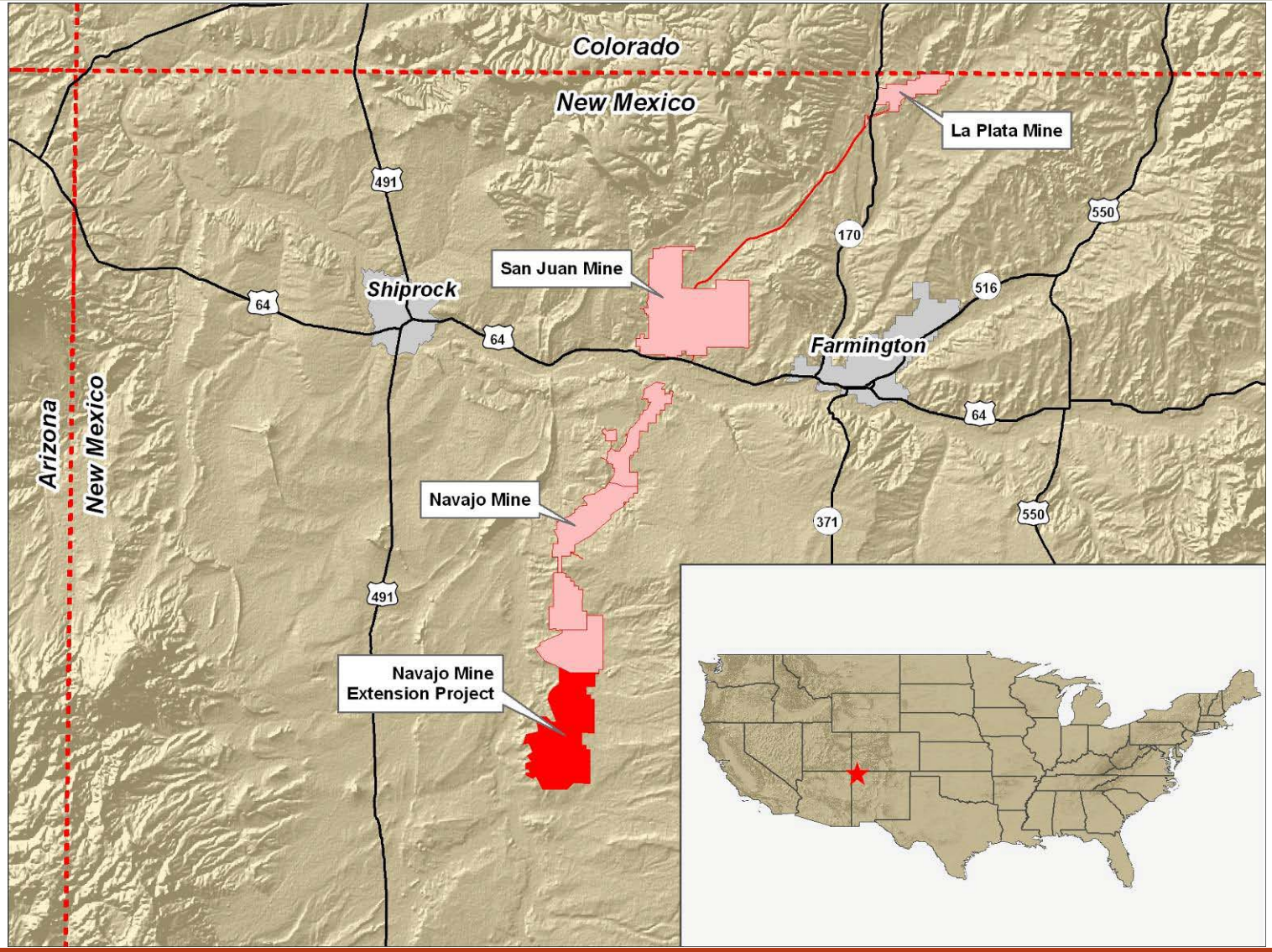
We have Pride in our Heritage

We have an overriding commitment to health, safety, the environment and the community. We strive for Zero Harm.

We supply a vital fuel source to meet the energy needs of millions of homes and workplaces in the Southwest of the United States. Our wages, royalties, taxes, donations, and the things that we buy personally and for our business creates wealth for the community in which we live.

We are *energizing* the future.

Regional Location of New Mexico Coal Operations



Regional Topography

Photographs showing undisturbed natural topography adjacent to the mine sites.

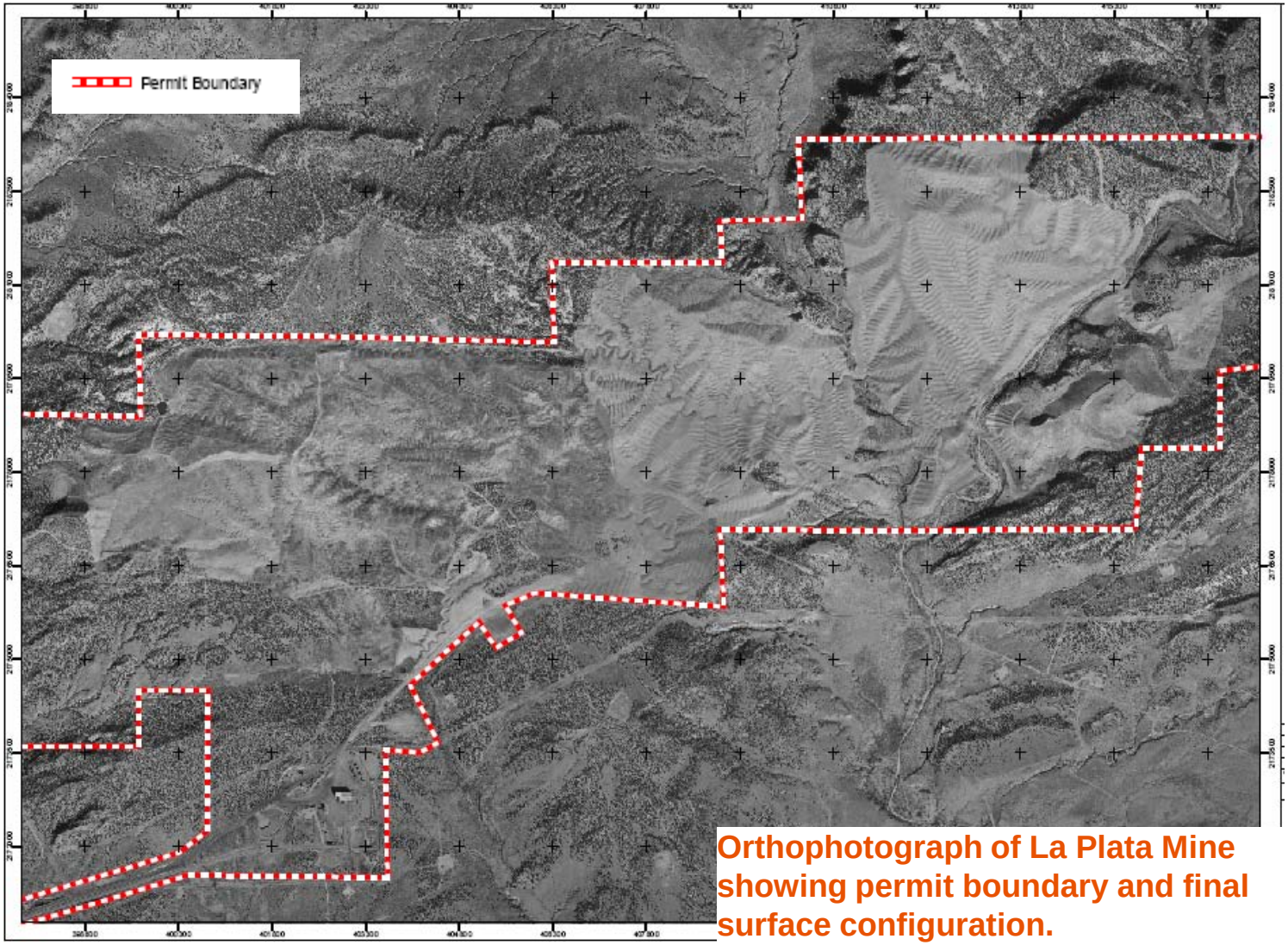
Photographs by EQ Dept. Personnel Unless otherwise noted

SJCC - La Plata Mine

Operational Details

- Operations began in 1986
- Truck/shovel operations
- Reclamation activities completed Spring 2009
- Over 1,650 acres reclaimed
  - 1,400 acres reclaimed using fluvial geomorphic approach

SJCC - La Plata Mine



Orthophotograph of La Plata Mine showing permit boundary and final surface configuration.

SJCC - La Plata Mine

Buckeye and Elk Point (Panel 5 Highwall)

- Deepest final pit at LPM

Photographs showing final pit (upper right) and final construction (lower left).

Arrow indicates the same landmark pinion/juniper area.

SJCC - La Plata Mine

Younger Bluffs

- Final highwall area
  - Adjacent to natural sandstone outcrop

Photographs showing final pit (upper right) and final construction (lower left).

Arrow indicates the same landmark notch area.

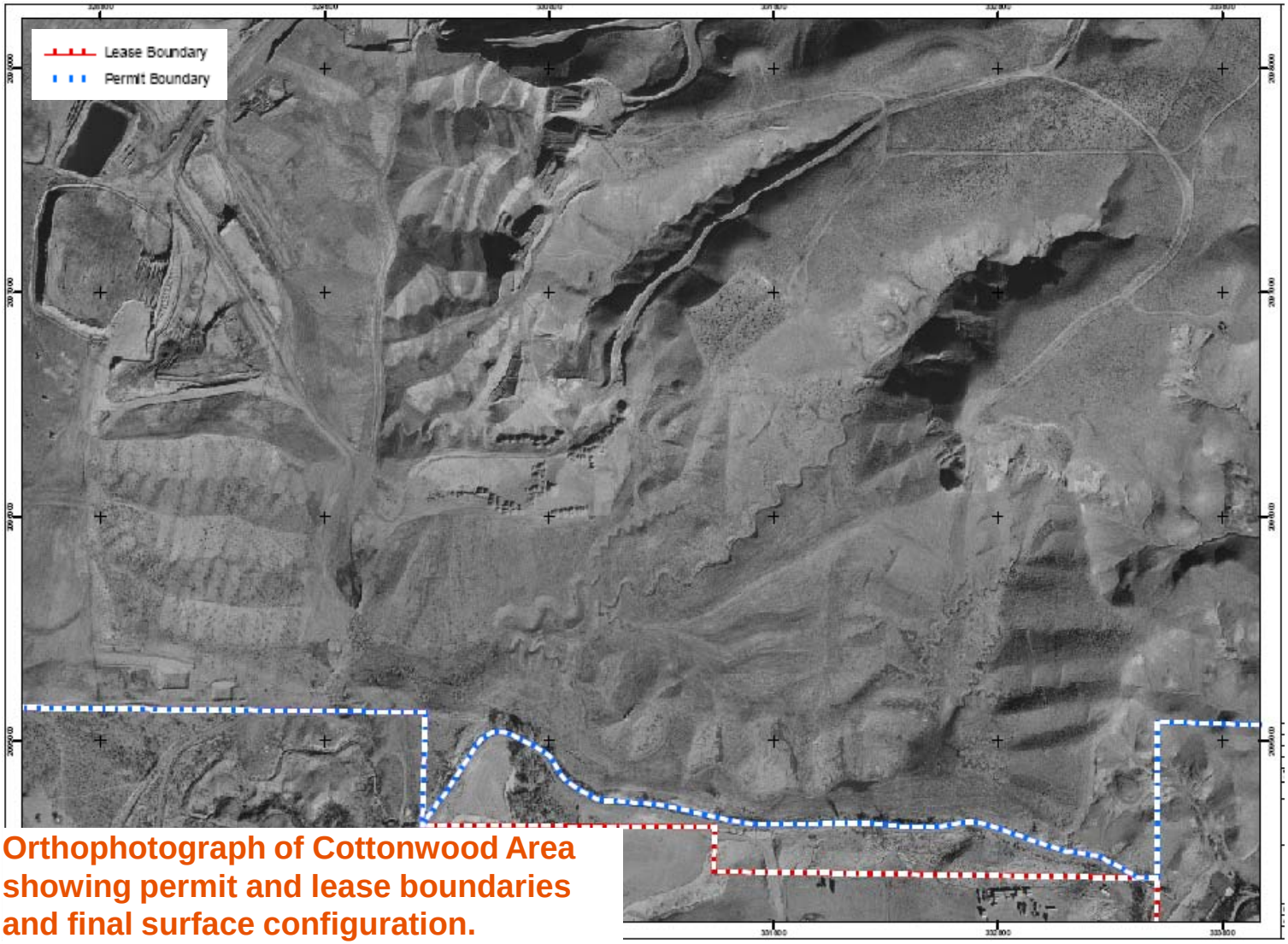
SJCC – San Juan Mine

Operational Details

- Mining began 1974
  - Surface dragline operation
- Transitioned to underground operation in 2002
- Reclamation activities ongoing
- Approximately 2,700 acres reclaimed
  - 400 acres reclaimed using fluvial geomorphic approach

Photographs of San Juan underground mine portal area (lower left) and plant and stack out area (upper right).

SJCC – San Juan Mine



Orthophotograph of Cottonwood Area showing permit and lease boundaries and final surface configuration.

SJCC – San Juan Mine

Cottonwood Mining Area – During mining

Photograph of Cottonwood Area during mining operations.

Arrow shows landmark reference.

SJCC – San Juan Mine

Cottonwood Mining Area – During Landform Construction

Photograph of Cottonwood Area during landform construction.

Arrow shows landmark reference.

SJCC – San Juan Mine

North Pinon Mining Area

Photographs showing final construction (lower left) and after topdressing and seeding (upper right).

Arrow indicates the same channel meander.

BNCC – Navajo Mine

Operational Details

- Multi-dragline surface mine
- Located entirely on the Navajo Reservation
- Mining began in 1963
- Produces 8.5M tons of coal annually
- Reclaimed 7,600 acres to date
  - 44 acres using fluvial geomorphic approach

Photograph by Ken Logan, Mine Engineer

BNCC – Navajo Mine

Barber Ramp 3 Project

- Haulage ramp to final dragline pit (44 ac.)
- Goals of project
  - Apply fluvial geomorphic approach
  - Optimize material handling
- Total construction time was 22 days over a span of 2 months
- To be seeded spring 2009

Photograph by Cary Cooper, Mine Engineer

BNCC – Navajo Mine

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Channel Construction

- A-channels keyed into regrade
- A-channel excavation to build ridges

Photographs showing construction process. Dozer used to key in channels to build ridges (upper right) and smoothing out channel and sub-ridge (lower left).

Photographs by Cary Cooper, Mine Engineer

Navajo Mine Slides

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Topdressing Activities

- Scrapers delivered topdressing
- Dozers spread topdressing
- Seeding and mulching this spring

Photographs showing final construction after topdress lay-down.

Photographs by Cary Cooper, Mine Engineer

BNCC – Navajo Mine Extension Project

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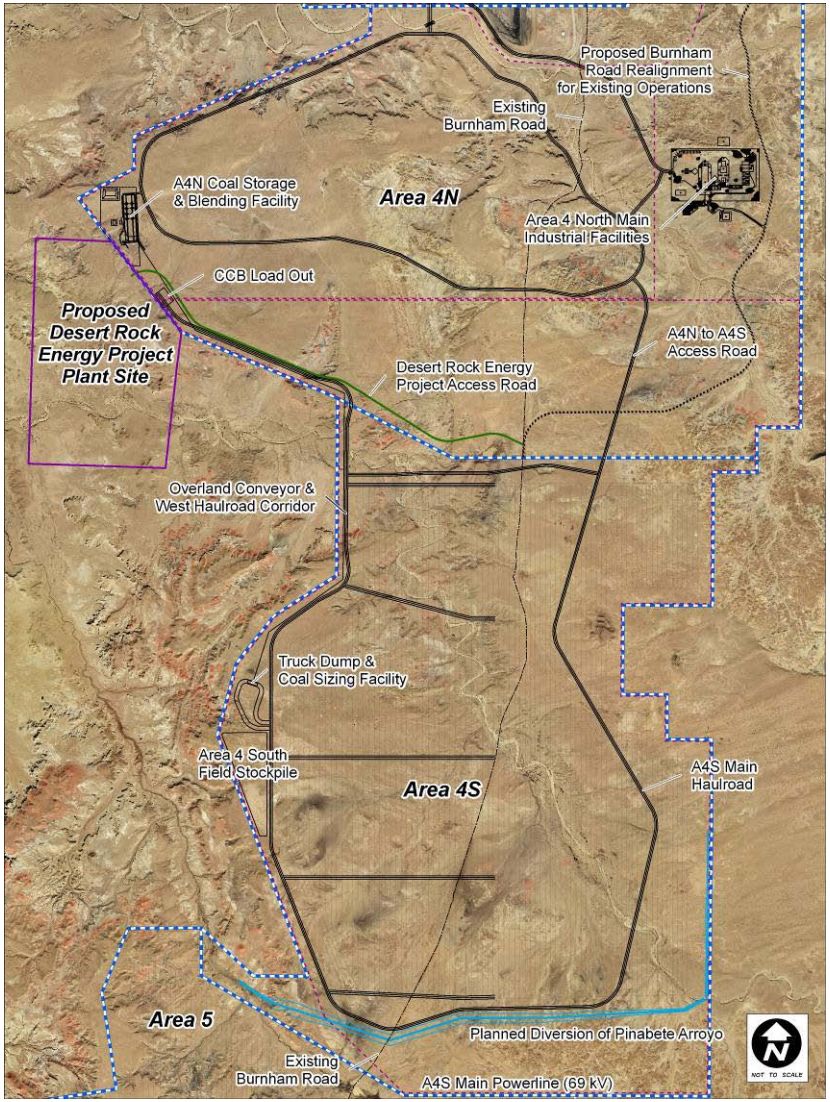
Operational Details

- Proposed surface operation
  - 50 year mine life
  - Multi-dragline operation
  - 13,000 acre permit area
  - SMCRA permit to be completed in 2009



BNCC – Navajo Mine Extension Project

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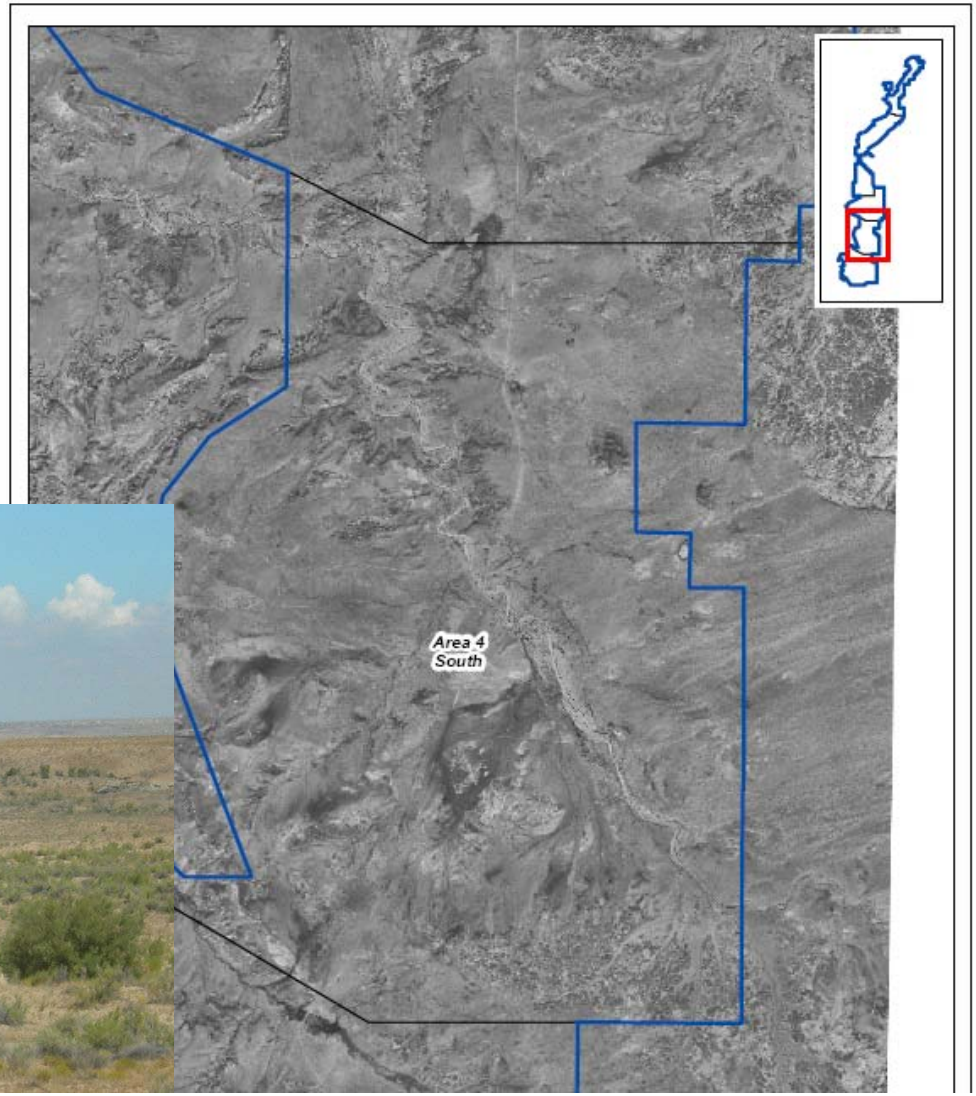
Area 4 South

- Relatively flat terrain
- Area divided by Pinabete Arroyo
  - 44 square mile upstream watershed
  - Temporarily diverted during mining
- Arroyo to be reconstructed for watershed
- Used fluvial geomorphic approach



BNCC – Navajo Mine Extension Project

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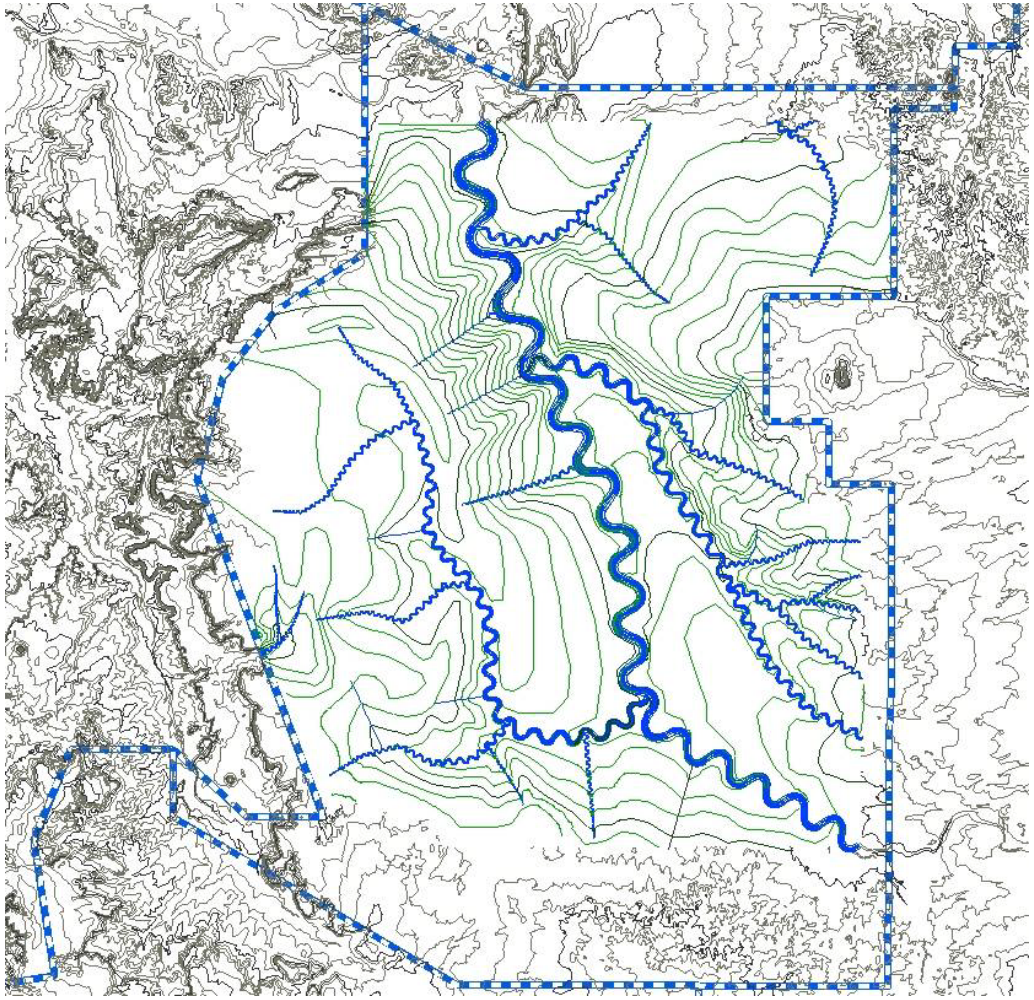
Fluvial Geomorphic Setting

- Wide flat sandy arroyo
- Smaller areas of steeper topography with A-channels
- Bedrock control in channels

BNCC – Navajo Mine Extension Project

Conceptual AOC for Area 4 South

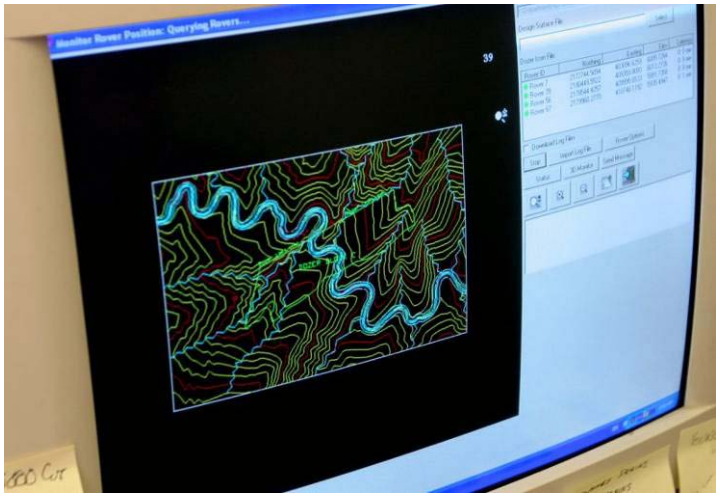
- Goals of AOC
  - Create a stable landform supporting vegetation that is compatible, diverse, effective and permanent
  - Incorporate applicable fluvial geomorphic reclamation principles
  - Meet material handling goals
  - Provide for stable and permanent placement of CCBs
  - Compatible with contemporaneous construction requirements
- Milestones of AOC
  - First fully integrated fluvial geomorphic reclamation design
  - Reconstruction of major arroyo

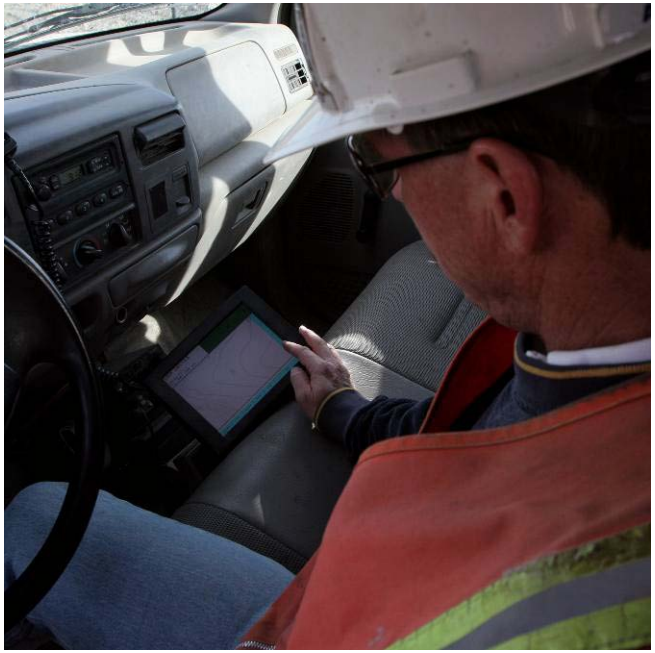


General Reclamation Photos

Landform Construction Activities

- Engineer designs can be communicated:
  - To the dozer fleet
  - To the shift foreman
- Foreman and dozer can track progress





General Reclamation Photos

Landform Construction Activities

- Primary grading
  - Truck/shovel or truck/loader
  - Dragline
- Final grading and drainage construction by dozer

Photographs showing benches cut into spoil before primary regrade (upper right) and dozer using stakes as reference to construct channels (lower left) at LPM.

General Reclamation Photos

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Topdressing Activities

- Delivered by truck or scraper
- Spread by dozer

General Reclamation Photos

Seeding and Mulching Activities

- Seed bed may be prepared by deep chiseling
- Seed is broadcast or drilled
- Mulch is then spread and crimped

General Reclamation Photos

Irrigation Treatments

- San Juan Mine and Navajo Mine provide irrigation treatments
  - Germination
  - Support cycle
  - Second growing year

Photographs showing irrigation treatments: SJM Cottonwood Area with irrigation network on steeper slopes (upper right) and Navajo Mine with irrigation network on flatter slopes after initial treatments.

2004 U.S. Department of Interior National Reclamation Awards

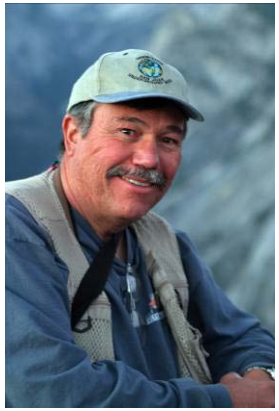
2004 Excellence in Surface Coal Mining & Reclamation National Award

L to R: Collette Brown (EQ/SJCC)
Tim Ramsey (EQ/SJCC)
Gary Lansdale (Manger/SJCC)
Steve Funk (Production/SJM)
Larry Tsosie (Operator/SJM)
Jim Luther (EQ/SJCC)

2004 The Best of the Best Award

Acknowledgements

Left to right: Cary Cooper, Mining Engineer, Navajo Mine;
Daphne Place, Environmental Engineer, Navajo Mine Extension Project; &
Collette Brown, Environmental Specialist, Navajo Mine Extension Project
(Co-authors)



Mickey Ginn
Sr. Environmental Specialist,
San Juan Coal Company
(Contributor)

Left to right: Jeremy Niemeier, Environmental Specialist;
Trevor Harvey, Environmental Specialist; &
Steven Perkins PhD, Environmental Specialist
New Mexico Operations Environmental Quality Department
(Contributors)

Matt Owens
Environmental Specialist,
Navajo Mine Extension Project
(Contributor)

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