# Application of Geomorphic Principles for Surface Coal Mine Reclamation in Wyoming

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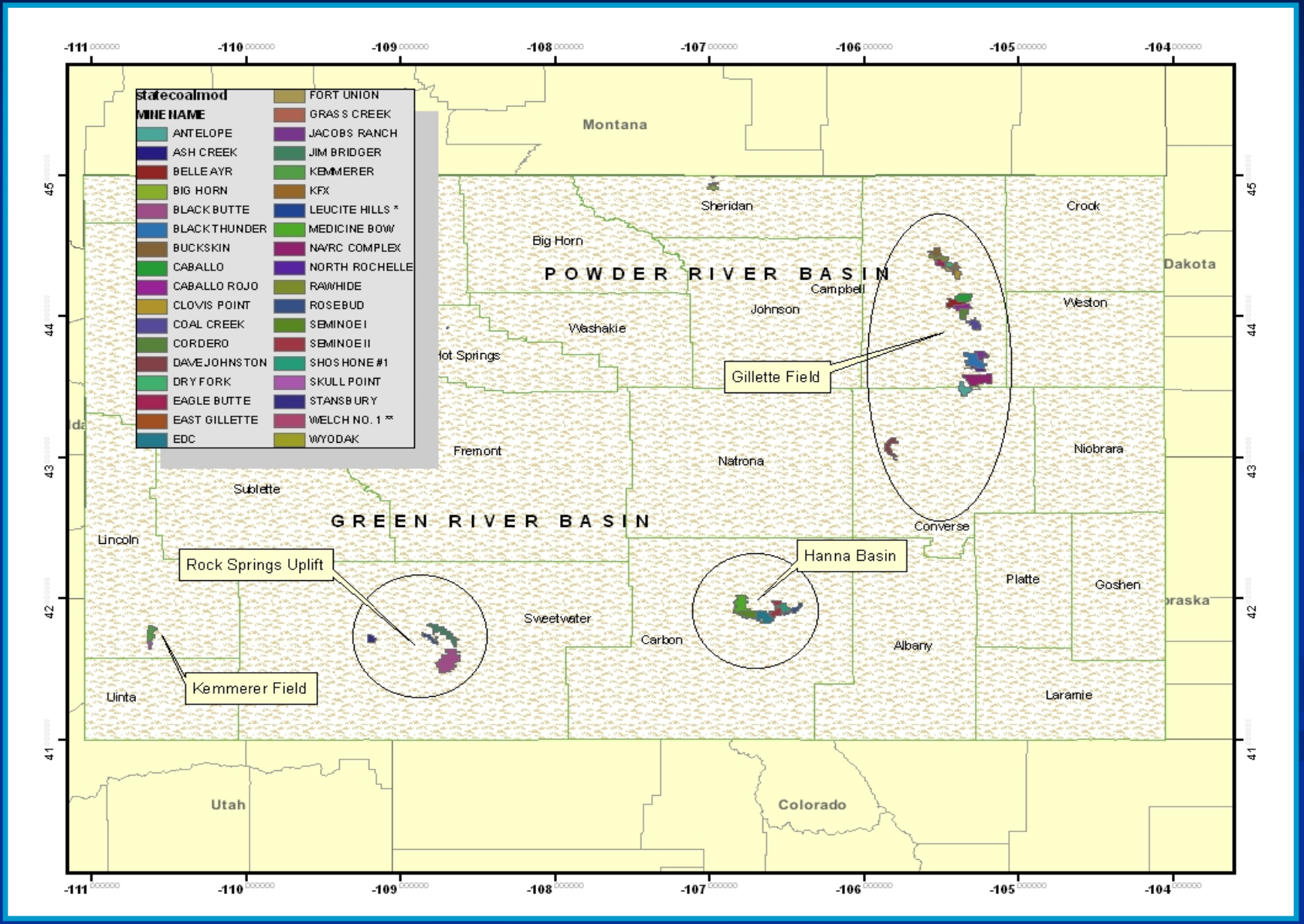
# Agenda

- Orientation and Background
  - Location
  - Climate
  - Geology
- Methods
  - Inventory and recreate
  - Empirical relationships and regression studies

# Wyoming Coal Mines



# Geology & Soils

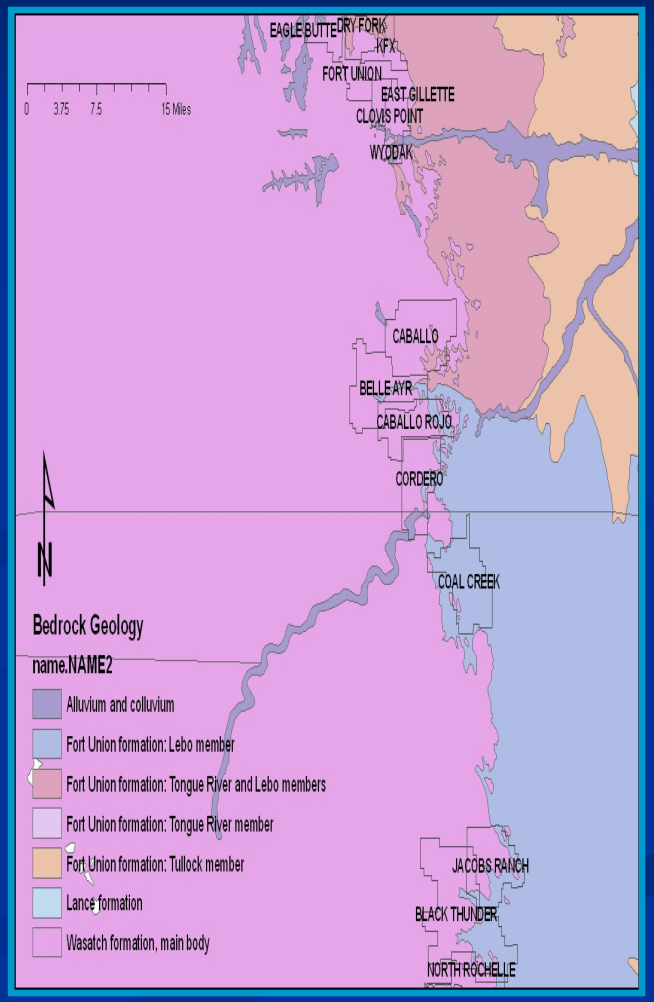
Late Tertiary sedimentary
- Wasatch Formation
- Fort Union Formation

Cretaceous sedimentary
- Lance Formation

Sandstones, siltstones and shale

Residuum and alluvium from parent material

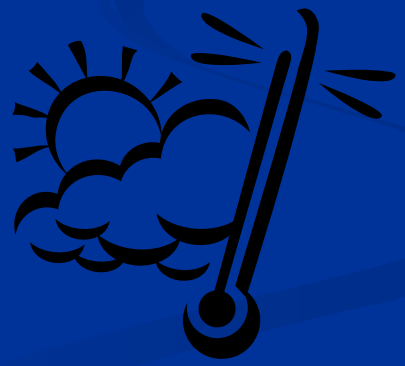
Poorly developed soils
- Hapalargids
- Camborthids
- Torriorthents (slopes)

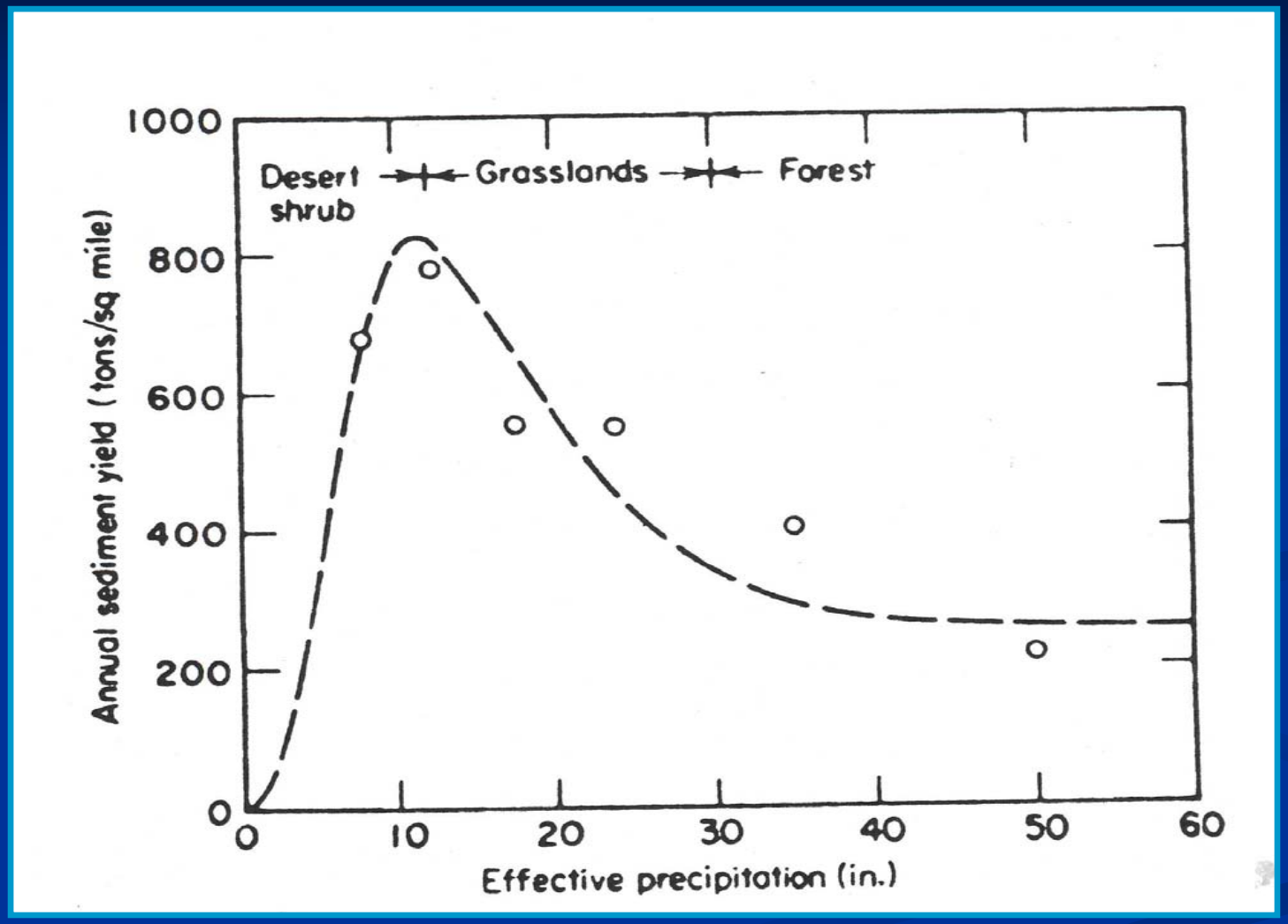


# Climate

- Landform Variability
- Chemical and Mechanical weathering
- Organic development and associated acids
- Frost action and fracturing

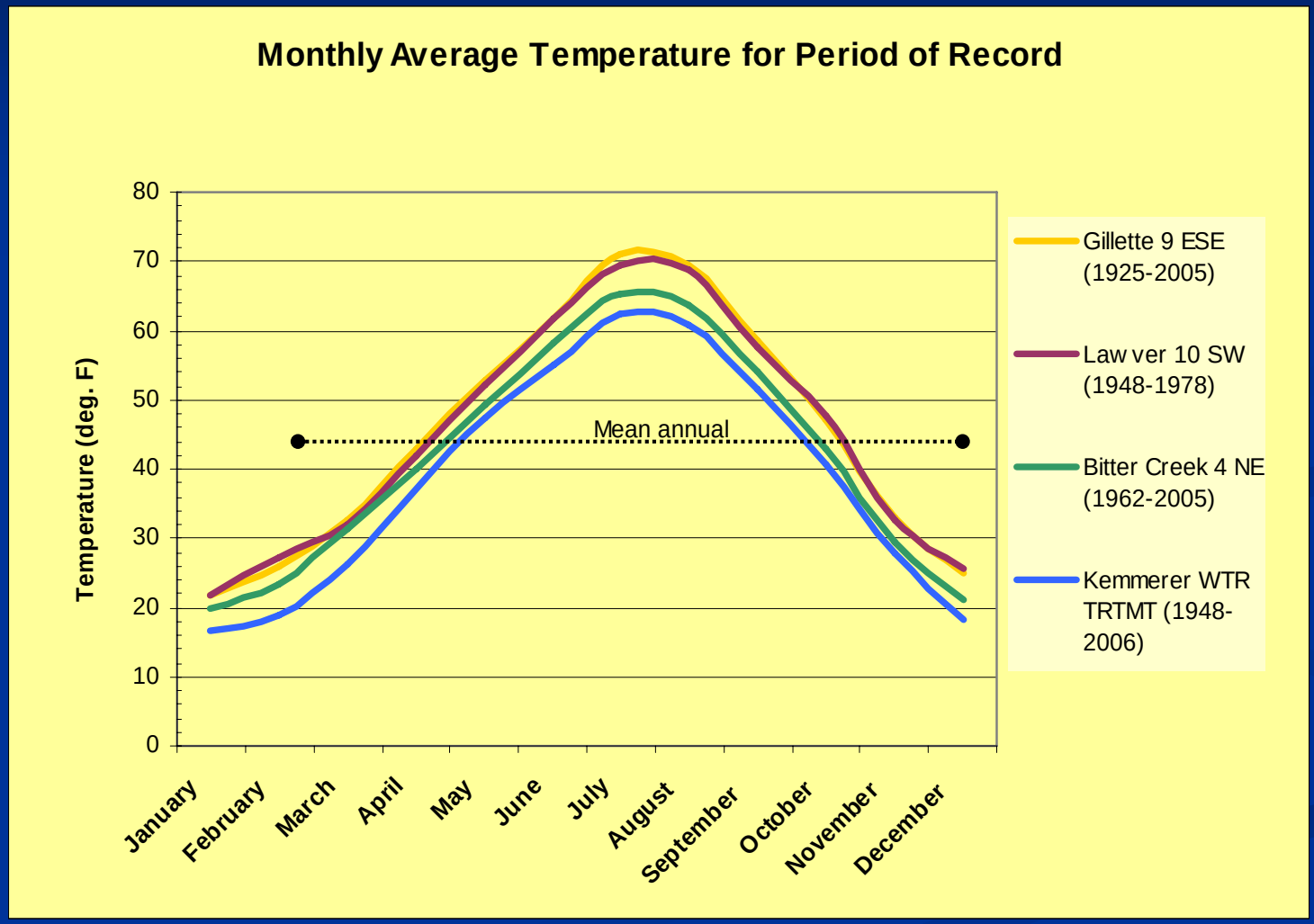
(Peltier, 1950)



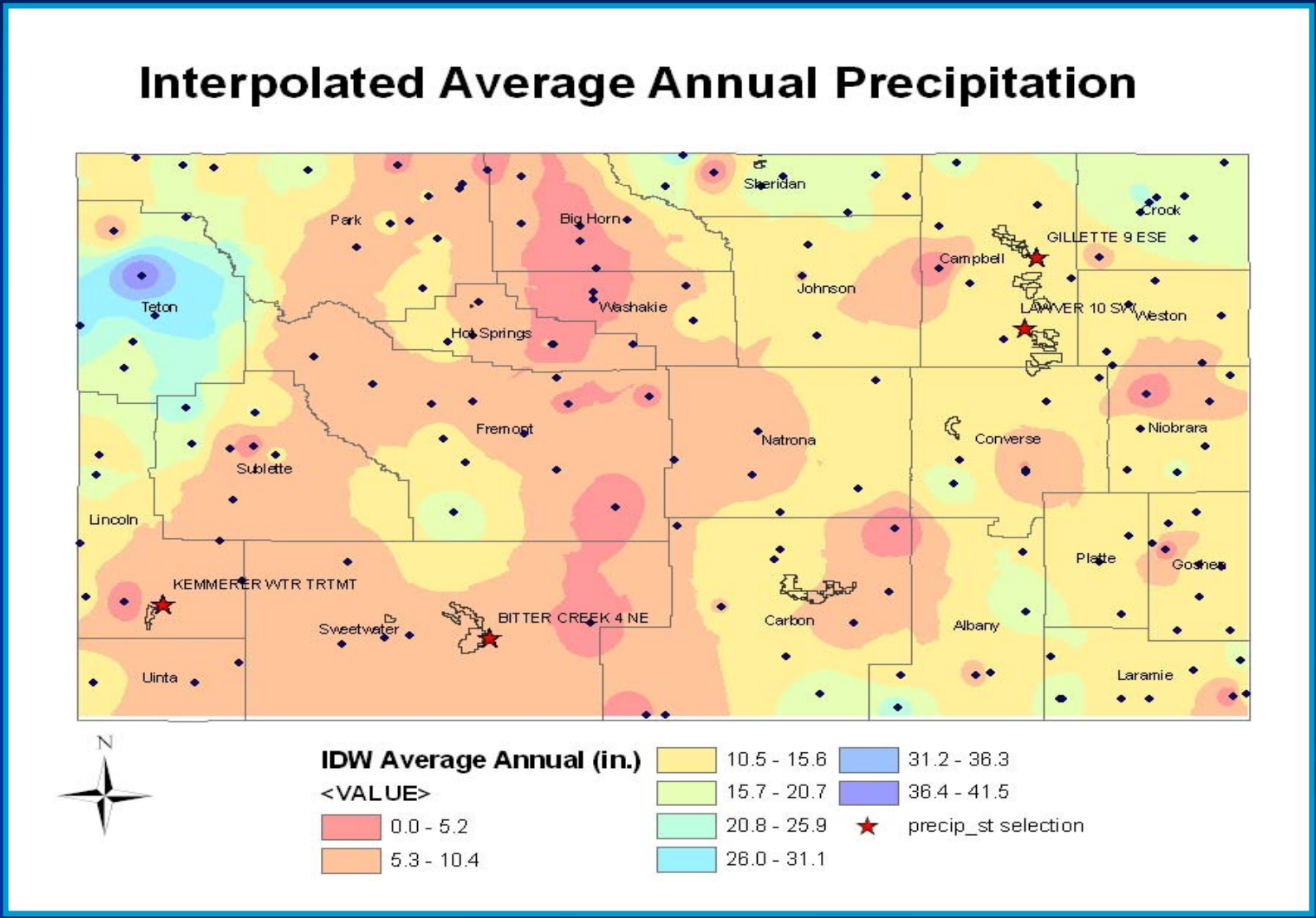



Variation of sediment yield with climate as based on data in the United States (Langbien and Schumm, 1958)

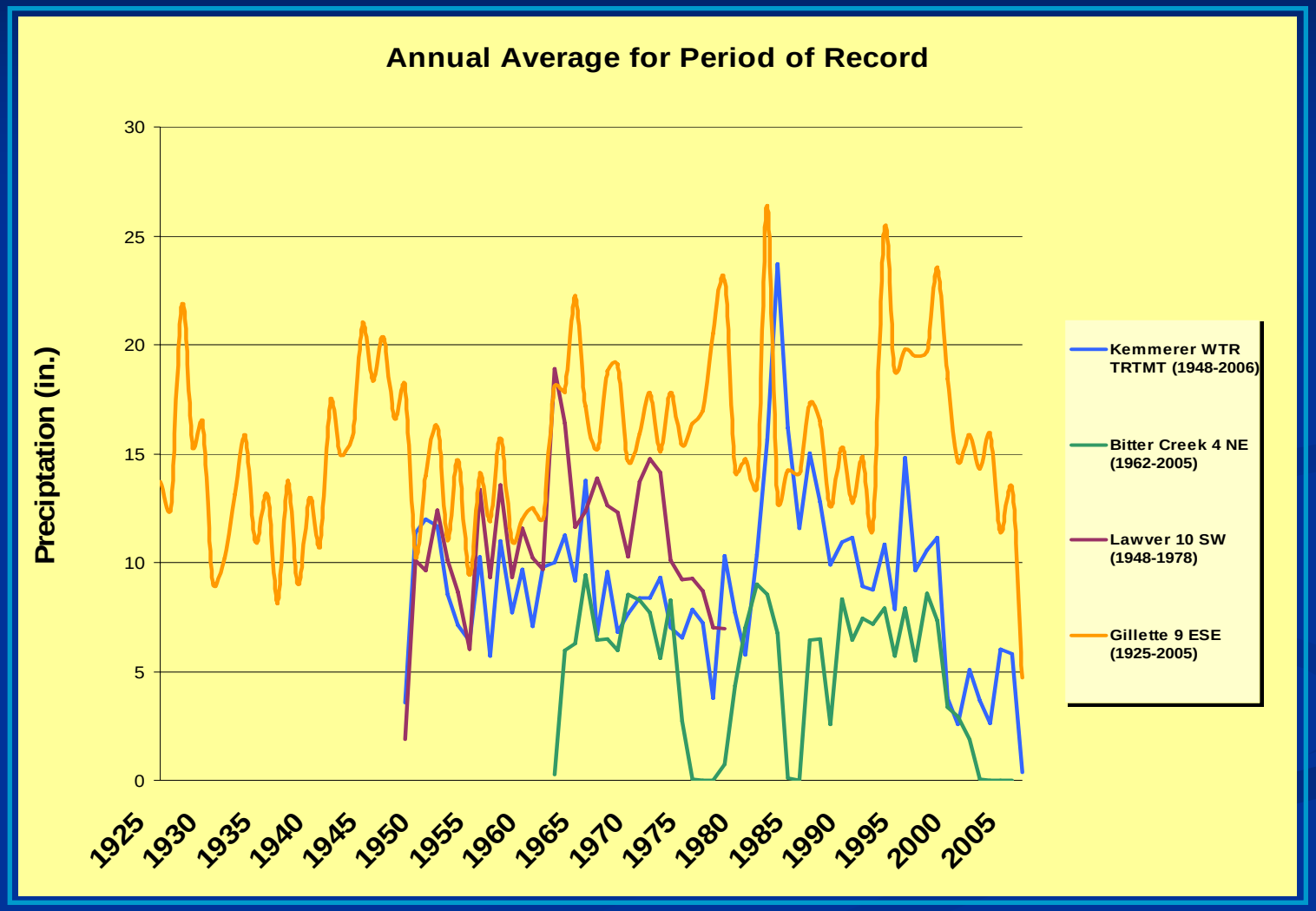
# Temperature



# Precipitation



# Precipitation (cont.)



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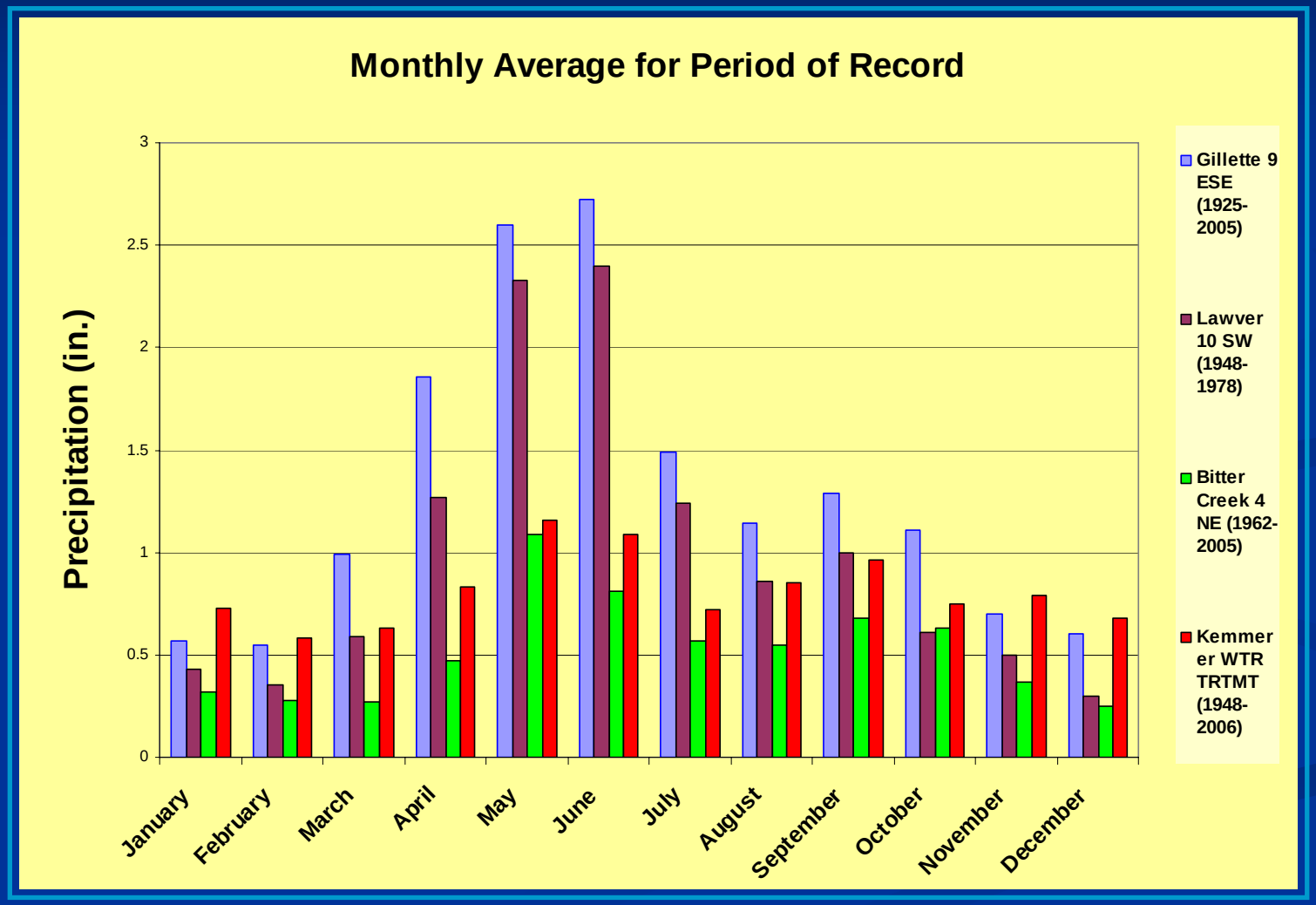


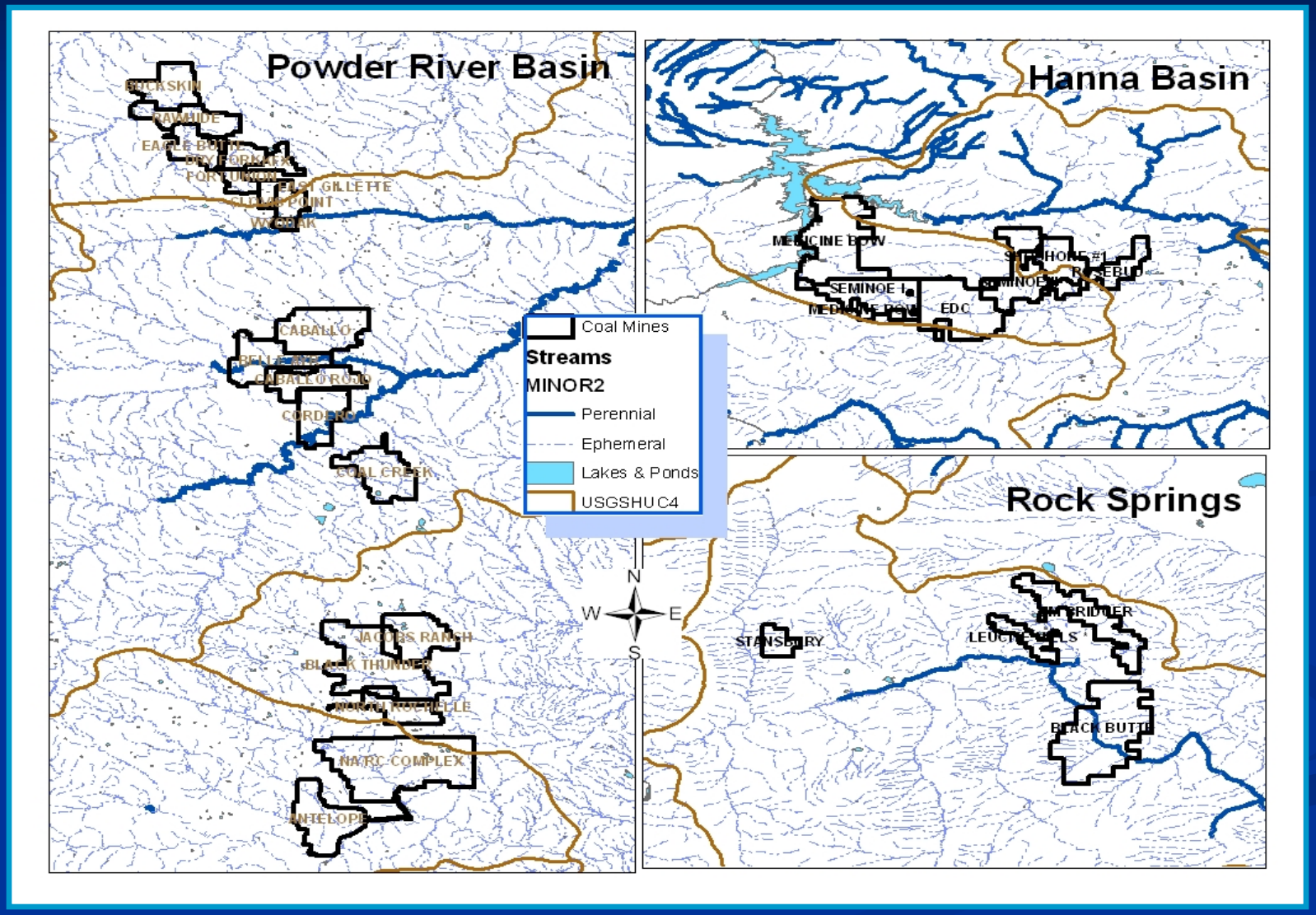
# Climate

Semiarid

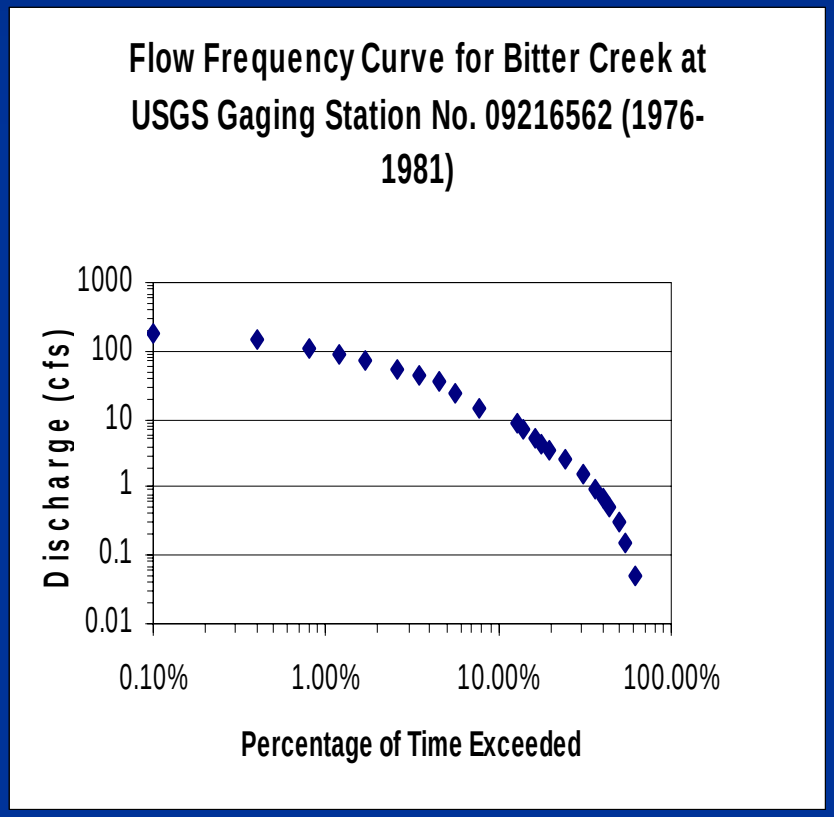
- Dominant Geomorphic Processes
  - Running water
  - Weathering (especially mechanical)
  - Rapid mass movements
- Landscape characteristics
  - Pediments
  - fans
  - Angular slopes with coarse debris
  - badlands

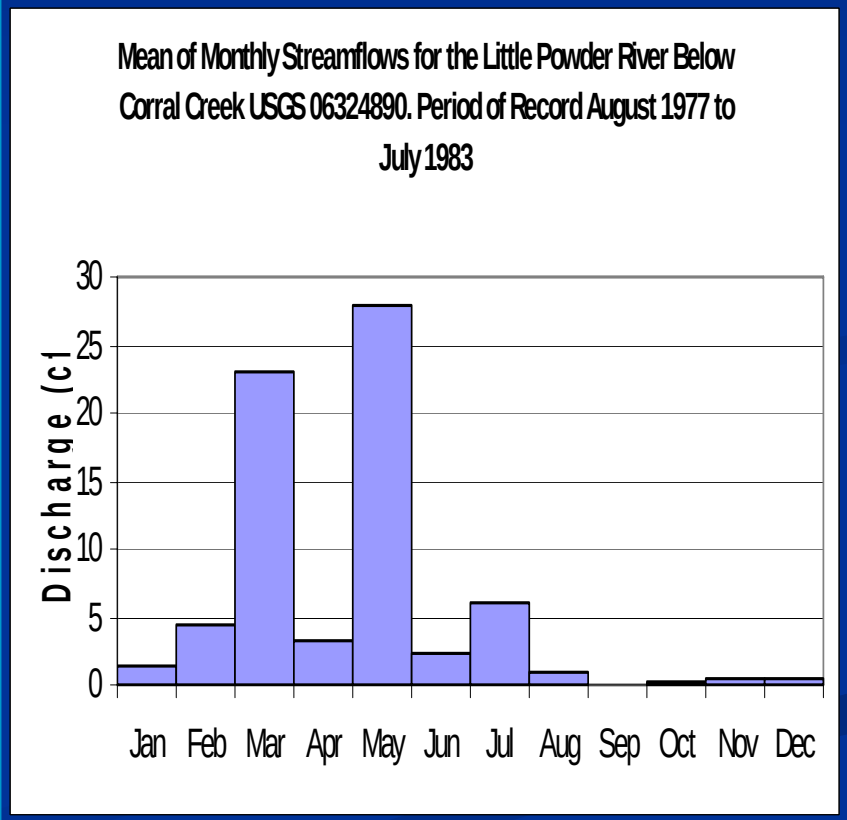
(Wilson, 1968)

# Surface Water Systems



# Surface Water Systems

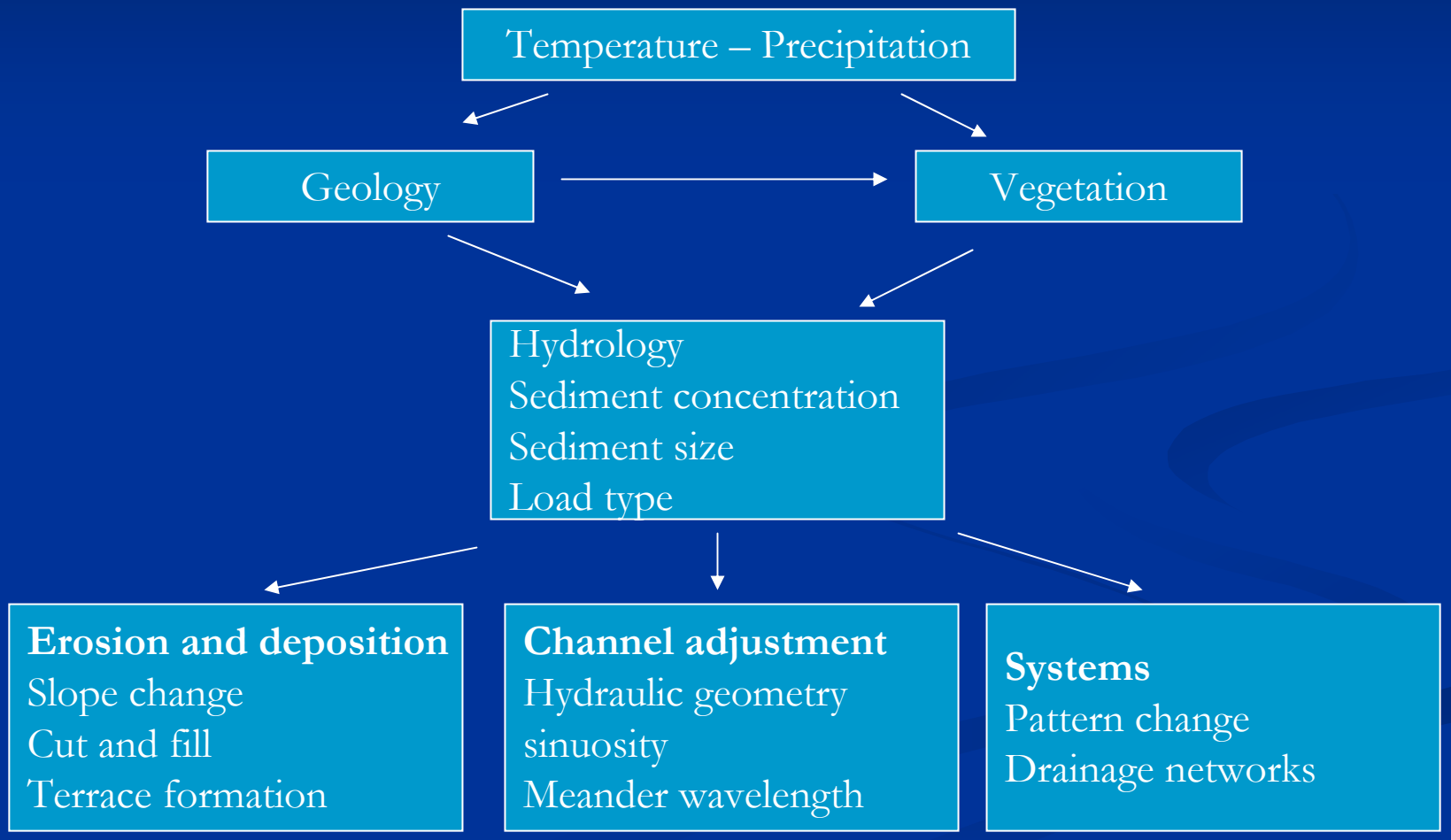


# Process Geomorphology

- 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)

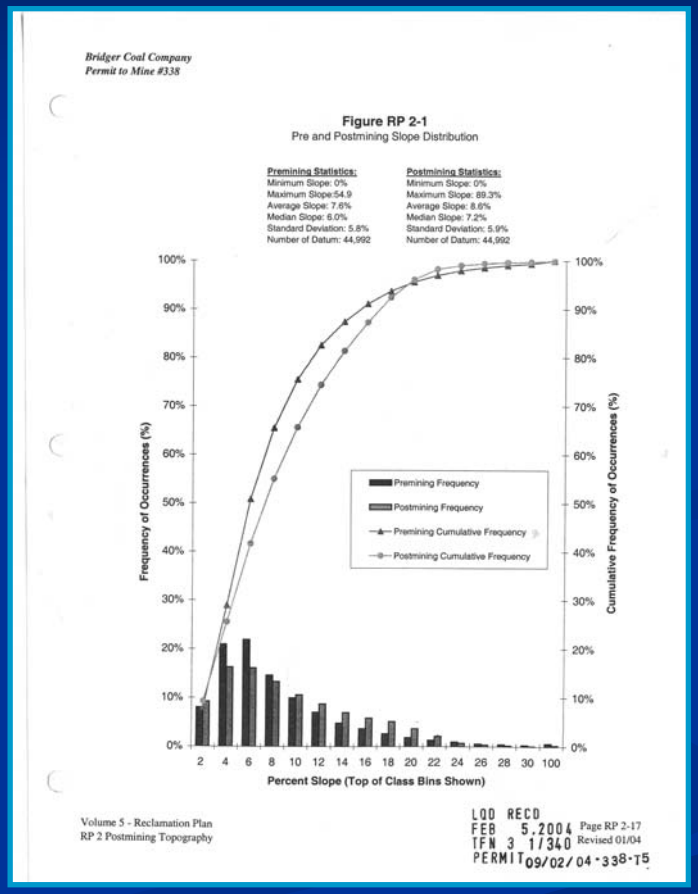
# Describing Landforms

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

# 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

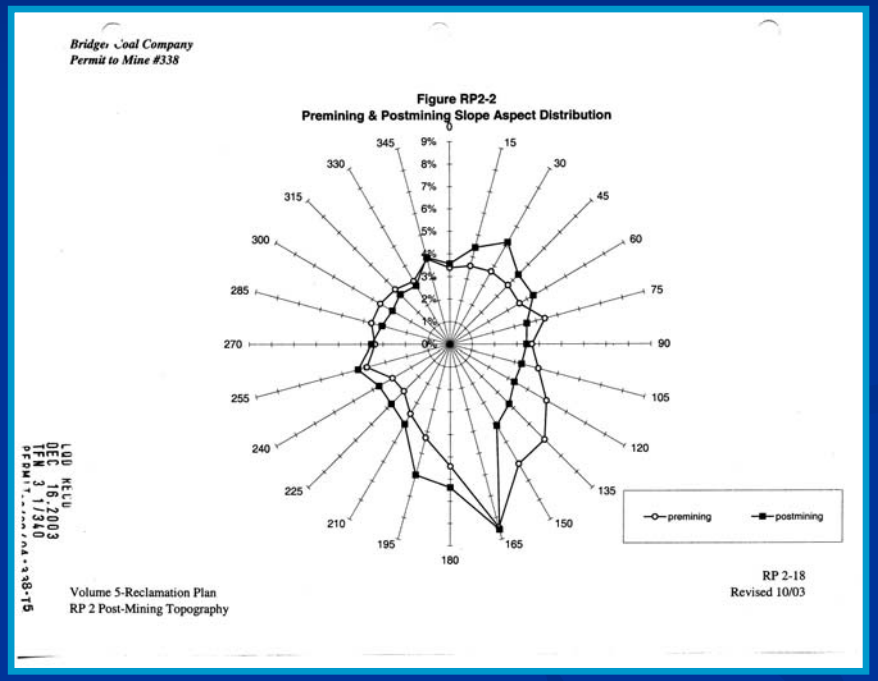



Slope distribution from Bridger Coal Mine Permit #338, 2006

# 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)

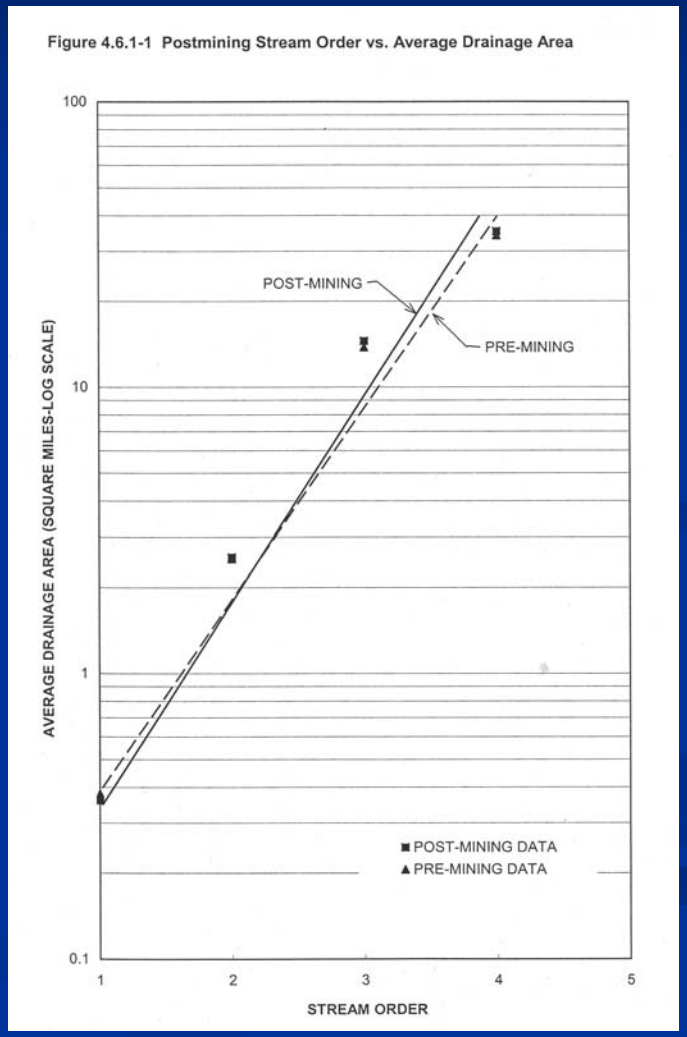
# Drainage Basin Morphometry

- 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.)

**Areal Relationships**

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

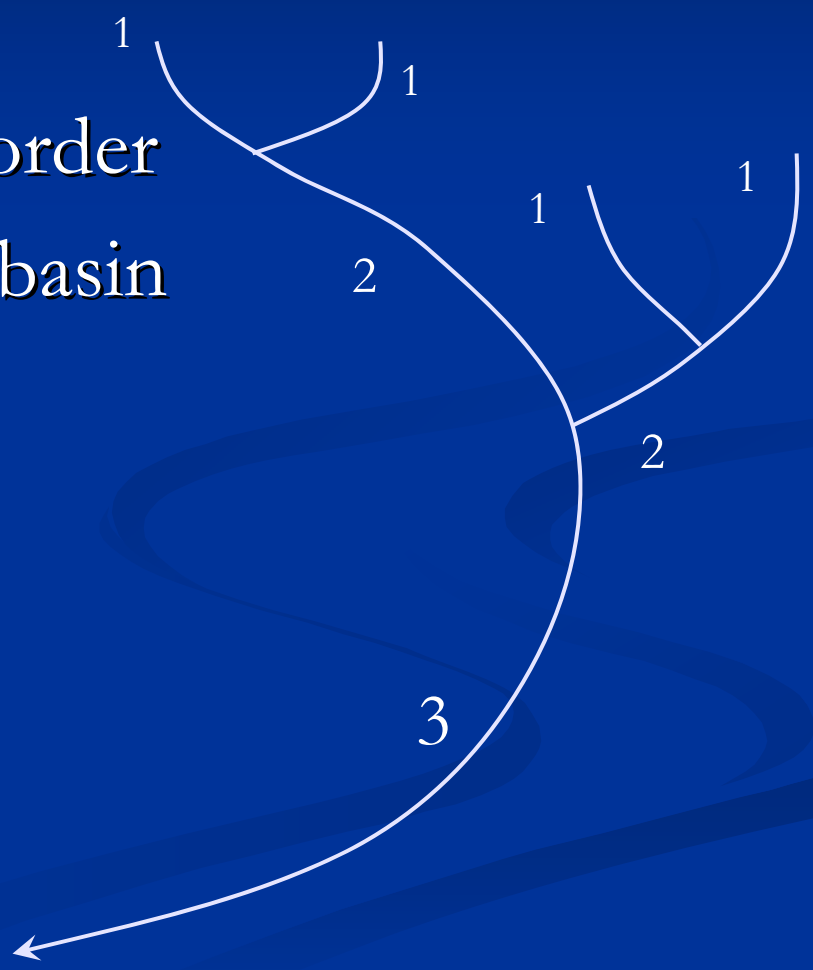



(Eagle Butte Mine Permit #420, 2006)

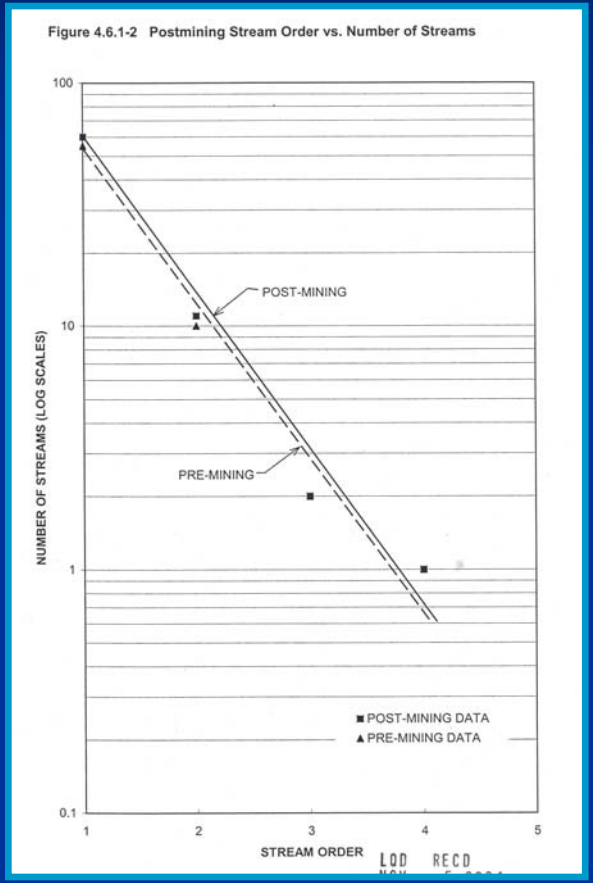
# Drainage Basin Morphometry (cont.)

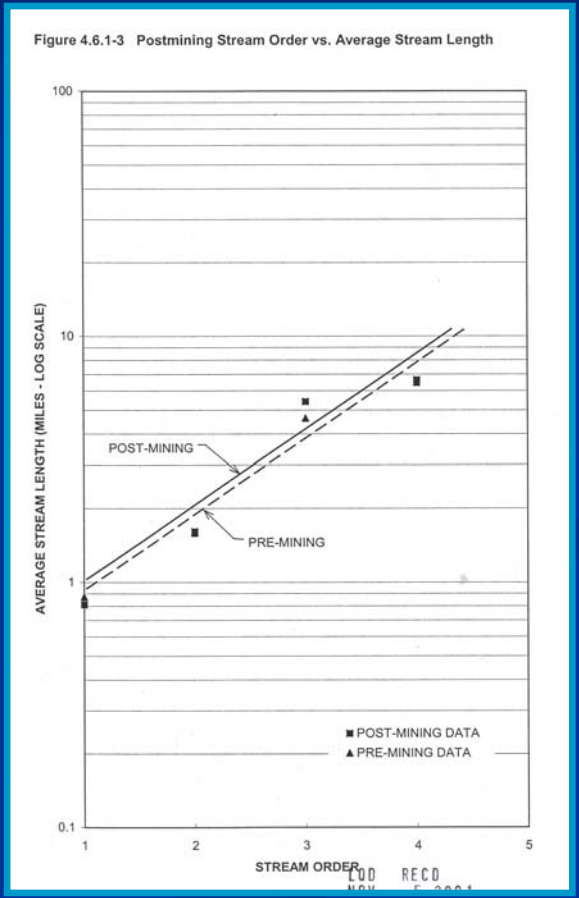
**Linear Relationships**

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



# Drainage Basin Morphometry (cont.)




(Eagle Butte Mine Permit #420, 2006)

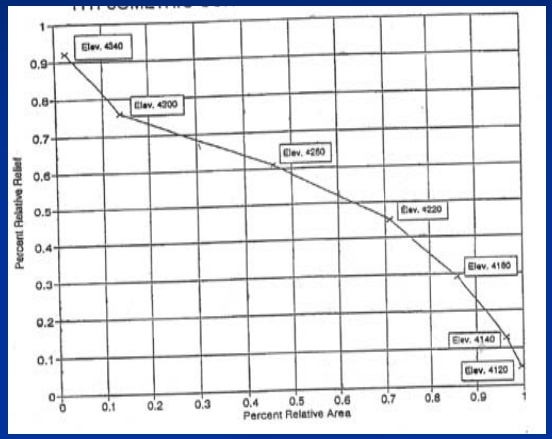
# Drainage Basin Morphometry (cont.)

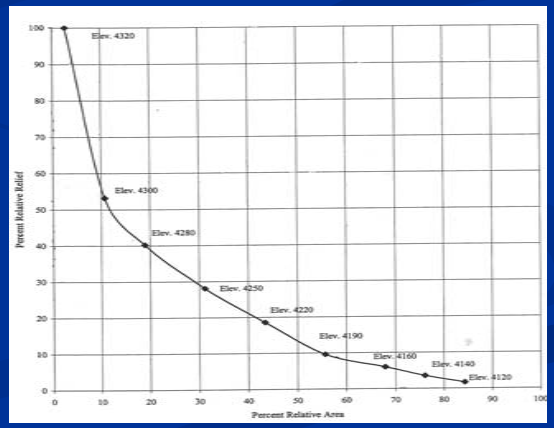
## Relief Relationships

### 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

% Relative Relief



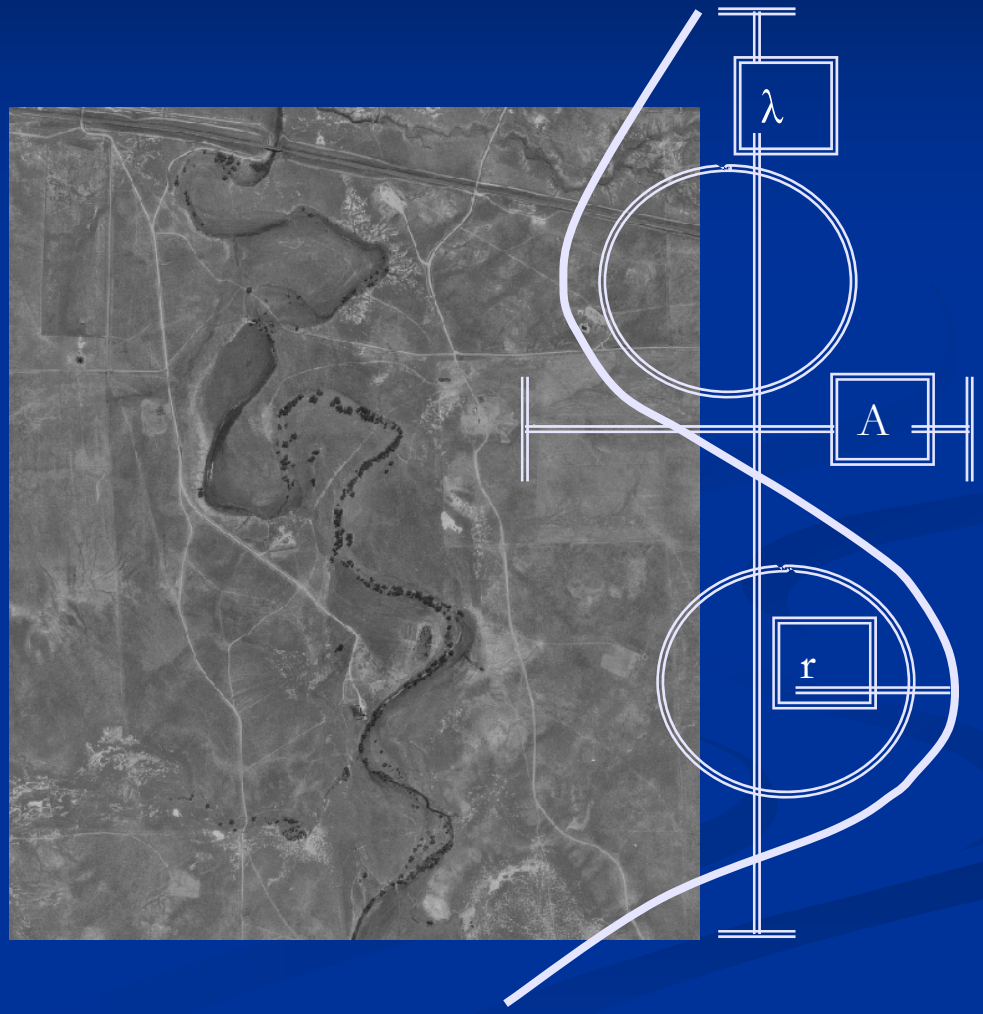

% Relative Area

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

# 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

**Regression analysis for various natural drainage basin variables in eastern Powder River Basin (Martin et al., 1988)**

| 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.)

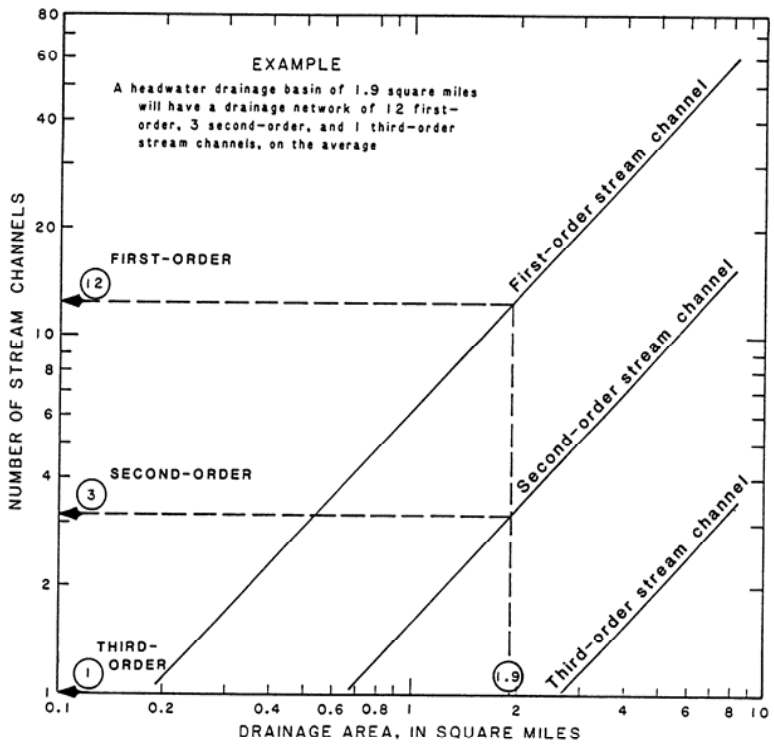



Figure 44.--Relation of number of stream channels to drainage area.

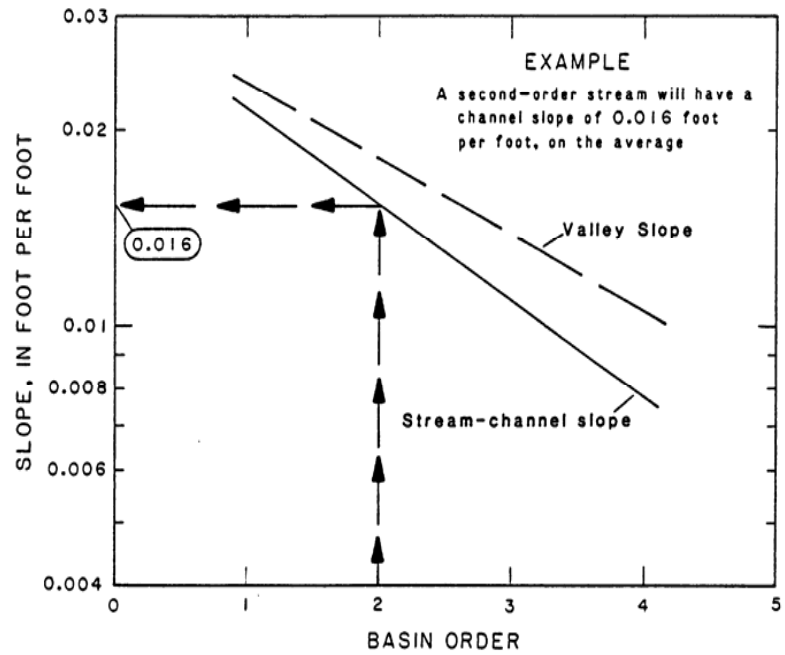



Figure 45.--Relations of stream-channel and valley slopes to drainage-basin order.

Regression analysis for various natural drainage basin variables in eastern Powder River Basin (Martin et al., 1988)

# Empirical Relationships (cont.)

| Dependent Relationship | Source |
|---|---|
| **Wavelength** | |
| $\lambda = 6.6\ w^{0.99}$ | Inglis (1949) |
| $\lambda = 10.9\ w^{1.01}$ | Leopold and Wolman (1957) |
| $\lambda = 4.7\ r^{0.98}$ | Leopold and Wolman (1957) |
| $\lambda = 30\ Q_{bf}^{0.99}$ | Dury (1965) |
| **Amplitude** | |
| $A = 18.6\ w^{0.99}$ | Inglis (1949) |
| $A = 10.9\ w^{1.04}$ | Inglis (1949) |
| $A = 2.7\ w^{1.1}$ | Leopold and Wolman (1957) |

w = width (ft) at bankfull stage

$Q_{bf}$ = bankful discharge (cfs)

# Closing Remarks

# Questions?

# Bibliograpy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