Modeling Sediment Loss on Geomorphic Graded Reforestation Lands in Kentucky

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

Richard C. Warner, Carmen T. Agouridis, and Christopher D. Barton

April 29, 2009

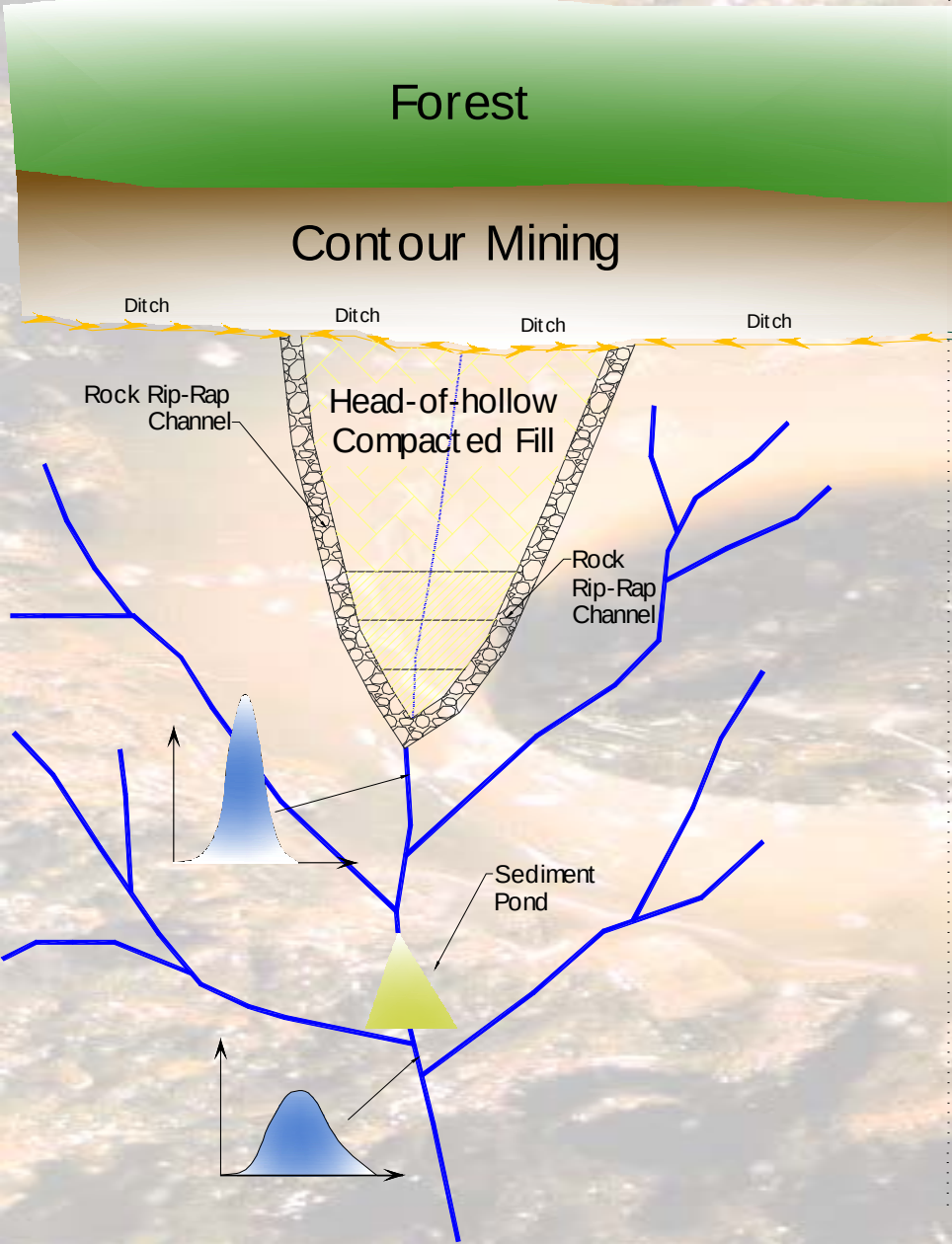
Sustainable Mining/Reclamation

- Similar (minor changes)
  - Hydrology
  - Sediment
  - Water quality
    - chemistry
    - organic material
    - nutrients
  - Visual
    - geomorphic
      - land form
      - natural streams
    - forest

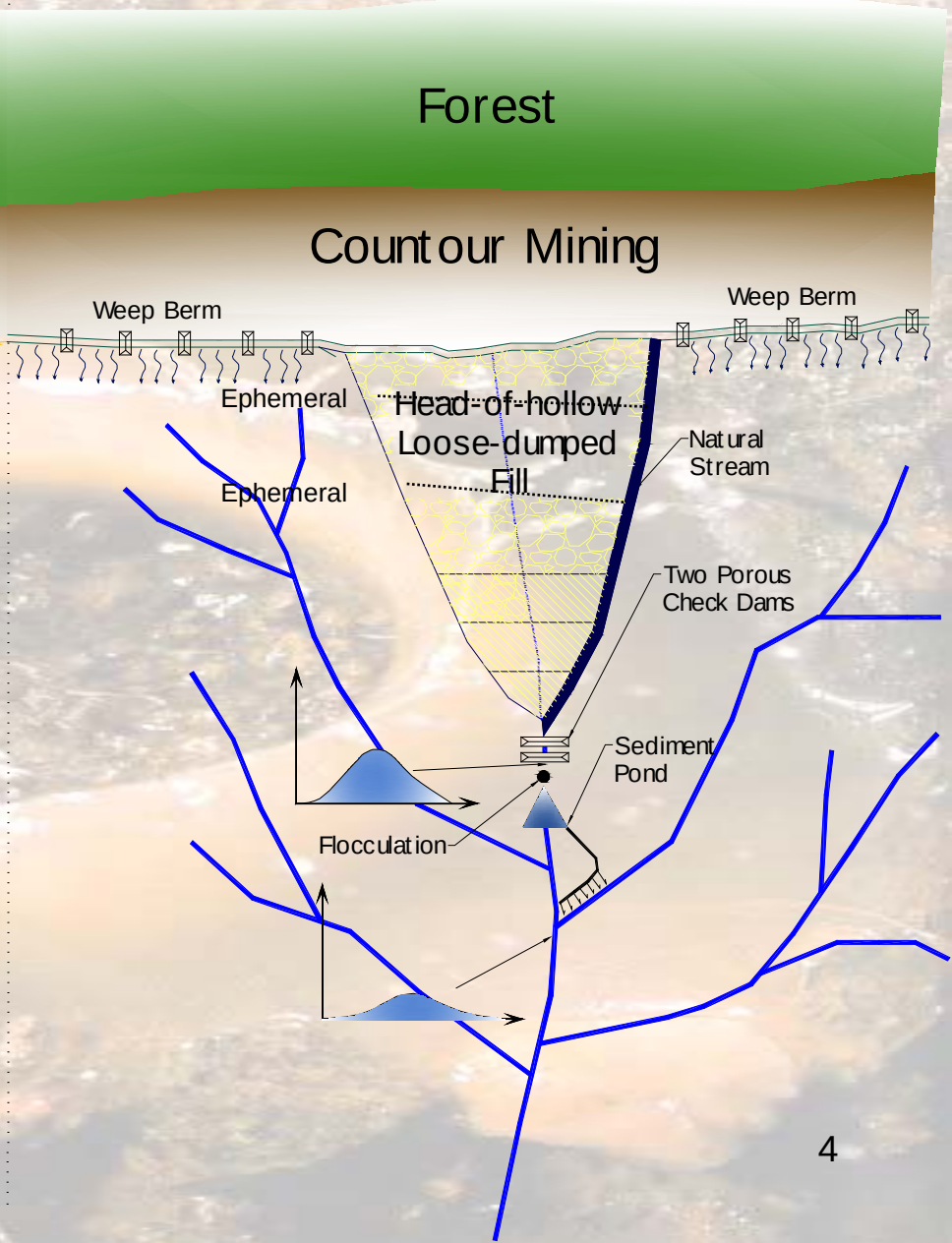
Objective

- Contrast hydrologic and sediment response of two alternative head-of-hollow fill design and reclamation techniques
  - Traditional (compacted spoil with grass cover)
  - Geomorphic (landform, natural streams and Forest Reclamation Approach)

CURRENT



FUTURE



Objective

- Design a head-of-hollow fill that mimics the natural landform, forest, hydrology and erosion of pre-development natural Appalachian forest
  - peak flow
  - runoff volume
  - hydrograph characteristics
  - erosion rates
  - sediment concentration and loads

Key Modeling Timeframes

- Natural forest
- Traditional head-of-hollow fill
  - compacted spoil
  - grass vegetated cover
- Geomorphic head-of-hollow
  - loose-dumped spoil overlays compacted fill
  - ephemeral and intermittent streams
  - forest cover

Key Modeling Parameters

- Hydrologic
  - curve number
  - time of concentration
  - unit hydrograph shape
- Sedimentologic
  - erodibility (K)
  - eroded particle size distribution (EPSD)
  - cover factor (C)
  - length-slope factor (LS)
  - slope geomorphic shape

Little Millseat Storm Events

- **Pre-Development Monitoring**
- Robinson Forest Data
  - 12 storm events
  - 2000-2004
  - 28.4 to 67.6 mm rainfall
- **CN Mean – 83**
- CN= **73** currently used in **KY Permit** Applications

Natural Forest Curve Numbers: Literature

Location	Area (ha)	CN	Source
Southern Ohio	20	77	Bonta et al. (1997)
Eastern Kentucky	82	**85**	Hawkins (1993)
Eastern Kentucky	116	**93**	Hawkins (1993)
Eastern Kentucky	93	**91**	Hawkins (1993)
Eastern Kentucky	93	86	Springer et al. (1980)
Eastern Kentucky	93	88	Springer et al. (1980)
Eastern Kentucky	93	88	Springer et al. (1980)
Eastern Kentucky	202	**83**	Taylor et al. (2009)
Western North Carolina	46	55	SCS (1972)

Compacted Mine Spoil

- **Hydrology** - Flooding (increase peak flow)
- **Sediment** - High erosion rates (until vegetation establishment)
- **Visual** - Not a forest, no stream, flat

Compacted Spoil Curve Numbers: Literature

Location	Area (ha)	CN	Reclamation Method	Source
Western Kentucky	-	82-86	Constructed profile; heavy compaction	Ward (1981)
Southern Ohio	10-17	87-97	Graded spoil; planted to grass and trees	Bonta et. al. (1997)
Pennsylvania	3-32	83-88	Graded spoil; topsoil and revegetation	Ritter and Gardner (1991)
North Dakota	8.8×10^{-4}	96-97 [1]	Unspecified	Schroeder (1987)

Compacted Spoil Study Site Characteristics

- Drainage area: 7.7 ha (19.3 ac)
- Slopes: 1.3% upper catchment, 14% lower catchment
- Soils
  - Weathered spoil (sandstone and shale)
  - Compacted
  - Infiltration rate ~ 2 mm/hr (0.08 in/hr)
- Hydrologic soil group B

Compacted Spoil

- **Monitoring**
- 42 storm events
- May 1990 to Sept. 1991
- Rainfall 6 to 59 mm
- **CN Mean: 85** (P. Taylor et al., 1995)
  - Range 62 to 94

Ohio

Kentucky
31 12:34PM

West Virginia

Tennessee

Loose-dumped Spoil Curve Number

- Highland Coal (1984) – Bowser-Morner, Inc.
- head-of-hollow (end-dumped)
- generated rainfall
  - antecedent application of 2.1 in
  - 2.5 in/hr for ½ hour
- measure runoff volume
- curve number = 35

Loose-dumped Spoil Curve Number

- Starfire (May – Nov, 2000) – UK Agr. Engr.
- Loose-dumped spoil surface runoff plots
- 3 monitoring locations – spoil and diversion
- natural rainfall
  - RF7 – 14 events, RF8 – 0 events, RF9 4 events
- runoff only from adjacent outslope and diversion

Loose-dumped Spoil Curve Number

- Starfire (1998 - 2000) – UK BAE.
- Loose-dumped spoil surface infiltration plots
- 38 5m X 5m lysimeters
- Spoil 6 to 8 ft deep (ROM)
- Annual infiltration rate – 32.2%
- Natural Appalachian forest - ~ 30 – 35%

Loose-dumped Spoil Curve Number

- Depression Storage Calculation
- Starfire Mine – UK BAE
- Depressions will contain >6 in rainfall
- Conclusion: no surface runoff except for spoil piles at boundary adjacent to streams

Loose-dumped Spoil Curve Number

- Bent Mountain (July 2005 – Nov 2006) – UK
- Loose-dumped spoil
  - Brown weathered sandstone
  - grey un-weathered sandstone
  - ROM sandstone and shale
- 6 monitoring locations –
- natural rainfall
  - 12 events
  - measure runoff volume
- No surface runoff
- Mean curve number (interflow) – 77

Curve Numbers Measured at Study Sites

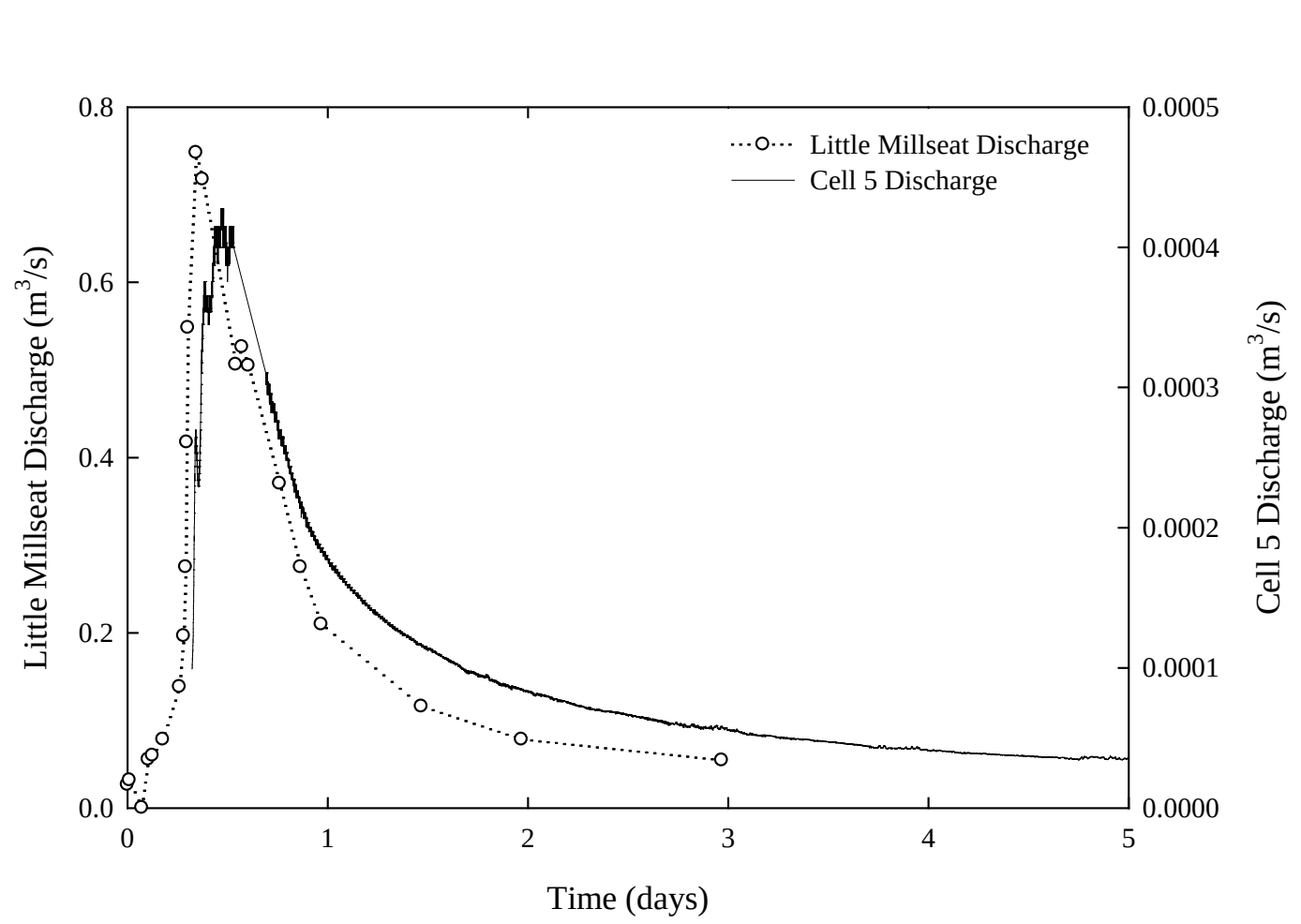
- Forested (Little Millseat)
  - Mean: 83 (T. Taylor et al., 2007)
- Compacted spoil (Starfire)
  - Mean: 85 (P. Taylor et al., 1995)
- Loose-dumped spoil (Bent Mountain)
  - Mean: 77 (T. Taylor et al., 2007)
  - no surface runoff

Starfire - 10 years growth

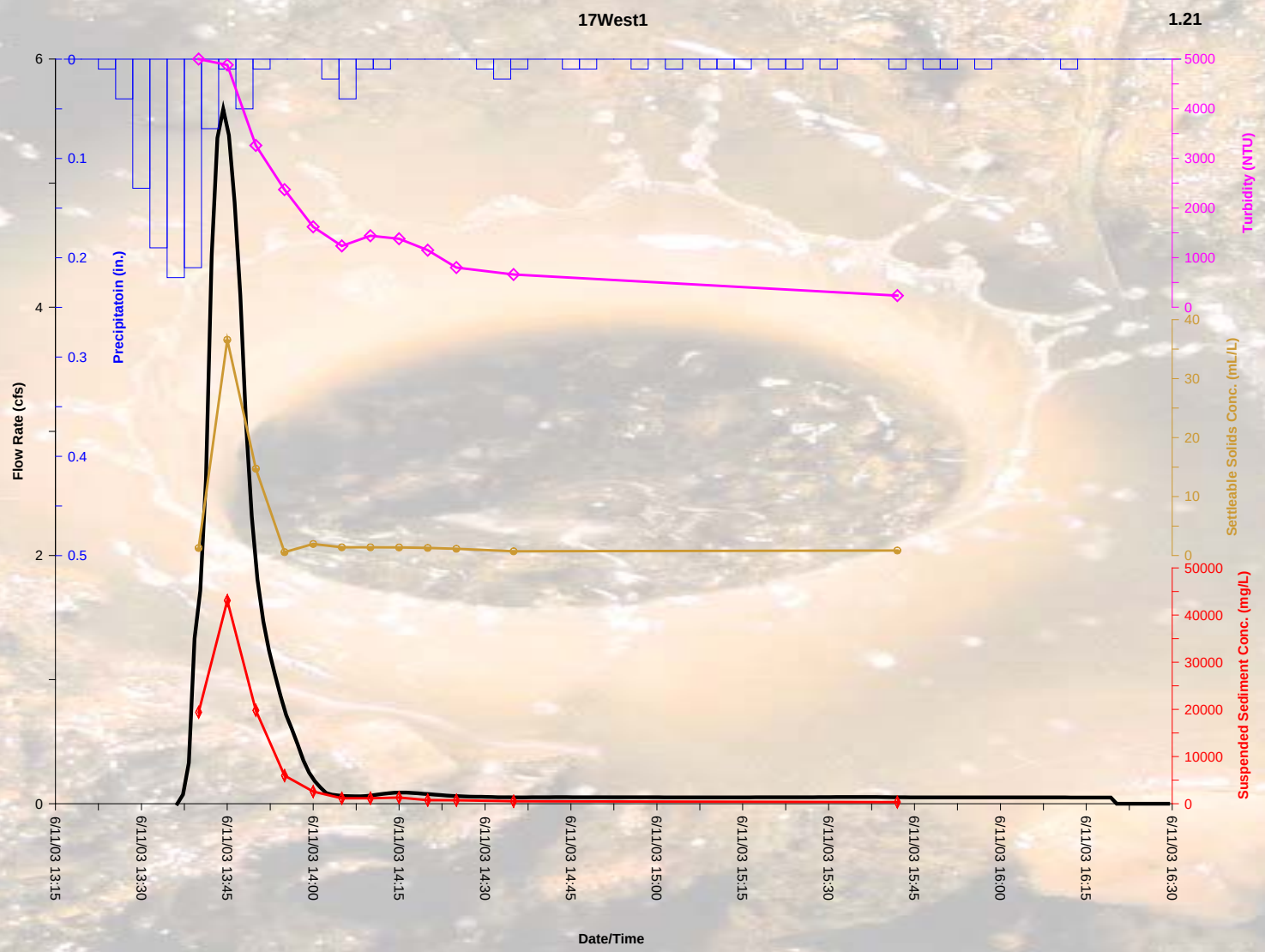
Loose-dumped versus Compacted

- Hydrologic Inputs
  - Time of concentration
    - forest (few hours)
    - loose-dumped (many hours)
    - compacted (fraction of an hour)
  - Unit hydrograph shape
    - forest loose-dumped (slow to very slow)
    - compacted (medium to fast)

Natural Forest & Loose-dumped Spoil Hydrographs



Compacted Spoil Hydrograph



Geomorphic Head-of-Hollow Fill Reclamation Approach

- **Advantages**
- **Hydrology (similar to pre-mining forest)**
  - Reduce peak flow
  - Increase flow duration (intermittent streams)
  - Increase evapotranspiration
- **Sediment**
  - Erosion rate and sediment load (similar to pre-mining forest)
- **Visual**
  - Reconstruct a forest
  - Watershed provides for the natural stream
    - nutrients/carbon
    - forest liter
- **Water chemistry**

Key Modeling Parameters

- Hydrologic
  - curve number
  - time of concentration
  - unit hydrograph shape
- Sedimentologic
  - erodibility (K)
  - eroded particle size distribution (EPSD)
  - cover factor (C)
  - length-slope factor (LS)
  - slope geomorphic shape

K-factors

- Starfire Mine Soil & Spoil Analysis
- K-factors
  - Undisturbed forest topsoil (0.206 – 0.256)
  - 0-2 month old spoil (0.126 -0.133)
  - 2 to 6 month old spoil (0.139 – 0.145)
- Modeling inputs
  - forest – 0.23
  - 0-2 month spoil – 0.13
  - 2 – 6 month spoil – 0.14

C -factor

- Function of
  - Vegetation (forest or grass)
  - Surface roughness
  - Surface rock fragment
- Forest (0.002)
- Compacted spoil with grass cover (0.1)
- Loose-dumped spoil (without forest) (.02)

Slope shape and length factors

- Slope shape
  - Convex
  - Uniform
  - Concave
  - Complex
- Gradient
- Length

Slope inputs

- Forest
  - L 25ft, S 50%, Complex
- Traditional Compacted Spoil (crown)
  - L 150ft, S 2%, Uniform
- Geomorphic Loose-dumped Spoil (crown)
  - L 20ft, S 40%, Uniform

SEDCAD Modeling Inputs

- Area: 100 ac forest, 80 ac crown
- Design storm: 2.5 in NRCS Type II -24 hour
- Forested
  - Time of concentration: .36 hr
  - Unit hydrograph shape: slow
- Compacted spoil
  - Time of concentration: .22 hr
  - Unit hydrograph shape: fast
- Loose-dumped spoil
  - Time of concentration: 1.5-2 hr
  - Unit hydrograph shape: slow

SEDCAD Results

LandUse	Peak flow (cfs)	Runoff Vol. (ac-ft)	Sediment (tons)	Peak Sediment (mg/L)
Forest	40.1	5.9	4.4	980
Geomorphic	12.5	4.5	5.7	1340
Traditional	93.2	8.6	14.9	2470

The Alternative