Valley Fill Design and Construction to Improve Ecological Performance

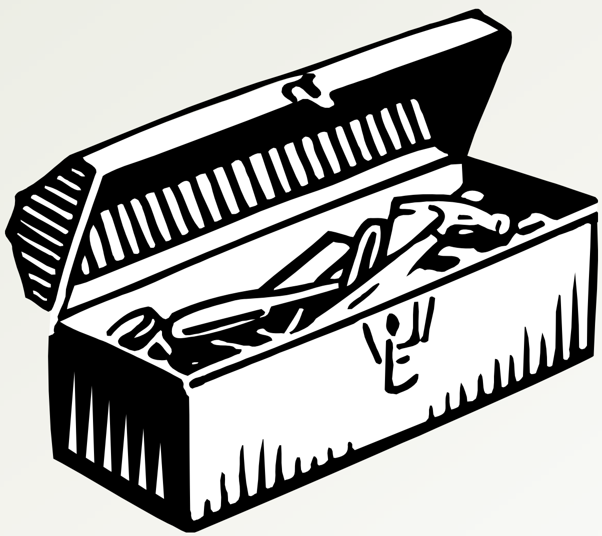
Drs. Richard C. Warner and Carmen T. Agouridis

Presentation Outline

- Current challenges
- Comprehensive approach
- BMPs
- Middlefork Development
- Guy Cove project
- Path forward

Toolbox of BMPs

- Performance
- Cost
- Adaptability to current mining
- Transferability
- Need for demonstration projects
- Data needs (monitoring)
- Regulatory impediments



Current Surface Mining Challenges

- Develop effective source reduction and treatment systems
  - Reduce specific conductance and selenium
  - Reduce adverse impacts on aquatic ecosystems
- Mimic forest hydrologic balance
  - Maintain ephemeral, intermittent and perennial flow regimes
  - Reduce flooding

Current Surface Mining Challenges

- Reduce adverse water quality impacts of previous mining (mine seeps)
- Re-establish a high-value hardwood forest (FRA)
- Replace headwater stream systems
  - Form and function

Comprehensive Approach

- Sustainable mining and reclamation
- Systems approach
- Incorporation of new surface mine designs, source reduction methods, and treatment technologies
  - Integration with natural systems
- Conduct applied research
  - Evaluate and verify performance of alternative mining methods and BMPs
  - Develop design methods (SMCRA permitting)
- Monitoring
- Conduct technology transfer training
  - Demonstration sites

Sustainable Mining/Reclamation

- Similar (acceptable level of change)
  - Hydrology
  - Sediment
  - Water quality
  - Aquatic invertebrates and terrestrial species
  - Land use - land cover
    - Geomorphic
      - Land form
      - Natural streams
    - Forest

BMPs

1. Identification and isolation of conductivity-producing spoil
   - High and dry (valley fills and back-stacked spoil)

2. Valley fill under-drains
   - Select low-reactive durable rock
   - Provide filtering mechanism

3. Spoil minimization (KY FPOP)
   - Approximate original contour (stack spoil higher on fills)
   - Minimize impacted stream length

BMPs

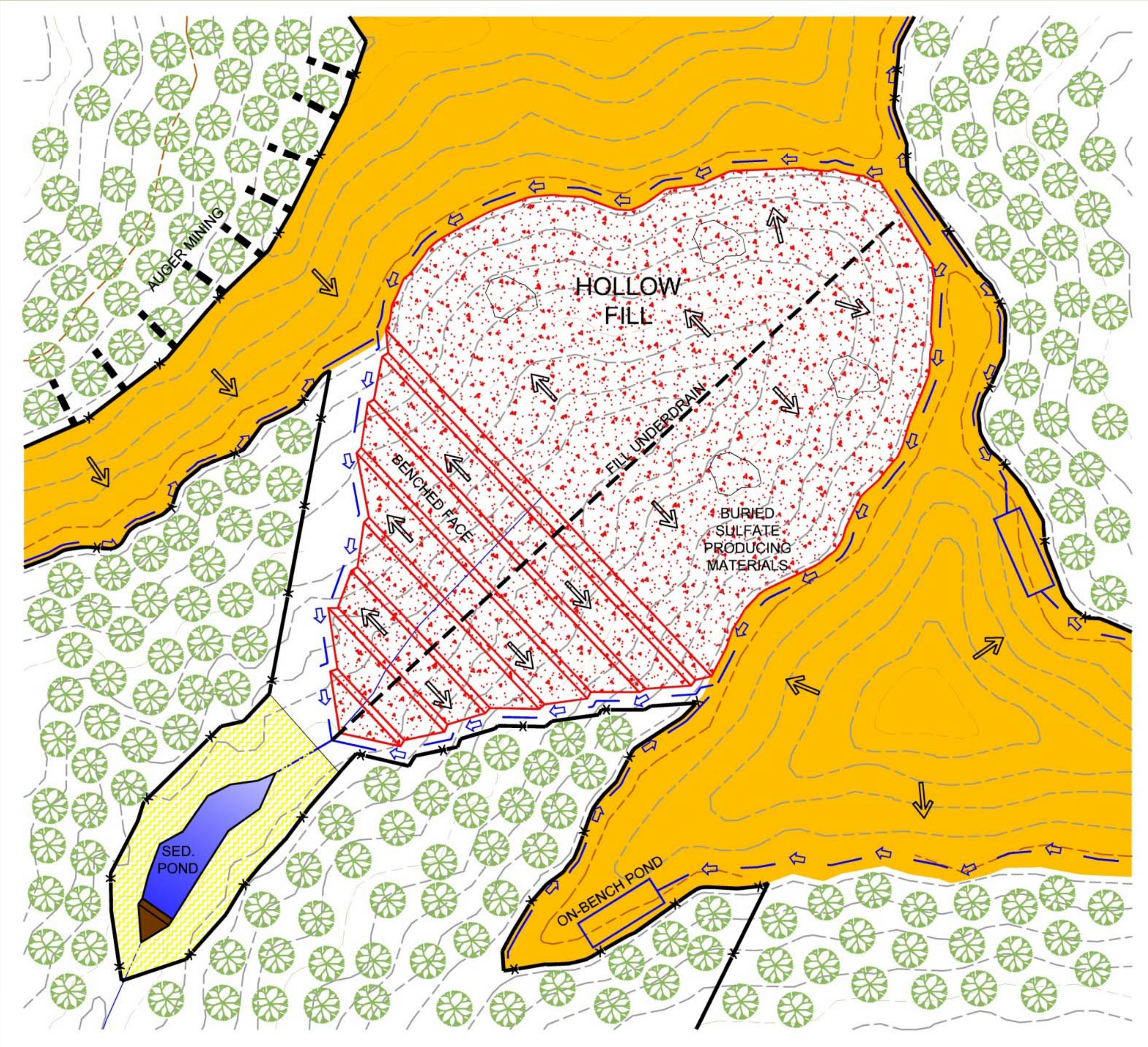
4. Weep berms-forest passive treatment system

5. Sediment pond treatment system
   - Flocculation to reduce TSS, TDS, and ionic precipitates
   - Floating siphon (cleanest water and enables controlled discharge)
   - Diffuse discharge to riparian zone (CEC & organic material)

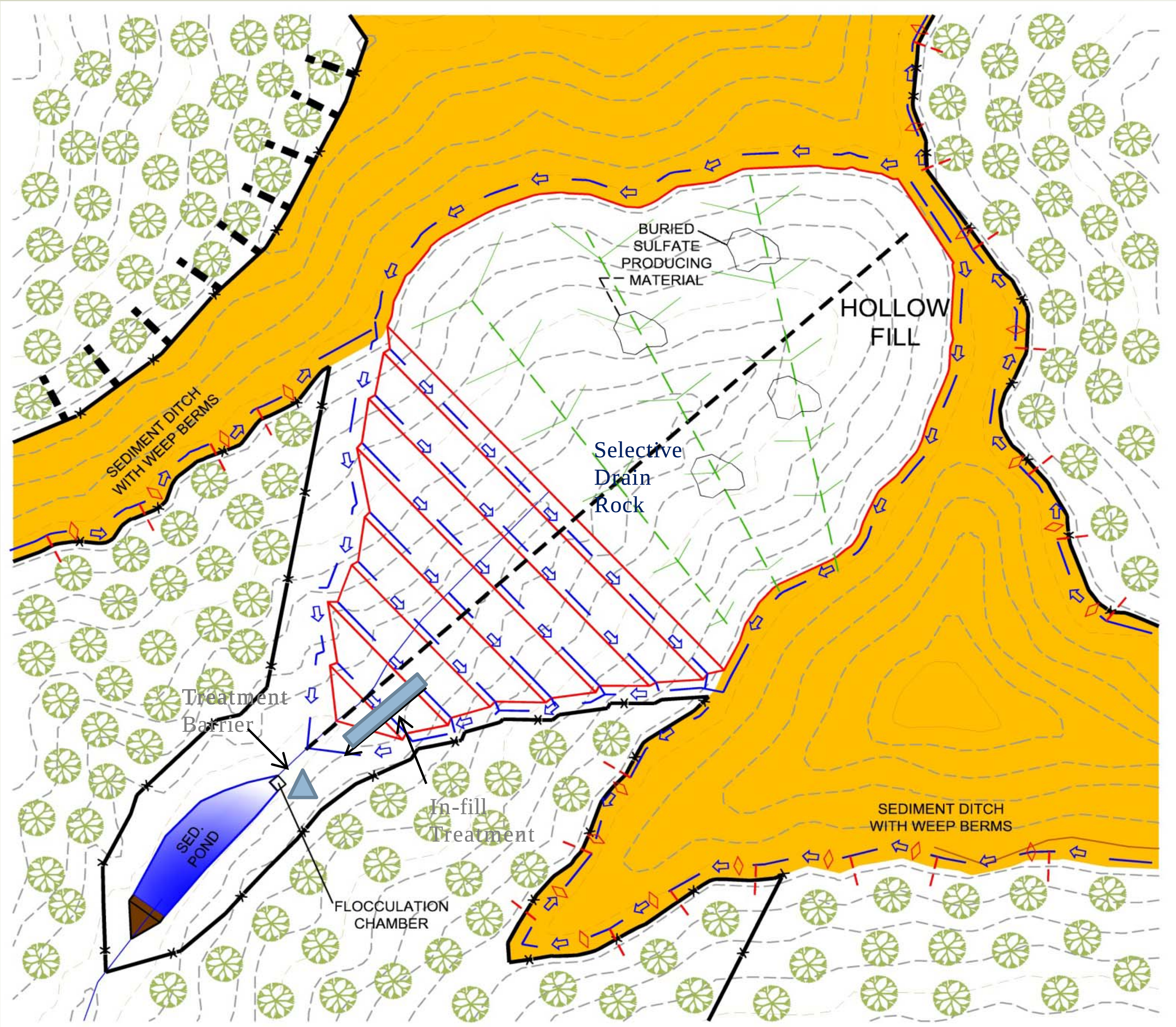
6. Forestry Reclamation Approach (ARRI)

7. Natural stream systems

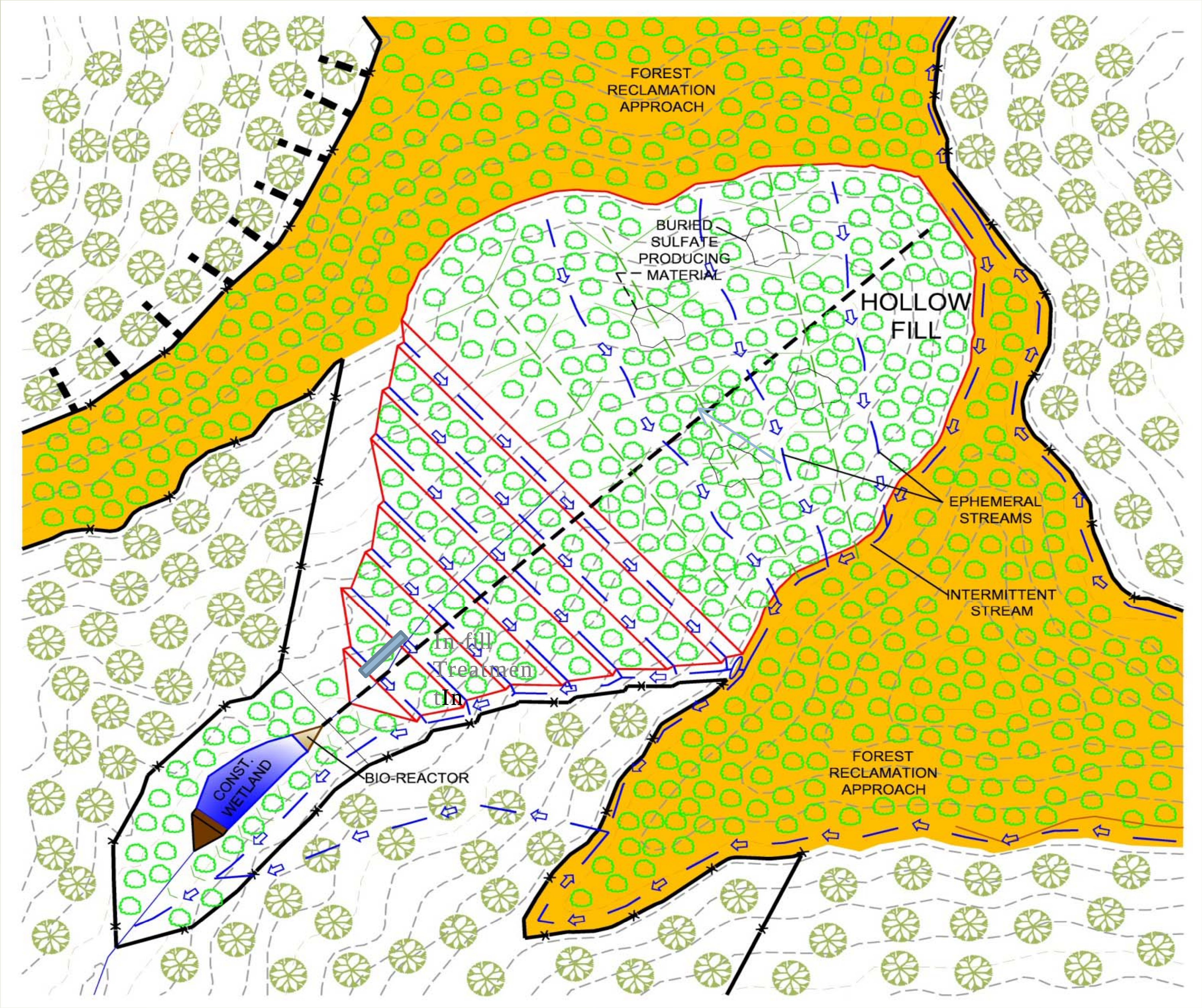
Present Method



Proposed (Active Mining) Method



Proposed (Post-Mining)Method



Geological Layers: Top to Bottom

- Thin soil
- Weathered sandstone
- Unweathered sandstone
- Unweathered shale
- Coal
- Clay
- Repeat starting with unweathered sandstone

Water Movement

- Inter-granular (small overall component)
- Primary flow routes
  - Faults, tectonic joints, bedding-plane partings
  - Stress-relief fractures (primary mechanism)
    - Occurs at outer edge of valley

Highwall and Valley Fill Hydrology

- Primary source of water
  - During Construction - rainfall
  - After crown completed - coal seam(s)
    - Water moves through remaining coal seams (contour mining) to highwall or valley fill boundaries
      - <u>Therefore do NOT place high conductivity-producing material on side or bottom</u>
    - Infiltration through final crown (minor, if compacted)
    - For traditionally constructed fills - surface runoff routed to and through under-drain (high leaching potential)

Understanding Generation of Conductivity

- Geologic materials
- Weathered versus unweathered
- Size (contact area) – smaller particles generate higher conductivity
- Contact time – longer duration generates higher conductivity
- Quantity of flow through material

Design of Valley Fill Underdrain

- Build underdrains with:
  - Large durable rock
  - Low conductivity-producing strata
  - Reduce entry of small particles
  - Reduce migration of water through fill to underdrain
- Results in:
  - High flow rate capacity
  - Short contact time, and hence …
  - Low conductivity generation in the underdrain

Traditionally Constructed Valley Fills (~7,000) and Bench Ponds

- Range 1,500 to 3,500 µS/cm
- If 1,800 µS/cm
  - Sulfate – 1,300 to 1,450+ mg/L
  - Manganese – 20 to 40+ mg/L
  - Iron – 0.5 to 4 mg/L
  - Calcium – 100 to 150 mg/L
  - Magnesium – 150 to 250 mg/L
  - *Source Guy Cove (Univ. of KY) at toe of fill prior to restoration*

Water Quality Constituents

Constituent	Unmined	Valley Fill
Conductivity µS/cm	34 - 133	159 – 2,540
Sulfate mg/L	11 - 22	155 – 1,520
Calcium mg/L	3 – 12	39.0 - 269
Magnesium mg/L	2 – 7	28 - 248
Bicarbonate mg/L	6 - 35	11 - 502
pH	6.1 – 8.3	6.3 – 8.9
Hardness	17 - 72	225 – 1,620

Weathered vs. Unweathered Mine Spoil

- Weathered overburden (upper 10 to 25 ft)
  - 200 to 560 µS/cm
- Exposed unweathered mine spoil
  - 400 to 3,480 µS/cm
- *Source - Lee Daniels*
  - *Southwestern VA spoil*

Underground Mine Seeps

- Higher conductivity water
  - 2,400 to 3,800 μS/cm

1a. Field Identification of Conductivity-Producing Geologic Strata

- Rotary air drill (generate fines) or geologic cores
  - Conducted during coal reserve and acid-base accounting assessments
- Conductivity potential of geologic strata
  - Field leach testing procedures
  - Identification of both high conductivity generation potential and low-reactive strata
- Research – linkage of conductivity (and specific constituents) with traditional acid-base accounting methods (U.S. EPA Region 4 RARE grant)

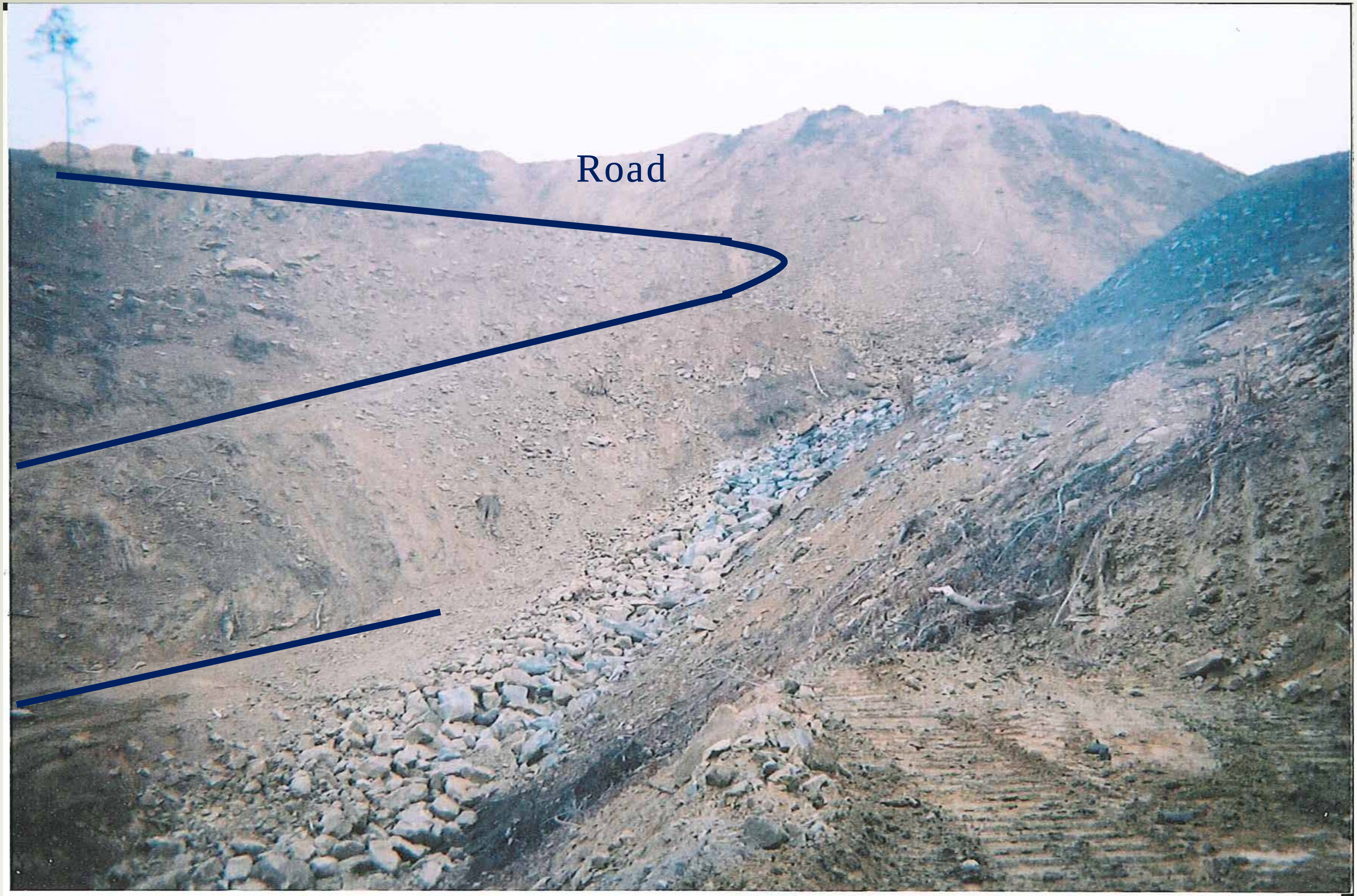
1b. Isolate Conductivity-Producing Spoil

- Mine operations
  - Remove with a loader (coal fines, residue and conductivity-producing strata)
  - Place high and dry
    - Backfill
    - Valley fill
  - Isolate with selective spoils
    - Weathered shales and sandstones and non-reactive clays
    - Compaction for low infiltration rate
    - Positive (crowned) drainage
  - Do <u>NOT</u> place conductivity-producing spoil near bottom or adjacent to sides of highwall or valley fill

2. Valley Fill Underdrains

- Identify and place a durable low-reactive rock drain
  - Large rock: 1 to 4 ft (blasting method)
  - Filtering techniques
    - Placement of thick layer prior to rainfall
    - Geotextile
  - Truck and place (no end-dump)

Construction Road and Under-drain



Durable, Low-reactive Large Rock Underdrain

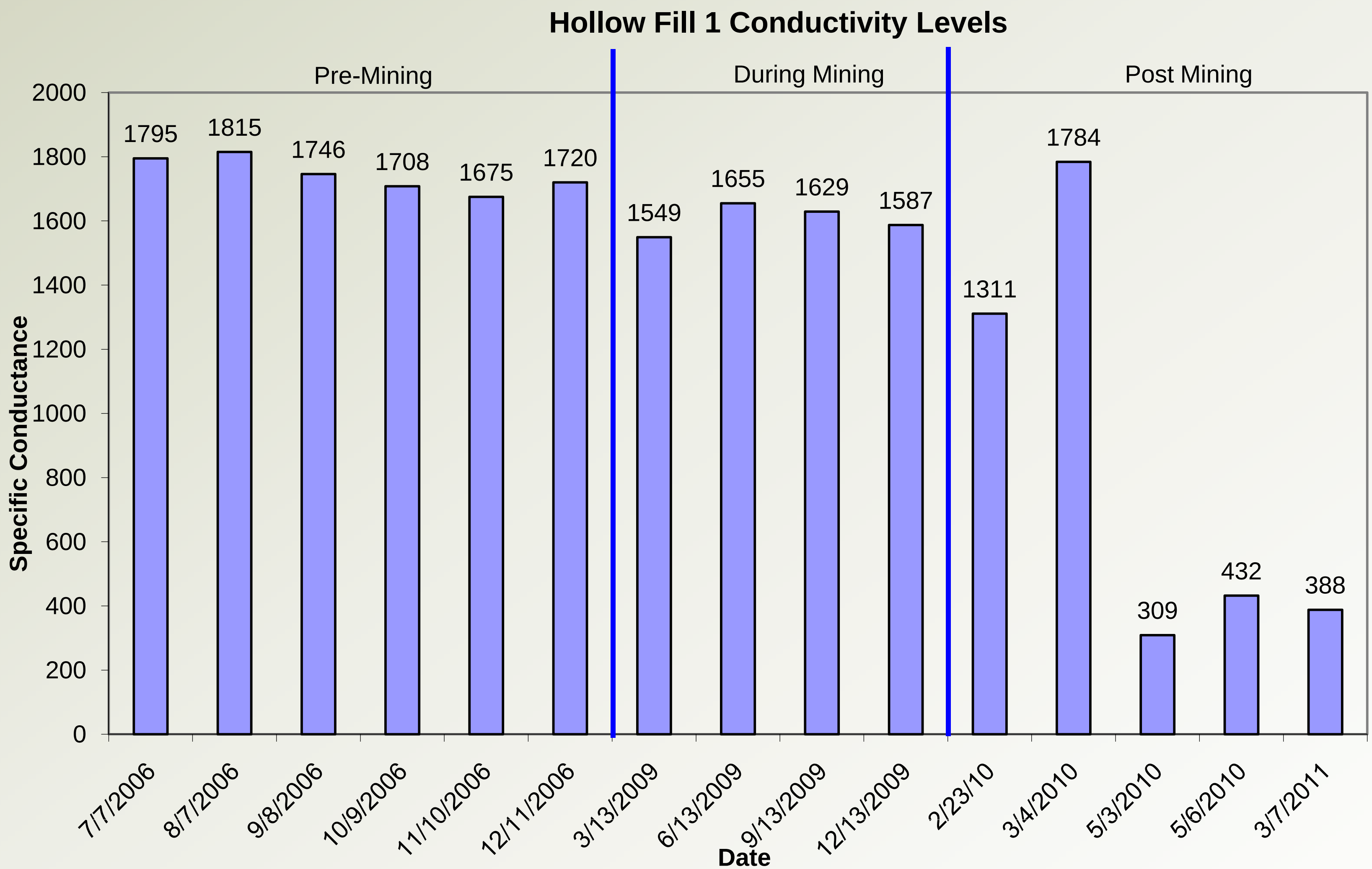
Valley Fill Sequential Lift Construction Technique

- Ability to place and isolate conductivity- and selenium-producing spoils
- Avoid perched compacted layers and potential for fill face seeps
- Concurrent reclamation of lift face and bench
- Compacted crown

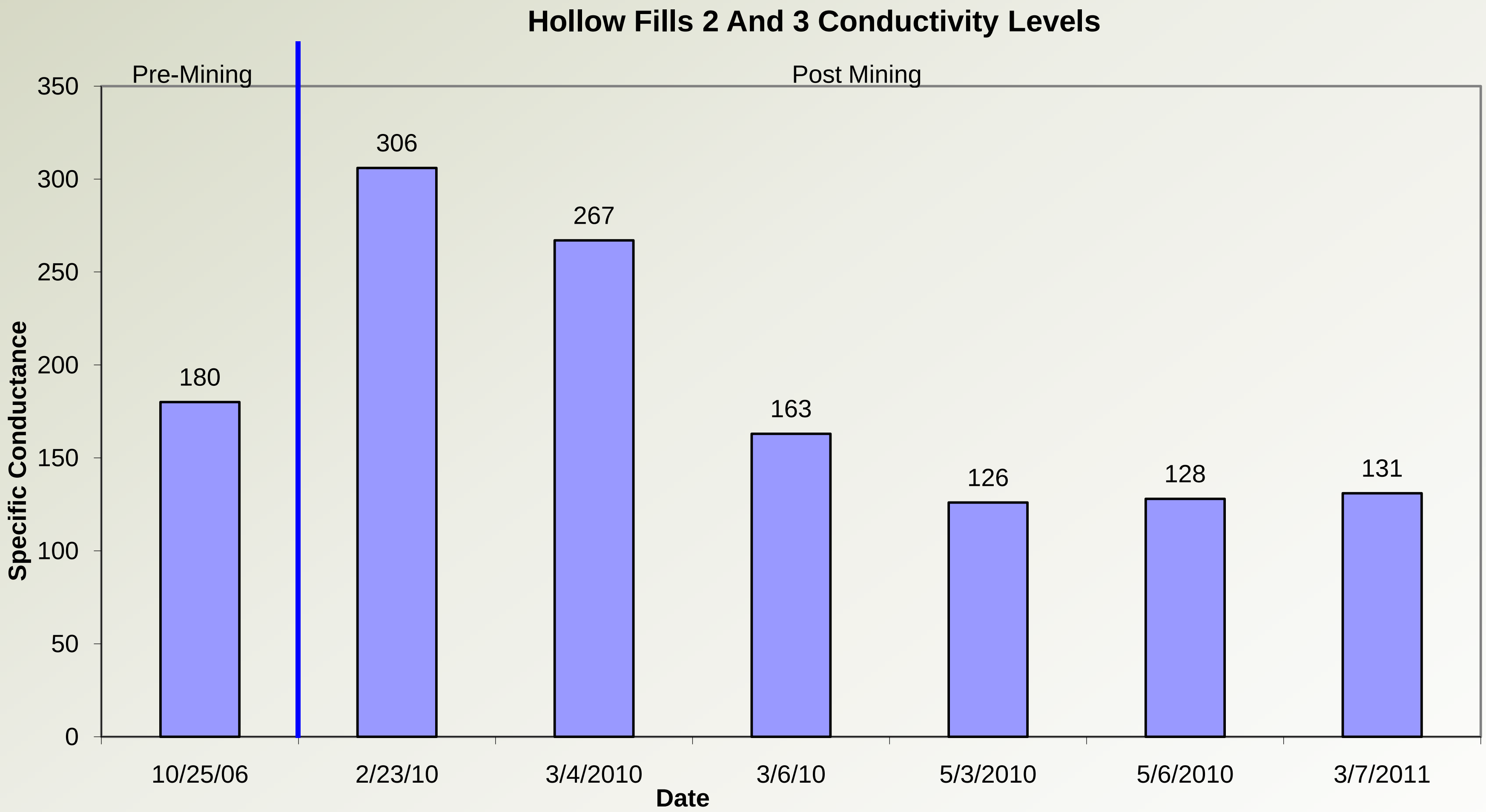
Conductivity from Valley Fills Using Source Reduction and Rock Drain Construction Techniques

- *Middlefork Development Permit No. 0179 Results*

Results from Re-mining



Results from New Mining



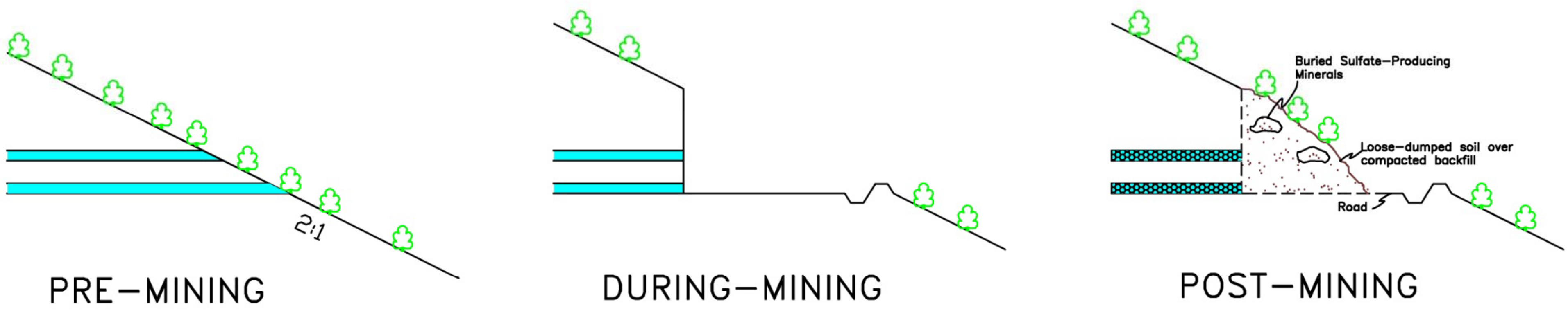
Valley Fill Conductivity Reducing BMPs

- Performance – achieved target specific conductance (4 fills)
  - < 500 µS/cm for prior mining affected fills
  - < 250 µS/cm for virgin fills
- Cost - $0.12 per ton of coal extracted
- Anticipate highly adaptable
- Need applied research (field verification) for fills in different geological areas (transferability)

Valley Fill Conductivity Reducing BMPs

- Regulatory considerations
  - Allow two concurrent fills with partial footprint disturbance and alternate filling
  - Fill from bottom to top
  - Allow filling above the bottom-most coal seam (regulations in-place – FPOP)
- Regulatory impediment - None

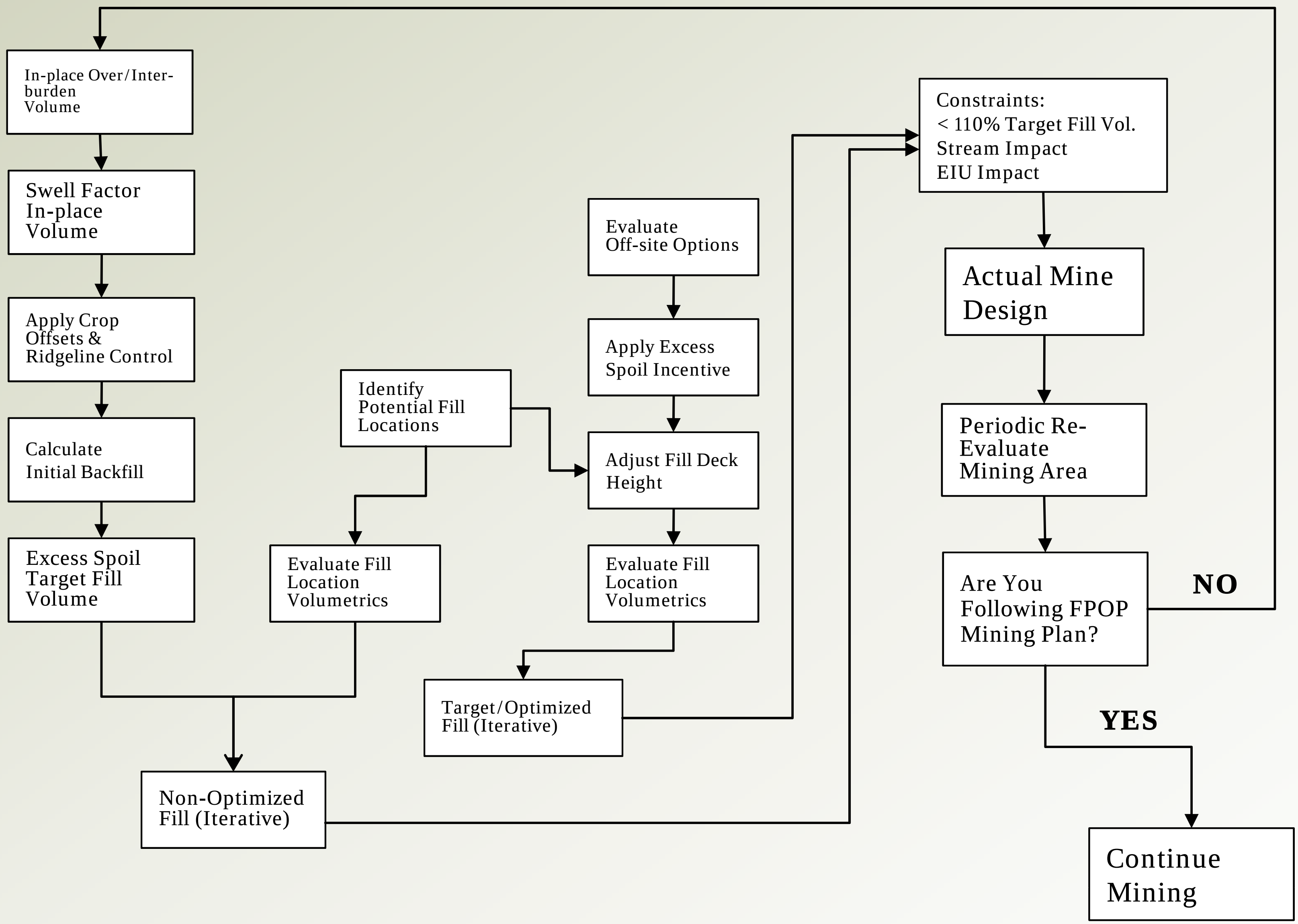
Typical Contour Mining Sequence



3. Fill Placement and Optimization Process

- FPOP
- Kentucky Department of Natural Resources
  - Reclamation Advisory Memorandum (RAM) #145
- Disclaimer – read RAM # 145
  - Presentation is based on my understanding but rules are complicated to follow

Fill Minimization Flow Diagram



Overview – Calculations

- Quantity of spoil that will be generate for mine permit
- *Minus*
- Quantity of spoil that can be backfilled (BKF)
  - Offsets with 2.4H: 1V approximation
- *Equals*
- What remains is Excess Spoil (ES)

Initial Backfill Calculation

- Setbacks from lowest seam
  - Outcrop berm: 15 ft
  - Perimeter access road: 20 ft
  - Diversion width

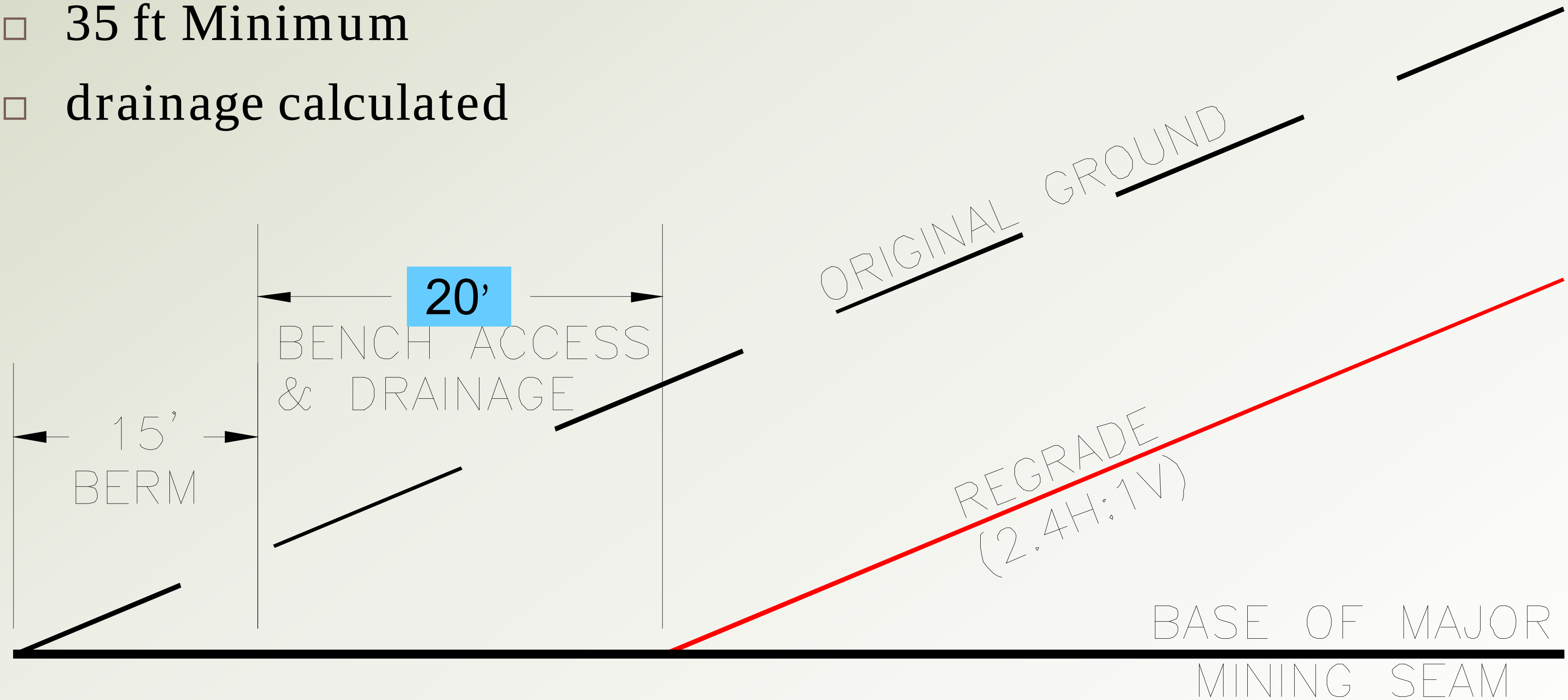
$$\frac{\textbf{((mined area (ac) x 0.125 ac-ft) x length}}{\textbf{cross-sectional area of ditch}}$$

  - Cross-sectional area of ditch based on
    - Depth: 3 ft
    - Sideslopes: 2H:1V

AOC / Fill Minimization

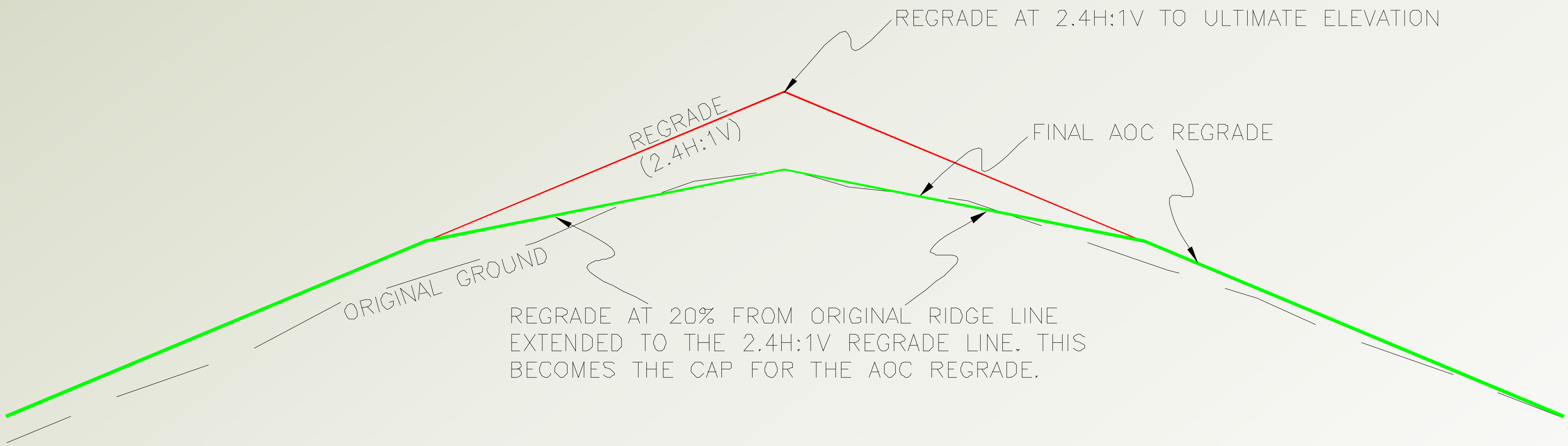
The Regrade Template:

- 15 ft berm
- 20 ft road
- 35 ft Minimum
- drainage calculated



AOC / Fill Minimization

- The Regrade Template:
  - Applying the regrade cap



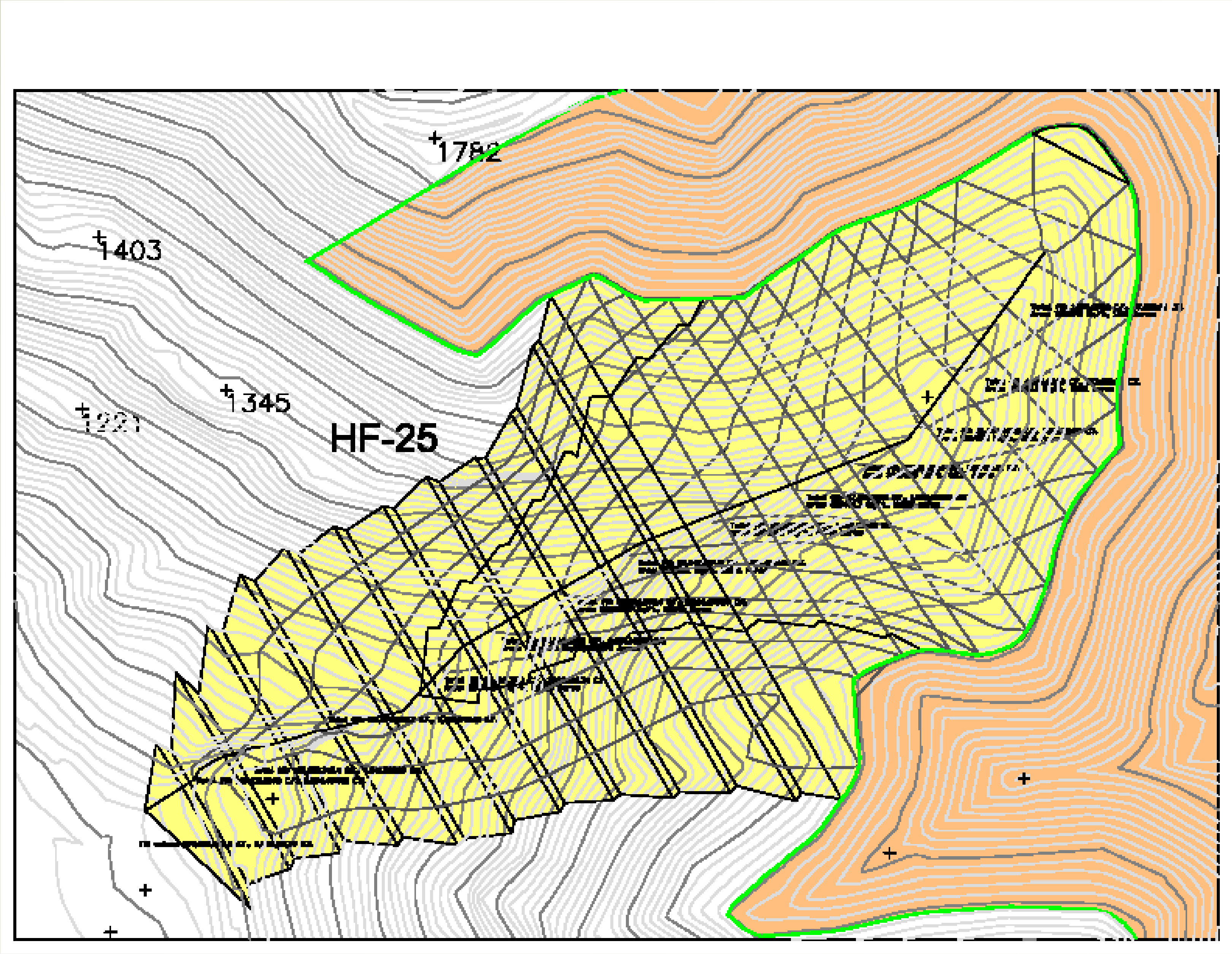
Fill Volumes and JD Stream Lengths

- Determine incremental fill volumes and associated JD stream lengths covered by fill

Fill deck is located at base of lowest coal seam

- Locate all potential excess spoil fill sites
- For each potential fill site, complete the following:
  - Start initial fill toe at upstream stability point (~20°)
  - Calculate fill volume (option – use 2.4H:1V)
  - Calculate intermittent stream length covered by fill
    - Jurisdictional Determination (JD)
  - Calculate stream quality
    - Ecological Integrity Unit (EIU)

AOC / Fill Minimization



Fill Volumes and JD Stream Lengths

- Continued …
  - Proceed downstream at 200 ft increments and calculate incremental increase in fill volume
  - Develop an Excel table for each fill
    - JD stream length
    - Incremental fill volume
    - Cumulative fill volume
    - EIU
    - Cumulative fill volume/cumulative stream length

VF-01				
Stream length (ft)	**Incremental Fill Volume (yd³)**	**Cumulative Fill Volume (yd³)**	**Cumulative EIU**	**Ratio Cum. Vol./Stream (yd³/ft)**
0	0	0	--	--
130	13,200	13,200	82	101.5
330	17,330	30,530	208	92.5
530	29,340	59,870	334	113.0
730	89,063	148,933	460	204.0
930	146,342	295,275	586	317.5
1,130	188,722	483,997	712	428.3
1,330	157,321	641,318	838	482.2
1,530	142,156	783,474	964	512.1
1,730	140,210	923,684	1090	533.9
1,930	133,432	1,057,116	1216	547.7
2,130	124,321	1,181,437	1342	554.7
2,330	155,720	1,337,157	1468	573.9
2,530	165,344	1,502,501	1594	593.9

Initial Fill Optimization

- From Excel spreadsheet, determine:
  - Minimum length of JD streams impacted
    - Based on all potential fills and stream lengths associated with these fills to accommodate the mine permit excess fill volume (ES)
  - Determine associated total EIU

- This calculation will be used in the USACE's 'stream saved' assessment

VF-01				
Stream length (ft)	Incr. Fill Volume (yd³)	Cum. Fill Volume (yd³)	EIU	Ratio Cum. Vol/Stream (yd³/ft)
0	0	0		
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1,930	133,432	1,057,116	1,216	547.7
2,130	124,321	1,181,437	1,342	554.7
2,330	155,720	1,337,157	1,468	573.9
2,530	165,344	1,502,501	1,594	593.9

VF-02				
Stream length (ft)	Incr. Fill Volume (yd³)	Cum. Fill Volume (yd³)	EIU	Ratio Cum. Vol/Stream (yd³/ft)
0	0	0		
290	15,755	15,755	160	54.3
490	17,642	33,397	270	68.2
690	19,334	52,731	380	76.4
890	17,221	69,952	490	78.6
1,090	18,641	88,593	600	81.3
1,290	22,345	110,938	710	86.0
1,490	36,421	147,359	820	98.9
1,690	48,721	196,080	930	116.0
1,890	58,987	255,067	1,040	135.0
2,090	87,600	342,667	1,150	164.0
2,140	23,564	366,231	1,190	171.1

VF-03				
Stream length (ft)	Incr. Fill Volume (yd³)	Cum. Fill Volume (yd³)	EIU	Ratio Cum. Vol/Stream (yd³/ft)
0	0	0		
210	18,725	18,725	141	89.2
410	24,325	43,050	275	105.0
610	78,642	121,692	409	199.5
810	98,342	220,034	543	271.6
1,010	134,763	354,797	677	351.3
1,210	152,333	507,130	811	419.1
1,410	165,239	672,369	945	476.9
1,610	133,000	805,369	1,079	500.2
1,810	128,653	934,022	1,213	516.0

VF	Excess Spoil (yd³)	Stream Length (ft)	EIU
VF-01	1,502,501	2,530	1,594
VF-03	507,130	1,210	811
Total	2,009,631	3,740	2,405

Recalculate for Raised Fill Deck

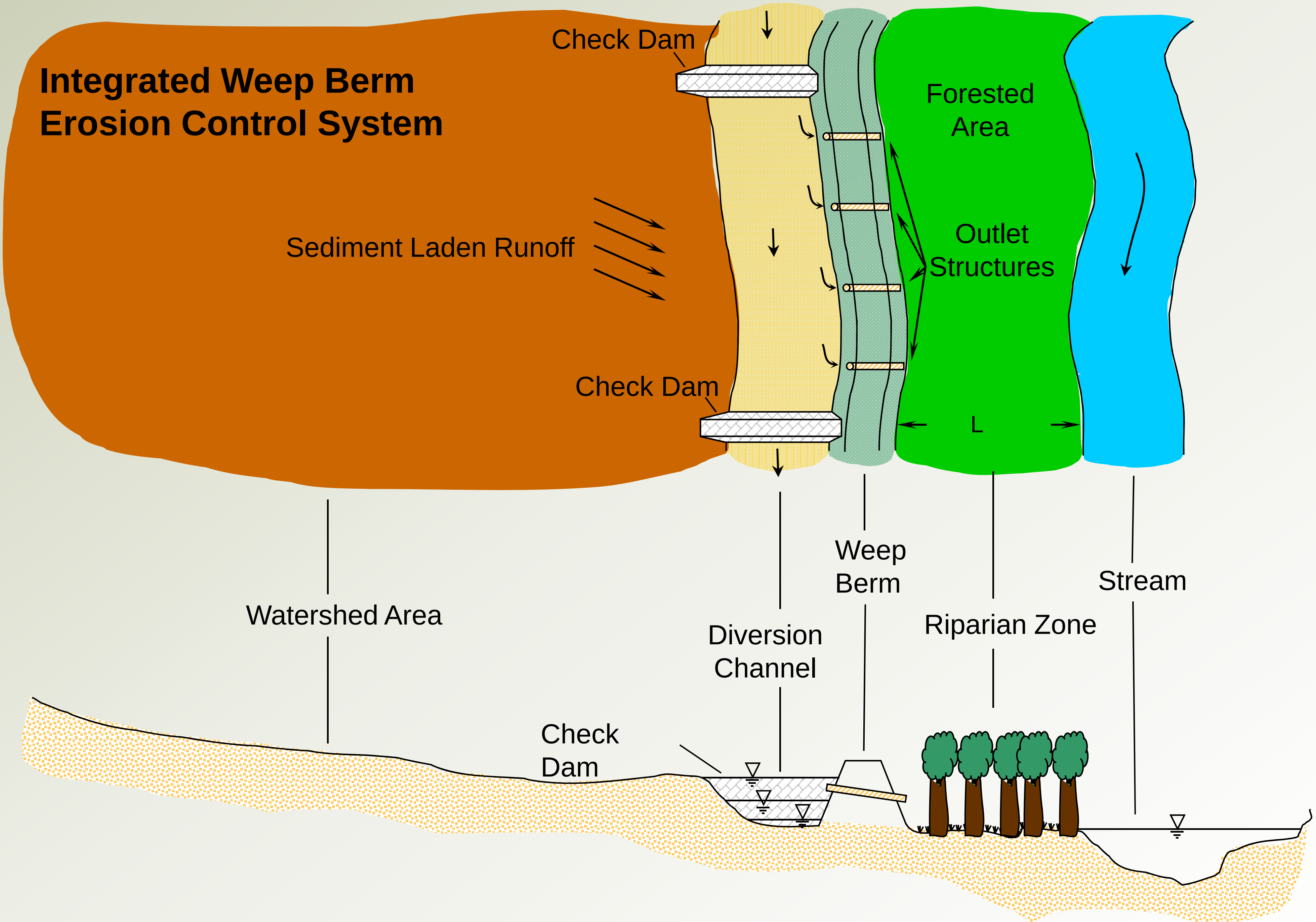
- Recalculate all fills for **raised fill deck**
- That's right, do it again based on creating a fill that is higher
  - Some complicated rules to follow with credits, incentives and adjustments to determine raised fill deck elevation (sort of like taxes!)
- Calculations are watershed based

FPOP Costs

- Engineering consulting costs
  - 3 to 5 weeks for typical mine
  - $12,000 to $20,000

4. Transition Diversion to Weep Berm

- Design features
  - Check dams installed along the diversion
    - Sediment ditch
  - Controlled diffuse flow to forest
    - Rock burritos and/or increased base infiltration rate
  - Forest passive water quality attenuation
    - CEC, organic material, soil and geology
    - Infiltration and filtration
- Eliminates/reduces bench ponds (cost savings)



Integrated Weep Berm
Erosion Control System
Check Dam
Sediment Laden Runoff
Check Dam
Forested Area
Outlet Structures
L
Watershed Area
Diversion Channel
Weep Berm
Riparian Zone
Stream
Check Dam

Advantages of Weep Berms

- Readily integrated into current mining operations and reclamation
- Cost-effective sediment and water quality treatment systems
- 99+% treatment of runoff volume
- Reduces peak flow
- Increases base flow
- Reduces runoff to valley fills and reduces size of sediment ponds
  - Locate pond closer to fill – lessens stream loss

August 2000

Weep Berm Performance

- Georgia
  - Construction site, storm water and sediment control (GA funded)
- Georgia
  - Construction site, comparison of weep berm and silt fence (EPA funded)
- Peru (copper and zinc mine)
  - Treatment of sediment and metals (Antimina)
- Ghana (gold mine)
  - Treatment of sediment and metals through elephant grass (Newmont)
- Kentucky
  - Passive water treatment (sediment, pathogens and nutrients) – intensely grazed area
- Kentucky
  - Passive water treatment (sediment, pathogens and nutrients) – horse muck storage facility

Weep Berm BMP

- Performance
  - Not yet used in Appalachian coal mining
  - Peak flow reduction and high-efficiency sediment treatment - verified at construction sites
  - Reduction of metals and other water quality constituents – successful at other mines and locations
- Cost
  - Expect cost-neutral with savings associated with elimination/size-reduction of bench ponds
- Adaptable to current contour and area mining

Weep Berm BMP

- Need applied research (field verification)
  - Conductivity reduction
  - Performance of various design and mining situations
  - Forest as a passive treatment system
  - Berm stability, etc.
- Regulatory impediment
  - No discharge NPDES permit (diffuse source)
  - Removal of natural earthen barrier and replace with engineered berm (will require OSM experimental practice)

5. Sediment Pond Treatment System

- Flocculation to reduce TSS, TDS, adsorptive and ionic precipitates
- Floating siphon (cleanest water and enables controlled discharge)
- Diffuse discharge to riparian zone (CEC and OM)
- Uptake plants (sulfate and selenium)

Flocculation

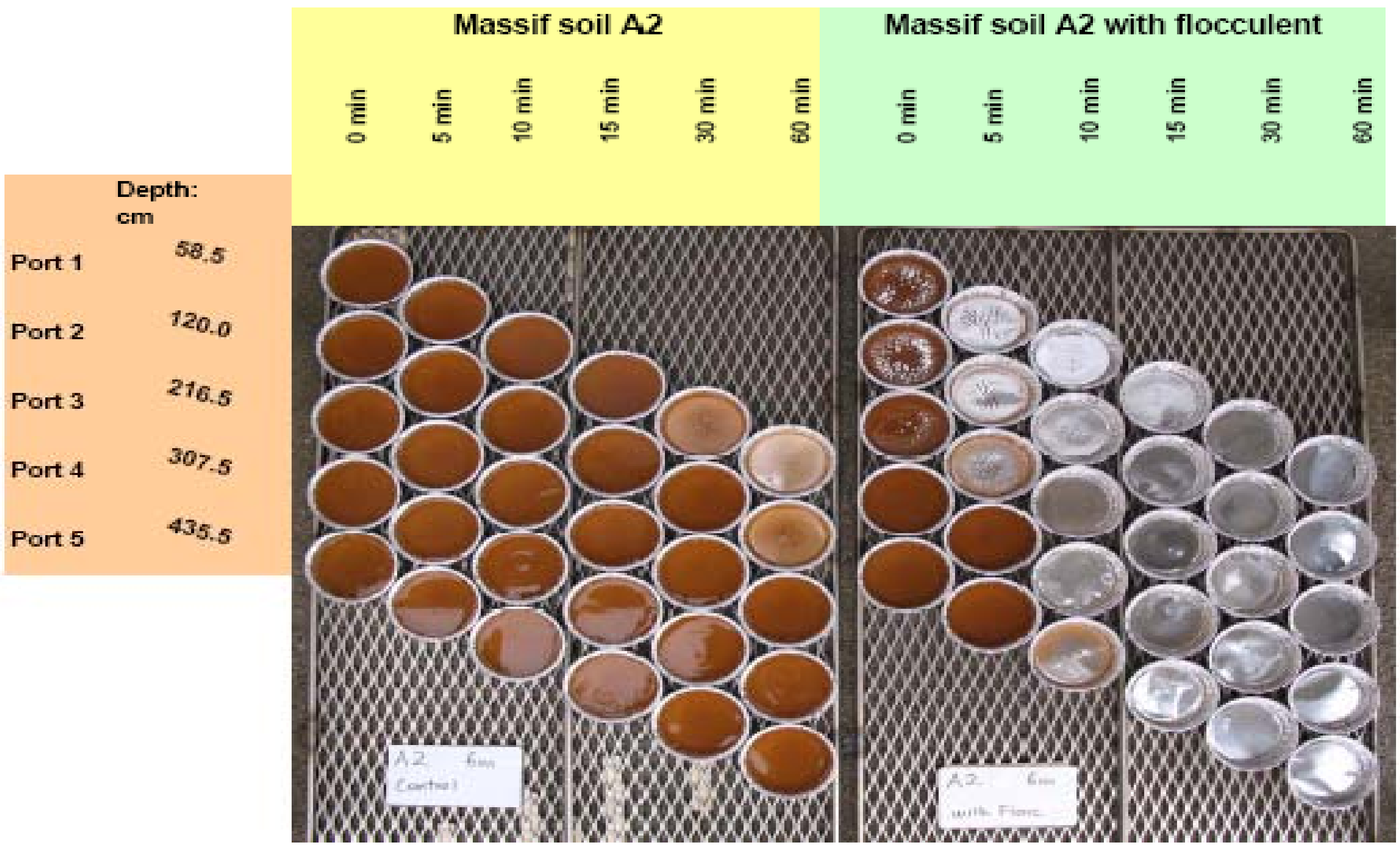
- Highly effective sediment and precipitate removal (fine particles and associated adsorbed chemical constituents)
- Water quality treatment
- Located up-gradient of treatment pond (rapid mixing)
- Passively introduce flocculent as function of inflow
  - Storm event driven during active mining
  - Less flow fluctuation once fill completed

Flocculation

- Targeted use in high sediment/water chemistry time frames (active mining and/or prior mining impacts)
- Down-size sediment ponds (capital versus operating)
- Environmentally safe flocculants (APAM)
- Encouraged to meet EPA 280 NTU performance at construction sites
- Integrate with floating siphon for best results

Flocculation and Leaching Test Columns

Flocculation Performance



Floating Siphon and Down-gradient Treatment Train

- Floating siphon discharge to down-gradient treatment train (optional)
  - Decant cleanest water
    - First flush retained
    - Storage of next runoff event
      - ~ 99+% of annual rainfall – design for 10-yr 24-hr
      - ~ 95% of annual rainfall – design for 2 yr- 24-hr
    - Constant discharge rate to down-gradient filtration/treatment system (optional)

Treatment Pond BMP

- Performance – apparently some use in Appalachian coal mining but unaware of performance study
  - Peak flow reduction and high-efficiency sediment treatment
    - Verified at hard rock mining sites
  - Reduction of metals and other water quality constituents
    - Successful at other mines
- Cost
  - Expect cost-neutral or slight increase
    - Savings associated with capital investment reduction
    - Flow-proportional flocculent dispenser ~ $20-25K (relocate and reuse after fill performance achieved) and flocculent cost

Treatment Pond BMP

- Highly adaptable to current sediment pond designs
- Need applied research (field verification)
  - Sediment effluent reduction
  - Storm and annual treatment performance
    - Function of amount of area disturbance and size of storm event
  - Reduction of specific conductance and/or metals of interest, etc.
- Regulatory impediment – None

Need for Watershed Approach

- Riparian buffer and upland areas provide ecological functions
  - Water quality
  - Nutrient cycling
  - Organic matter supply
  - Temperature modification
  - Habitat provision

Recreating a Forest

How do we go from this...

Active Mine Site
Pike County, Kentucky

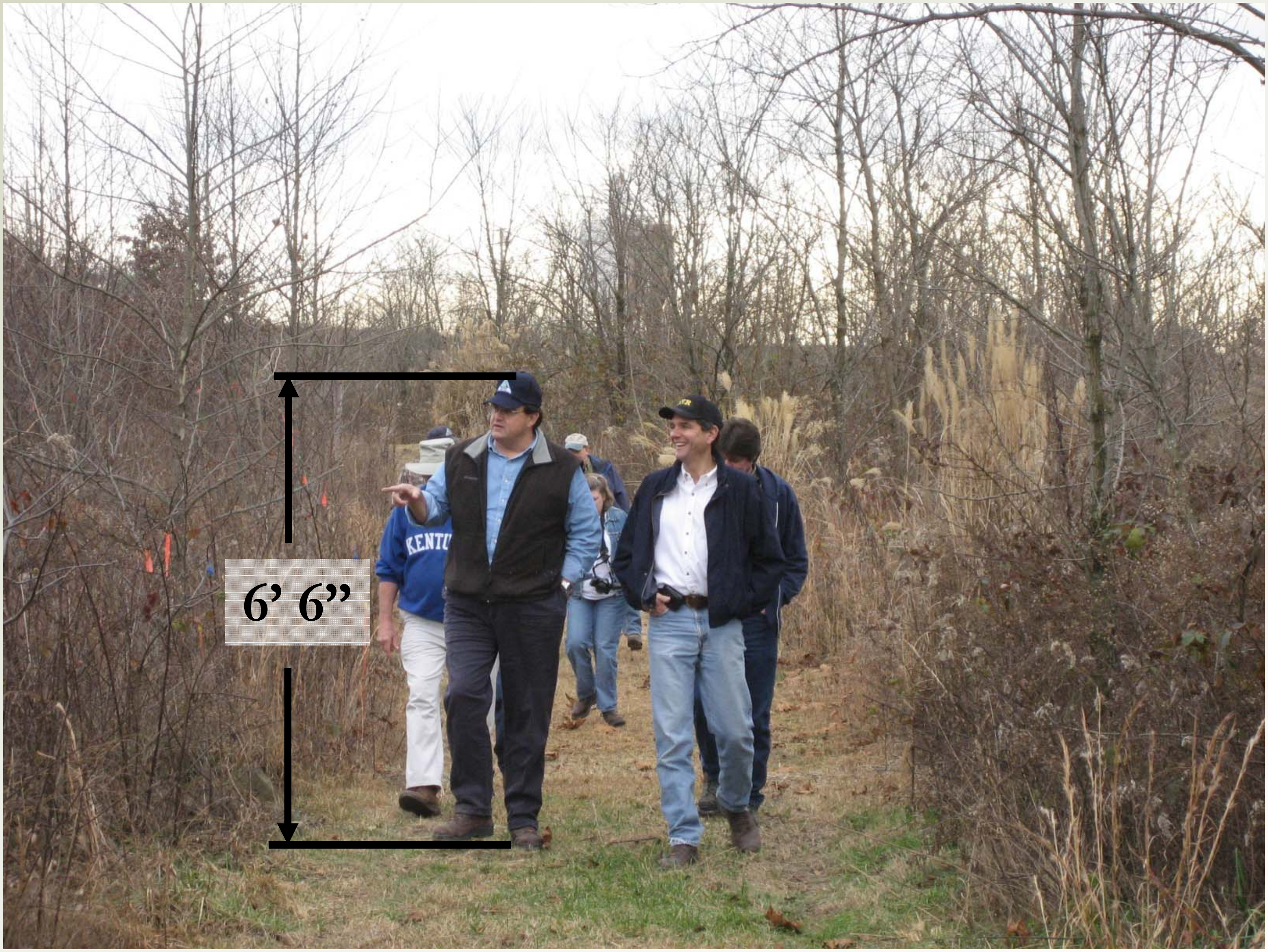
... to this?

Mixed Hardwood
East Tennessee
(Pre-SMCRA)

Forestry Reclamation Approach

- Select best available growth medium
- Minimize compaction
- Select appropriate tree species
- Use compatible grass cover
- Use proper tree planting techniques

FRA Works

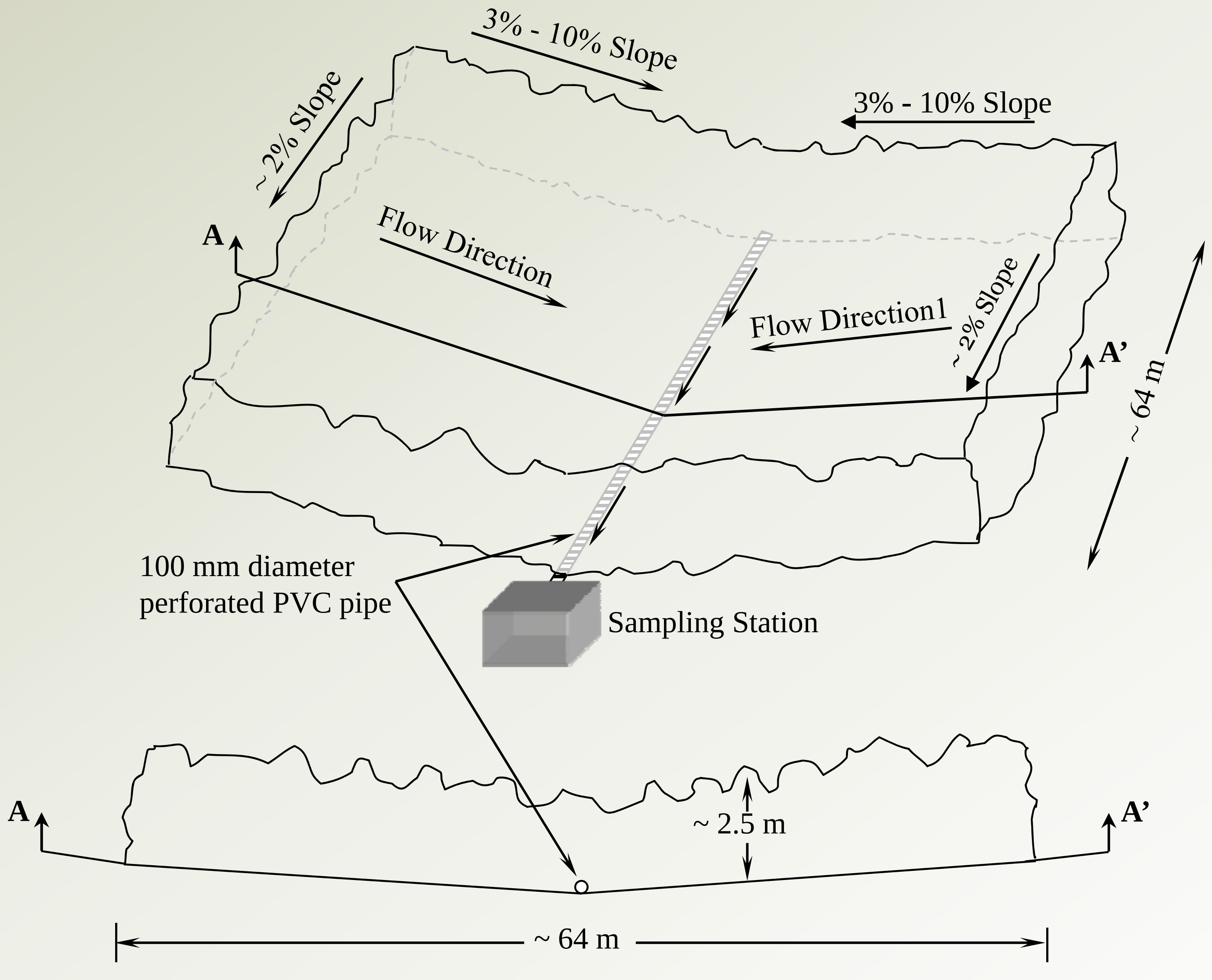


10 Years Later …

What about the Water?

Bent Mt

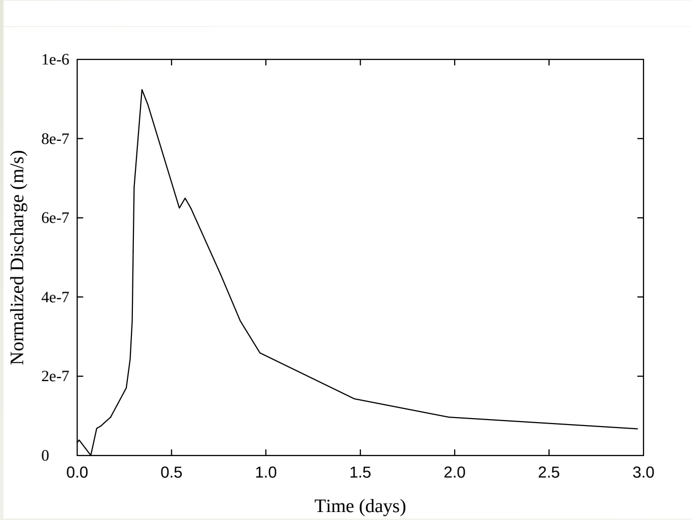
Loose-Dump Hydrology



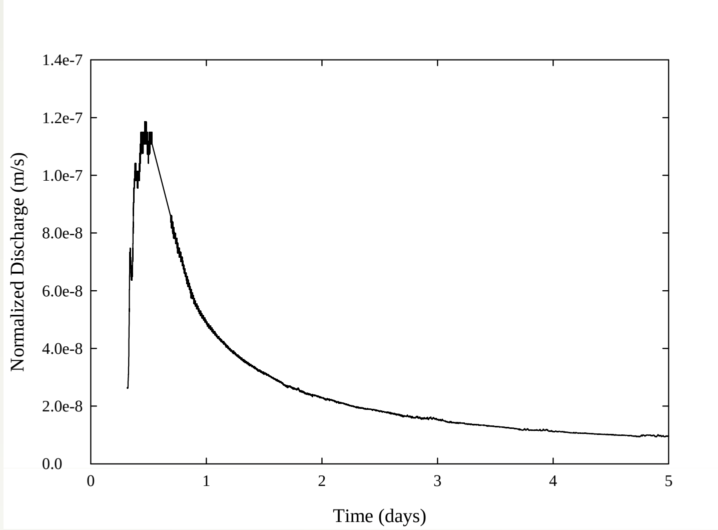
Loose-Dump Hydrology

What Did We Learn?

- Mean CN loose-dumped spoil (82) = mean CN forested watershed (83)
- Normalized hydrographs exhibit strong similarity
- PHC could be achieved
  - Pre- and post-mining hydrologic regimes are essentially same



LMS



BM

Taylor, 2007
Taylor et al., 2009

What Did We Learn?

- Low discharge volumes
  - Averaged 12% rainfall)
- Low peak discharges
  - Between 2.5×10^{-5} and 3×10^{-3} $m^3\ s^{-1}$
- Long discharge duration
  - Averaged 6 days

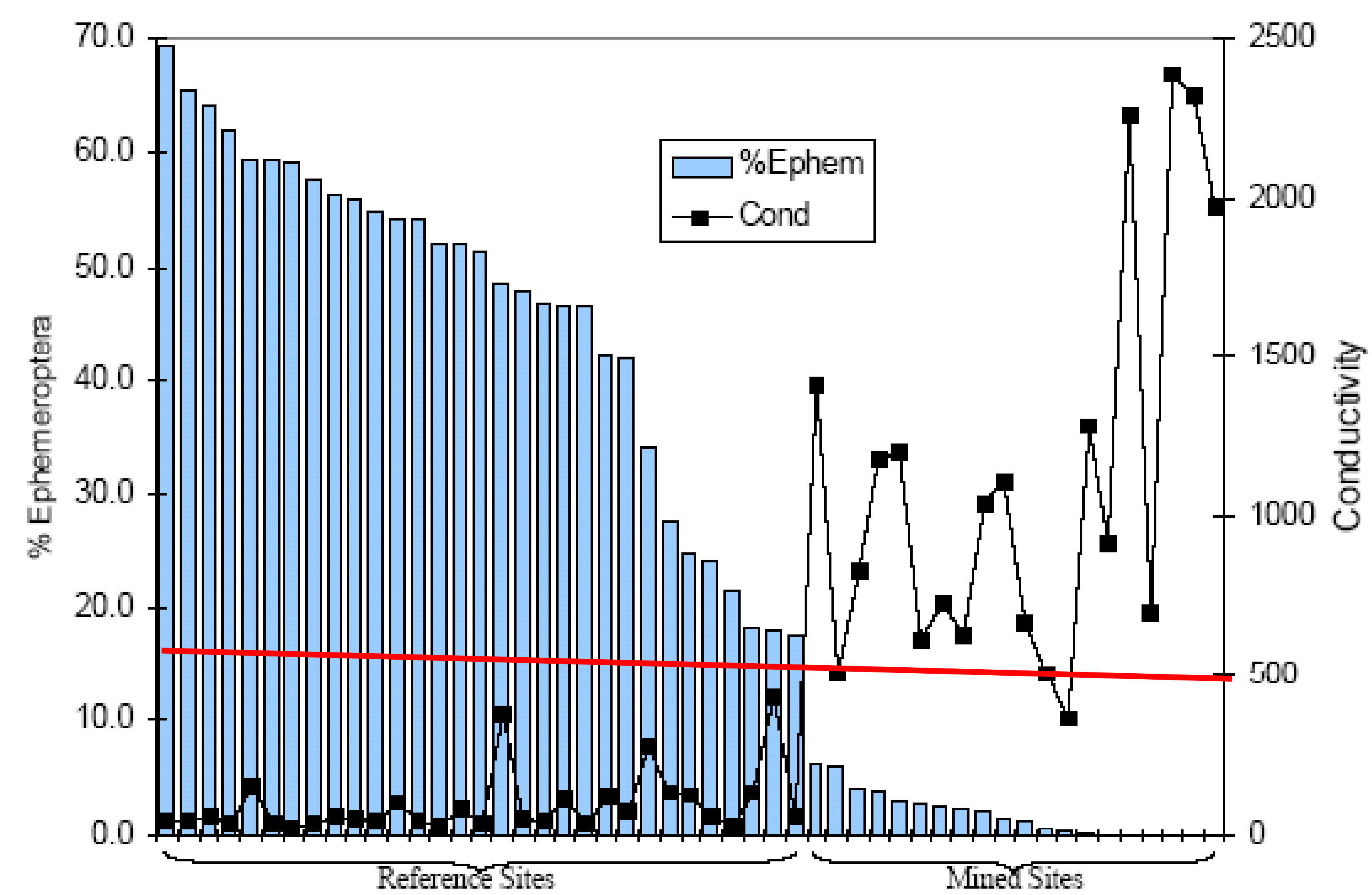
Taylor, 2007
Taylor et al., 2009

Loose-Dump WQ

- Examined pH, EC, turbidity, SS and SSC (Taylor, 2007)
- Angel (2008) monitored many other parameters as well (Ca, K, Mg, Na, SO_4, etc.)

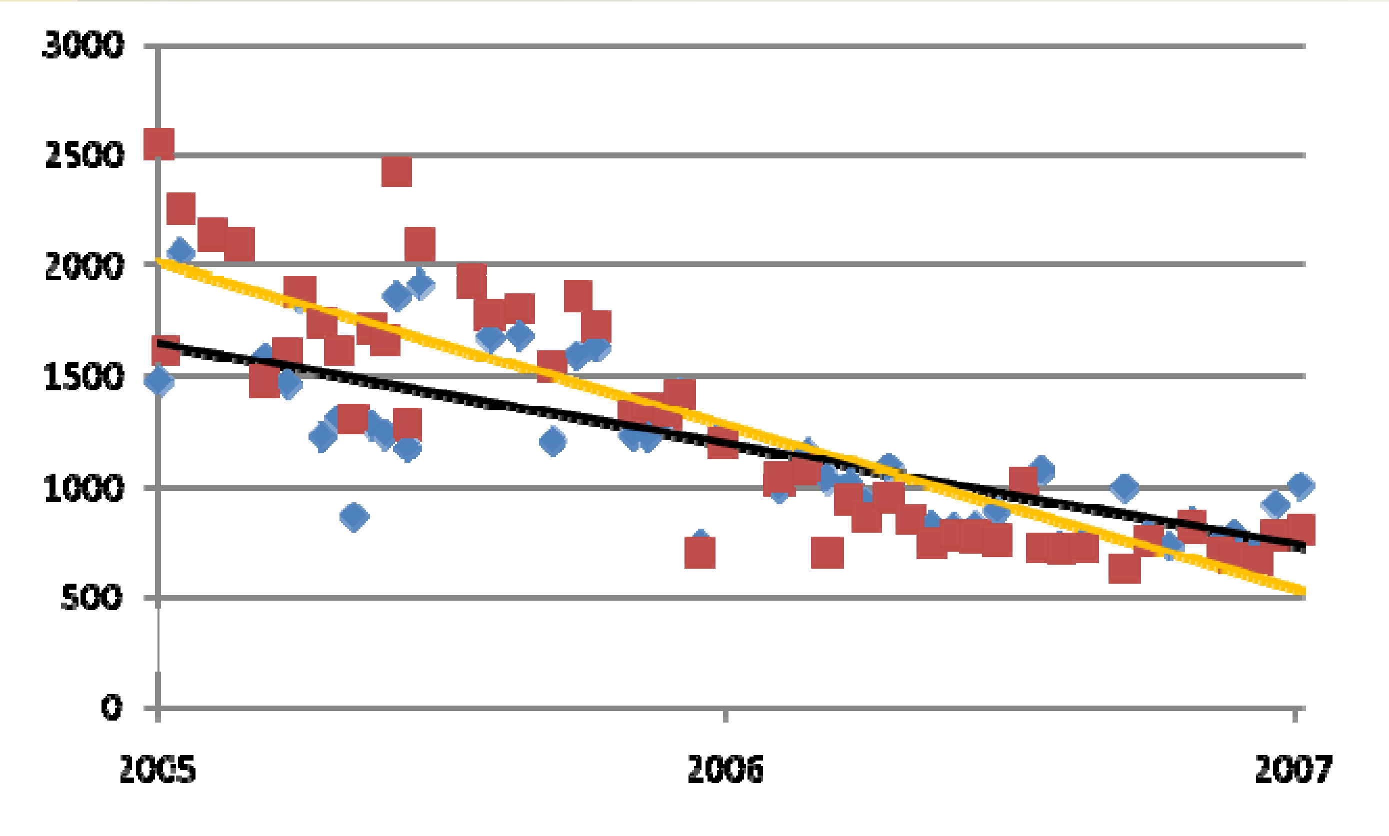
Taylor, 2007
Angel, 2008

What is the EC Threshold?



Bent Mt. EC Trends

Mixed Spoil

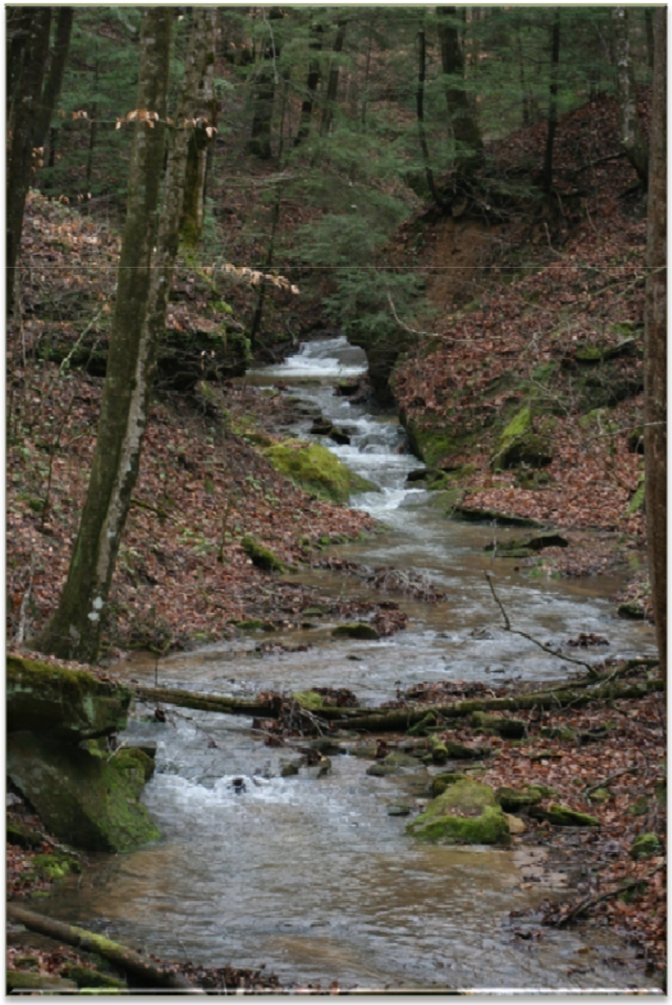


Test Cell	Mean EC (µS/cm)
Brown	416
Gray	380
Mixed	290

Guy Cove Project

Funding: $1,674,380
Fee In Lieu of Program

Restored Hollow Fill
(UK Laurel Fork Mine – Guy Cove)



Un-mined Headwater Stream
(UK Robinson Forest – L. Millseat)

Proof-of-Concept

What did we set out to do?

- Change head-of-hollow fill design
  - Establish headwater stream system
  - Recreate forested watershed
  - Improve water quality
  - Improve habitat
- Technology transfer
- Continue research

Design Components

- Valley Reconfiguration
- Hydrologic Modifications
- Intermittent Channel
- Vernal Ponds
- Ephemeral Channels
- Plantings


Before


After

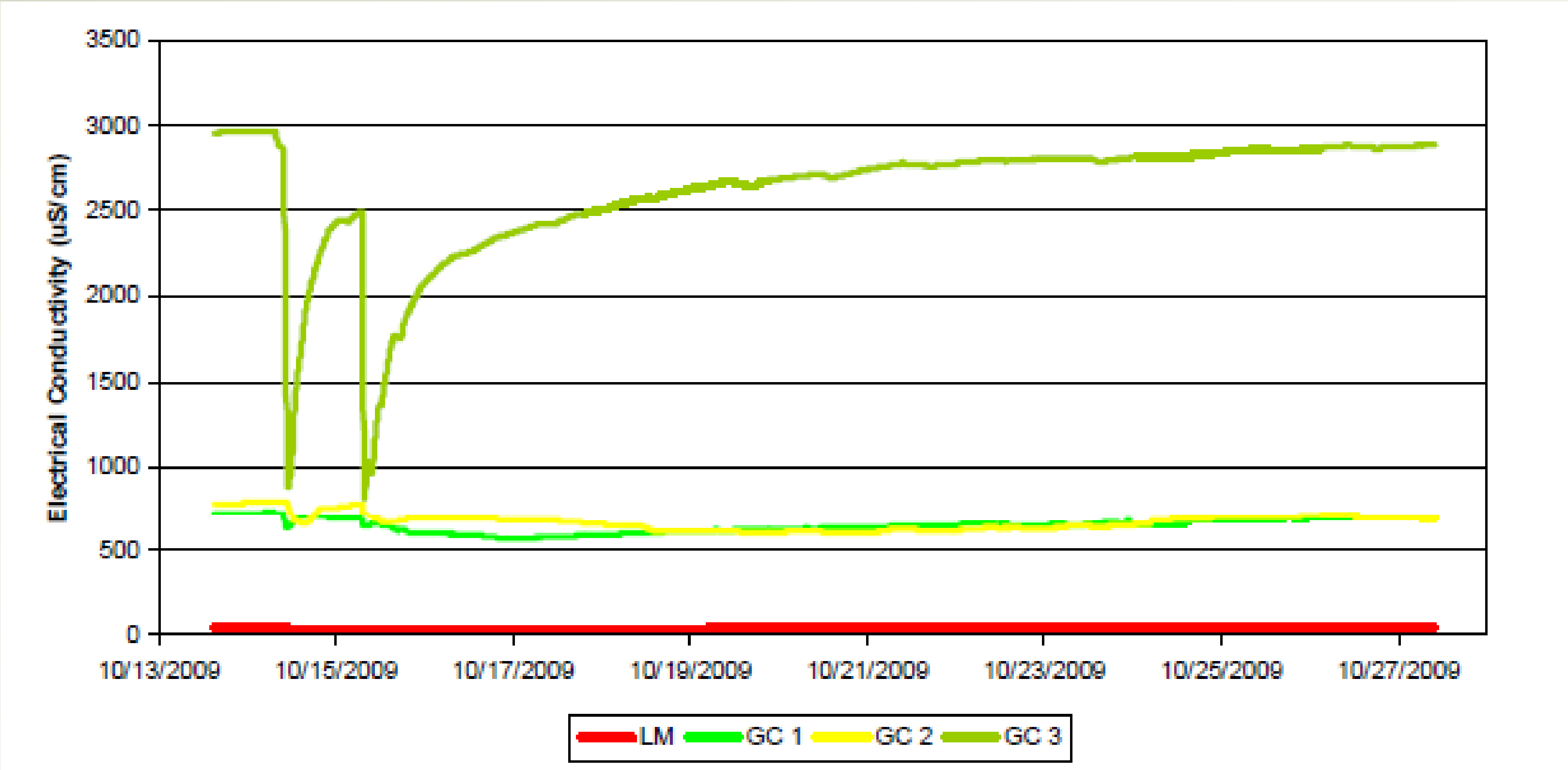

TURBO CHIEF
WERSCREEN
CALL 800-227-0534

Newly Constructed Habitat

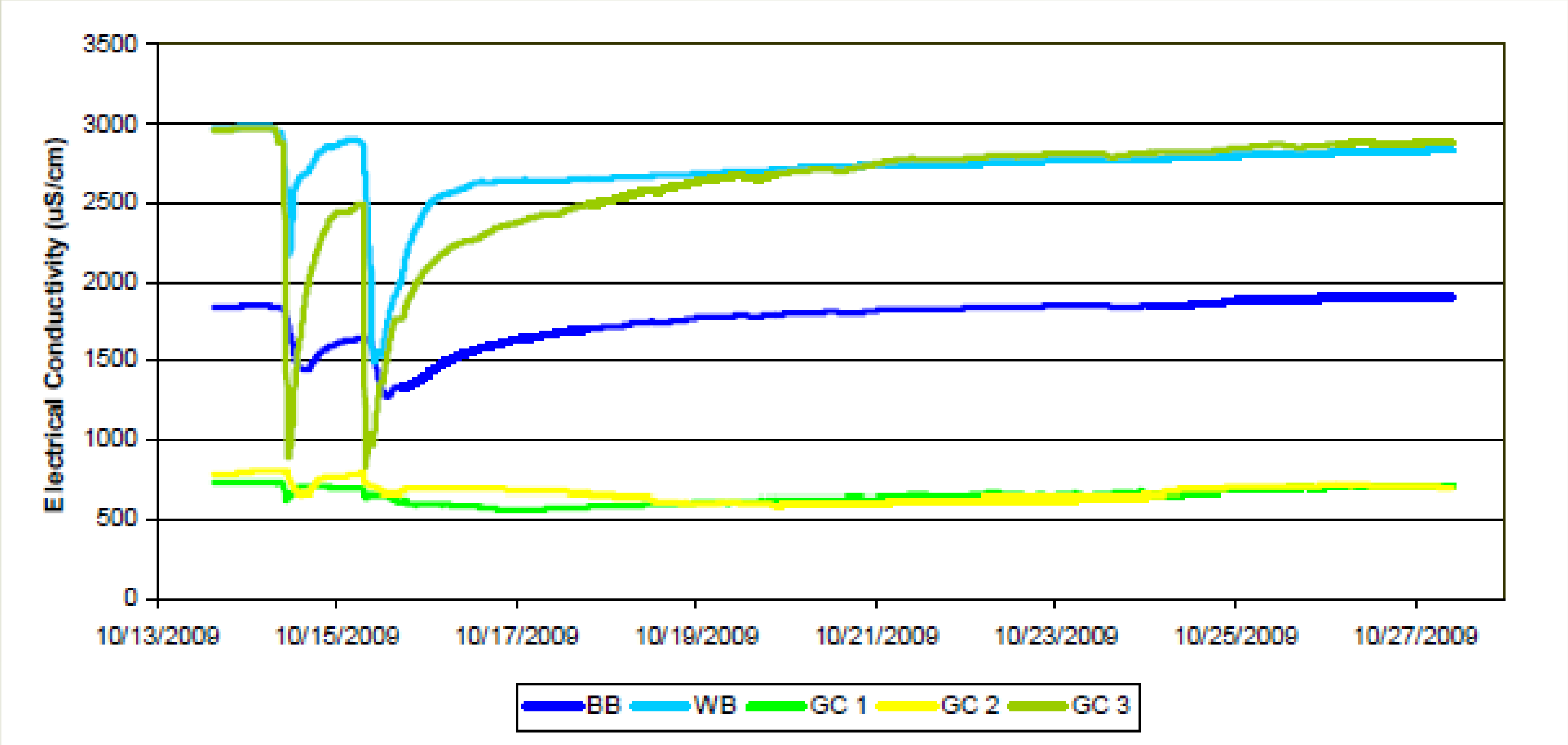
- Intermittent channel ~ 3,280 ft
  - Crown: 2,495 ft
  - Face: 385 ft
  - Toe: 400 ft
- Ephemeral channels ~ 1,680 ft (n=4)
- Vernal ponds ~ 0.3 ac (n=25)
- Loose-dump: 10.5 ac
- Reforestation ~ 40 ac (30,000 trees planted)

Monitoring Locations

Conductivity: GC vs. LMS



Conductivity: GC vs. VFs



Preliminary Habitat Results

- Presence of salamanders and aquatic invertebrates in pools

Macroinvertebrate Sampling: March 17, 2010

Stream	Density (#/m^2)	Total Insect Richness	EPT Richness	% EPT
Little Millseat	3,206	26	18	56
Guy Cove Restored	1,721	25	11	20
Guy Cove Toe	47	4	0	0
Wharton Branch	28	4	1	20

Stream Creation on Valley Fill BMP

- Performance
  - Limited data from a retrofit traditionally constructed valley fill
    - Shows establishment of aquatic invertebrates indicative of acceptable water quality
- Cost
  - Cost savings compared to stream mitigation fund
    - Current cost for stream mitigation ~ $250 to $375/linear foot
    - Expected cost to much less than in lieu fee
- Adaptable to valley fill designs using FPOP

Stream Creation on Valley Fill BMP

- Need applied research (field verification)
  - Incorporation of conductivity reducing (BMPs) and FRA into a new stream re-creation valley fill
  - Infiltration rate along stream bed
  - Enhancements of stream function through the addition of woody debris
  - Planting of large (~ 15 ft) riparian zone trees
  - Re-cycling stream prior to next valley fill construction
  - Assessment of flow regime, etc.
- Regulatory impediment – OSM experimental practice required

Monitoring Requirements for Research Needs

- Continuous monitoring
  - Rainfall
  - Runoff
  - Conductivity (ionic species, periodic)
  - Turbidity
  - Aquatic invertebrates (seasonal)
- Monitor up- and down-gradient of various treatment systems
- Monitoring down-gradient of prior mining seeps

Specific Conductance Perspective

- Large variance
- Related to recent rainfall
- Decreases over time with implemented BMPs
- Regulatory value(s)
  - Active versus closure (reclamation) – temporary versus long term
  - Single sample (**bad idea**)
  - Average (or moving average) – NPDES approach (30 day average)
  - Acceptable short-term exceedance
- Impact is a function of:
  - Ionic species and/or metals
  - Concentration
  - Duration
  - Frequency
  - Life cycle - EPT

Questions