Stream Restoration Solutions for Challenging Environments

West Virginia Mine Drainage Task Force Symposium & 15th International Mine Water Association Congress (WVTF & IMWA)

April 22, 2024: 3:00 – 4:40 PM, Stream Renewal and Treatment, Salon D

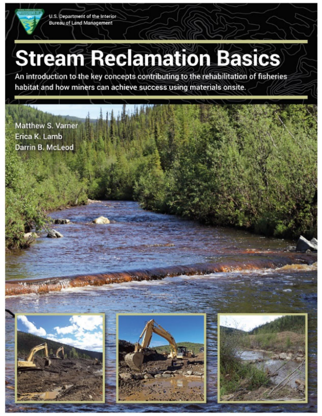
Mary Beth Berkes

Introduction

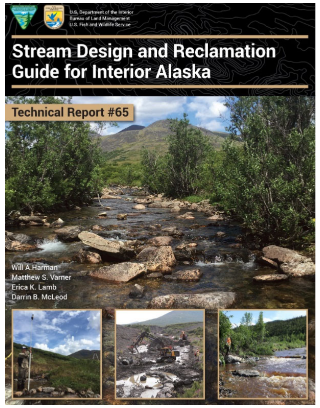
- **Technical Leader at GAI Consultants, Inc**
  - Engineering & Environmental Consulting Firm
  - Offering Services Related to Abandoned Mine Remediation and Reclamation, Environmental Permitting, Civil & Geotechnical Engineering
- **Team Specializes in Water Resources Design, Hydraulic Modeling**
  - Focus on Water in the Natural Environmental
  - Flooding, Bridge Replacements, Stream & Wetland Restoration Design
- **Conservationist**
  - Love for the Outdoors
  - Personal Goal to Preserve Resources for the Next Generation

Stream Reclamation and Mined Land

- **Bureau of Land Management Publications**
  - Unstable Streams are Left after Mining and Sometimes Even After Reclamation
  - Instability Results in Loss of Stream Function, Degraded Fish Habitat, Water Quality Impacts
- **Stable Natural Channel System Critical for Flow Management at Reclamation Sites**
  - Transport Runoff
  - Prevent Erosion and Flooding
- **Goal**
  - Apply These Ideas to Three Unique Case Study Sites to Show Effectiveness and Practical Applications for the Mining Industry



Mined Land



Reclaimed Mine Land

Goals & Agenda

- **Stream Restoration Overview**
- **Challenges with Reclaimed Lands**
- **Case Studies with Solutions to be Applied**
  - Steep Terrain in West Virginia
  - Natural Conditions through a Culvert Crossing
  - Open Area, Erosion Prone Soil
- **Considerations**
  - Balancing Stability, Constructability, Cost
- **Benefits**
  - Gaining Environmental Uplift Across a Range of Landscape Types and Conditions
- **Questions & Discussion**

Ideal Environment

Challenging Environment

Stream Restoration Overview

- Wikipedia: *"Work conducted to improve the environmental health of a river or stream in support of biodiversity, recreation, flood management, and/or landscape development."*
- Goal: To Restore an Impacted Reach to an Original or Reference State
- Multi-disciplinary: Combines Civil Engineering, Ecology, and Environmental Planning

Before Restoration

3 Years Post-Restoration

Goals & Challenges of Mine Land Reclamation

- **Establishing Effective Conveyance**
  - Manage Storm Flows, Transport Runoff Downslope
  - Prevent Flooding On-site or Impacting Property
- **Re-establish Historic Drainage Patterns**
  - Restore Site Hydrology and Stream Function
  - Address Degraded Fish Habitat
  - Improve Water Quality
- **Promote Recreation**
  - Providing Site Access
- **Challenges Encountered**
  - Conveyance Down Steep Hillsides
  - Roadway Crossings
  - Erosion Prone Soil and Unvegetated Land
- **Case Study Presented for Each Challenge Above**

Reclaimed Mine Land

Case Study – Conveyance on Steep Terrain

- **Manufactured Materials vs Native Materials**
  - Riprap Conveyance is a Common Solution
  - Natural Materials (Log and Boulders) Available at Similar Cost
  - Step Pools Equally Effective with Ecological Benefits!

Riprap for Effective Conveyance on Steep Terrain

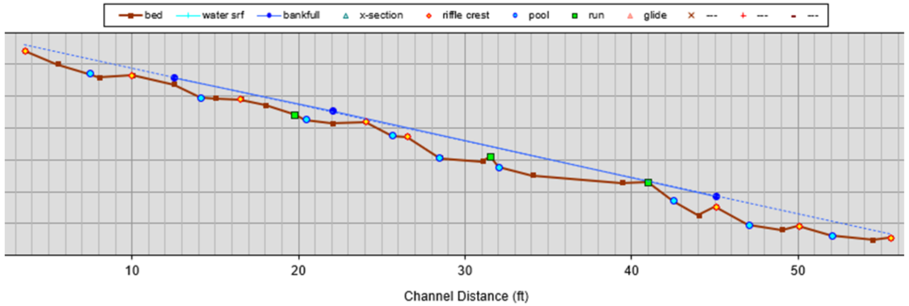
Design Reaches: Rock and Log Step Pools

Case Study – Conveyance on Steep Terrain

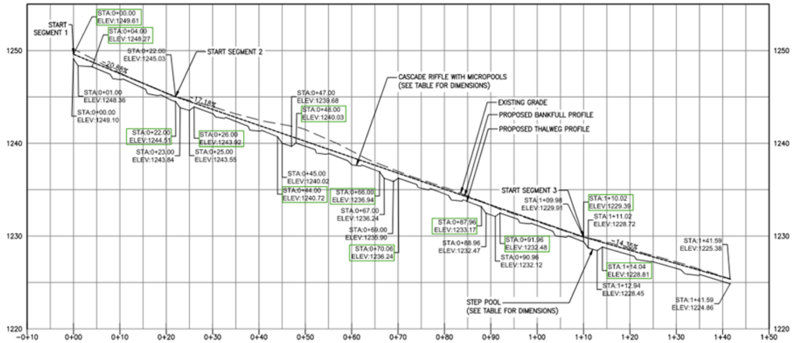
- **Designing Step Pools Using a Reference Reach**
  - Build a System Structurally and Ecologically Comparable to a Natural Channel
  - Design Based on Field Data and Comparing Dimensionless Ratios

Reference Reach

Design Reach



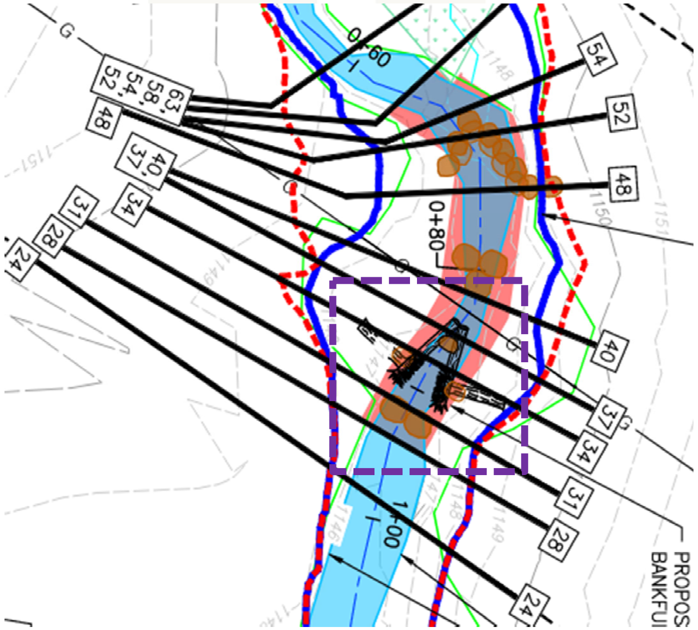
Reference Profile



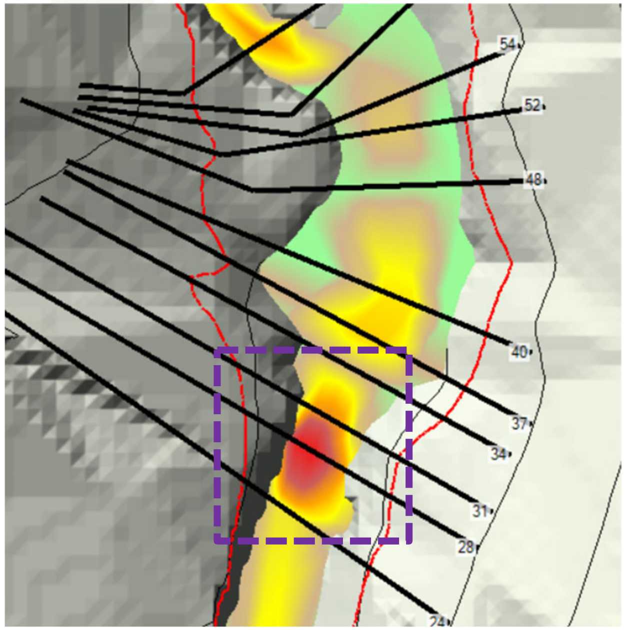
Design Profile

Case Study – Conveyance on Steep Terrain

- **When Design Ratios and Reference Conditions are Exceeded**
  - Topographic Constraints Require Higher Drops
  - Budget or Construction Access Constraints can Warrant Greater Spacing Between Pools
- **Use Hydraulic Modeling to Identify Areas of High Shear Stress to Value Engineer Design**

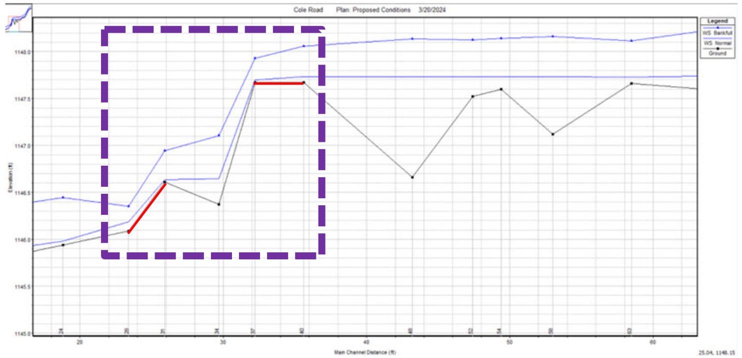


Cross Section Location Map and Design Plan



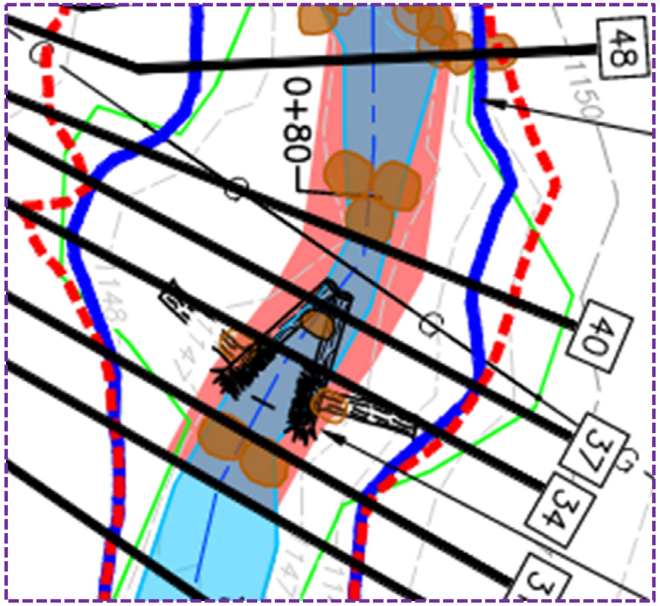
Hydraulic Modeling Output: Higher Shear Stresses After Drops

Description	Cross Section	Froude No.	Shear (psf)	Particle Moved (mm)*	D_{84} of Bed Mix (mm)	D_{84} Stable?	D_{50} of Bed Mix (mm)
Upstream of Work	120	0.49	0.31	23	100	Stable	25
Upstream of Work	107	1.01	1.17	92	100	Stable	25
Upstream of Work	92	0.38	0.22	16	100	Stable	25
Upstream of Work / Upstream ROW Limit	87	0.34	0.17	12	100	Stable	25
Upstream of Work	78	0.98	0.95	74	100	Stable	25
Upstream of Work	72	0.23	0.11	8	100	Stable	25
Upstream of Work	63	0.92	1.01	79	100	Stable	25
Upstream Start of work; Pool	**58**	**0.17**	**0.06**	**4**	**100**	**Stable**	**25**
Start Rock J-Hook; Riffle	**54**	**0.28**	**0.14**	**10**	**305**	**Stable**	**305**
J-Hook Invert; Riffle	**52**	**0.33**	**0.18**	**13**	**305**	**Stable**	**305**
Max Pool (A-A); Meander Pool	**48**	**0.07**	**0.01**	**1**	**100**	**Stable**	**25**
Boulder at End of Structure; Riffle	**40**	**0.65**	**0.58**	**44**	**305**	**Stable**	**305**
Log Cross Vane Invert; Riffle	**37**	**0.79**	**0.7**	**54**	**305**	**Stable**	**305**
Max Pool; Pool	**34**	**0.19**	**0.07**	**5**	**100**	**Stable**	**25**
Boulder at End of Structure (C-C); Riffle	**31**	**1.00**	**1.22**	**96**	**305**	**Stable**	**305**
Tie in to Existing; Riffle	**28**	**2.15**	**3.67**	**302**	**305**	**Stable**	**305**
Downstream of Work / Downstream ROW Limit	24	0.46	0.31	23	100	Stable	25
Downstream of Work	9	0.60	0.57	43	100	Stable	25
Downstream of Work	5	1.01	1.19	93	100	Stable	25

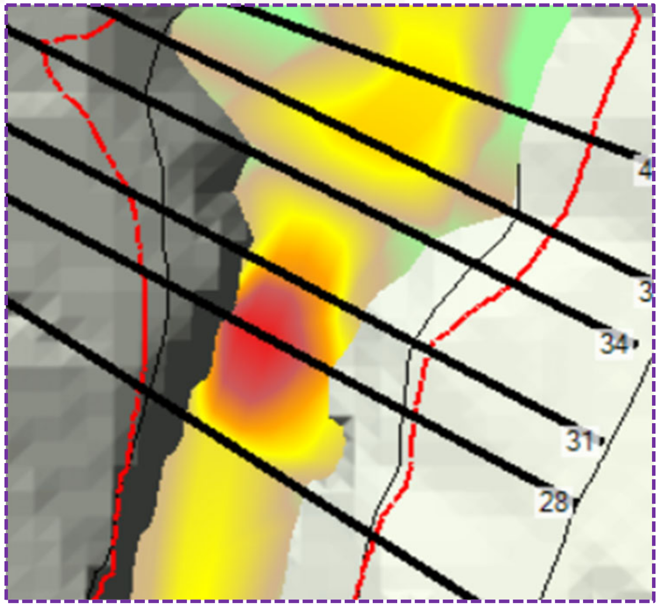


Case Study – Conveyance on Steep Terrain

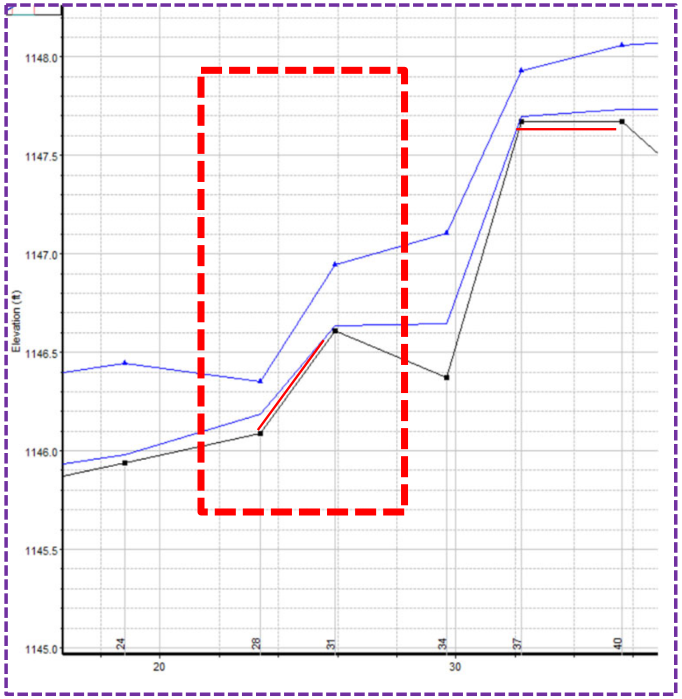
- **Use Hydraulic Modeling to Identify Areas of High Shear Stress to Value Engineer Design**



Cross Section Location Map
and Design Plan

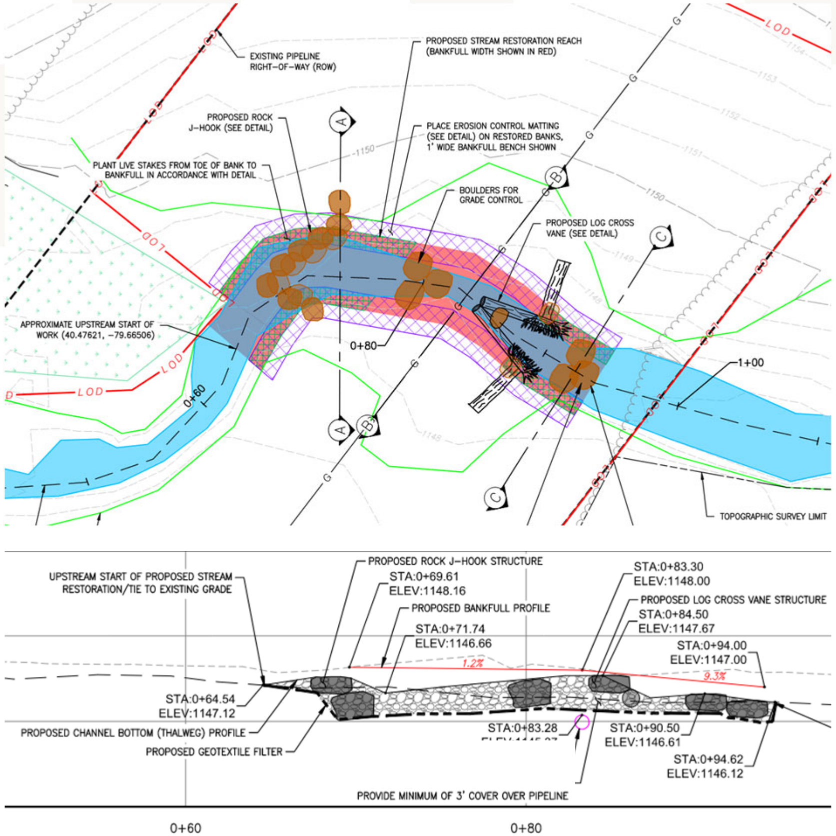


Hydraulic Modeling Output: Higher Shear
Stresses After Drops



Case Study – Conveyance on Steep Terrain

- **Use Hydraulic Modeling Results to Identify Areas of High Shear Stress and Improve Design for Added Stability**



Design Update: Extra Boulders Buried/Subgrade at Locations of High Shear or Velocity

Constructed Restoration Reach

Case Study – Conveyance on Steep Terrain

- **Natural, Effective Conveyance on Steep Slopes**
  - Comparable Material Cost and Construction to Manufacturer Linings
  - Runoff Conveyance with Ecological Benefits!
- **Benefits**
  - Increased Energy Dissipation: Flat, Deep, Pools
  - Bank Erosion Less Likely
  - Increased Habitat Diversity
  - Native Bed Material: Promotes Balanced Sediment Transport Downstream
  - Improved Water Quality

Step Pool Construction

Restored Reach Post Construction

Case Study – Culvert Crossing

- **Reclamation Often Requires Roads for Access and Recreation**
- **Natural Channel Design Approach in Conjunction with Culvert Replacement**
  - Consider Confined Environment, Topographic Constraints: Simple, Constructible Design
  - Stream Restoration to Provide Grade Control Upstream, Through, and Downstream of Crossing
  - Logs and Rocks Appropriate for Stream Size will Blend in with Surroundings

Before Restoration

3 Years Post-Restoration

Case Study – Culvert Crossing

- **Challenges**
  - Maintaining Balanced Sediment Transport
  - Material Loss at Inlet, Deposition in Pool at Outlet
- **Recommendations**
  - Grade Control Through Structure and at Inlet: Fish Baffles an/or Boulders

Inlet

Inlet: As-Built Condition

Inlet: Year 4 Monitoring

Outlet

Outlet: As-Built Condition

Outlet: Year 4 Monitoring

Case Study – Culvert Crossing

- **Monitoring Results, USEPA Habitat Assessment Valuation (HAV) to Measure Success**
  - Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macriinvertebrates, and Fish, Second Edition, EPA 841-B-99-002, 1999 EPA Office of Water
  - Compare to Reference Reach and Projection: 10 Individual Parameters Scored from 1-20
  - Parameters Improved: Bank Stability, Vegetative Protection
  - Overall Scores: Baseline (138), Projected-Year 5 (126), Year 4 Restoration (135)

HAV Summary Table

HAV Parameters (High-Gradient)	*RBP Reference Score (Pre-Impact Condition)*	Estimated RBP Five Year Maturity[1]	2023 Restoration Score (Post-Construction)
Date	*11/19/2014*	Estimated	5/30/2023
1. Epifaunal Sub. and Avail. Cover (0-20)	13	11	15
2. Embeddedness (0-20)	16	14	14
3. Velocity/Depth Regime (0-20)	15	15	15
4. Sediment Deposition (0-20)	15	13	10
5. Channel Flow Status (0-20)[2]	16	16	15
6. Channel Alteration (0-20)	14	12	12
7. Frequency of Riffles or Bends (0-20)	17	17	17
8. Left Bank (LB) Stability (0-10)	7	6	8
8. Right Bank (RB) Stability (0-10)	7	6	8
9. LB Vegetative Protection (0-10)	5	5	8
9. RB Vegetative Protection (0-10)	5	5	8
10. LB Riparian Veg Zone Width (0-10)	7	4	3
10. RB Riparian Veg. Zone Width (0-10)	1	2	2
Habitat Assessment Value	*138*	126	135
Narrative Score	*Sub-Optimal*	Sub-Optimal	Sub-Optimal

[1]RBP parameter scores were estimated in the Plan to demonstrate how the restoration reach would perform following construction .
[2]Channel flow status subject to natural seasonal conditions, which may provide for a higher parameter score in the spring than late summer.

Parameters to be evaluated in sampling reach

Habitat Parameter	Condition Category: Optimal	Suboptimal	Marginal	Poor
1. Epifaunal Substrate/ Available Cover	Greater than 50% of substrate favorable for epifaunal colonization and fish cover; mix of snags, submerged logs, undercut banks, cobble or other stable habitat and at stage to allow full colonization potential (i.e., logs/snags that are not new fall and not transient).	30-50% mix of stable habitat; well-suited for full colonization potential; adequate habitat for maintenance of populations; presence of additional substrate in the form of newfall, but not yet prepared for colonization (may rate at high end of scale).	10-30% mix of stable habitat; habitat availability less than desirable; substrate frequently disturbed or removed.	Less than 10% stable habitat; lack of habitat is obvious; substrate unstable or lacking.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
2. Pool Substrate Characterization	Mixture of substrate materials, with gravel and firm sand prevalent; root mats and submerged vegetation common.	Mixture of soft sand, mud, or clay; mud may be dominant; some root mats and submerged vegetation present.	All mud or clay or sand bottom; little or no root mat; no submerged vegetation.	Hard-pan clay or bedrock; no root mat or vegetation.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
3. Pool Variability	Even mix of large-shallow, large-deep, small-shallow, small-deep pools present.	Majority of pools large-deep; very few shallow.	Shallow pools much more prevalent than deep pools.	Majority of pools small-shallow or pools absent.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
4. Sediment Deposition	Little or no enlargement of islands or point bars and less than <20% of the bottom affected by sediment deposition.	Some new increase in bar formation, mostly from gravel, sand or fine sediment; 20-50% of the bottom affected; slight deposition in pools.	Moderate deposition of new gravel, sand or fine sediment on old and new bars; 50-80% of the bottom affected; sediment deposits at obstructions, constrictions, and bends; moderate deposition of pools prevalent.	Heavy deposits of fine material, increased bar development; more than 80% of the bottom changing frequently; pools almost absent due to substantial sediment deposition.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
5. Channel Flow Status	Water reaches base of both lower banks, and minimal amount of channel substrate is exposed.	Water fills >75% of the available channel; or <25% of channel substrate is exposed.	Water fills 25-75% of the available channel, and/or riffle substrates are mostly exposed.	Very little water in channel and mostly present as standing pools.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

Parameters to be evaluated broader than sampling reach

Habitat Parameter	Condition Category: Optimal	Suboptimal	Marginal	Poor
6. Channel Alteration	Channelization or dredging absent or minimal; stream with normal pattern.	Some channelization present, usually in areas of bridge abutments; evidence of past channelization, i.e., dredging, (greater than past 20 yr) may be present, but recent channelization is not present.	Channelization may be extensive; embankments or shoring structures present on both banks; and 40 to 80% of stream reach channelized and disrupted.	Banks shored with gabion or cement; over 80% of the stream reach channelized and disrupted. Instream habitat greatly altered or removed entirely.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
7. Channel Sinuosity	The bends in the stream increase the stream length 3 to 4 times longer than if it was in a straight line. (Note - channel braiding is considered normal in coastal plains and other low-lying areas. This parameter is not easily rated in these areas.)	The bends in the stream increase the stream length 1 to 2 times longer than if it was in a straight line.	The bends in the stream increase the stream length 1 to 2 times longer than if it was in a straight line.	Channel straight; waterway has been channelized for a long distance.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
8. Bank Stability (score each bank)	Banks stable; evidence of erosion or bank failure absent or minimal; little potential for future problems. <5% of bank affected.	Moderately stable; infrequent, small areas of erosion mostly healed over. 5-30% of bank in reach has areas of erosion.	Moderately unstable; 30-60% of bank in reach has areas of erosion; high erosion potential during floods.	Unstable; many eroded areas; "raw" areas frequent along straight sections and bends; obvious bank sloughing; 60-100% of bank has erosional scars.
SCORE ___ (LB)	Left Bank 10 9	8 7 6	5 4 3	2 1 0
SCORE ___ (RB)	Right Bank 10 9	8 7 6	5 4 3	2 1 0
9. Vegetative Protection (score each bank) Note: determine left or right side by facing downstream.	More than 90% of the streambank surfaces and immediate riparian zone covered by native vegetation, including trees, understory shrubs, or nonwoody macrophytes; vegetative disruption through grazing or mowing minimal or not evident; almost all plants allowed to grow naturally.	70-90% of the streambank surfaces covered by native vegetation, but one class of plants is not well-represented; disruption evident but not affecting full plant growth potential to any great extent; more than one-half of the potential plant stubble height remaining.	50-70% of the streambank surfaces covered by vegetation; disruption obvious; patches of bare soil or closely cropped vegetation common; less than one-half of the potential plant stubble height remaining.	Less than 50% of the streambank surfaces covered by vegetation; disruption of streambank vegetation is very high; vegetation has been removed to 5 centimeters or less in average stubble height.
SCORE ___ (LB)	Left Bank 10 9	8 7 6	5 4 3	2 1 0
SCORE ___ (RB)	Right Bank 10 9	8 7 6	5 4 3	2 1 0
10. Riparian Vegetative Zone Width (score each bank riparian zone)	Width of riparian zone >18 meters; human activities (i.e., parking lots, roadbeds, clear-cuts, lawns, or crops) have not impacted zone.	Width of riparian zone 12-18 meters; human activities have impacted zone only minimally.	Width of riparian zone 6-12 meters; human activities have impacted zone a great deal.	Width of riparian zone <6 meters: little or no riparian vegetation due to human activities.
SCORE ___ (LB)	Left Bank 10 9	8 7 6	5 4 3	2 1 0
SCORE ___ (RB)	Right Bank 10 9	8 7 6	5 4 3	2 1 0

Case Study – Culvert Crossing

- **Monitoring Results, Habitat Assessment Valuation (HAV) Shows Success**
  - Parameters Improved: Bank Stability, Vegetative Protection, Riffle Frequency
  - Deposition was Only Parameter to Under Perform
  - Overall Scores: Baseline (138), Projected-Year 5 (126), Year 4 Restoration (135)
- **Also Demonstrating Geomorphic Improvements**
  - Meeting Success Criteria, Holding Up Through Storms, Less Flooding

Impacted Reach

Post-Construction

Year 3 Monitoring

Case Study – Open Area, Erosion Prone Soil

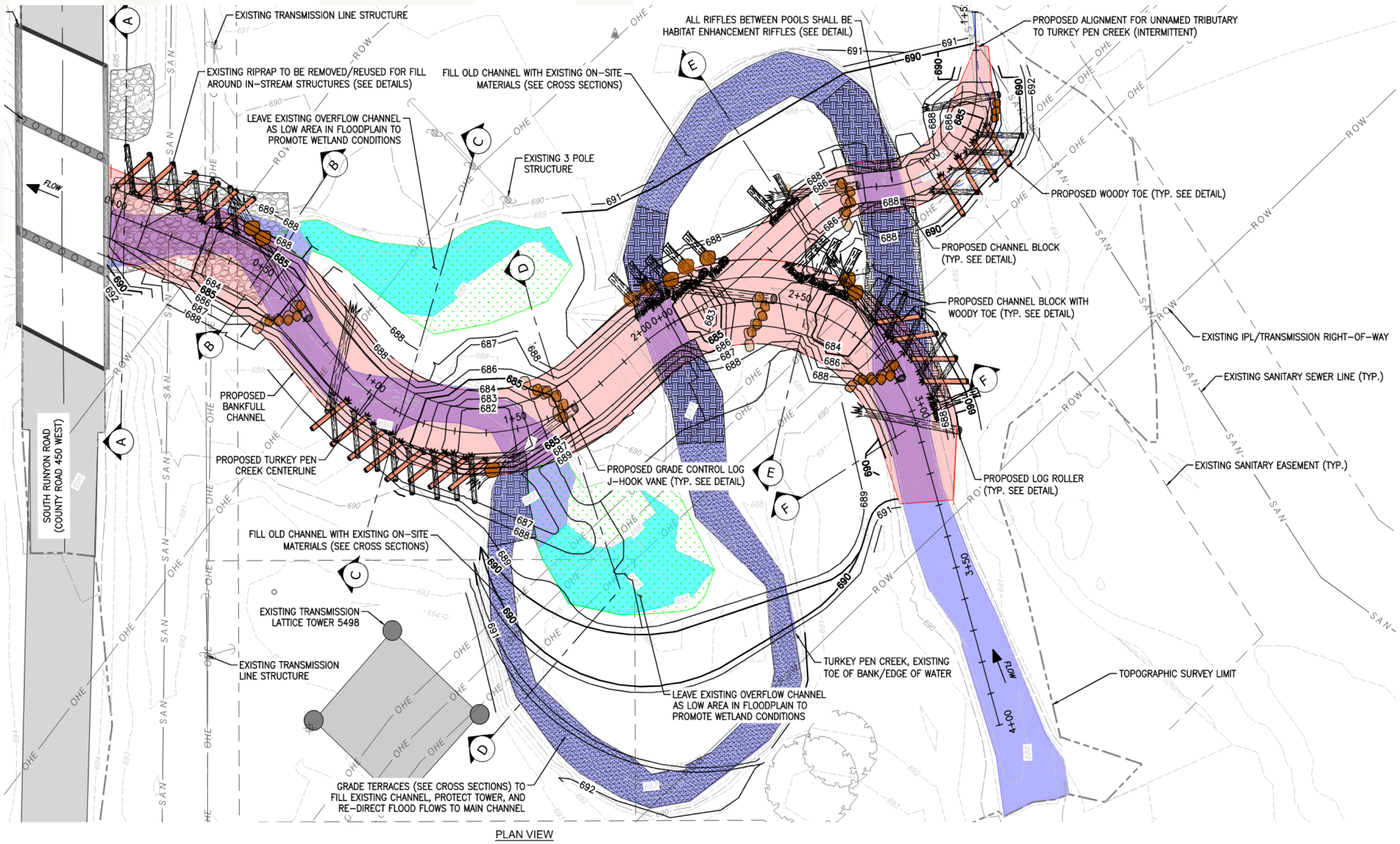
- **Challenge: Stream Prone to Movement Due to Sandy Soil, Limited Bank Vegetation**
- **Solution: Reference Reach for a Stable Dimension, Pattern, Profile – Change Alignment**
  - Reduce Bank Heights, Install Erosion Control Matting and Vegetation on Banks

Unstable Stream

Restoration Through Realignment

Case Study – Open Area, Erosion Prone Soil

- **Design Highlights**
- ***Relocate Stream***
  - Remove Sharp Bends
  - Restore Historic Floodway
  - Align with Bridge
- ***Multi-Stage Channel***
  - Bankfull (Red), Terraces
  - Reduce Bank Height
  - Floodplain Connectivity
- ***In-Stream Structures***
  - Grade Control
  - Bank Stabilization
  - Habitat Enhancement



Case Study – Open Area, Erosion Prone Soil

- **Solution: Focus on Stable Alignment and Banks**
  - Achieved Through Multi-stage Channel, Terracing, Designed Bankfull Area

Case Study – Open Area, Erosion Prone Soil

- **Solution: Focus on Stable Alignment and Banks**
  - Achieved Through Multi-stage Channel, Terracing, Designed Bankfull Area

Unstable Stream

During Construction

Post Construction

What Can be Applied from these Case Studies?

- **Mine Land Reclamation Goals are Similar to Stream Restoration Goals**
  - Effective Conveyance: Protection of Property from Risk of Erosion and Flooding
  - Promote Recreation and Reconnection to the Environment

Effective Conveyance on a Reclamation Site

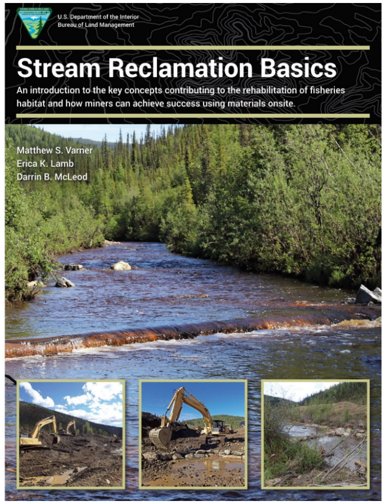
Effective Conveyance on a Stream Restoration Site

Benefits of Successful Restoration

- **Case Studies Showed Habitat Improvements Including:**
  - Balanced Sediment Transport
  - Native Species Revegetation
  - Effective Conveyance of Storm Flows and Surface Runoff
  - Decreased Bank Erosion and Flood Control
  - Increasing Aquatic Habitat and Bedform Diversity
  - Improved Water Quality
  - Recreational opportunity
  - Visually Pleasing and Functional Systems in Harmony with Nature

Conclusions

- **Goal: Achieving Effective Conveyance on Reclamation Sites**
- **Case Studies: Adaptable Solutions for Reclamation**
  - Steep Terrain: Step Pools for Conveyance
  - Culvert Crossings: Balance with Surroundings
  - Erosion Prone Soil: Multi-Stage Channel
- **Restored Streams Structurally and Ecologically = Ref Reaches**
- **Encouraged to Apply Above Techniques to Similar Site Constraints Faced During Reclamation: BLM Guidance Docs**



Questions and Discussion

- *"Implementing a river ethic will leave better tracks for those who follow."* – Dave Rosgen

WVTF IMWA 2024

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