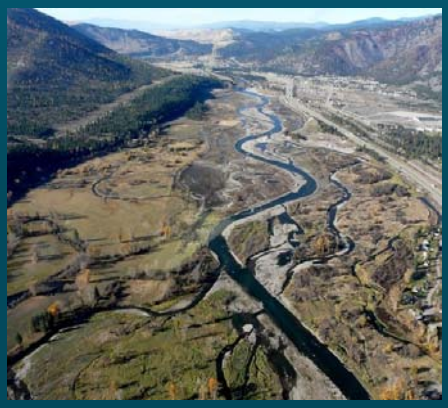
Association of Montana Floodplain Managers 2012 Conference

Approaches to Evaluating Stream Restoration Structures



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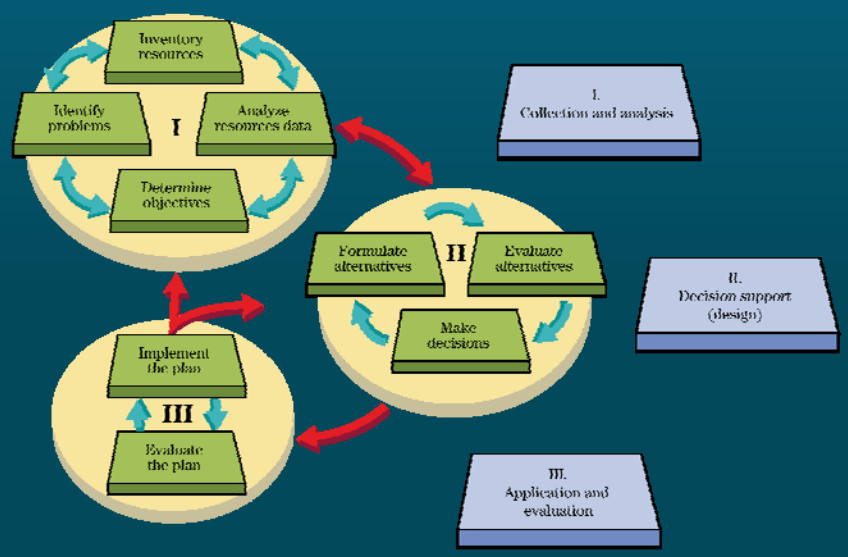
Whitefish, MT. & Corvallis, OR.

Mitch Price, PE, CFM
Water Resources Engineer

Presentation Overview

- Project Scoping & Restoration Design Framework
- Phase 1 - Planning level assessments
- Phase 2 - Design level assessments
- Phase 3 – Implementation examples

NRCS Stream Restoration Design Framework



NRCS NEH654.

Stream Restoration Design Framework

- Phase 1:
  - Identify Stakeholders
  - Establish Goals and Objectives
  - Build Multidisciplinary Team
  - Assess River Ecosystem and Limiting Habitat Factors

- Phase 2:
  - Develop Restoration Strategy
  - Develop Performance Criteria
  - Design Restoration Treatments
  - Combine Treatments → Habitat Actions
- Phase 3:
  - Implementation
  - Monitoring
  - Adaptive Management

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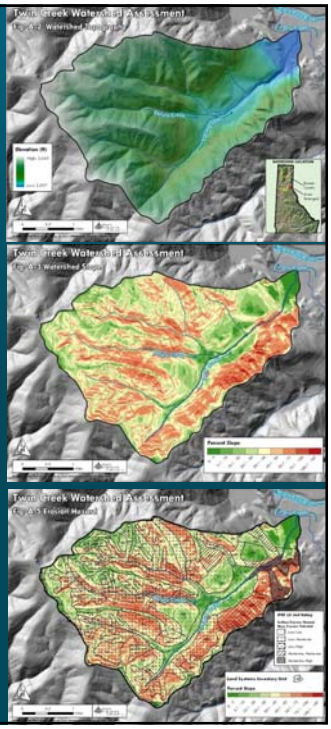
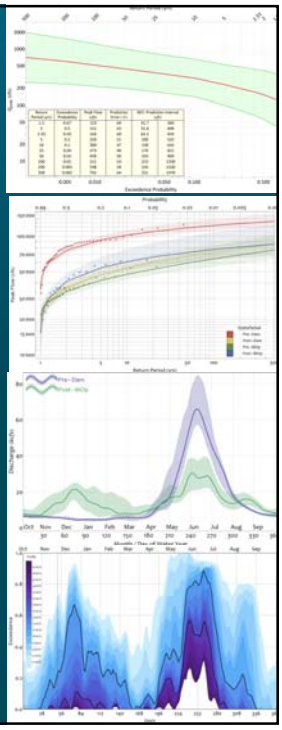
Pre-Design Assessments

- Watershed Scale
  - Hydrologic Regime
  - Ecosystem Function
    - Fisheries Habitat
    - Vegetation
  - Sediment Budget
- Reach Scale Geomorphic Assessment
  - Stream Types
  - Floodplain Connectivity
  - Hydraulic Response
  - Reach Stability
  - Sediment Regime



Hydrologic Assessment

- Identify Dominant Runoff Signatures & Hydroperiods
  - Snowmelt - Rain On Snow – Rainfall
  - Regulation or Irrigation impacts
- Peak Flow Estimates
  - Flood History.
  - MT Regional Regressions. WRIR03-4308
  - Bulletin 17B. FFA.
  - Evaluate Uncertainty
- Daily Flows
  - Measured or Synthetic
  - Quantiles & Exceedance Probabilities
  - Duration Analysis
  - Rates of Change: Flashy Hydrology.



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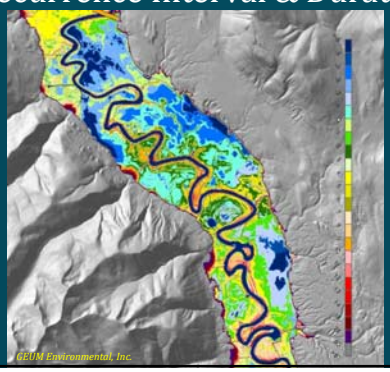
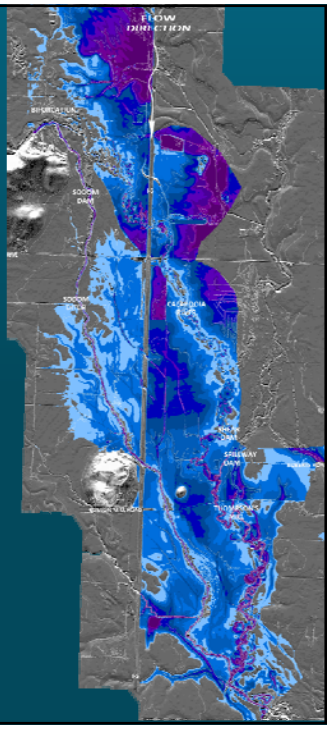
Geomorphic Assessment

- Floodplain Connectivity
  - Entrenched vs. Perched vs. Balanced.
  - Alluvial fans.
  - Channel Migration Zone
  - Recurrence Interval & Duration

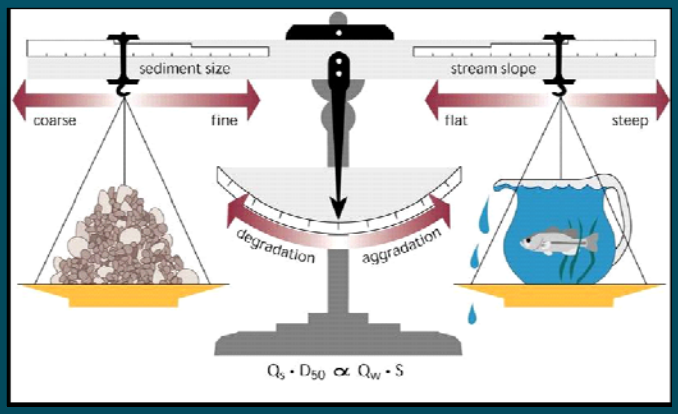




Geomorphic Context

- "Stable" channels develop geometry resulting from applied sediment load and the available energy (gradient and flow) to route it.

Wolman & Miller, 1960



From: Federal Interagency Stream Restoration Working Group. 1998. Stream Corridor Restoration: Principles, Processes, and Practices.

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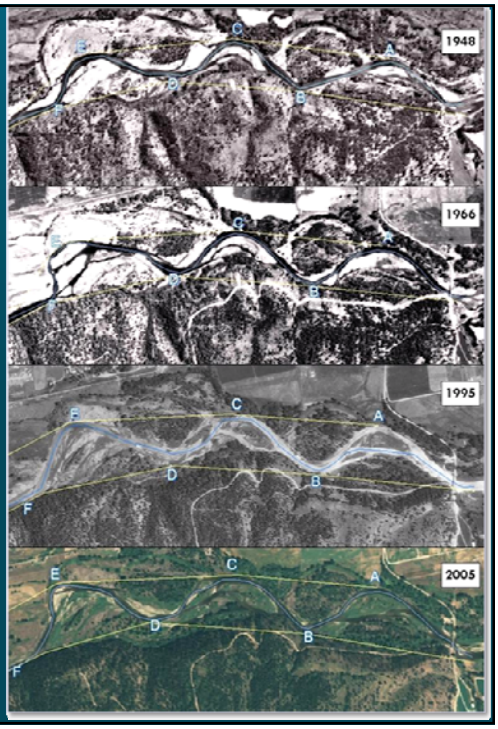
River Trends & Probable Form

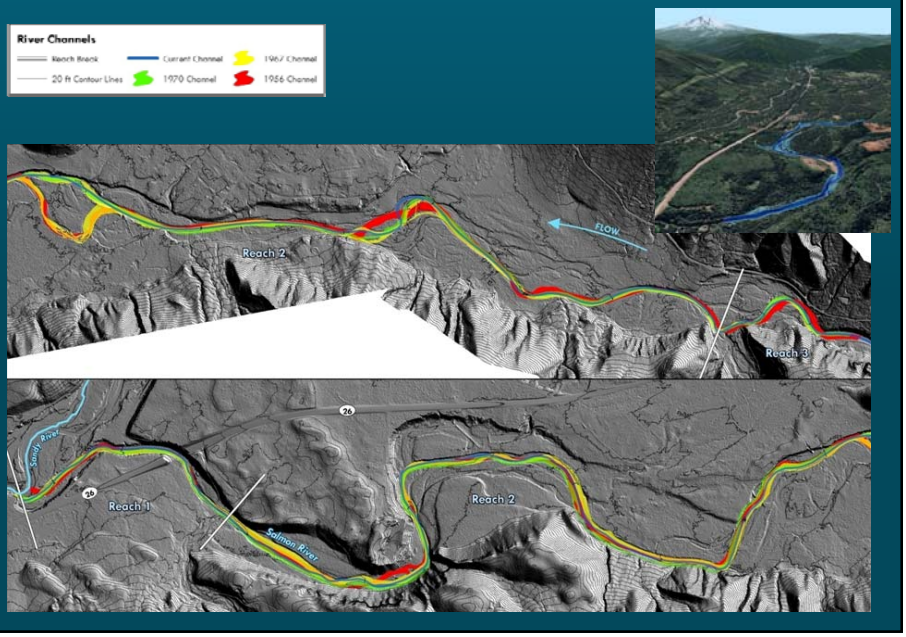
Summary of channel planform metrics in CFR near Clinton, MT for years 1948, 1966, 1995 and 2005.

Year	Planform Metric (ft)			
	Meander Length (ft)	Radius of Curvature(ft)	Belt Width (ft)	Sinuosity (ft/ft)
1948	2329	722	684	1.11
1966	2355	586	834	1.18
1995	2717	811	939	1.14
2005	2778	755	942	1.22

- Observations
  - Lateral Migration Rates
  - Planform Characteristics
  - Sediment Storage
    - (bar volume / unit chl length)
  - Range of Natural Variability ±30%.

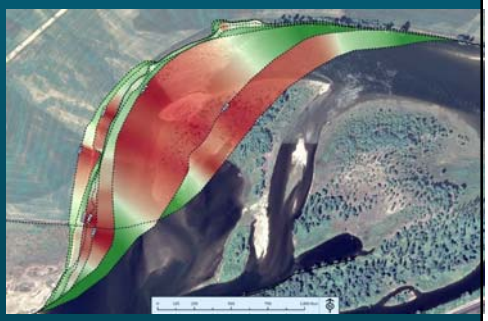


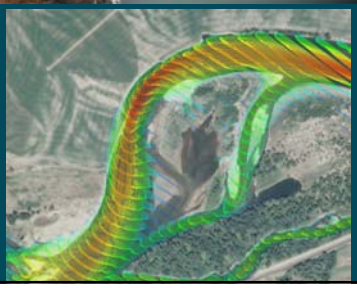
Geomorphic Planform Assessment



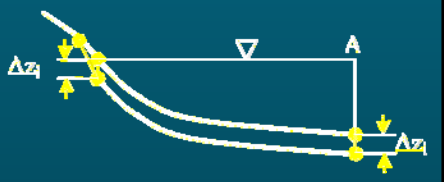
Lateral Reach Stability

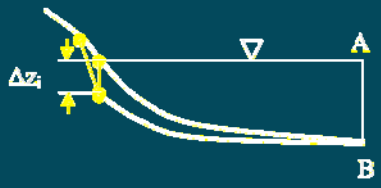
- Bank Erosion & Stability

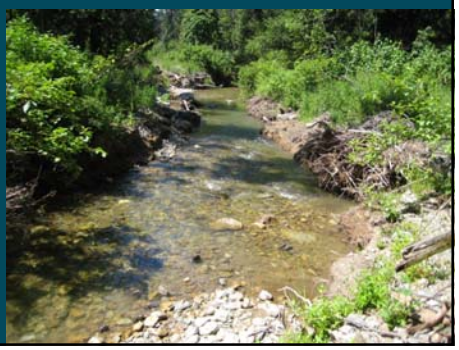




Vertical Reach Stability







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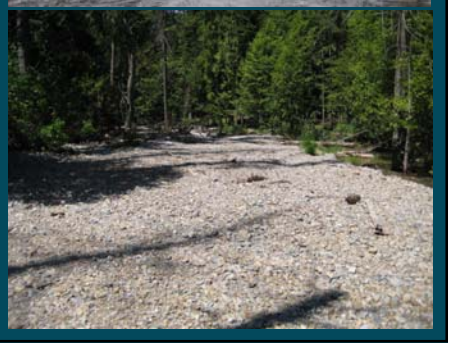
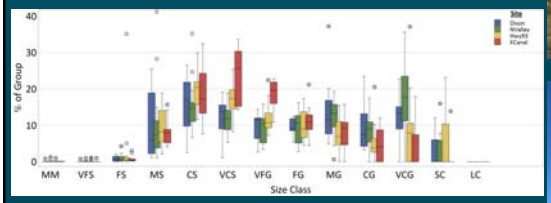
Sediment Regime Assessement

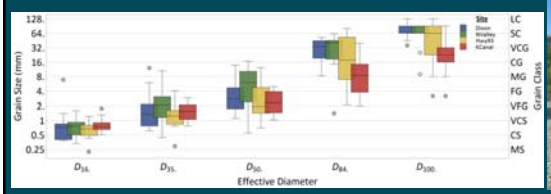
- Sediment sources
  - Upland watershed
  - Bank contributions
  - Bed storage
- Load estimates
  - tons / {day; year; 10y}
- Transport capacity & reach response
  - Aggrading / Degrading
  - Laterally Migrating / Stable
- Supply limited / Transport Limited.
- Effective discharge & Channel maintenance flows

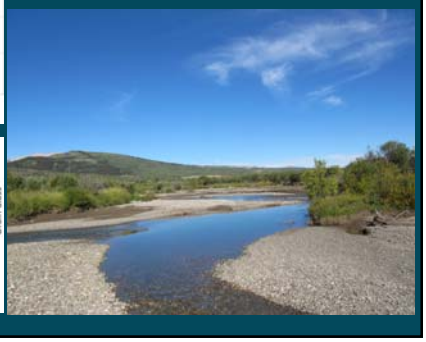


Sediment Regime Assessment – Bed Gradations

- Degree of armoring
- Surface vs. Subsurface
- Mobile particle sizes
- Downstream fining







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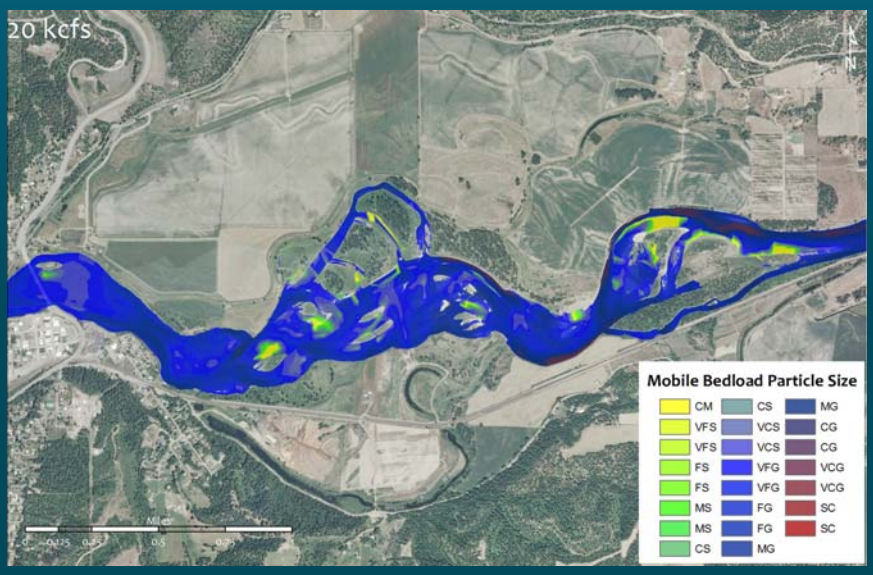
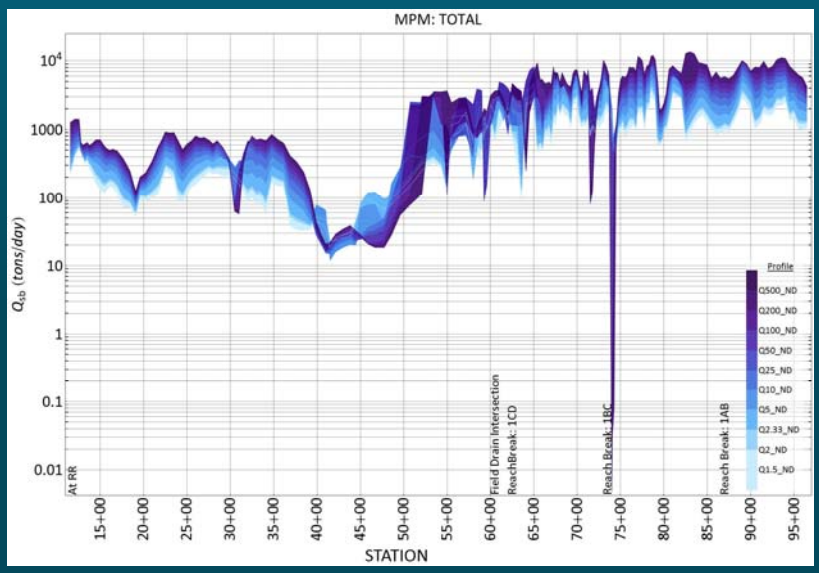
Reach Scale Sediment Mobility



Reach Scale Sediment Transport Capacity



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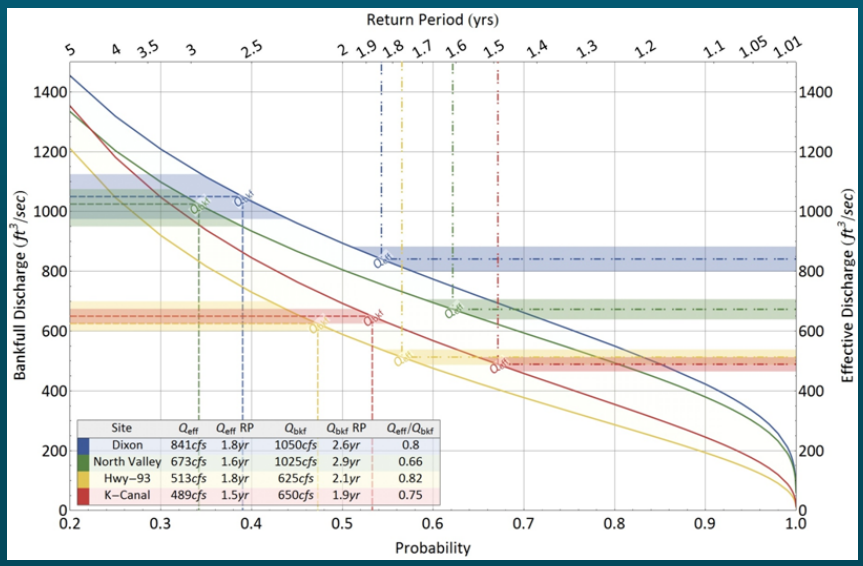
Channel Forming Discharge

- Recurrence Interval, Q_{ri}
  - Flood frequency recurrence (typ 1-2 yr)
  - Duration within a given period of record.
- "Bankfull", Q_{bkf}
  - Point of incipient flooding
  - Geomorphic indicators → deposition/vegetation
  - Sensitive to reach type and stability.
- Effective, Q_{eff}
  - Conditions which transport the greatest quantity of sediment for a given time period.
  - Sediment transported proportional to work done on channel boundary.

Bankfull Discharge: Q_{BKF}

Effefctive Discharge, Q_{EFF}



Phase 1 – Example Limiting Factors

- Altered hydrology
- Impaired habitat
- Floodplain disconnection / encroachment
- Lack of flood attenuation / flood risks
- Exacerbated erosion & stability
- Unbalanced sediment regime

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Phase 2 Project Planning Framework

- Project Planning
  - Goals and Objectives
  - Design Criteria
  - Performance criteria for determining success
  - Uncertainty and Expectations
  - Monitoring metrics and adaptive management framework
- Restoration Design Approach
  - Restoration Potential & Expectations
  - Components of the river system
  - Integrate multiple disciplines *:*

    Biologist/Ecologist → Hydrologist / Geomorphologist → Engineer → Contractor
  - Implement combined treatments into habitat actions.

Example Goals and Objectives

- Goal 1 - Restore a naturally functioning system that is appropriate for the geomorphic setting and site constraints.

- Objective 1 - Reconstruct a meandering channel and broad floodplain that gradually transition to an entrenched channel with a narrow, sloping floodplain.

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Phase 2 - Project Expectations

- Short Term Restoration Expectations (0-15 yrs)
  - Structures will maintain channel form
  - Channel form dictates lateral & vertical channel stability
  - Vegetation provides streambank/floodplain stability.
  - Structures remain stable for design flood events
  - Enhanced habitat by bank stabilization & grade control structures
  - Bank erosion rates are low
  - Natural processes are maintained
- Long Term Restoration Expectations (15+ yrs)
  - Vegetation dictates lateral channel stability
  - Channel armoring processes dictate vertical stability
  - Vegetation communities are established and provide habitat and other riparian/wetland functions
  - Structures decompose & become buried
  - Habitat created by bed forms & vegetation
  - Bank erosion rates are low
  - Natural processes govern

Phase 2 – Restoration Approaches

- Objective → Develop a resilient restoration design that promotes natural river function and addresses limiting factors by integrating a suite of reach scale components including:

•Floodplain Reconnection

•Bank Reconstruction

•Bioengineering

•Channel Shaping

•Energy Dissipation

•Grade Control

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MT Floodplain and Joint Permit Criteria

- Certain projects may require a licensed engineer to design to the following criteria:
  - a) The project can withstand a 100-year flood event
  - b) The project will not adversely affect surrounding landowners upstream, downstream, across stream, or adjacent to the proposed project area
  - c) The effect of the proposed project on the 100-year base flood elevation.

Phase 2 – Restoration Approaches

- Floodplain Reconnection.

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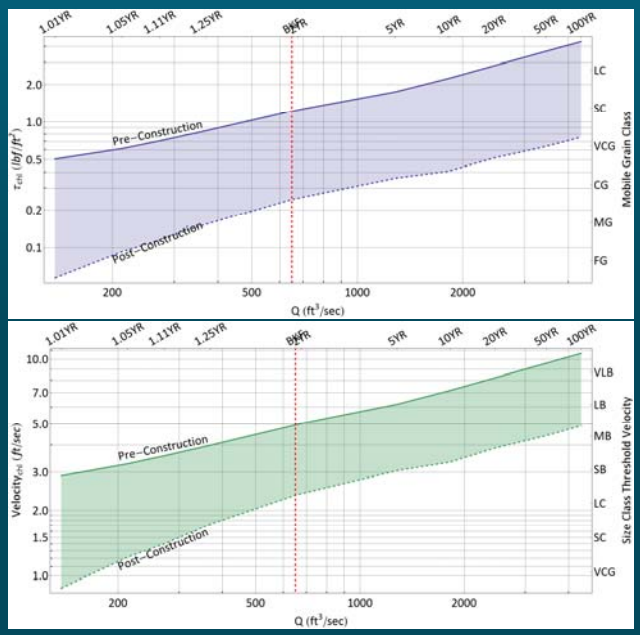
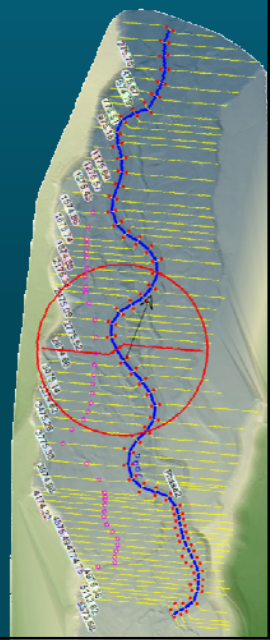
Floodplain Reconnection & Hydraulic Response





Restoration Approaches: Floodplain Design

- Features:
  - Terraces
  - Side channels
  - Floodplain roughness
  - Floodplain grading
    - Activate at $<Q_2$
    - Flood wave steering via superelevation.
    - Flood storage & attenuation via wetlands
  - Springs & tributaries
  - Revegetation design

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Restoration Approaches: Side Channels

- Side Channel Function
  - Provide flood and ice jam relief.
  - Irrigate off channel areas
  - Provide off channel aquatic refugia during floods.
- Side Channel Design
  - Inactive at baseflow.
  - Convey 5-10% of peak overbank flow
  - Orient to minimize avulsion risk.
  - Transport Bed Material $<D_{50}$

Restoration Approaches: Floodplain Grading

- Roughness
- Micro-topography
- Large organic debris
- Flood attenuation

Restoration Approaches: Upper Bank Grading

- Smooth transitions
- Stage progressive hydraulics
- Minimize erosion
- Vegetation roughness

Restoration Approaches: Bank Reconstruction

- Bioengineering - Vegetated Soil Lift Function

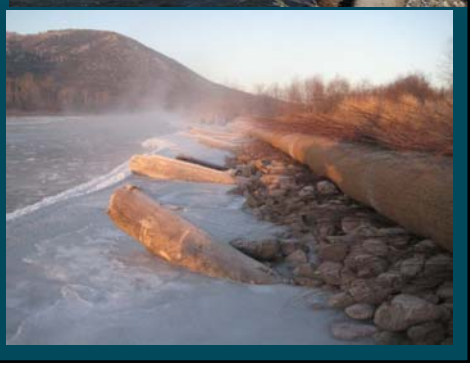
– Revegetation Technique.

– Short term bank protection

– Reduce erosion

– Promote vegetation

– Adds habitat



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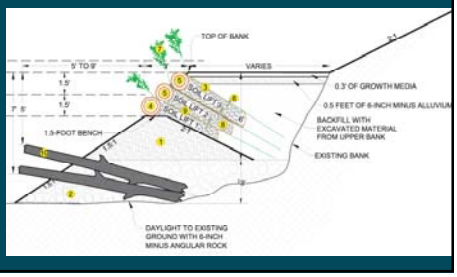
VSL Performance Criteria

Metric	VSL Performance Criteria
Purpose	Revegetation. Bank stabilization, reduce NBS via increased channel margin roughness
Composition	Soil, coir logs, wood, biodegradable fabric, alluvium, plants
Design Life	5 to 7 years
Nominal Design Event*	20 year RI flood depending on stream type and shear regime
Hydraulic Thresholds*	τ_{ave}: <1.5 lbf/ft^2 V_{ave}: 6 ft/sec with integrated structures
Sediment Thresholds*	Subgrade mobile size @ $Q_{bkf} < D_{84\text{-}95}$
Modes of Failure	Subgrade erosion, settlement, flanking, tearout, vegetation mortality
Placement	Toe wood ideally submerged at all flow levels. In flashy systems balance submergence with energy dissipation.
Spacing	Continuous between integrated structures.
Other	Subject to early failure risk until vegetation establishes. Geotechnical considerations.



Restoration Approaches: VSL Construction

Elk Creek Contracting. Heron, MT.

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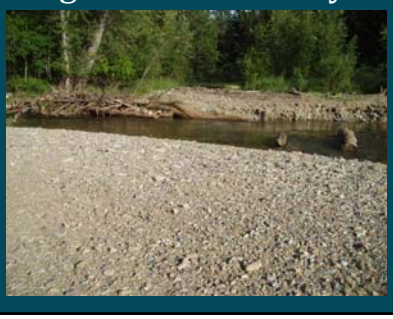
Restoration Approaches: VSL Construction

TNT Excavating. Ovando, MT.

VSL – Typical Modes of Failures

- Piping
- Tearout
- Flanking
- Toe scour
- Settlement
- Vegetation mortality



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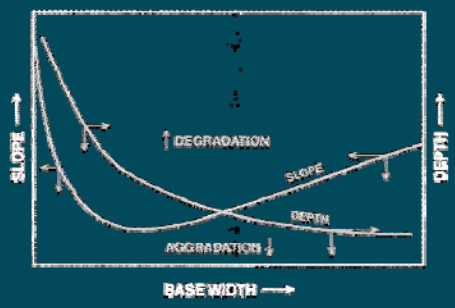
Channel Grading – Multiple Design Methods

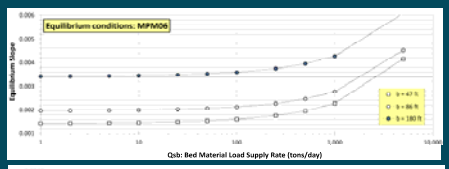
- Threshold channel design
- Deformable channel design
- Stable channel design
- Equilibrium channel design
- Geomorphic precedence
- Natural channel design
- Eco-hydraulics

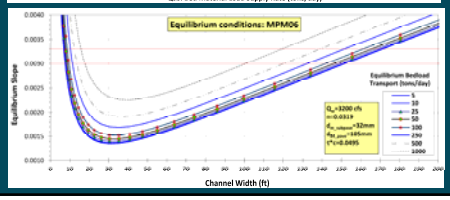
Integrate select methods and evaluate design performance with iterative calibrated reach scale hydraulic modeling.

Restoration Approaches: Channel Design

- Design for "General Scour & Aggradation"
- Provide capacity to transport & cyclically store supplied sediment load over the long term such that channel neither aggrades nor degrades.
- Integrate hydraulic geometry with planform ∝ slope







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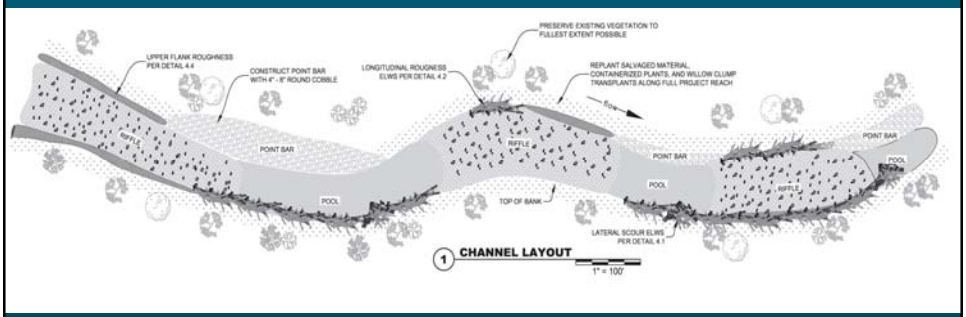
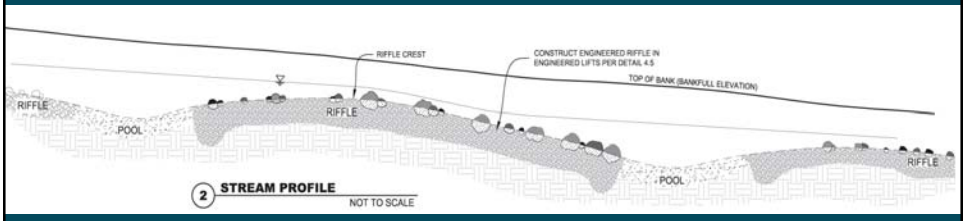
Geomorphic Unit Sequencing – Plan & Profile

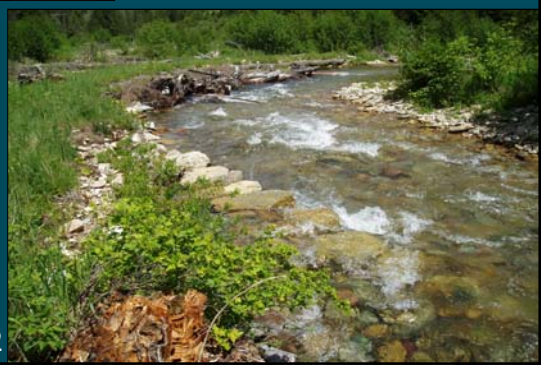




Example Meander Sequence

- VSL and ELJ treatments
- Submerged boulder grade control
- Run-pool-glide-riffle sequences

2006 As-Built Condition



2008 Year 2

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Example Structure Sequencing

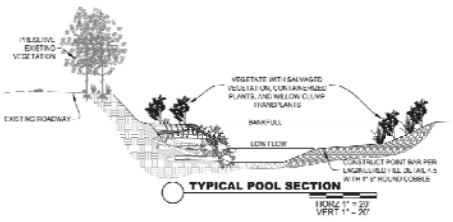
- VSL , LV & ELJ treatments
- Run-pool-glide-riffle sequences

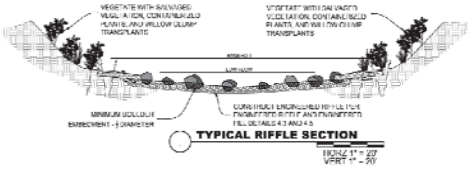
VSL and J-Hook Vane Sequence

ELJ and VSL Sequence

Multi-Stage Hydraulic Geometry

- Baseflow @ ~1/3 of bankfull. Design for fish passage
- Active channel conveys Q_{bkf}
- Staged terraces: 5-10 yr, 10-20 yr +
- Balance hydraulic response & transport capacity with boundary gradation & stability criteria.





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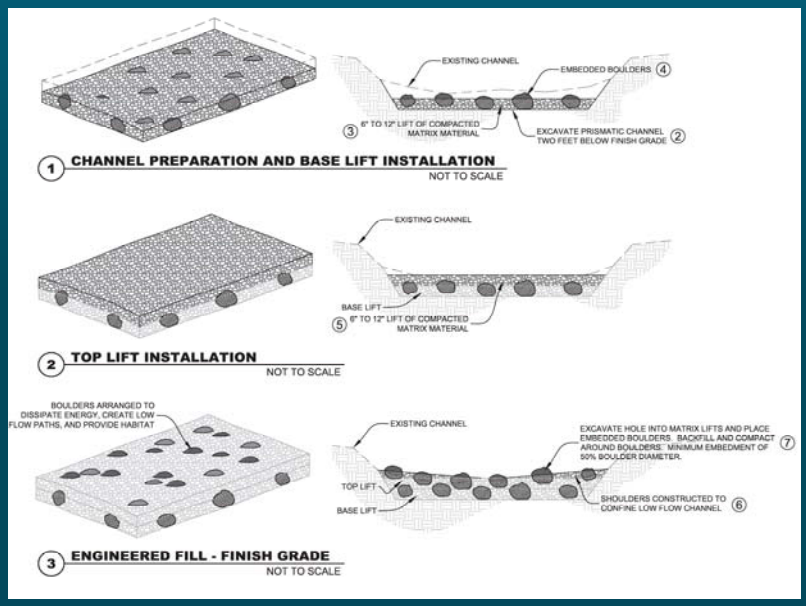
Channel Bed Construction

- Dynamic Stability
- Gradations and Transport Capacity
- Alluvial vs. angular rock.
- Engineered alluvial fill:
  - Gravels & Cobbles: $D_{16} - D_{84}$ provide structural matrix.
  - Boulders: $>D_{120}$ provide aquatic habitat, scour resistance & energy dissipation.
  - Fines: $<D_{16}$ can be pressure washed into the matrix material to seal the streambed & reduce percolation losses if necessary.

Example Channel Bed Construction Detail



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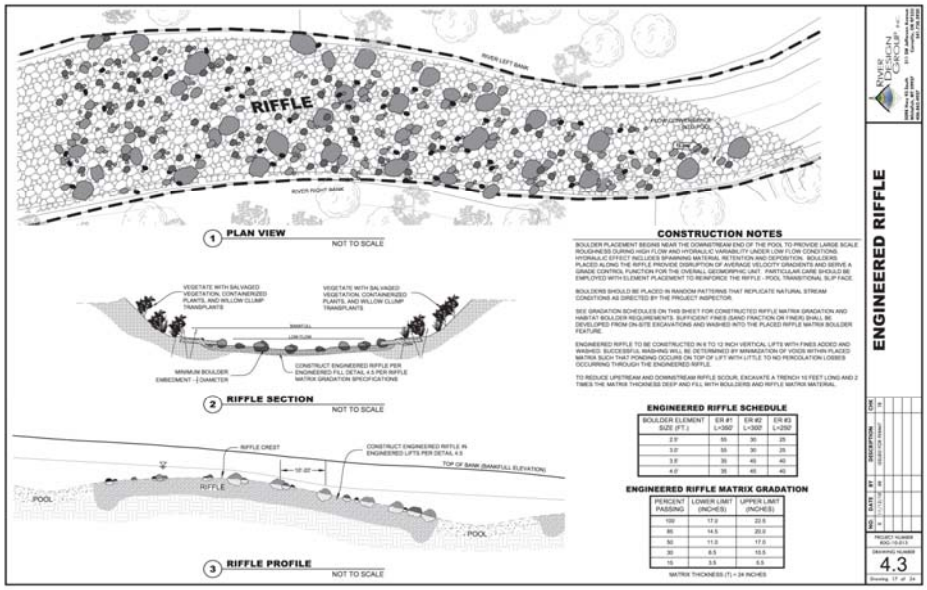
Engineered Riffles

- Function as a geomorphic unit to maintain grade between glide & run features.
- Provide energy dissipation via scaled roughness with discharge

Example Contractor Plan Sheet



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Boulder Grade Control

Function

- Interim structure
- Dissipate energy
- Sediment transport through structure
- Submerged at all flow levels
- Natural in appearance

BGC Performance Criteria

Metric	BGC Performance Criteria
Purpose	Grade control, energy dissipation, channel bed roughness, flow steering, floodplain connection
Composition	Boulders & alluvium ($D_{35} \rightarrow D_{120+}$)
Design Life	15-30 years until failure of bank stabilization structures & lateral migration.
Minimum Design Event*	20-25 year RI flood
Hydraulic Thresholds*	τ_{ave}: 1-2+ lbf/ft^2 V_{ave}: 8-10 ft/sec
Sediment Thresholds*	Transport sediment via cyclical bed change upto D_{84}. Max mobile size @ $Q_{bkf} < D_{95}$
Modes of Failure	Scour & Deposition
Placement	On the channel bed in a riffle or glide feature
Spacing	1-2 * W_{bkf}
Other	Large roughness elements <10% of flow area at Q_{bkf}. Use gradual facet slope transitions to balance hydraulics.

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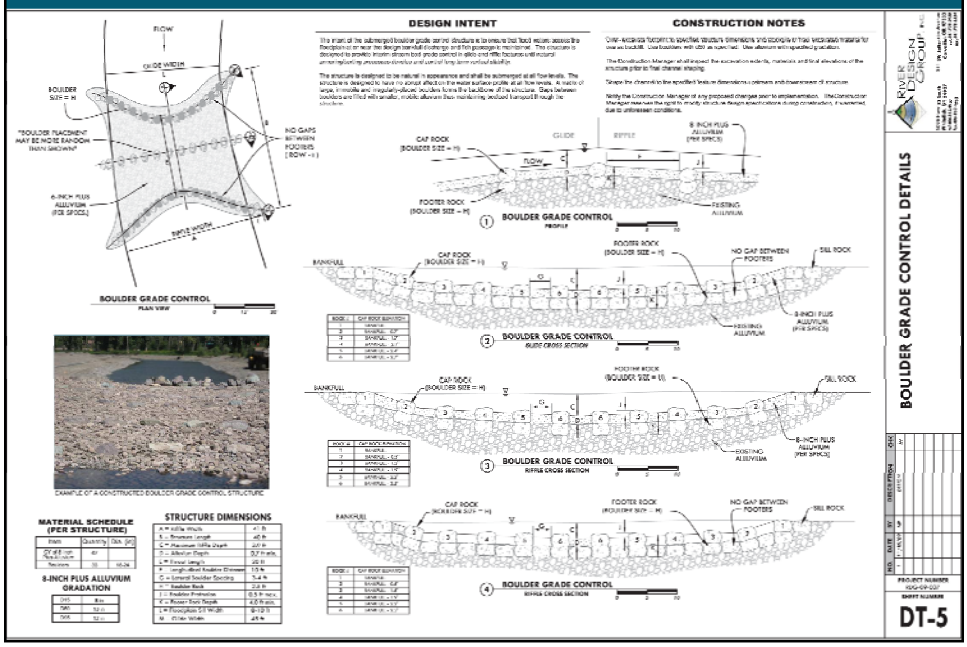
Example Contractor Plan Sheet



Large Wood Structures

Function

- Bank stabilization.
- Flow steering
- Pool development
- Emulate naturally occurring stable accumulations of wood debris

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ELWS Installation Types

- Stream-bank revetment
  - On outside meander bank in a pool feature.

- Stream-bed deflector
  - Near side channel entrance

ELWS Performance Criteria

Metric	ELWS Performance Criteria
Purpose	Provide bank stabilization by reducing near bank stress through increased roughness and flow steering.
Composition	Wood, alluvium, boulders constructed to perform as a contiguous unit.
Design Life	~25-30 years.
Minimum Design Event*	20-25 year RI flood
Hydraulic Thresholds*	τ_{ave}: 2-3+ lbf/ft^2 V_{ave}: 8-10 ft/sec
Sediment Thresholds*	Balance transport capacity through run-pool-glide sequence with pool energy dissipation.
Modes of Failure	Structural component failure, Buoyancy, Sliding, Scour, Flanking, Deposition
Effective Length	~0.15-0.25 * W_{bkf}
Size	Should not occupy more than 10% of A_{bkf} or extend more than 15% across channel.
Spacing	~0.9-1.1 * W_{bkf}
Installation	Insure ELWS functions as a composite unit. Ballasted with boulders and soil, and installed below scour depth

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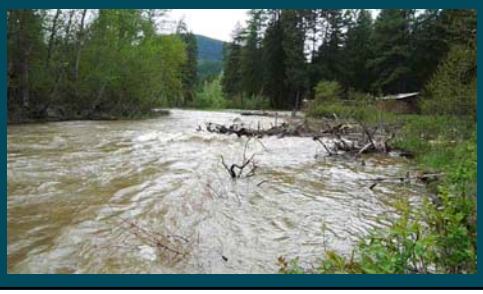
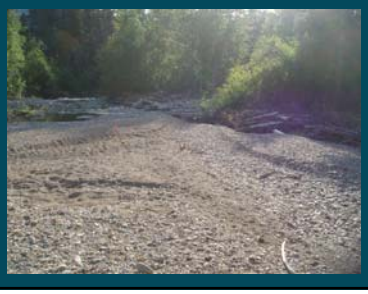
ELWS Modes of Failure

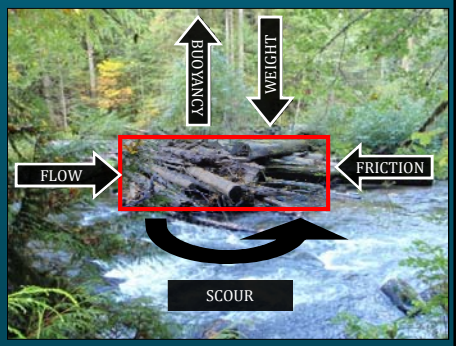
- Structural Component Failure
- Buoyancy
- Sliding
- Scour
- Flanking
- Deposition





ELWS Factor of Safety

$$FS = \frac{\text{Resisting Forces}}{\text{Driving Forces}}$$



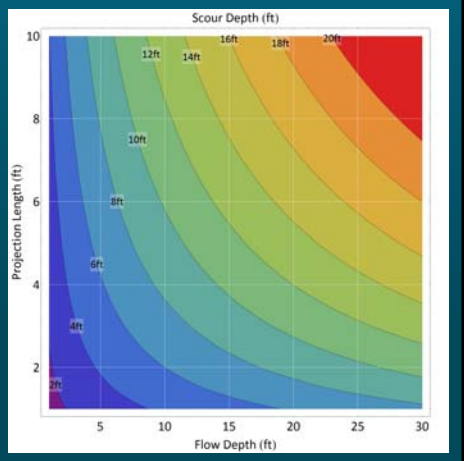
FS =1 equilibrium.

For ELW structures it is recommended that FS be 2.0 or greater for buoyancy & sliding due to uncertainties and future adjustments.

ELWS Example Calculations for Local Scour

Modified Laursen:

$$\frac{y_s}{y_a} = 1.3\left(\frac{Wo}{y_a}\right)^{0.48}$$



where

y_s = scour depth (ft)

y_a = depth of flow at the structure (ft)

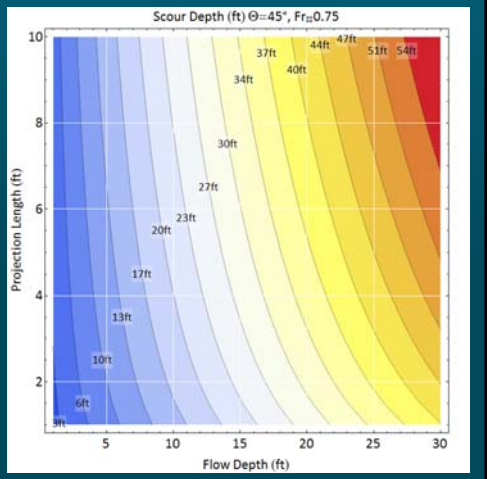
W_o = length of structure projected normal to flow (ft)

EM 1110-2-1601 (USACE 1994).

ELWS Example Calculations for Local Scour

Modified Froehlich:

$$\frac{y_s}{y_a} = 2\left(\frac{\theta}{90}\right)^{0.13}\left(\frac{Wo}{y_a}\right)^{0.43} F_r^{0.61} + 1.0$$



where

y_s = scour depth (ft) below the water surface

y_a = depth of flow at the structure (ft)

W_o = length of structure projected normal to flow (ft)

θ = angle of embankment to flow (deg.)

F_r = Froude number of flow upstream of abutment

EM 1110-2-1601 (USACE 1994).

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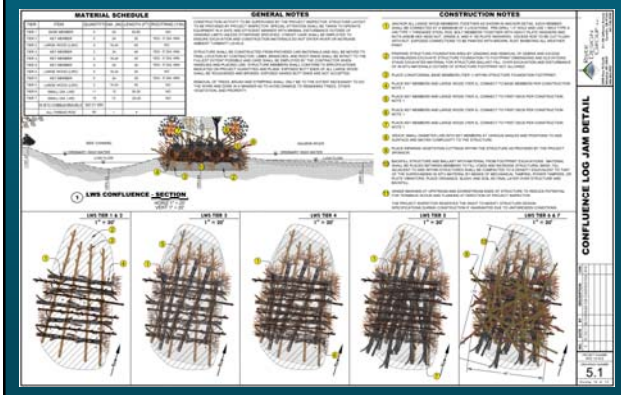
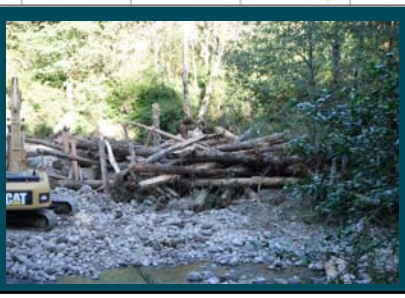
ELWS Construction





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