ADDRESSING GEOMORPHIC AND HYDRAULIC CONTROLS IN OFF-CHANNEL HABITAT DESIGN

Conor Shea - Hydrologist
U.S. Fish and Wildlife Service
Conservation Partnerships Program
Arcata, CA
Learning Objectives

• Examine Landscape and Watershed Controls that Create and Maintain Off-Channel Habitats

• Explain Controls on Typical Off-Channel Habitat Features:
  – Location on Landscape
  – Site Controls
  – Design Concepts
Guiding Principle for Restoring or Creating Aquatic Habitat

Successful Projects:

• Clearly Identify Habitat Goals and Objectives
• Identify and Recognize Landscape and Watershed Scale Controls
• Work With Geomorphic Processes and Remove Constraints
• Incorporate Geomorphically Appropriate Elements and Features
Independent Landscape Drivers

• Geology
  – Controls topography (slope and confinement)
  – Sediment Type and Supply

• Climate
  – Controls amount of water (discharge)
Watershed Controls on Morphology and Habitat
Role of Flow Regime

Flow regime
- Magnitude
- Frequency
- Duration
- Timing
- Rate of change

- Water quality
- Energy sources
- Physical habitat
- Biotic interactions

Ecological integrity

after Karr 1991
Flow and Sediment Controls on Morphology and Habitat

- Bank strength, Wood supply
- Floodplain Sediment
- Valley confinement
- Channel slope
- Channel Substrate
- Sediment supply, Sediment size
- Discharge
Successful Projects Work with Controlling Processes and Remove Constraints

- Climate and Geology
- Watershed Controls
- Flow and Sediment Regimes
- Fluvial Processes & Channel Morphology
- Habitat Structure & Complexity
- Biotic Response
Successful Projects Identify and Recognize Landscape and Watershed Scale Controls
Channel Slope as an Organizing Principle in Habitat Design

Montgomery and Buffington, 1997
Slope Controls on Sediment Properties

**UPLAND (STEEP) → LOWLAND (SHALLOW)**

- CHANNEL SUBSTRATE SIZE ↓
- BANK COHESION ↑
- FLOODPLAIN SUBSTRATE SIZE ↓
- FLOODPLAIN EROSIVITY ↑
- DEPTH OF ALLUVIUM ↑
- SOURCE TO SINK
Slope Controls on Channel Morphology

UPLAND (STEEP) → LOWLAND (SHALLOW)

- CHANNEL WIDTH ↑
- FLOODPLAIN WIDTH ↑
- WIDTH/DEPTH RATIO ↑
- SINUOSITY ↑
- CONFINEMENT ↓
- CHANNEL PATTERN:
  STRAIGHT ->
  BRAIDED ->
  MEANDERING ->
  DISTRIBUTIVE

Stanley Schumm, 1977
Slope Controls on Habitat Characteristics

UPLAND (STEEP) → LOWLAND (SHALLOW)

- WOOD SUPPLY ↑
- WOOD LENGTH / CHANNEL WIDTH RATIO ↓
- CHANNEL COMPLEXITY ↑↓
- COVER ↑↓
- TEMPERATURE ↑
- TEMPERATURE VARIATION ↓
- SHREDDERS -> GRAZERS -> FILTER FEEDERS
## Channel Slope Zones

<table>
<thead>
<tr>
<th>Slope</th>
<th>Category</th>
<th>Salinity</th>
</tr>
</thead>
<tbody>
<tr>
<td>≈ &gt; 5%</td>
<td>Above Anadromy</td>
<td>Fresh</td>
</tr>
<tr>
<td>≈ 1% to 5%</td>
<td>Steep</td>
<td>Fresh</td>
</tr>
<tr>
<td>≈ &lt; 1%</td>
<td>Lowland</td>
<td>Fresh</td>
</tr>
<tr>
<td>&lt; 1%</td>
<td>Estuary</td>
<td>Fresh/Brackish</td>
</tr>
<tr>
<td>&lt; 1%</td>
<td>Tidal</td>
<td>Brackish/Saline</td>
</tr>
</tbody>
</table>

Note: Slope Categories are Fuzzy
Temporal and Spatial Variation in Habitat Use by Salmonids

<table>
<thead>
<tr>
<th>SLOPE ZONE</th>
<th>FALL</th>
<th>WINTER</th>
<th>SPRING</th>
<th>SUMMER</th>
<th>FALL</th>
<th>WINTER</th>
<th>SPRING</th>
<th>SUMMER</th>
</tr>
</thead>
<tbody>
<tr>
<td>STEEP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LOWLAND</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ESTUARY</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TIDAL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Map Habitat Use Through Time and Space
Example: Coho Salmon
- Extended Dry Season
Habitat Varies in Space and Season

<table>
<thead>
<tr>
<th>SLOPE ZONE</th>
<th>FALL</th>
<th>WINTER</th>
<th>SPRING</th>
<th>SUMMER</th>
<th>FALL</th>
<th>WINTER</th>
<th>SPRING</th>
<th>SUMMER</th>
</tr>
</thead>
<tbody>
<tr>
<td>STEEP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LOWLAND</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ESTUARY</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TIDAL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Off-Channel Habitat Design

Clearly Identify Habitat Goals and Objectives

Design Features Should:

• Support Specific Life-stage and Seasonal Habitat Needs
• Conform to Landscape and Watershed Controls
• Address Location within Watershed
Design Elements for Off-Channel Habitat in Steep Channels

Objectives:
- Summer Rearing
- High Flow Refugia

Design Elements
- Use of Bars Features
- Vegetated Bars/Islands
- Anabranche Channels
- Wood Structures
Bar Forms

Bars Require:
- High Sediment Supply
- Variable Flow Regime

Alternate (Point) Bars
- Attached to Bank
- Mobile/Persistent
- Topographic Steering
- Resistant Banks

Medial (Center) Bars
- Split Flow
- Mobile
- Weak Bank Strength
Off-Channel Enhancements Using Alternate Bars

**Back Bar Features:**
- High Flow Refugia
- Summer Rearing
- Habitat Complexity (High Velocity Gradient)
- Water Quality

*Source: Trinity River Restoration Program*
Evolution of Cutoff Chutes & Alcoves

Chutes Form When Head Loss Cause Upstream Water Surface to Overtop Bar

Create by:
• Lowering Back Bar Height
• Increasing Head Loss By Adding Wood
Effect of Wood Loading

\[ \tau_0 = \rho ghS \]

Increased Wood Loading increases:
- flow depth
- energy slope

Activate Off-channel Areas by Adding Wood

Manga and Kirchner 2000
Habitat Value of Medial Bars

Medial Bars:
• Mobile/Low Stability
• Create Flow Heterogeneity
• Overtopped by Flows Less than Bankfull

Widen Channel Belt by Eroding Banks and Lead to:
• Vegetated Bars
• Islands
• Anabranchn (Split) Channels
Vegetated Bars & Islands

**Vegetated Bars**
- Bars Colonized by Vegetation
- Persistent
- Overtopped by Flows Less than Bankfull

**Islands**
- Vegetated Bars which Accumulate Sediment and Grow in Elevation Above Bankfull
- Length Scales to Pool-Riffle Sequence
- Long-term Persistence

**Habitat Benefits**
- Cover
- Increased Bank Length
- Velocity Complexity
Apex Bar Jam

Abbe and Montgomery, 1996
Apex Bar Jam in Mattole
Engineered Log Jam
Anabranchn Channels

- Channels with Longer Separation
- Multiple Pool-Riffle Sequences
- Island Widths Multiple Channel Widths
- Unconfined Anabranches (Type 5) May Form from
  - Erosion of Floodplain
  - Avulsion into Tributary Channel

Figure 7. (A) Gravel-dominated, laterally active system (type 5); (B) gravel-dominated stable system (type 6)

Nanson and Knighton, 1996
Constructing an Anabranch: Design Issues

- Location
- Entrance Configuration
- Exit Configuration
- Middle Dependent on Boundary Conditions
Anabranch Channel Location

Specific Requirements -- Not Random

• Stable Anabranch Channels
  – 5% - 20% of Total Flow
  – Separated at Flows ≥ Bankfull Discharge
  – Typically Have Slope Advantage $S_s > S_m$

• Entrance at Riffle Head

• Generally on Inside of Bends

• Hard Point at Bifurcation

• Employ Abandoned Channels and Tributary Channels
Stable Entrance Characteristics

- Expanding Approach Channel Width
- Transverse Bed
- Head Drop In Main Branch
- Inlet Step In Side Branch
- Slope Advantage ($S_s > S_m$)
- Limited Bifurcation Angle
- Branch Asymmetry ($W_s << W_m$)
- Flow Separation Above Bankfull

Burge 2006
Confluence Characteristics

- Downstream Bar On Minor Channel Side
- Avalanche Faces At Confluence
- Enhanced Scour in Channel Below Confluence
Design Elements for Off-Channel Habitat in Lowlands

Objectives:
• Wet Season Rearing
• Summer Cool Water Refugia
• Floodplain Access
• Movement
• Cover
• Complexity

Design Elements
• Cutoff Chutes
• Backwater Channels
• Seasonal Wetlands
• Anastomosised Streams
• Avulsions
• Wood Jams
Backwater Channel

Formed Where Downstream Grade Control Elevates Water Surface

Appropriate for Lowland Stream Because:

$$L_b = \frac{h}{S_f}$$
Backwater Channel Design:
Salt Creek
Backwater Sediment Issues

If Sediment Load is present:
- Channel Entrances May Become Blocked
- Off-Channel Pools May Fill with Fine Sediment
- Raising Backwater Height May Result in Channel Aggradation
Anastomosed Streams and Avulsions

Avulsion:
• Rapid shift of channel belt into new location.
• Associated with channel aggradation and sinuous streams.
• New channels typically steeper than original.

Anastomosed Streams:
• Channel form with parallel channels separate by wide, cohesive, vegetated floodplains.
Anastomosing Channel Benefits

- Multiple Channels
- Complex Habitat

Use in Restoration Requires:
- Wide Floodplain
- Low Potential for Land-use Conflicts

Taiya River, AK

Abbe, Brooks, and Montgomery, 2003
Opportunities:
• Access to Off-Channel Habitat
• Cross-basin Connectivity

Hazards
• Channel Capture
• Flooding
• Stranding
Other Lowland Design Issues:

- Lack of Cover and Water Temperature
- Groundwater Connection
- Anoxic Soils
- Riparian Disturbance
Design Elements for Off-Channel Habitat in Estuaries

Objectives:
• Wet Season Rearing
  – Freshwater Refugia
  – Permanently Flooded
• High Flow Refugia
• Movement
• Cover
• Complexity

Design Elements
• Seasonal Freshwater Wetlands
• Wood Jams
• Channel Connectivity
• Cross Connections
• Restore Side-channels
• Tide Gate Improvements
Summary

• Clearly Identify Habitat Goals & Objectives
• Address Landscape & Watershed Controls
• Select Appropriate Design Elements
• Allow Processes to Work