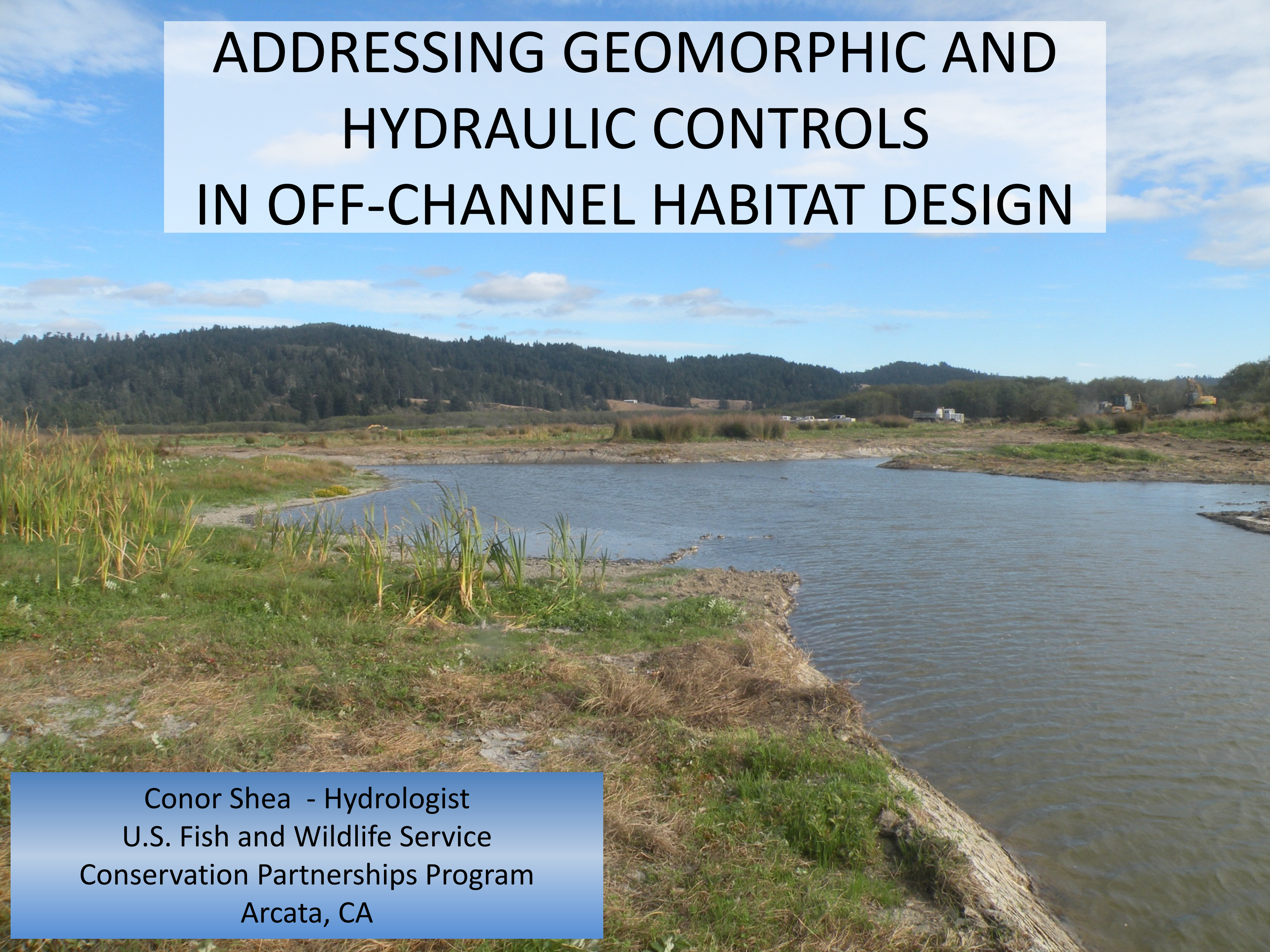
ADDRESSING GEOMORPHIC AND HYDRAULIC CONTROLS IN OFF-CHANNEL HABITAT DESIGN



Conor Shea - Hydrologist
U.S. Fish and Wildlife Service
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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

Hierarchy of Geomorphic Controls and Processes

Climate and Geology

Watershed Controls

Flow and Sediment Regimes

Fluvial Processes & Channel Morphology

Habitat Structure & Complexity

Biotic Response

Short-term response

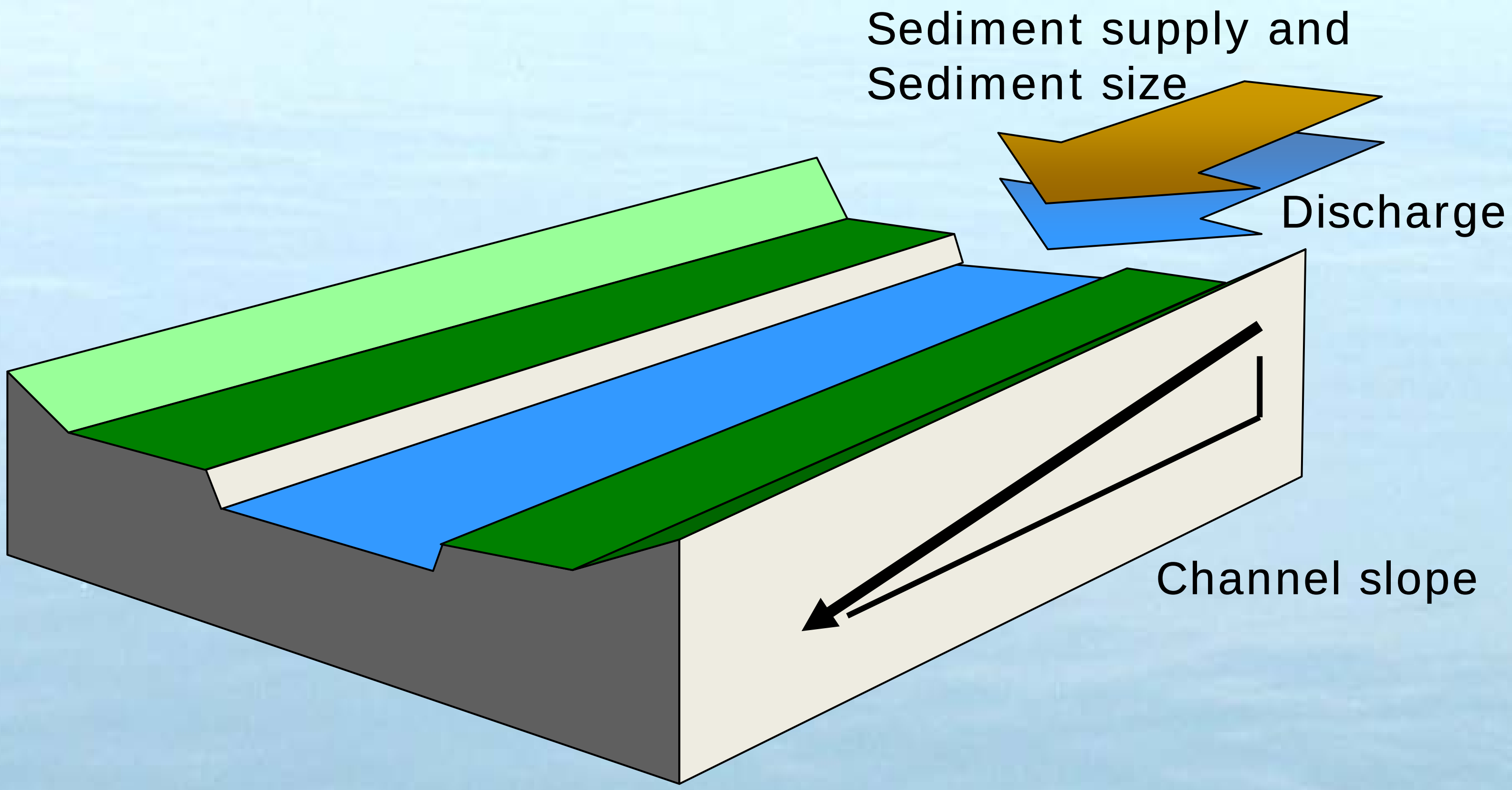
Longer-term feedback

Independent Landscape Drivers

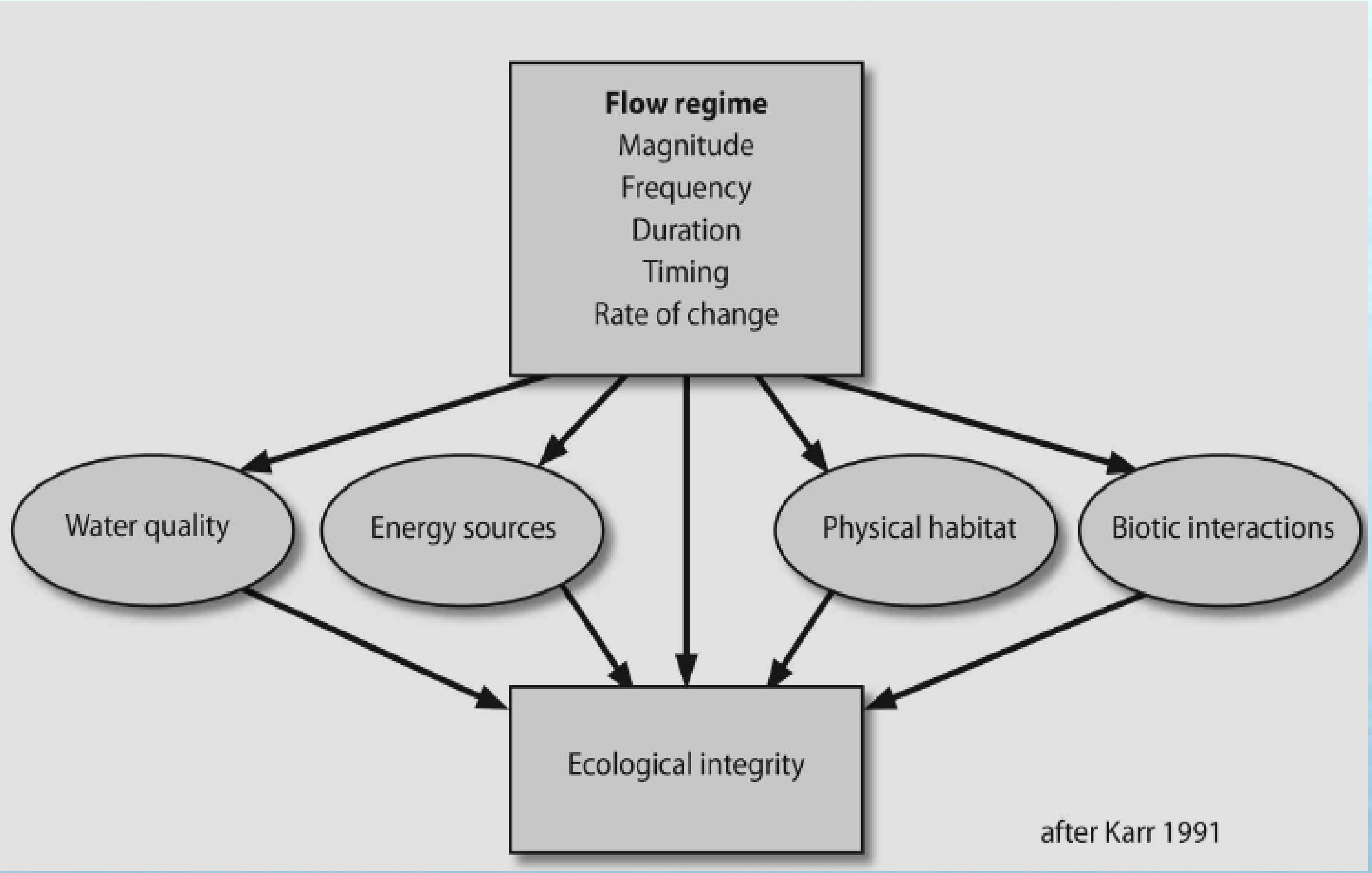
- Geology
  - Controls topography (slope and confinement)
  - Sediment Type and Supply

- Climate
  - Controls amount of water (discharge)

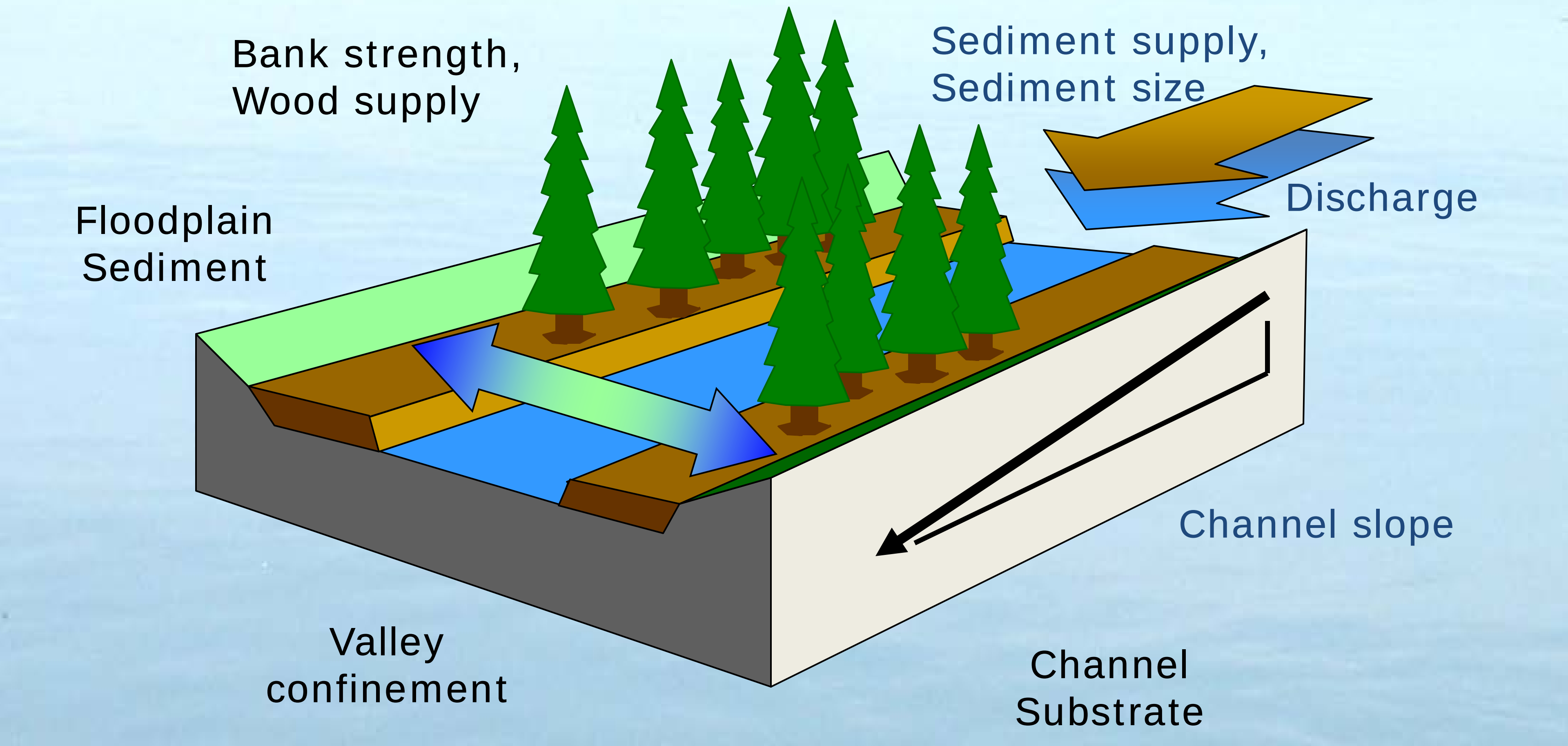
Watershed Controls on Morphology and Habitat



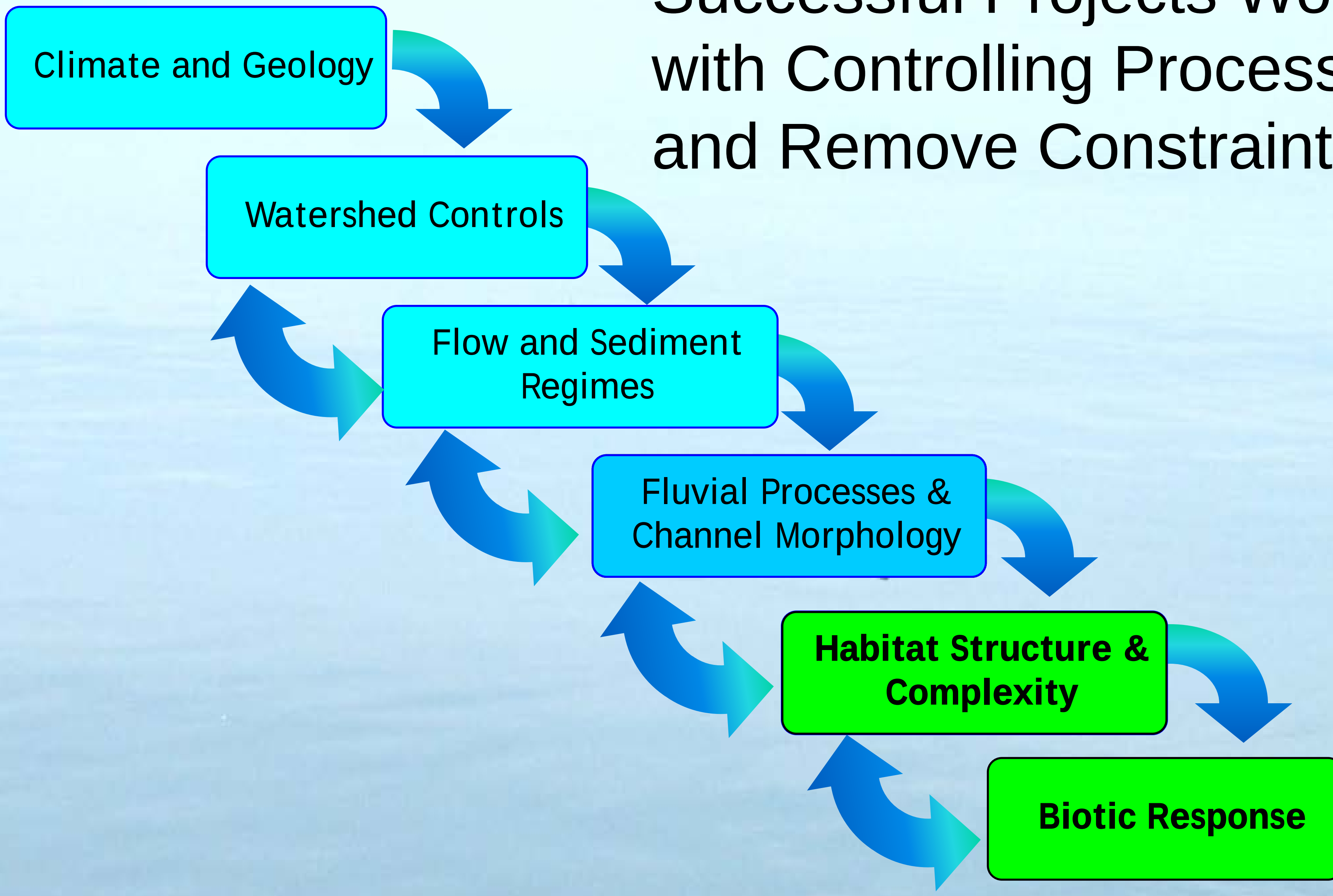
Role of Flow Regime



Flow and Sediment Controls on Morphology and Habitat



Successful Projects Work with Controlling Processes and Remove Constraints

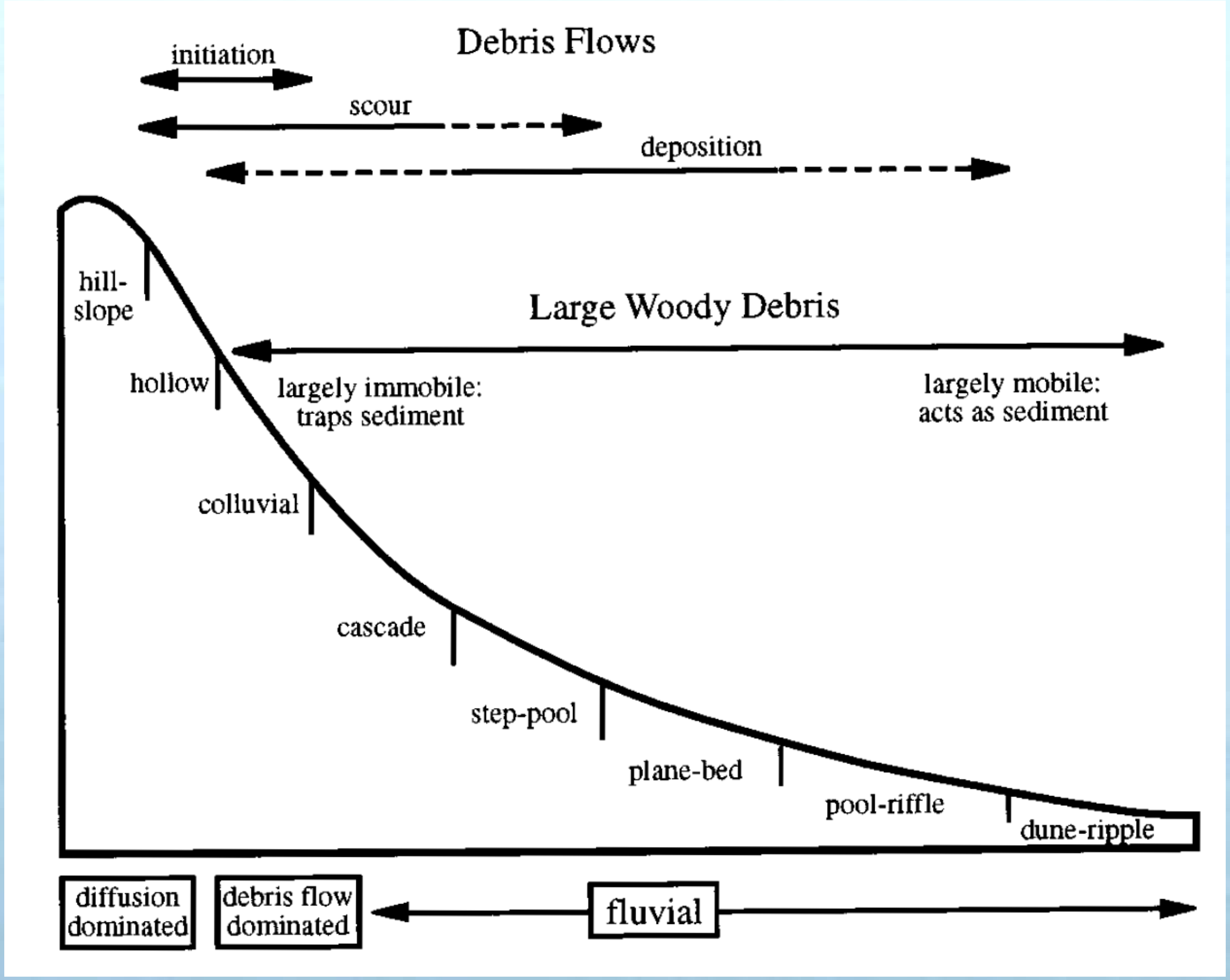


Landscape and Watershed Controls at the Reach (Project) Scale

- Slope:
  - Channel
  - Valley
  - Slope Breaks
- Sediment
  - Channel Substrate
  - Bank Material
  - Floodplain Material
  - Depth to Bedrock
- Valley Form
  - Confined/Unconfined
- Vegetation
  - Type
  - Strength
  - Wood Supply
- Water Supply
  - Hydrologic Regime
  - Temperature/DO

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

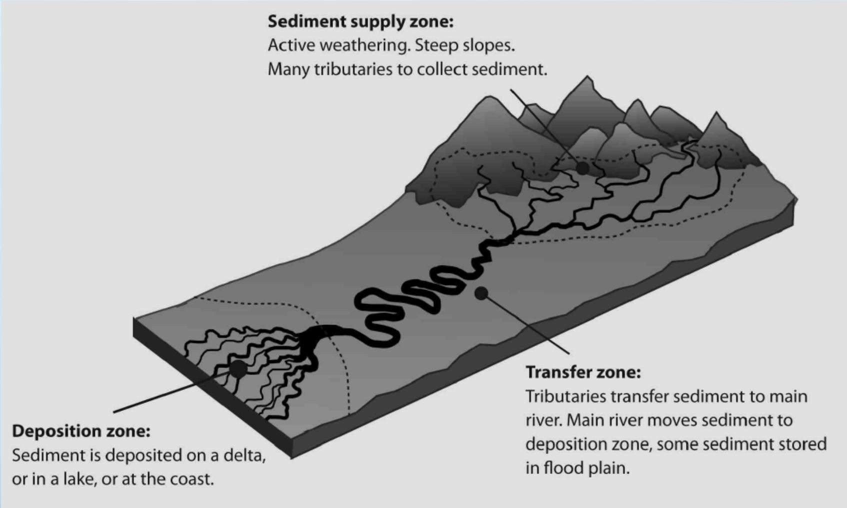
UPLAND (STEEP) → LOWLAND (SHALLOW)

- 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)

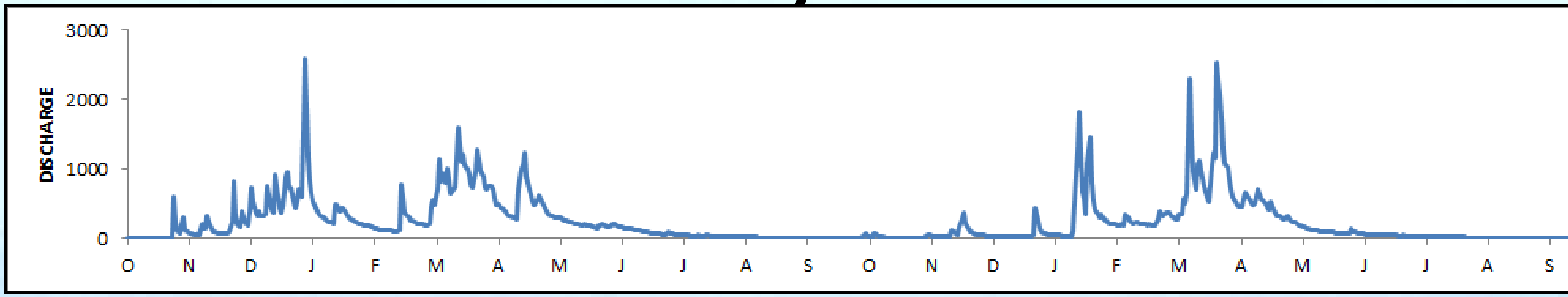
- WOOD SUPPLY ⇧
- WOOD LENGTH / CHANNEL WIDTH RATIO ⇩
- CHANNEL COMPLEXITY ⇧⇩
- COVER ⇧⇩
- TEMPERATURE ⇧
- TEMPERATURE VARIATION ⇩
- SHREDDERS -> GRAZERS -> FILTER FEEDERS

Channel Slope Zones

Slope	Category	Salinity
≈ > 5%	Above Anadromy	Fresh
≈ 1% to 5%	Steep	Fresh
≈ < 1%	Lowland	Fresh
< 1%	Estuary	Fresh/Brackish
< 1%	Tidal	Brackish/Saline

Note: Slope Categories are Fuzzy

Temporal and Spatial Variation in Habitat Use by Salmonids



SLOPE ZONE	SEASON							
	FALL	WINTER	SPRING	SUMMER	FALL	WINTER	SPRING	SUMMER
STEEP								
LOWLAND								
ESTUARY								
TIDAL								

DISPERAL

EMERGENCE

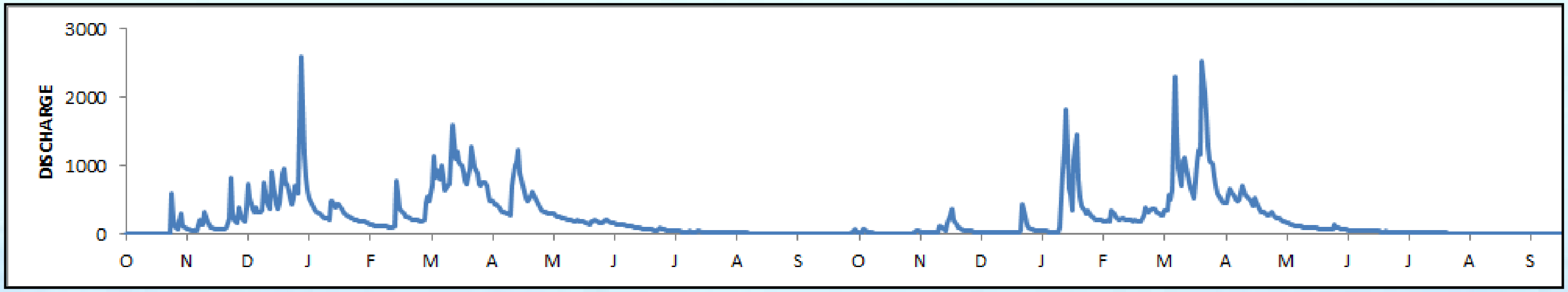
REARING

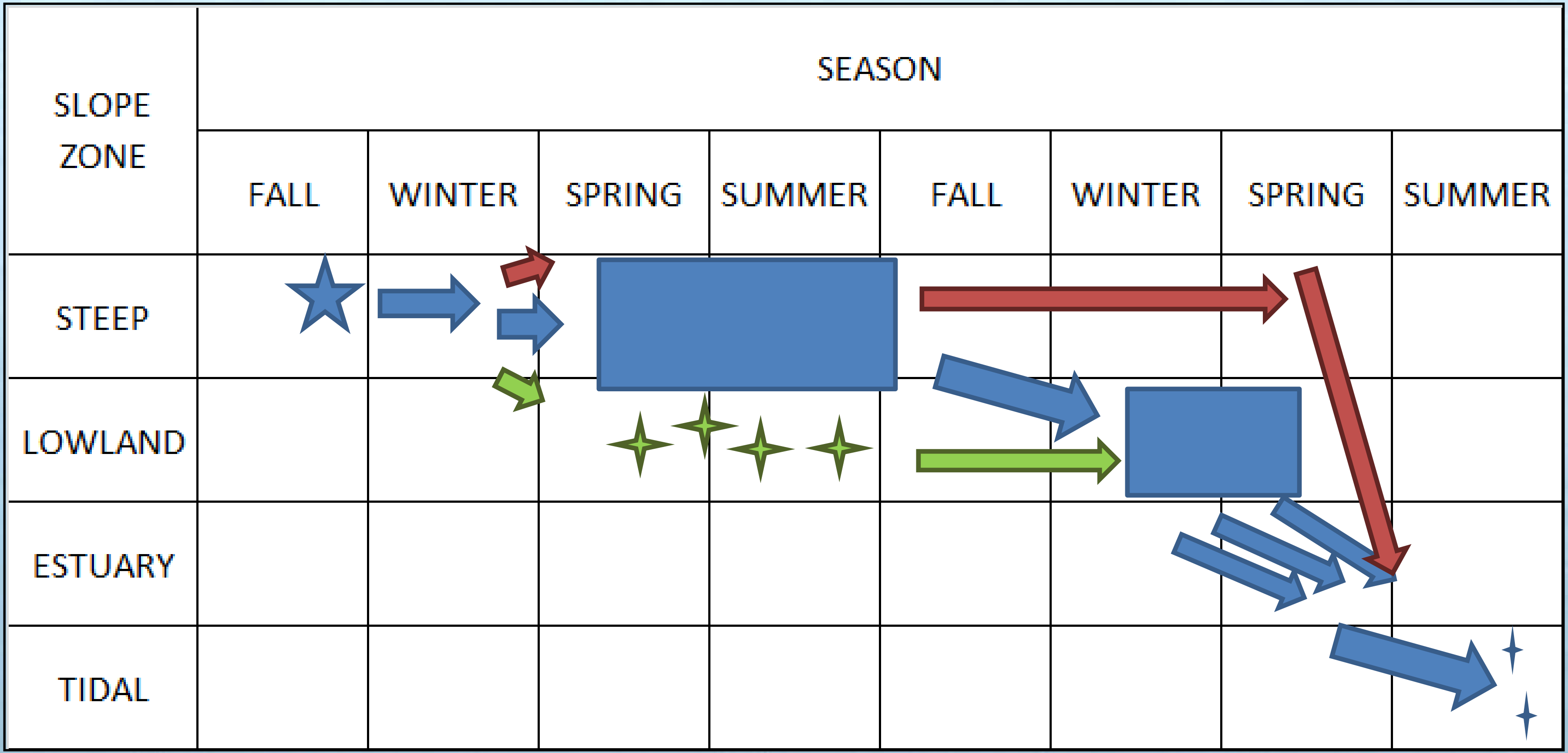
Map Hab… Throu… and Space

Example: Coho Salmon

- Extended Dry Season

Habitat Varies in Space and Season





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
- Anabranch Channels
- Wood Structures

Bar Forms

Bars Require:

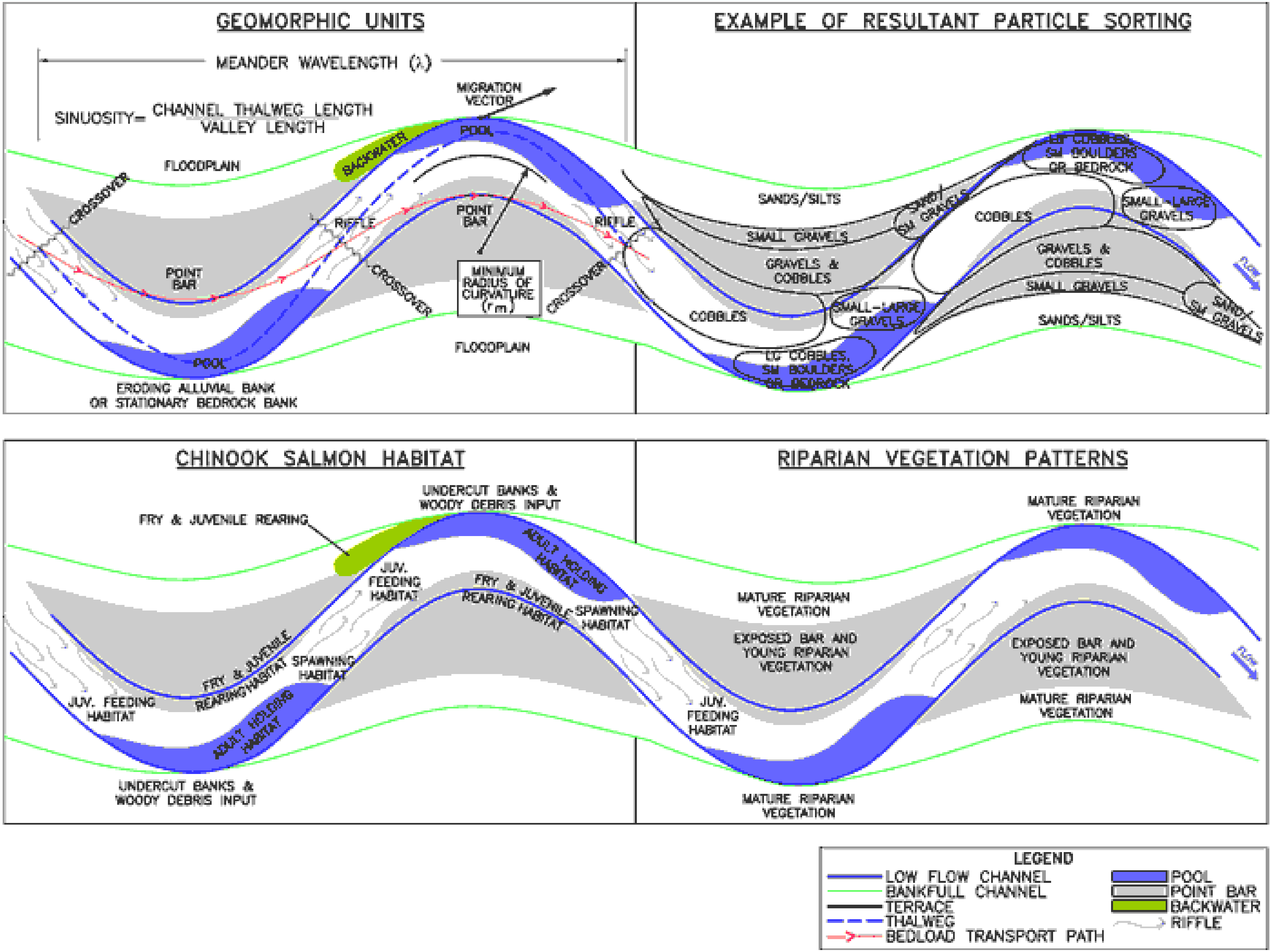
- High Sediment Supply
- Variable Flow Regime

Alternate (Point) Bars

- Attached to Bank
- Mobile/Persistent
- Topographic Steering
- Resistant Banks

Medial (Center) Bars

- Split Flow
- Mobile
- Weak Bank Strength

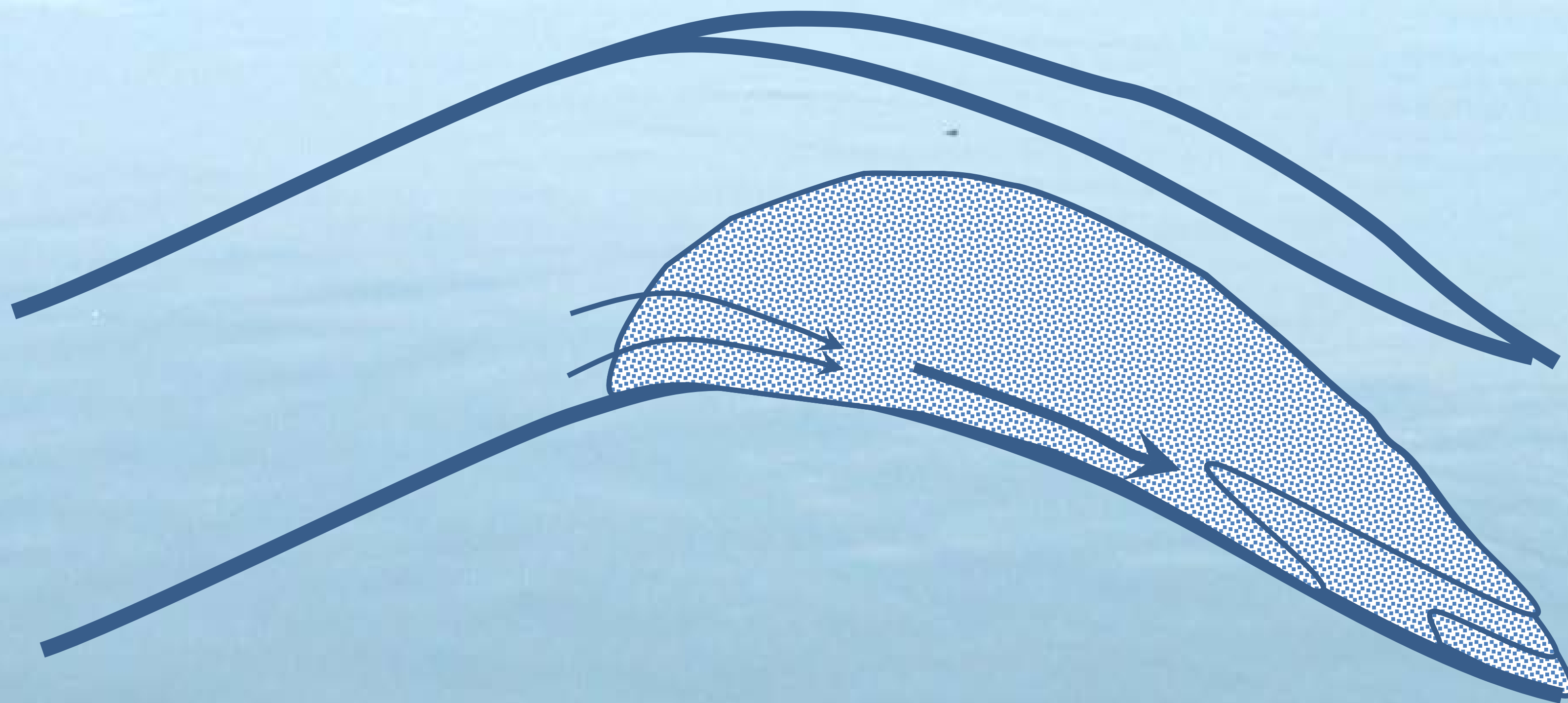

GEOMORPHIC UNITS
MEANDER WAVELENGTH (λ)
SINUOSITY= CHANNEL THALWEG LENGTH / VALLEY LENGTH
MIGRATION VECTOR
POOL
BACKWATER
FLOODPLAIN
CROSSOVER
RIFFLE
POINT BAR
MINIMUM RADIUS OF CURVATURE (rm)
FLOODPLAIN
ERODING ALLUVIAL BANK OR STATIONARY BEDROCK BANK
EXAMPLE OF RESULTANT PARTICLE SORTING
LG COBBLES, SM BOULDERS OR BEDROCK
SANDS/SILTS
SAND/SM GRAVELS
COBBLES
SMALL-LARGE GRAVELS
SMALL GRAVELS
GRAVELS & COBBLES
FLOW
CHINOOK SALMON HABITAT
UNDERCUT BANKS & WOODY DEBRIS INPUT
FRY & JUVENILE REARING
JUV. FEEDING HABITAT
ADULT HOLDING HABITAT
FRY & JUVENILE REARING HABITAT
SPAWNING HABITAT
RIPARIAN VEGETATION PATTERNS
MATURE RIPARIAN VEGETATION
EXPOSED BAR AND YOUNG RIPARIAN VEGETATION
LEGEND
LOW FLOW CHANNEL
BANKFULL CHANNEL
TERRACE
THALWEG
BEDLOAD TRANSPORT PATH
POOL
POINT BAR
BACKWATER
RIFFLE

Evolution of Cutoff Chutes & Alcoves

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

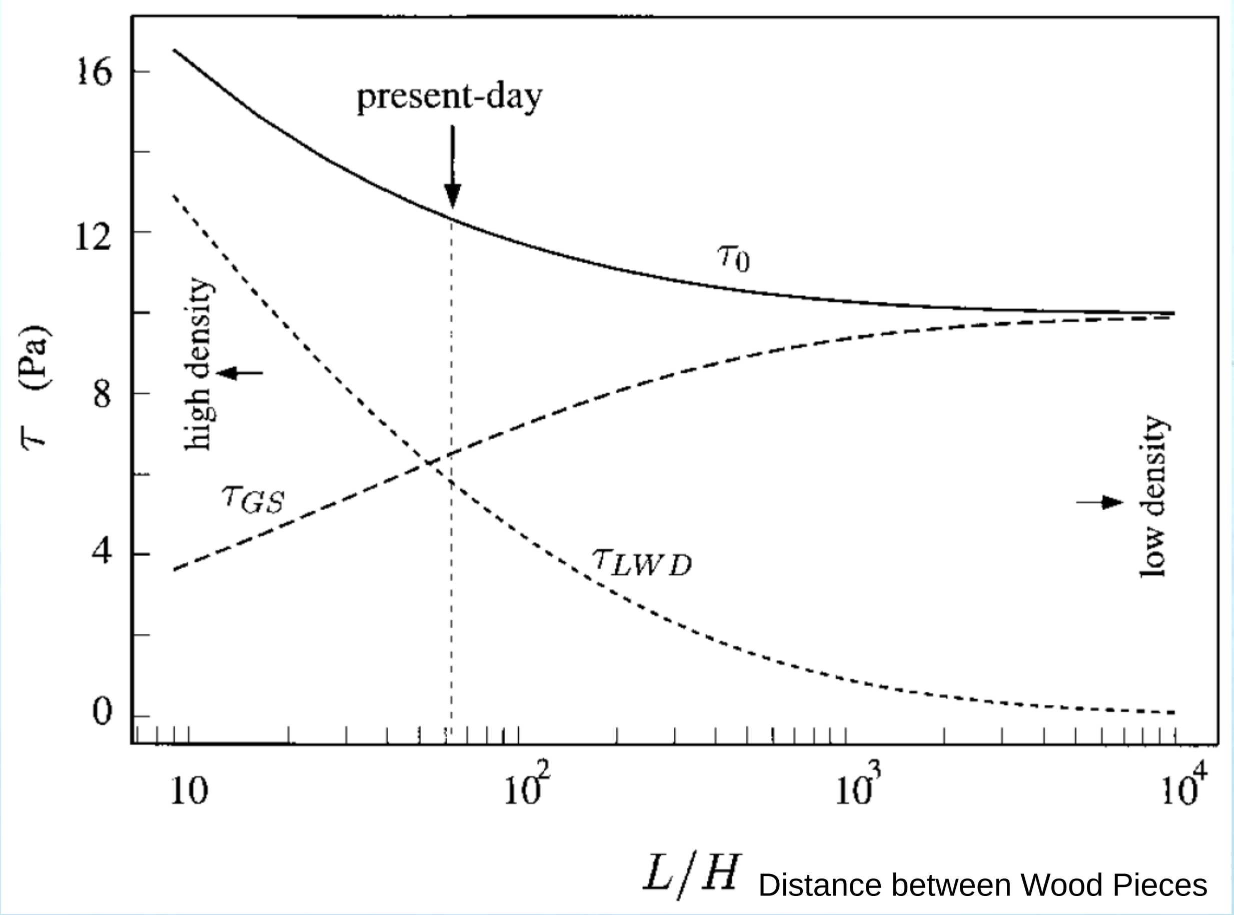
Create by:

- Lowering Back Bar Height
- Increasing Head Loss By Adding Wood



Effect of Wood Loading

$\tau_0 = \rho g h S$



Manga and Kirchner 2000

Increased Wood Loading increases:

- flow depth
- energy slope

Activate Off-channel Areas by Adding Wood

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
- Anabranch (Split) Channels

Vegetated Bars & Islands

Vegetated Bars

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

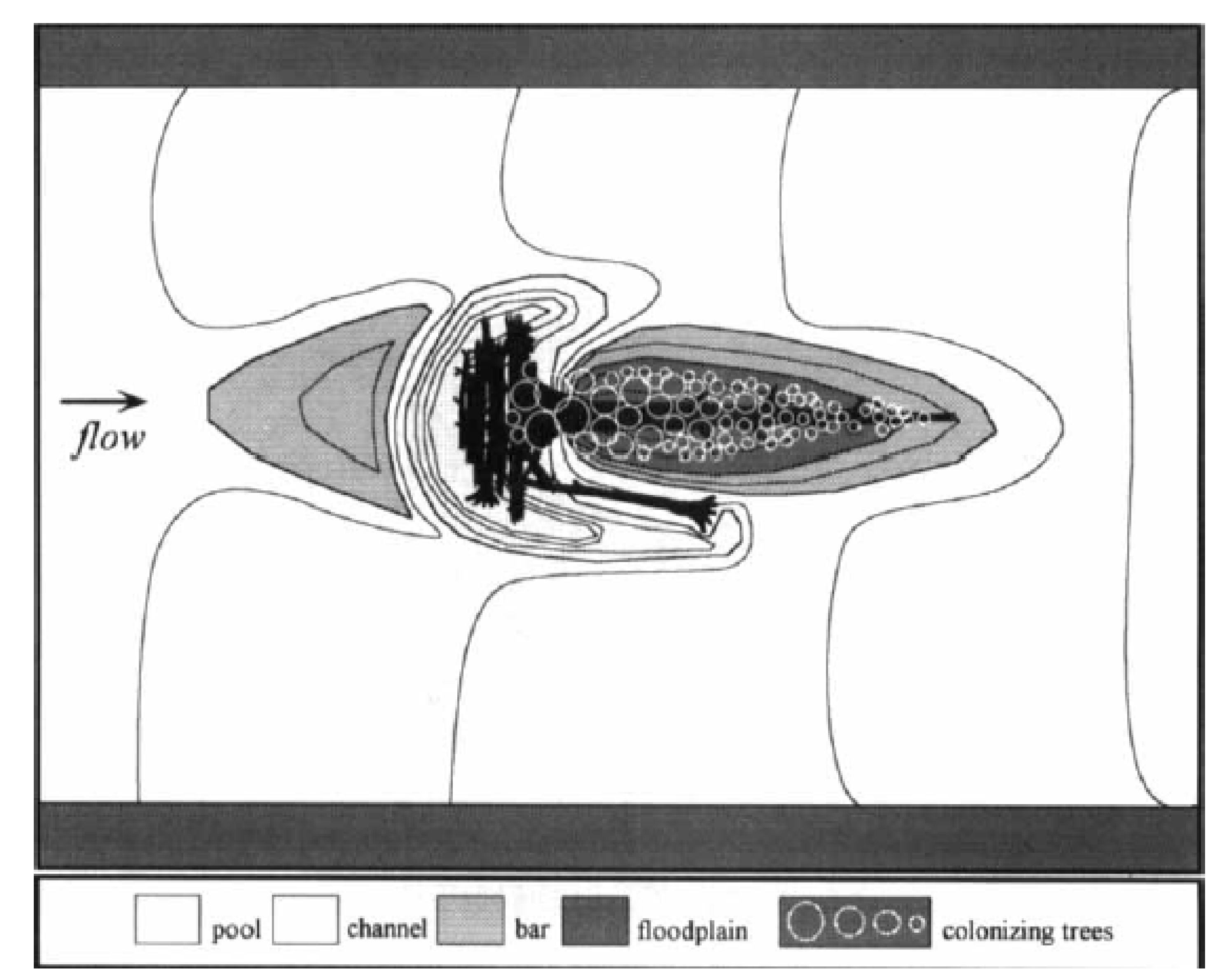
Islands

- 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 Jams

Apex Bar Jam in Mattole

Engineered Log Jam

Anabranch Channels

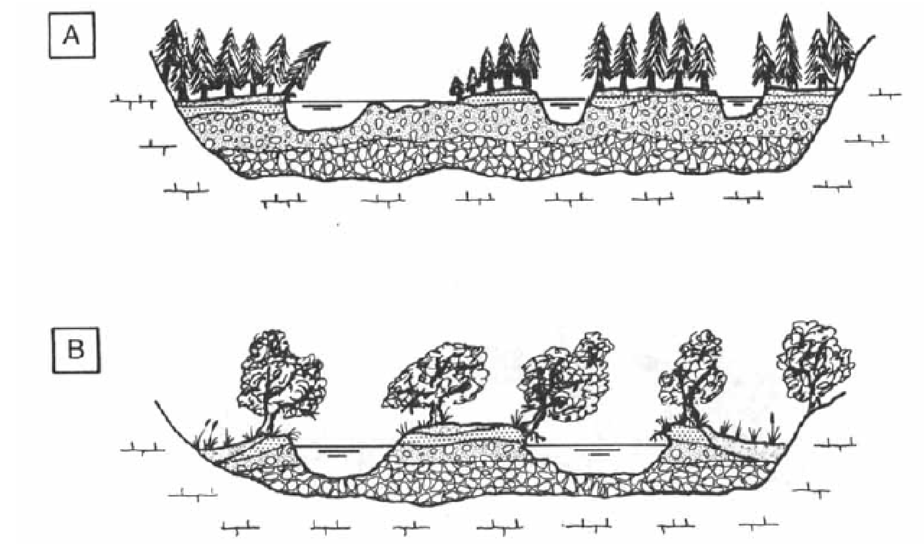


Figure 7. (A) Gravel-dominated, laterally active system (type 5); (B) gravel-dominated stable system (type 6)

Nanson and Knighton, 1996

- 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

Constructing an Anabranch: Design Issues

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

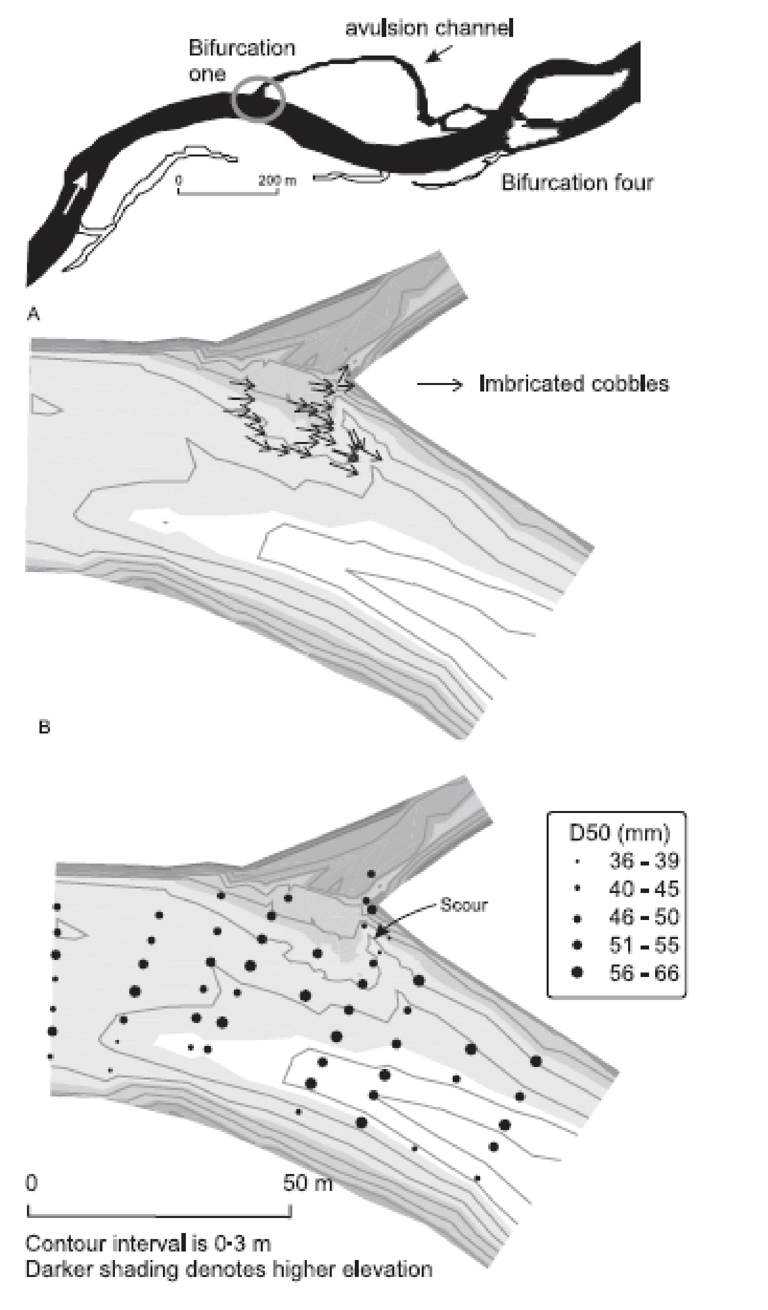
Anabranch Channel Location

Specific Requirements -- Not Random

- Stable Anabranch Channels
  - 5% - 20% of Total Flow
  - Separated at Flows $\geq$ 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

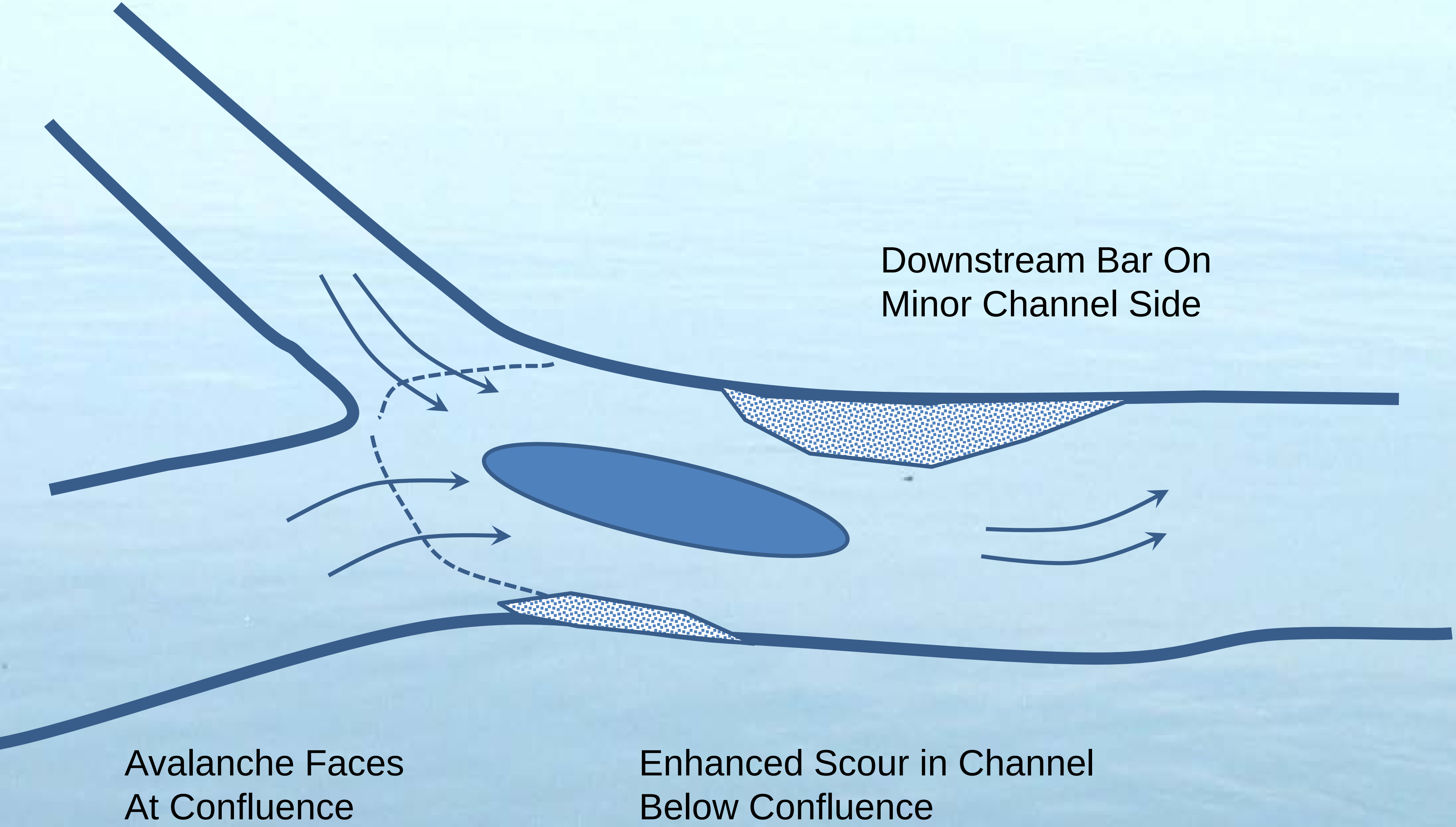
Stable Entrance Characteristics

- 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



Design Elements for Off-Channel Habitat in Lowlands

Objectives:

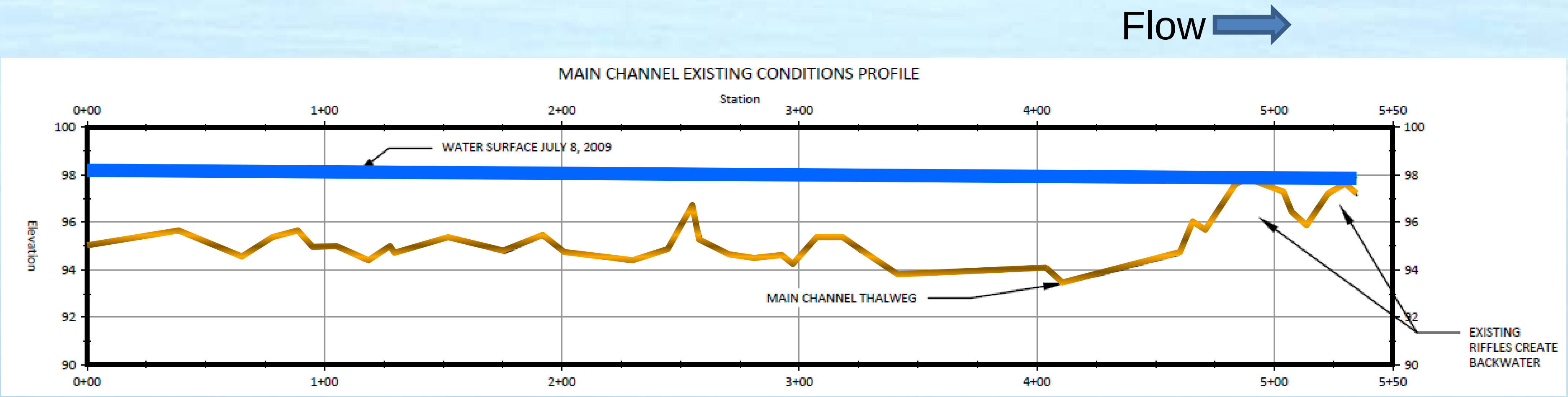
- Wet Season Rearing
- Summer Cool Water Refugia
- Floodplain Access
- Movement
- Cover
- Complexity

Design Elements

- Cutoff Chutes
- Backwater Channels
- Seasonal Wetlands
- Anastomosed Streams
- Avulsions
- Wood Jams

Backwater Channel

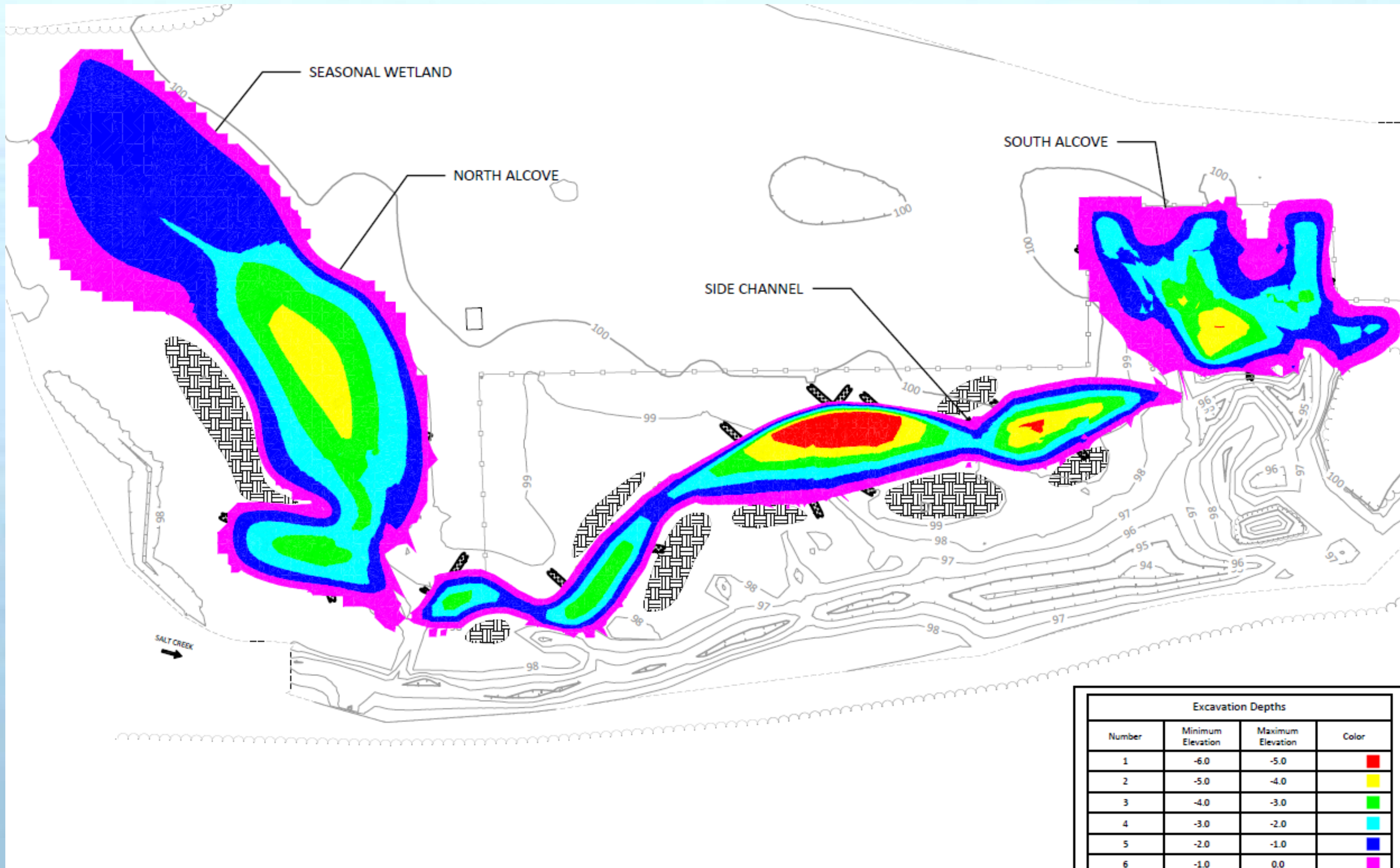
Formed Where Downstream Grade Control Elevates Water Surface



Appropriate for Lowland Stream Because:

$$L_b = h/S_f$$

Backwater Channel Design: Salt Creek

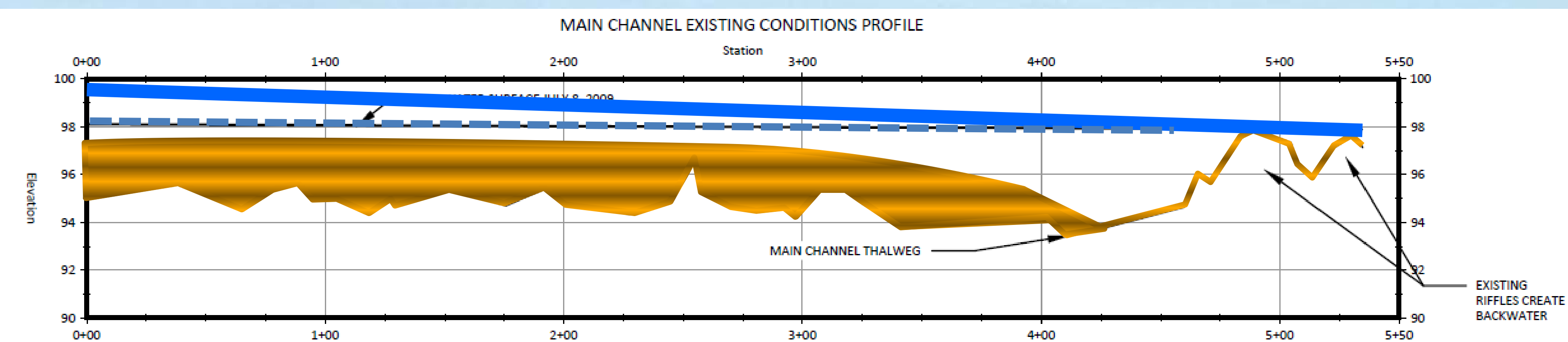


Excavation Depths			
Number	Minimum Elevation	Maximum Elevation	Color
1	-6.0	-5.0	
2	-5.0	-4.0	
3	-4.0	-3.0	
4	-3.0	-2.0	
5	-2.0	-1.0	
6	-1.0	0.0	

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

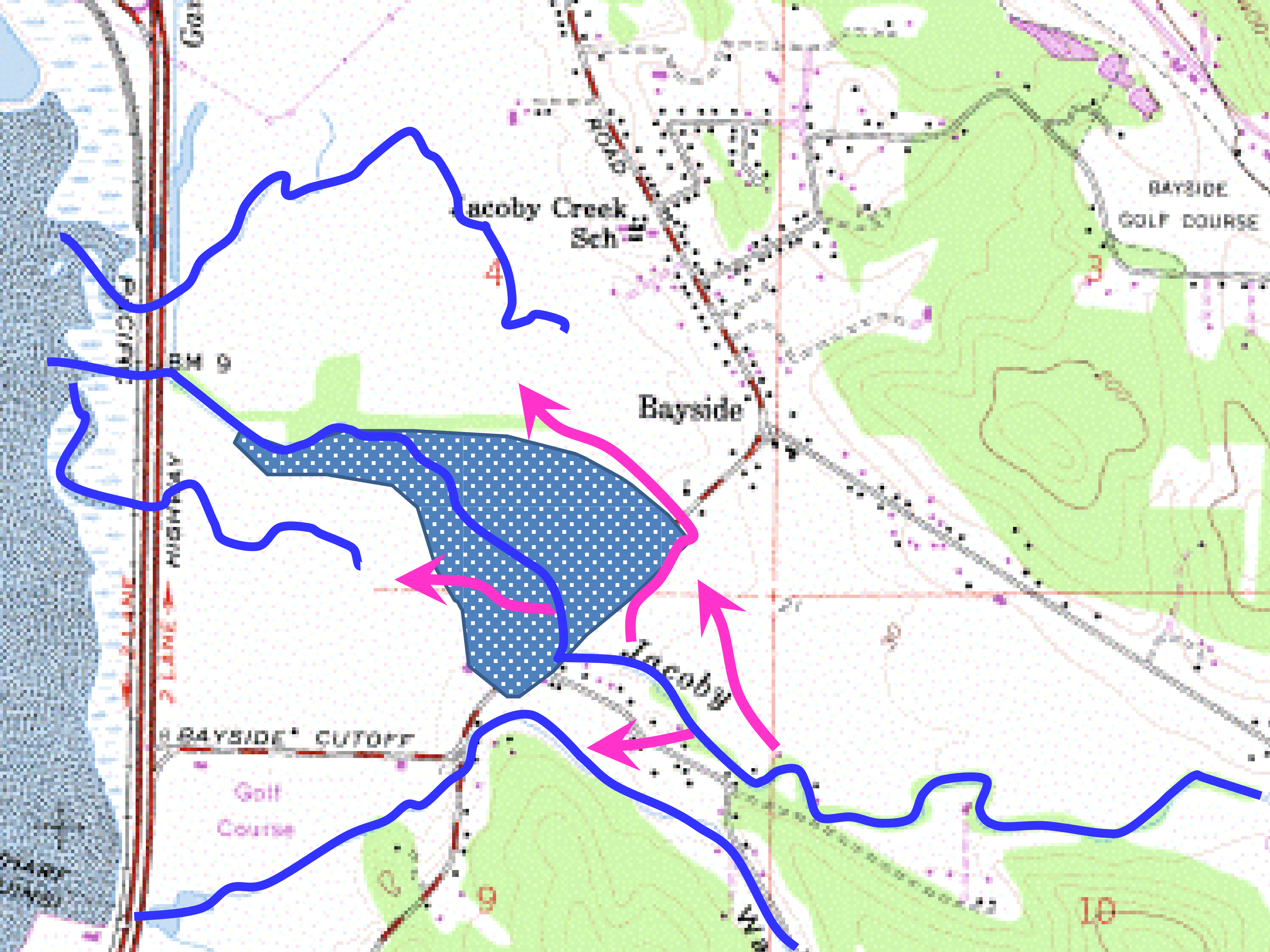
- Multiple Channels
- Complex Habitat

Use in Restoration Requires:

- Wide Floodplain
- Low Potential for Land-use Conflicts

Taiya River, AK

Abbe, Brooks, and Montgomery, 2003



Jacoby Creek
Sch
Bayside
BAYSIDE
GOLF COURSE
BM 9
HIGHWAY
BAYSIDE CUTOFF
Golf
Course
Jacoby
ROAD
4
3
9
10

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