DESIGN METHODS B: SEDIMENT TRANSPORT PROCESSES FOR STREAM RESTORATION DESIGN

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2ND ANNUAL NORTHWEST STREAM RESTORATION DESIGN SYMPOSIUM
SKAMANIA LODGE, STEVENSON, WASHINGTON
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SCOPE OF PRESENTATION

STREAM DYNAMICS, CHANNEL RESTORATION PLANS, & SEDIMENT TRANSPORT ANALYSES IN RELATION TO RESTORATION PLANS
STREAM DYNAMICS -- 1

WATER DISCHARGE IS VARIABLE

FLOODS ⇔ MODERATE FLUCTUATIONS ⇔ DROUGHTS

PROCESSSES CONTROLLED BY WATER DISCHARGE ARE TRANSIENT:

- CHANNEL EROSION
- SEDIMENT TRANSPORT
- SEDIMENT DEPOSITION
- DEBRIS MOVEMENT

STREAM DYNAMICS -- 2

RESPONSES TO STREAMFLOW EVENTS:

SOME ARE:
- IMMEDIATE - - - E.G., BANK COLLAPSE
- PROGRESSIVE - - - E.G., BANK EROSION, BAR GROWTH
- DELAYED - - - E.G., CHANNEL CUTOFF
  MAY OCCUR DURING NEXT FLOOD SEASON
  MAY ONLY OCCUR YEARS LATER

MOST ARE OVERLAPPING

THUS, RIVERS UNDERGO COMBINATIONS OF SHORT-TERM AND LONG-TERM ADJUSTMENTS
STREAM DYNAMICS -- 3

SEDIMENT MOVEMENT, ACCUMULATION, AND LOSS

FLOWING WATER IN CHANNEL

ALL ARE LINKED, WITH FEEDBACK & INTERPLAY

CHANNEL MORPHOLOGICAL FEATURES

LARGE DEBRIS MOVEMENT, ACCUMULATION AND LOSS

TYPES OF CHANNEL STABILITY

<table>
<thead>
<tr>
<th>TYPES</th>
<th>FEATURES</th>
<th>EXAMPLES</th>
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<tbody>
<tr>
<td>RIGID STABILITY</td>
<td>FIXED BOUNDARIES</td>
<td>LINED CHANNEL</td>
</tr>
<tr>
<td>STATIC EQUILIBRIUM</td>
<td>NO BOUNDARY CHANGES</td>
<td>COHESIVE CHANNEL</td>
</tr>
<tr>
<td>DYNAMIC EQUILIBRIUM</td>
<td>BOUNDARY CHANGES BUT</td>
<td>MEANDERING RIVER IN LARGE FLOODPLAIN</td>
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<tr>
<td></td>
<td>LONG-TERM BALANCE</td>
<td></td>
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<tr>
<td>DISEQUILIBRIUM</td>
<td>IMBALANCED SEDIMENT CONDITIONS</td>
<td>DISRUPTED FLUVIAL SYSTEM</td>
</tr>
<tr>
<td></td>
<td>QUICK CHANGE OF STATE EVOLVE</td>
<td>DAM + WATER DIVERSION</td>
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<tr>
<td></td>
<td>OVER TIME</td>
<td>DAM BLOCKING STREAM</td>
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<tr>
<td></td>
<td></td>
<td>BED AGGRAVATION</td>
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<td></td>
<td></td>
<td>CHANNEL WIDENING</td>
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<tr>
<td>ABRupt</td>
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<tr>
<td>PROGRESSIVE</td>
<td></td>
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<tr>
<td>• UPSTREAM</td>
<td></td>
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<tr>
<td>• DOWNSTREAM</td>
<td></td>
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<tr>
<td>• LATERAL</td>
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DYNAMIC CHANNEL STABILITY

NATURAL FLOWS AND SEDIMENT TRANSPORT CONDITIONS:
- ARE DYNAMIC OVER TIME
- MAY HAVE A WIDE RANGE BETWEEN "LIMITING" VALUES
- MAY PRODUCE MODERATE CHANNEL CHANGES AND ADJUSTMENTS

ALTERATIONS ARE INDICATED BY CHANGES IN CHANNEL FEATURES SUCH AS DEPTHS, WIDTHS, BED FEATURES, AND BANK LINES.

OVER TIME, THESE VARIATIONS LEAVE THE CHANNEL RELATIVELY UNALTERED IN ITS MAIN PLANVIEW AND TRANSECT FEATURES. HENCE, A GENERAL LONG-TERM STABILITY EXISTS.

RIVER DYNAMICS AND STABILITY
AT THE REACH SCALE

<table>
<thead>
<tr>
<th>UPSTREAM REACH</th>
<th>RESTORATION REACH</th>
<th>DOWNSTREAM REACH</th>
</tr>
</thead>
<tbody>
<tr>
<td>THIS REACH PROVIDES THE MAIN INPUTS TO THE RESTORATION REACH, LARGELY BASED ON UPSTREAM CONDITIONS</td>
<td>THIS REACH MUST TRANSPORT MATTER; IT MAY ALSO SUPPLY OR STORE MATTER</td>
<td>THIS REACH CONTROLS TRANSPORT DYNAMICS WITHIN THE RESTORATION REACH AND THE OUTPUTS FROM THAT REACH</td>
</tr>
</tbody>
</table>
RESTORATION PROJECTS AND SEDIMENT TRANSPORT QUESTIONS

WHAT ALTERATIONS ARE PROPOSED?
• REGARDING FLOWS?
• REGARDING PHYSICAL CHANGES?

PRESENT STATUS OF STREAM AND CHANNEL?
• REGARDING SEDIMENT SUPPLY, MOVEMENT, DEPOSITION?
• REGARDING CHANNEL STABILITY OR CHANGE?

WHAT “PROBLEMS” LED TO THE PROJECT?
• ARE THEY REAL OR PERCEIVED?
• ARE PROBLEMS AND CAUSES DOCUMENTED?
• HOW DO PROBLEMS AFFECT SEDIMENT PROCESSES?

PROJECT “PROCESS” TO RESTORE STREAM?
• ORGANIZATION OF PLANNING AND DESIGN?
• DATA COLLECTION?
• PLANS FOR CONSTRUCTION AND POST-CONSTRUCTION MONITORING?
• INCLUSION OF SEDIMENT PROCESSES EVALUATION?

SEDIMENT BEHAVIOR CHECKS TO IDENTIFY ANALYSIS NEEDS

WILL THE PROJECT ALTER:
- HYDRAULIC GEOMETRY OF THE CHANNEL?
- FLOW GRADIENTS ALONG THE CHANNEL?
- CHANNEL FLOW AND BOUNDARY ALIGNMENTS?
- BANK STABILITY?
- WATER FLOW PATTERNS WITHIN THE CHANNEL?
- WATER CAPABILITY TO TRANSPORT SEDIMENT?
- SEDIMENT SOURCES AND AVAILABILITY FOR TRANSPORT?
- SEDIMENT TRANSPORT ROUTES?
- SEDIMENT DEPOSITION ZONES?
CHANNEL DESIGN DECISIONS THAT AFFECT NEEDED TYPES OF SEDIMENT TRANSPORT ANALYSES

- Acceptable level of stream dynamism
- Planned extent of floodplain interaction
- Channel reconstruction plan and design
- Channel alignment and geometry details
- Planned "fixed" physical features (e.g., weirs)
- Desired morphological features (e.g., pools, riffles)
- Inclusion of habitat structures (e.g., boulders, alcoves, bank undercuts)

DEVELOPMENT OF STUDY PLAN TO EVALUATE SEDIMENT BEHAVIOR

STUDY AREA BOUNDARIES FOR SEDIMENT ANALYSES

- Longitudinal -- reaches
- Lateral -- banks, riparian zones, floodplain
- Vertical -- bed, canopy

STABILITY ASPECTS

- Stability requirements for project elements
- Assessment tools and methods of use

POTENTIAL PROBLEM SPOTS IN STUDY AREA

- Identification options

DATA

- Inventory of available data
- Data needs and collection plan

SOPHISTICATION

- Qualitative versus quantitative
SEDIMENT TRANSPORT ANALYSIS TOOLS

1. SEDIMENT MASS BALANCE AND TRANSPORT CONTINUITY ASSESSMENT
2. SOURCE – ROUTE – SINK ASSESSMENT
3. SEDIMENT AVAILABILITY VERSUS FLOW CAPABILITY ASSESSMENT
4. SEDIMENT INCIPIENT MOTION ASSESSMENT
5. GENERAL SEDIMENT TRANSPORT PREDICTION
6. STREAM POWER ASSESSMENT AND BALANCE

SEDIMENT ANALYSIS TOOLS -- 1

SEDIMENT MASS BALANCE AND TRANSPORT CONTINUITY ASSESSMENT

SUM OF SEDIMENT INPUTS - SUM OF SEDIMENT OUTPUTS = CHANGES IN SEDIMENT STORAGE

EXAMPLES:
- INDIVIDUAL STORM EVENTS AND ASSOCIATED TRANSPORT
- ANNUAL SEDIMENT TRANSPORT AND STORAGE CHANGE
- MULTI-YEAR PERIODS OF TRANSPORT AND STORAGE CHANGE
SEDIMENT ANALYSIS TOOLS -- 2

SOURCE – ROUTE – SINK ASSESSMENT
FOR DISTURBED SEDIMENT

<table>
<thead>
<tr>
<th>SOURCES</th>
<th>VARIOUS SUPPLY AREAS WITHIN CHANNEL AND WATERSHED WHERE SEDIMENT ORIGINATES ITS MOTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROUTES</td>
<td>WATERSHED AND CHANNEL WATERWAYS; TRANSPORT PROCESS ROUTES (E.G., OVERLAND, BED LOAD, SUSPENSION)</td>
</tr>
<tr>
<td>SINKS</td>
<td>VARIOUS DEPOSITION AREAS IN CHANNEL AND REACH, OR BEYOND (E.G., BARS, OVERBANK, DOWNSTREAM)</td>
</tr>
</tbody>
</table>

SEDIMENT ANALYSIS TOOLS -- 3

SEDIMENT AVAILABILITY
VERSUS
FLOW CAPABILITY ASSESSMENT

A “DOUBLE-CONDITION” MUST BE MET:

- THERE MUST BE SEDIMENT AVAILABLE TO BE MOVED
- THE FLOW MUST BE CAPABLE OF MOVING THE AVAILABLE SEDIMENT

REST ——— IF FLOW IS NOT CAPABLE OF MOVING SEDIMENT

TRANSPORT — AT CAPACITY, IF AVAILABLE — USE FORMULAS
— AT UNDERSUPPLY, IF LIMITED — “HUNGRY” WATER ?
SEDIMENT ANALYSIS TOOLS -- 4

SEDIMENT INCIPIENT MOTION ASSESSMENT

<table>
<thead>
<tr>
<th>STABILITY OF BED MATERIAL</th>
<th>INCIPIENT MOTION OF BED MATERIAL</th>
<th>GENERAL MOVEMENT OF BED MATERIAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Permissible Values</td>
<td>Critical Values</td>
<td>Governing Transport Parameters</td>
</tr>
<tr>
<td>Based on Velocity or Shear Stress</td>
<td>Based on Velocity or Shear Stress or Discharge</td>
<td>Based on Relations to Discharge</td>
</tr>
</tbody>
</table>

SEDIMENT ANALYSIS TOOLS -- 5

GENERAL SEDIMENT TRANSPORT PREDICTION

VARIABLES:
- CHARACTERISTICS OF THE FLOW, FLUID, CHANNEL, BOUNDARY, SEDIMENT

BED-MATERIAL FORMULAS
- BED LOAD AND SUSPENDED LOAD FROM STREAMBED
- SIMILARITY, LIFT, PROBABILITY, EQUAL-MOBILITY CONCEPTS

BED-LOAD TRACTIVE-LOAD FORMULAS
- EXCESS SHEAR STRESS OR ENERGY SLOPE OR DISCHARGE

SUSPENDED-LOAD FORMULAS
- CONCENTRATIONS, TURBULENCE, MOMENTUM EXCHANGE

TOTAL-LOAD FORMULAS
- COMBINED CONTRIBUTIONS TO TRANSPORT
SEDIMENT ANALYSIS TOOLS -- 6

STREAM POWER ASSESSMENT AND BALANCE

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FOR AN ALLUVIAL STREAM IN DYNAMIC EQUILIBRIUM, THERE IS A “BALANCE” OVER TIME AMONG VARIABLES:

\[ (Q \times Se) \sim (Q_{sed} \times D_{sed}) \]

WHERE:

- \( Q \) WATER DISCHARGE
- \( Se \) ENERGY SLOPE
- \( Q_{sed} \) SEDIMENT DISCHARGE
- \( D_{sed} \) SEDIMENT REPRESENTATIVE SIZE

AND WHERE \( (Q \times Se) \) IS THE UNIT STREAM POWER

TO MAINTAIN THIS BALANCE WHEN ONE TERM IS ALTERED, ONE OR MORE OTHER TERMS MUST RESPOND.

SEDIMENT TRANSPORT DESIGN ANALYSES -- 1

DESIGN FLOW MAGNITUDES

- DETERMINE FROM BASIN HYDROLOGY
- DETERMINE FROM CHANNEL HYDRAULICS

BED MATERIAL

- AVAILABLE TYPES AND SIZES
- PREFERRED SIZES (E.G., HABITAT NEEDS)
- STABILITY CONSIDERATIONS

MORPHOLOGIC FEATURES

- STABILITY CONSIDERATIONS
- POSSIBLE MANIPULATION TO CHANGE STABILITY

CHANNEL BOUNDARY ROUGHNESS OVER TIME

- BED AND BANK MATERIALS
- CHANNEL MORPHOLOGY AND VEGETATION
SEDIMENT TRANSPORT DESIGN ANALYSES -- 2

1. CHANNEL GEOMETRY | 5. FLOW PATTERNS
2. FLOW GRADIENTS | 6. BED STRESSES
3. CHANNEL ALIGNMENT | 7. BANK STRESSES
   AND CURVES | 8. SEDIMENT SOURCES
4. BANK STABILITY | 9. SEDIMENT AVAILABILITY

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10. INCIPIENT MOTION
11. GENERAL REACH TRANSPORT: IN => THROUGH => OUT
12. MASS BALANCE AND SEDIMENT CONTINUITY
13. DEPOSITION ZONES
14. SOURCE DEPLETION OR SUSTAINED MAINTENANCE
15. LONG-TERM BALANCE OR LONG-TERM TRENDS
15. EFFECTS OF FORCED AND DYNAMIC CHANGES

POST-CONSTRUCTION MONITORING

SOME QUESTIONS TO ASK

- HAS THE REACH HAD TIME & OPPORTUNITY TO ADJUST?
- ARE UNEXPECTED SEDIMENT-RELATED CHANGES HAPPENING OUTSIDE OF THE PROJECT BOUNDARIES?
- ARE SEDIMENT PROCESSES FUNCTIONING AS HAD BEEN HOPED FOR AND AS HAD BEEN PREDICTED?
- IS DYNAMIC STABILITY OF THE REACH AND CHANNEL BEING ACHIEVED?
- IS THE RESTORATION PROJECT NOW SELF-SUSTAINING AND WILL IT BE IN THE FUTURE?
MONITORING CHECKS ON SEDIMENT TRANSPORT PROCESSES

1. STREAMFLOW RECORDS --- (SEDIMENT-INFLUENCING EVENTS)
2. CROSS SECTION SHAPE AND SIZE --- (STREAMFLOW EFFECTS)
3. FLOW FIELD EVALUATION --- (SEDIMENT MOVEMENT EFFECTS)
4. REACH SLOPE & LOCAL SLOPES --- (SEDIMENT MOVEMENT EFFECTS)
5. LOCAL SCOUR AND DEPOSITION TRENDS --- (CHANGING SEDIMENT MOVEMENT OVER TIME)
6. CHANNEL MORPHOLOGY STATUS AND TRENDS --- (CHANGING SEDIMENT MOVEMENT EFFECTS)
7. INFLUENCE OF ADDED-SHIFTED-REMOVED “STRUCTURES” --- (SEDIMENT MOVEMENT EFFECTS)
8. SEDIMENT MASS BALANCE --- (HOW REACH IS ADJUSTING)
9. STABILITY-EQUILIBRIUM STATUS AND TRENDS --- (HAS REACH ADJUSTED?)

FOR MORE ON SEDIMENT DESIGN:

RIVER SEDIMENT TRANSPORT ANALYSES
-- 3-DAY SHORT COURSE --

Bradley (WEST) & Klingeman (OSU)
March 25-27, 2003
OSU Campus