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A PRACTICAL APPROACH TO FLOODPLAIN SEDIMENTATION MODELING USING HEC-RAS AND ASSOCIATED NUTRIENT RETENTION

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Background

Process-Based Restoration

1. Target Root Causes of Habitat and Ecosystem Change

- Processes (functions) impaired

2. Tailor Restoration to Local Potential

- Processes controlling restoration outcomes
- Ability to restore controlling processes

3. Match the Scale of Restoration to the Scale of the Problem

- Reach-scale, Watershed-scale, both
- Dependent on key causes of degradation

4. Be Explicit about Expected Outcomes

- Quantitative predictions of restoration are critical
- How much restoration is necessary
- Provide a range of possible outcomes

Process-based Principles for Restoring River Ecosystems

Beechie et al. (2010)

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Background

Prediction of Expected Outcomes

- Wilcock (2012)
  - Predictions need to be good enough to provide clear guidance
  - If uncertainty is understood…Highly uncertain predictions can be effective for decision making

- Wilcock et al. (2009) – BAGS (Bedload Assessment in Gravel-bedded Streams)
  - Framing the question about sediment transport predictions to reduce uncertainty/error
  - Difference between two transport rates = less uncertainty
  - Estimating the actual transport rate = more uncertainty

- Relative difference in sediment deposition/storage for:
  - Existing and proposed conditions
  - Multiple floodplain design scenarios

- Error/Uncertainty → not an excuse to ignore making predictions

Uncertainty?

USDA
United States Department of Agriculture
Forest Service
Rocky Mountain Research Station
General Technical Report RMRS-GTR-226
May 2009

Sediment Transport Primer

Estimating Bed-Material Transport in Gravel-bed Rivers

Peter Wilcock, John Pitlick, Yantao Cui

Stream Restoration in Gravel-bed Rivers

Gravel-bed Rivers: Processes, Tools, Environments, First Edition. Edited by Michael Church, Pascale M. Biron and André G. Roy.

Background

WETLAND CELL
BREACH
BREACH
SEDIMENT DEPOSITION
CREATED BERMS
WETLAND CELL

Methodology

1. Estimate sediment concentration entering project reach
2. Model (hydrologic) hydrographs for a range of flows accessing the floodplain
3. Incrementally model (hydraulic) portions of hydrographs that access the floodplain
4. Calculate trapping efficiency and floodplain shear stress
5. Calculate sediment discharge for each flow increment
6. Calculate sedimentation for modeled hydrographs
7. Calculate annual sedimentation

Methodology

1. Estimate sediment concentration entering project reach

- High flow tends to carry more than 90% of the sediment load (Kleiss 1996)
- Suspended concentration highly variable, including through hysteresis in a single storm event
- Regression analysis of 37 Maryland USGS gages
- Wide range of suspended sediment concentration between sites
    - Evaluate site conditions for relative concentration
- Alternative: develop sediment discharge rating curve or calibrate a suspended sediment transport model

Recurrence Discharge	Suspended Sediment Concentration (mg/l)
0.1Q1	66
0.25Q1	94
0.5Q1	180
1	430
2	720
10	840
100*	1300

*Data for 100-year event not available, logarithmic interpolation based on average values from the 1, 2, and 10-year event used to predict.

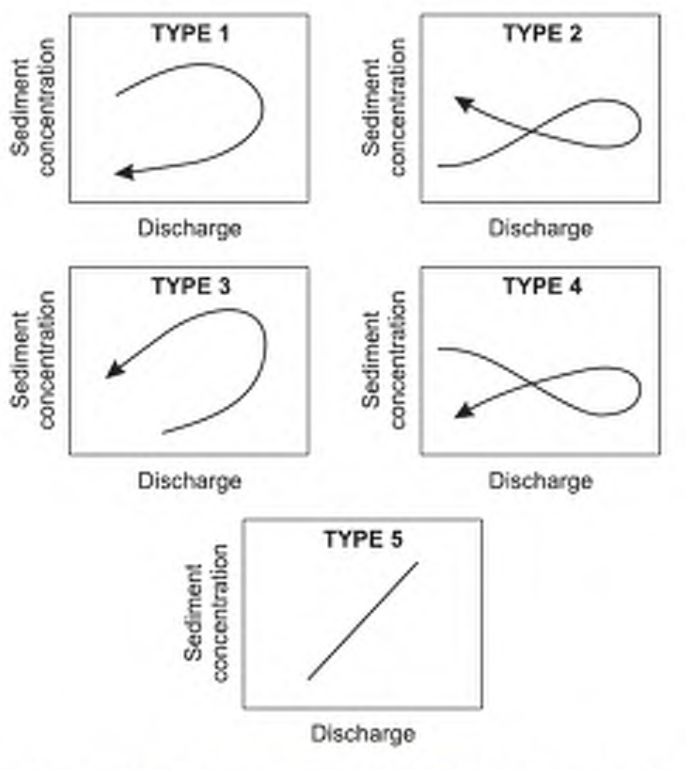


Fig. 1. Hysteresis types (after Williams, 1989; Kurashige, 1994). Arrows indicate direction through time. TYPE-1 clockwise, TYPE-2 figure eight, clockwise early in storm reversing to counterclockwise, TYPE-3 counterclockwise, TYPE-4 figure eight, counterclockwise early in storm reversing to clockwise, and TYPE-5 no exhaustion.

Gellis, A.C., Factors influencing storm-generated suspended-sediment concentrations and loads in four basins of contrasting land use, humid-tropical Puerto Rico, Catena (2012), http://dx.doi.org/10.1016/j.catena.2012.10.018

Methodology

1. Estimate sediment concentration entering project reach

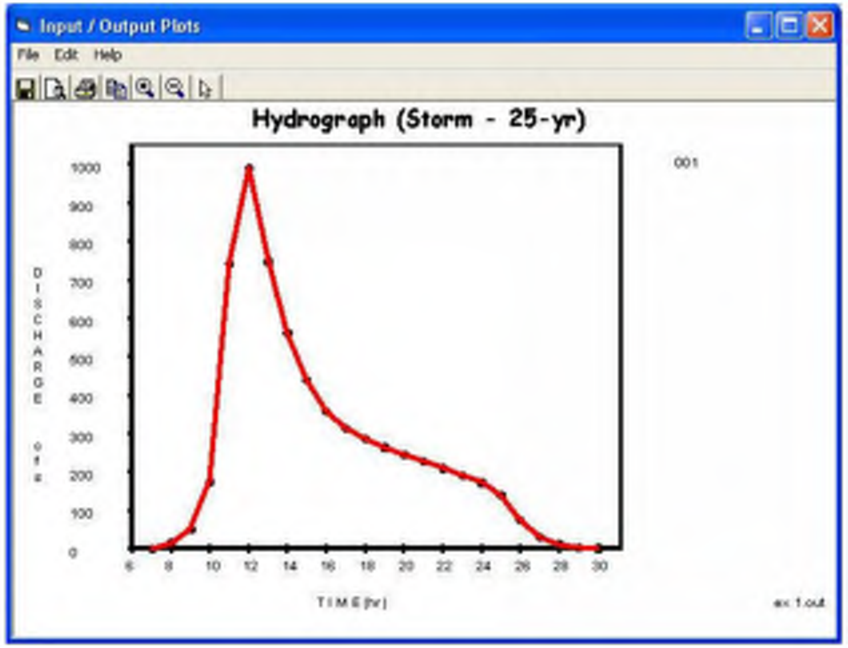




Methodology

2. Model hydrographs for range of flows accessing the floodplain

Recurrence Interval Discharge (Year)									
0.1Q1	0.25Q1	0.5Q1	1	2	5	10	25	50	100



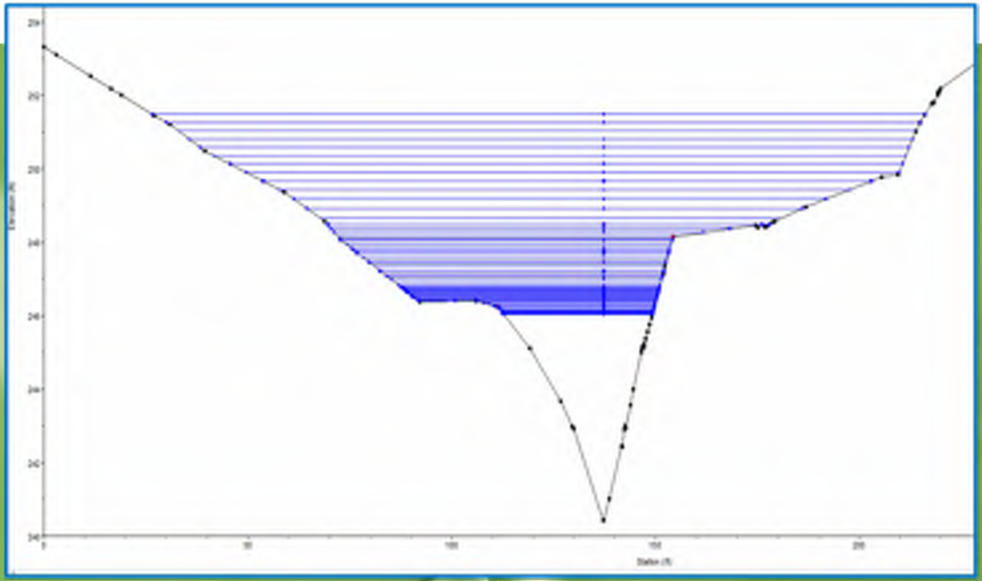
- Number of discharges – user specified
- Partial duration series
  - Ratios for Q less than 1 year
- Alternative
  - Instantaneous flow data
  - Unlikely to have larger discharges

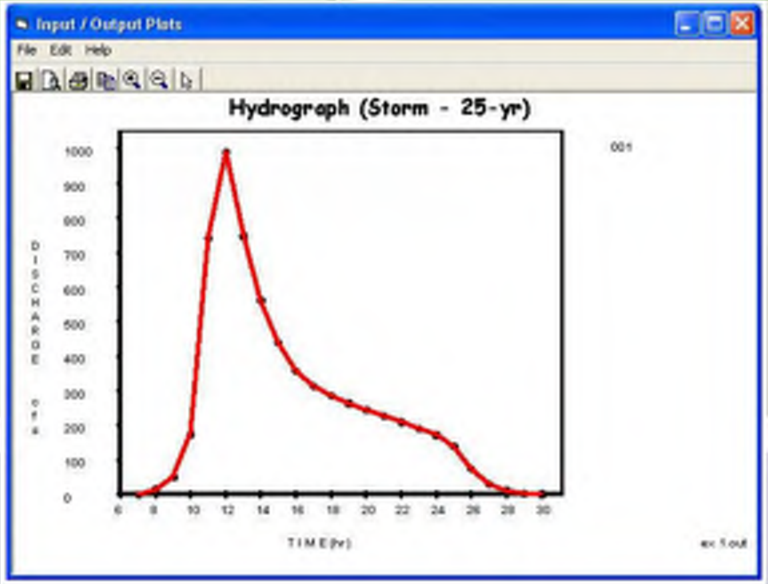
Recurrence Discharge	Ratio of Event to 1-year	
	Average	90% Confidence Interval
0.1Q1	0.26	(0.08 , 0.43)
0.2Q1	0.42	(0.23 , 0.60)
0.25Q1	0.47	(0.28 , 0.67)
0.33Q1	0.57	(0.35 , 0.78)
0.5Q1	0.71	(0.52 , 0.90)

Methodology

3. Incrementally model portions of hydrographs that access the floodplain

- A 1-D model such as HEC-RAS is expected to provide sufficient clarity to determine required characteristics (Asselman and van Wijngaarden 2002, Thonon et al 2005)
- Recommend 20 flow increments per hydrograph
- Model output required for the range of discharges that accesses the floodplain and for each floodplain:
  - discharge
  - the wetted area
  - the top width
  - the length
  - average shear
  - Floodplain breaches can also be modeled using a 1-D model





Methodology

4. Calculate trapping efficiency and floodplain shear stress

- Trapping efficiency is a function of fall/settling velocity, inundated floodplain area, and discharge (Asselman and van Wijngaarden 2002)
  - Dietrich 1982
  - 0.031 mm (medium/coarse silt) = 0.0009 m/s
  - 0.5 mm (medium/coarse sand) = 0.07 m/s
- Deposition unlikely in high shear environments
  - Critical shear stress for deposition is 2 Pa (Asselman and van Wijngaarden 2002)
  - Assume that above this threshold no deposition, but no remobilization of deposition

$$E = 1 - \exp^{-\omega_s\left(1-\frac{\tau_{FP}}{\tau_c}\right)*\frac{A_{FP}}{Q_{FP}}}$$

E is trapping efficiency
ω_s is fall velocity
τ_{FP} is floodplain shear stress
τ_c is critical shear stress for deposition
A_{FP} is planform floodplain area
Q_{FP} is the floodplain discharge

Methodology

5. Calculate sediment discharge for each flow increment

- Sediment discharge, the volume of sediment entering the floodplain over time, is determined by multiplying the discharge in the floodplain by the suspended sediment concentration

$$Q_s = Q_{FP} C$$

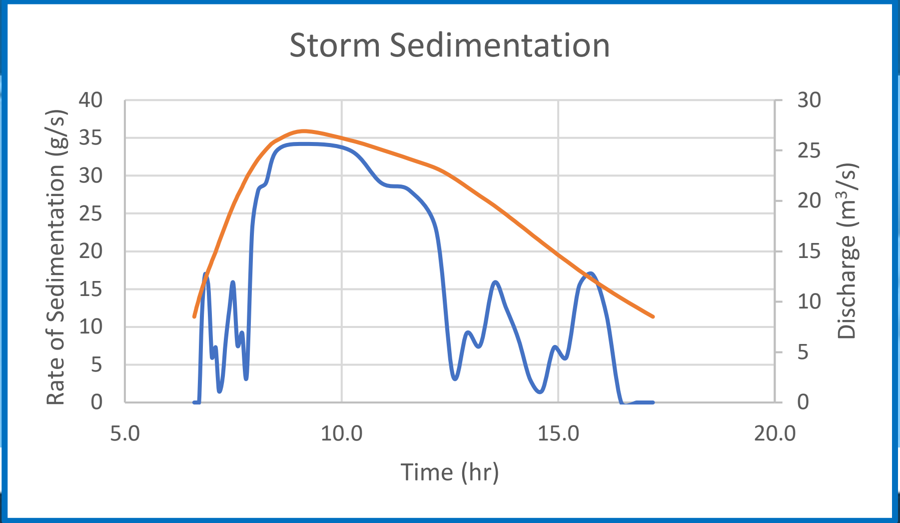
Q_s is suspended sediment discharge
Q_{FP} is the floodplain discharge
C is the suspended sediment concentration

Methodology

6. Calculate sedimentation for modeled hydrographs

- Rate of sedimentation can then be calculated as a function of trapping efficiency, and sediment discharge

- To determine the total sedimentation over the course of a storm, the rate of sedimentation needs to be multiplied by the appropriate time
  - Each flow profile modeled associated with time in hydrograph



$$S_i = Q_s E$$

S_i is rate of sedimentation
Qs is suspended sediment discharge
E is trapping efficiency

$$S = \sum S_i t_i$$

S is total storm sedimentation
t_i is time step duration

Methodology

7. Calculate annual sedimentation

Storm	S (tons)	Exceedance Probability	S (tons) Annualized
0.1	1.9	1000%	22
0.25	5.5	400%	16
0.5	10.2	200%	25
1	40.6	100%	28
2	72.1	50%	28
10	66.3	10%	10
100	159.3	1%	2
		Sum	131

$$Annual\ Deposition = \sum\left((p_{k+1} - p_k)\left(\frac{S_K + S_{k+1}}{2}\right)\right)$$

p is the exceedance probability
S is the recurrence interval storm deposition

- The amount of sediment can be annualized using the exceedance probability of each storm event
  - Trapezoidal approximation used as surrogate due to variability in deposition to recurrence interval storm

Methodology

Breached Floodplain Cells

- Breached floodplain cells can provide significant deposition through water storage
- Model flow through the breach
- Full floodplain cells can be modeled as reservoirs

$$T_E = 1 - e^{\left(-\frac{X\omega_i}{hV}\right)}$$

T_E is trapping efficiency
X is distance along direction of flow
ω_i is fall velocity
h is depth
V is average velocity

Case Studies

Case Study	Floodplain Access Flow	Suspended Sediment Concentration	Annual Sediment Deposition (tons/yr)	Relative Floodpalin Size
1	0.1Q1	High	131	Moderate/Wide
2	Q1	Average	2	Narrow
3	0.25Q1	High	15	Narrow/Moderate
4	0.5Q1	Average/High	12	Moderate
5	Q1 to Q2	High	222	Moderate/Wide; Floodplain Cells

- Sediment deposition potential dependent on suspended sediment concentration
- Floodplain width and project length important
- High floodplain shear stress is limiting
- Floodplain cells highly effective at deposition

Key Points

- Quantitative predictions are important to provide a general range of possible outcomes
- Predictions are going to be inaccurate…they only need to be good enough to provide clear guidance
- Be aware of which components of the model are most uncertain
- Evaluate a range of scenarios or model inputs…more realistic idea of possible outcomes
- Floodplain reconnection has the potential to store large amounts of fine sediment
- Floodplain cells have potential to store more sediment than open floodplains

Thank You!

Questions / Comments ?

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