Quantifying Performance of Stream Simulation Culverts in the Chehalis Basin, WA

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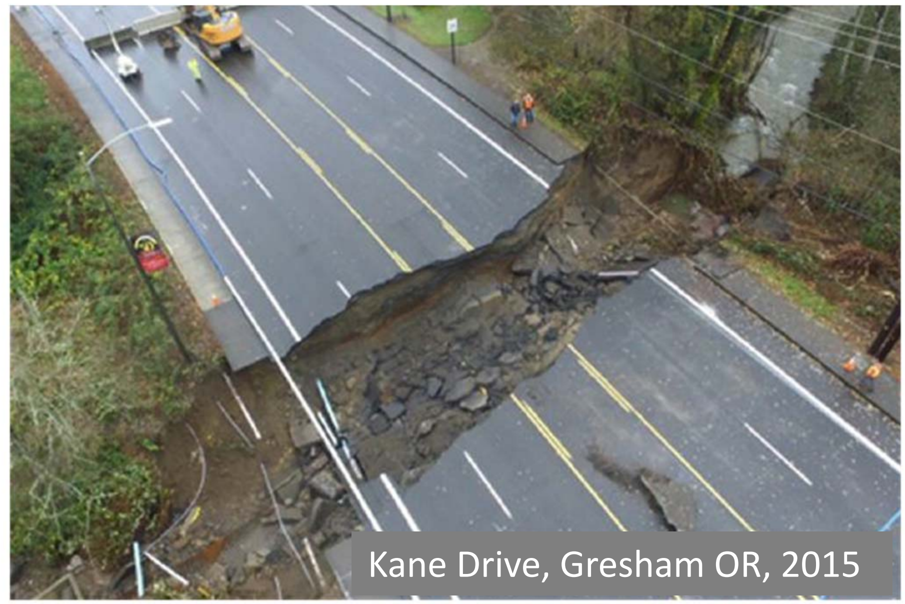
Stream Simulation in a Changing Environment

- Channel Approximating Structures
- Providing Multiple Species Passage
- Changing Watershed characteristics
  - Zoning Implications
  - Climate Change
- Changing Site Characteristics
  - Bank Full Width is dynamic
  - Continuity of flow and sediment
- Are Stream Simulation Culverts Resilient?



Kane Drive, Gresham OR, 2015

Methodology

- Collaborative
- Culvert performance metrics
- Chehalis Basin study sites
- 2D hydrodynamic modeling (Riverflow 2D)
- 2D mobile bed modeling (Nays2DH)
- Culvert performance evaluation tool

The Chehalis River Basin

- 7,000 km^2 watershed
- 8 major sub-basins
- 2,700 culvert passage barriers
- Focus of watershed, flood and species issues

Source: USFS National Map Data

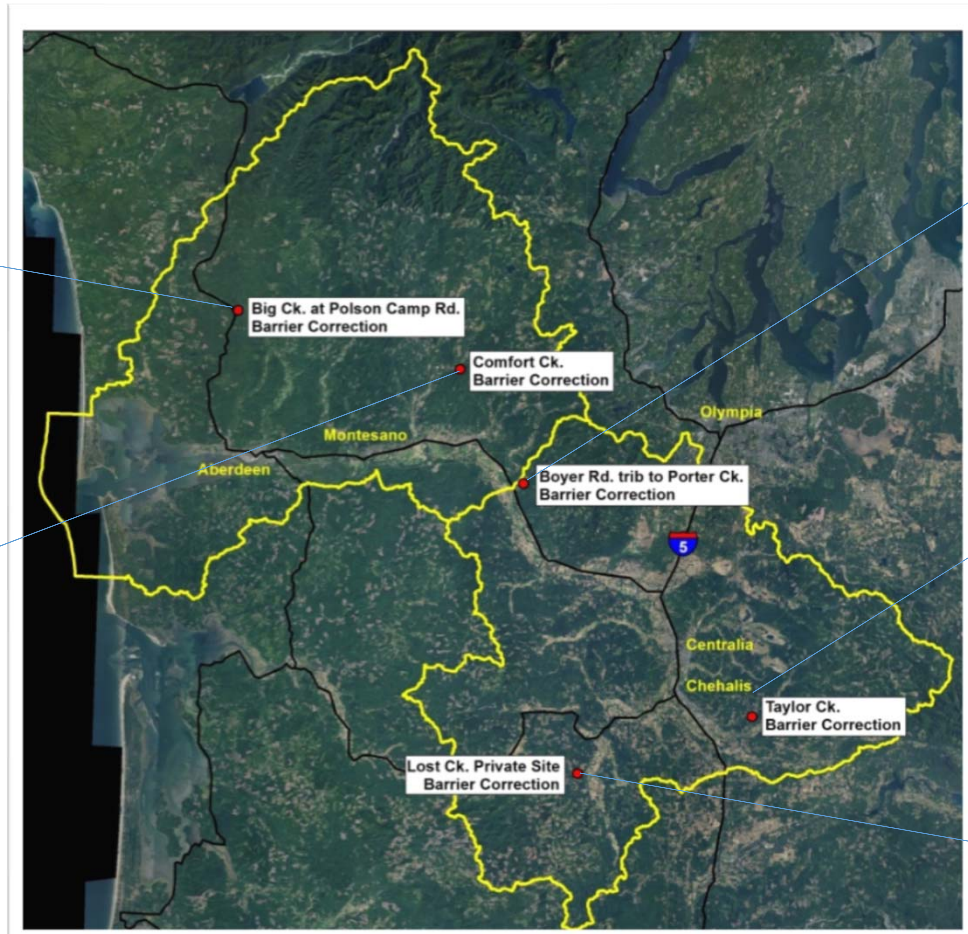
Site Selection Criteria

Stream slope	< 2%
Long Profile	Continuous
Skew angle	< 15^{o}
Entrenchment ratio	< 3
Flood-prone width	< 3 x BFW
Downstream control	No backwater effect
Morphological condition	Dynamic stability

Chehalis Basin Study Site Locations

Big Creek

Comfort Creek

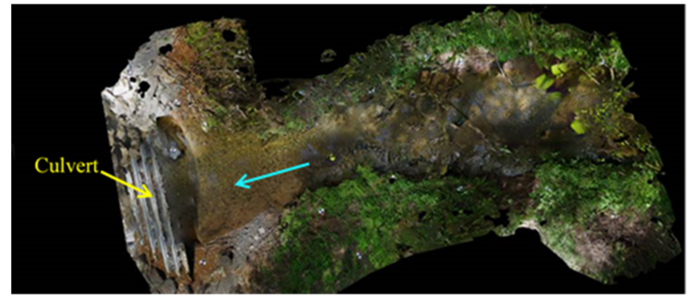


Boyer Road

Taylor Creek

Lost Creek

Study Site Characteristics



Study Site name	Drainage Area (SM)	Bankfull width (ft)	Upstream D50 (mm)	Culvert D50 (mm)	Mean precip (in/yr)	Q2* (cfs)	Q100* (cfs)
Big Creek	2.12	16	15	32	115	252	588
Comfort Creek	1.57	18.5	20	52	79	120	278
Boyer Road	1.21	16	22	31	60	67	155
Taylor Creek	1.87	11.5	50	44	48	76	174
Lost Creek	5.06	25	1	1	70	304	703

* Bankfull discharge (Q_2), and 100-year flood discharge (Q_{100}) determined using USGS Stream Stats

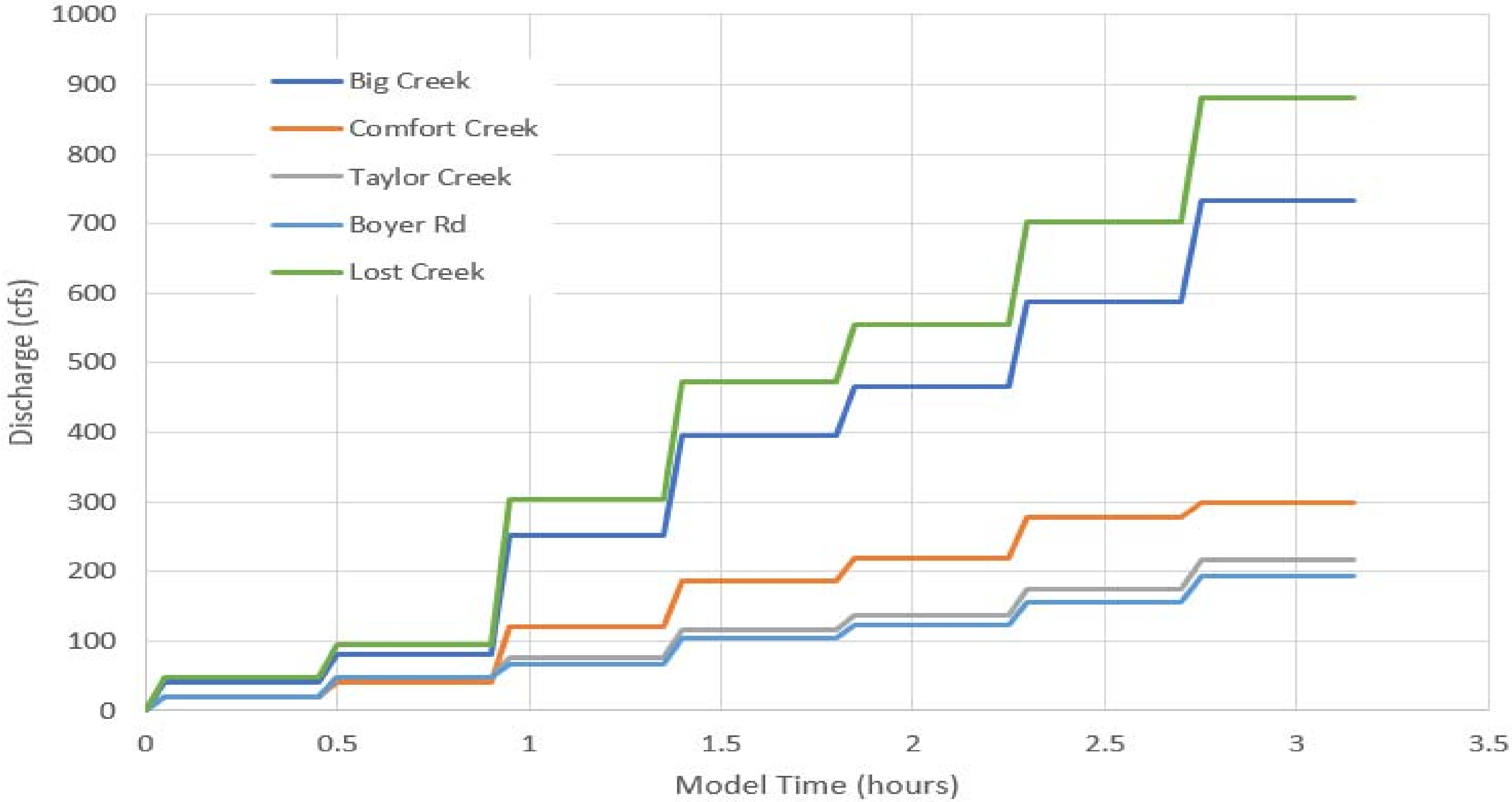
Climate Change

Study Site name	2059 % Change in Q bankfull	2099 % Change in Q bankfull	2059 % Change in Q 100	2099 % Change in Q 100
Big Creek	16.2	21.4	10	18.1
Comfort Creek	14.4	19.8	12.8	25
Boyer Road	14.6	20.1	19.2	31.1
Taylor Creek	15.7	19.1	14.2	24
Lost Creek	13.5	17.1	36	36.8

Climate Change Estimate = 22% Increase in Peak Flow

University of Washington Climate Impacts Group Estimates

Unsteady Hydrology

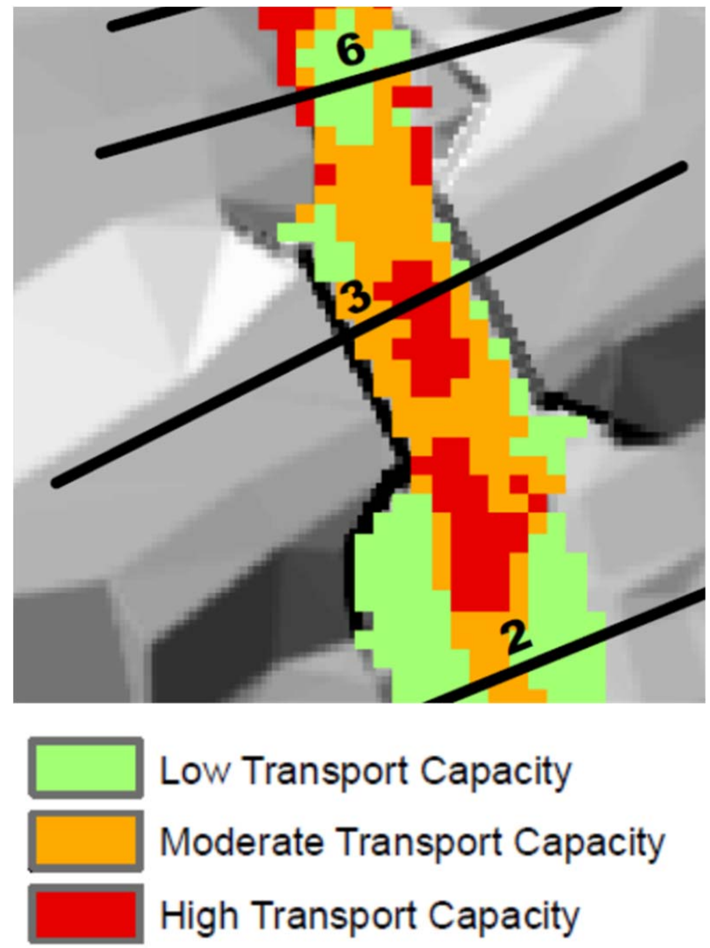


Geometries Used for Riverflow 2D

Culvert	Scenario					
	0.8BFW with Plane Bed	Existing Conditions with Plane Bed	BFW with trapezoidal channel	1.2BFW +2 with trapezoidal channel	1.5 BFW with trapezoidal channel	No Road fill plane bed
Existing Hydrology						
Big Creek						
Comfort Creek						
Boyer Road						
Taylor Creek						
Lost Creek						
Future Hydrology						
Big Creek						
Comfort Creek						
Boyer Road						
Taylor Creek						
Lost Creek						

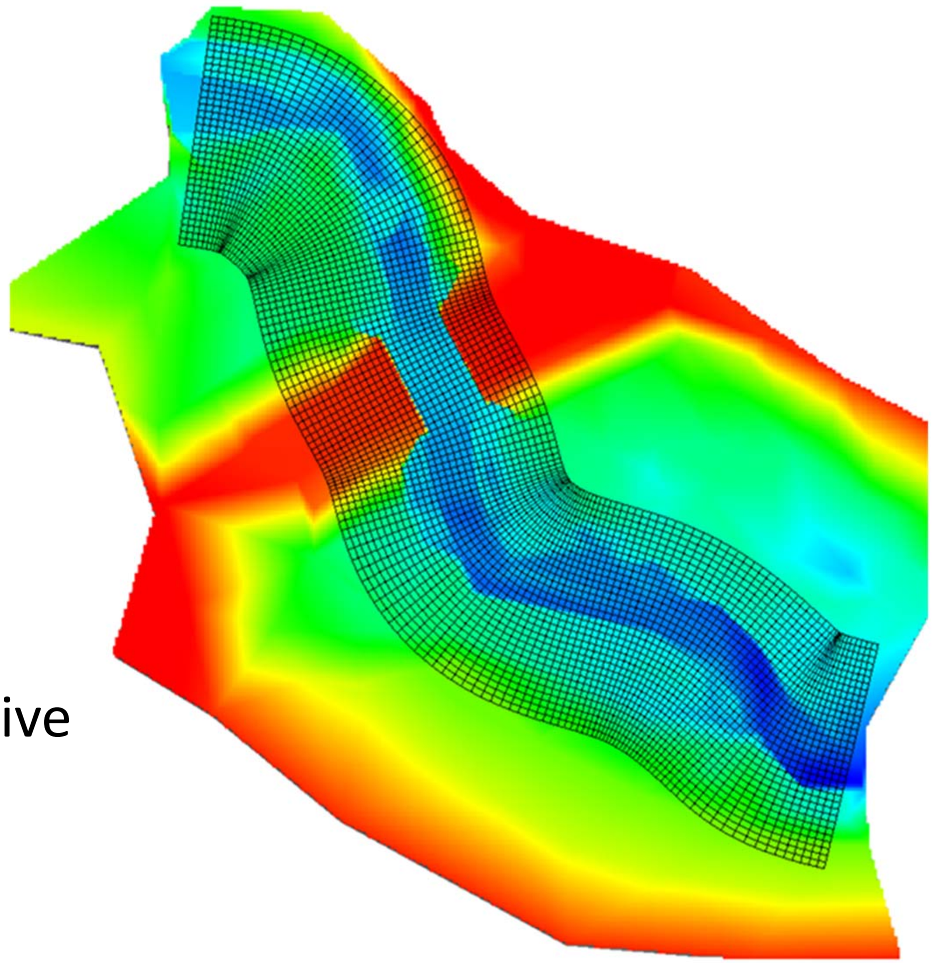
Initial Riverflow 2D Results

- Shear is a surrogate for sediment transport
- Culvert width is critical:
  - Too narrow - bed shear excessive
  - Too wide - energy loss; bed shear insufficient
- Introduction of substantial benches:
  - Improves continuity of flow, and
  - Appears to improve sediment continuity

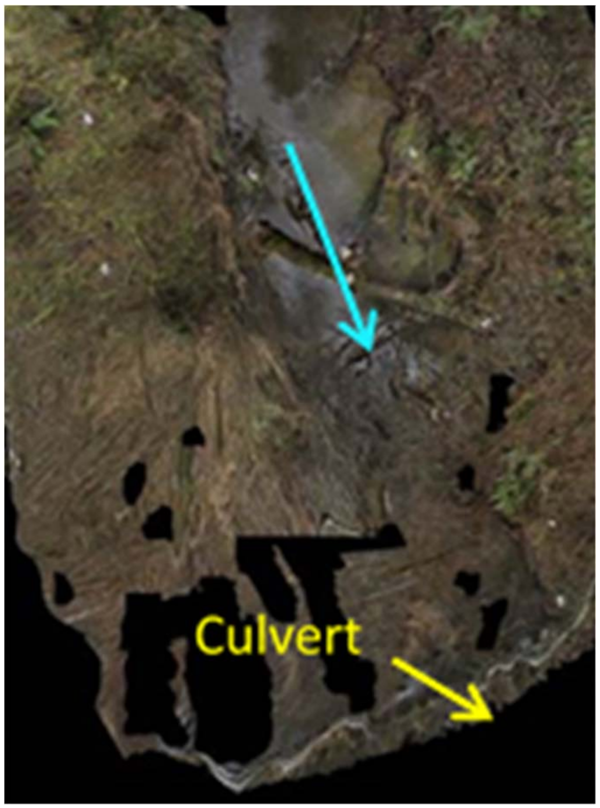


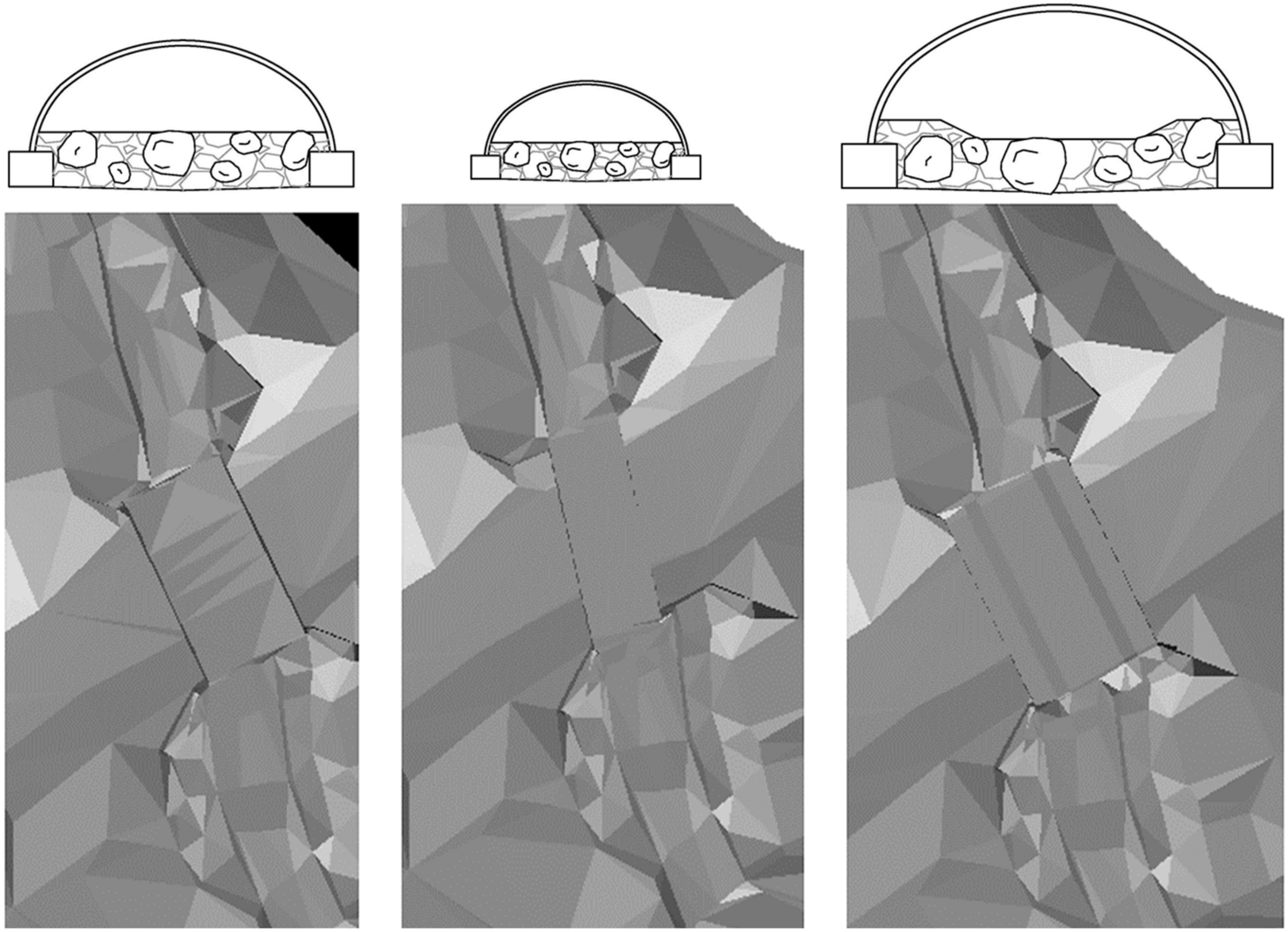
Mobile Bed Sediment Transport Model

- 2D sediment and bed morphology model
- Comfort Creek site only
- Q10 24-hr hydrograph:
  - Existing
  - Climate change
- International River Interface Cooperative (iRIC) software
- Nays2DH version 2.3 solver



Geometries for Nays2DH



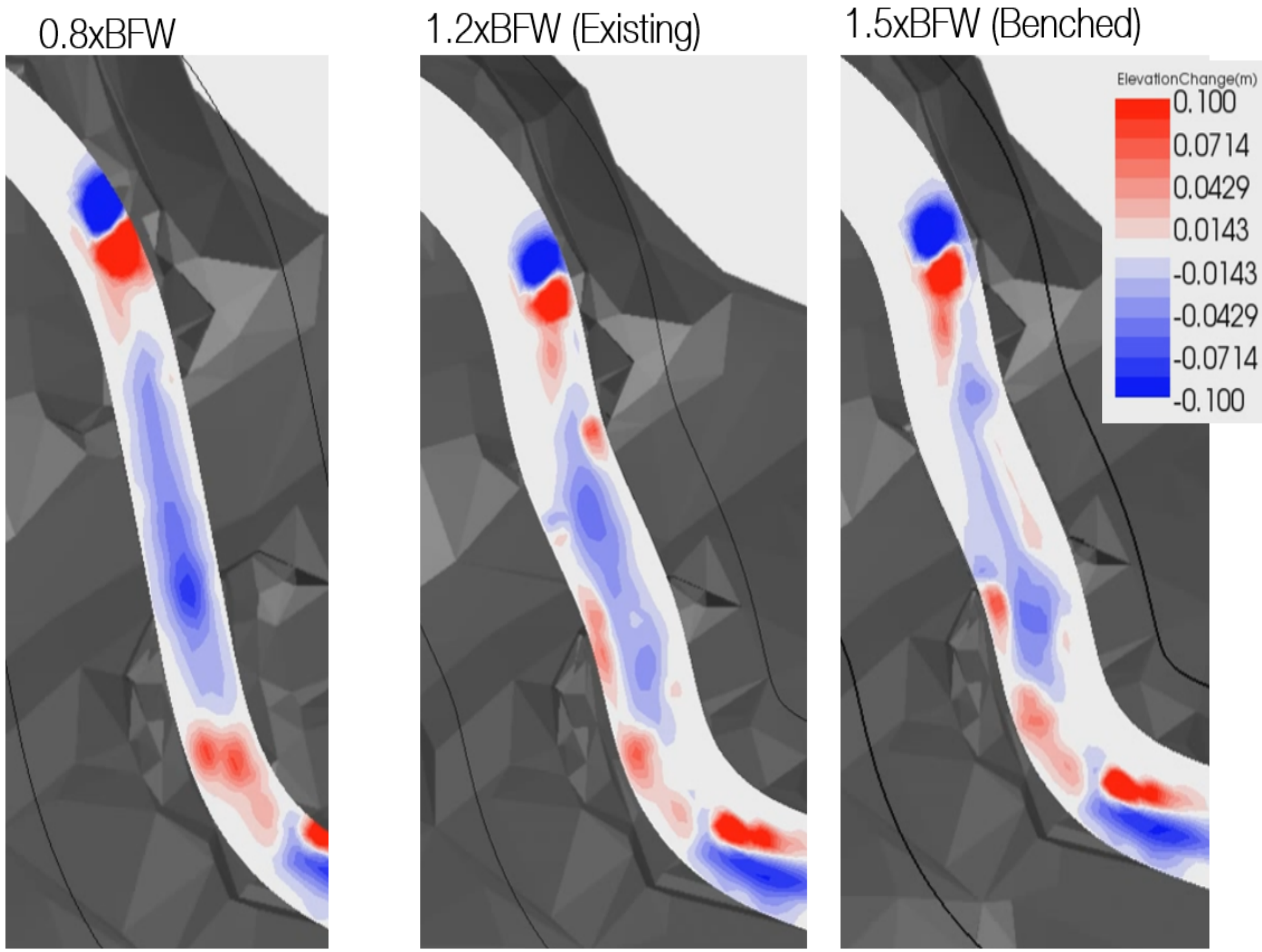


Existing- 1.2 X BFW   0.8 X BFW (Plane Bed)   1.5 X BFW (Benched)

Bed Changes

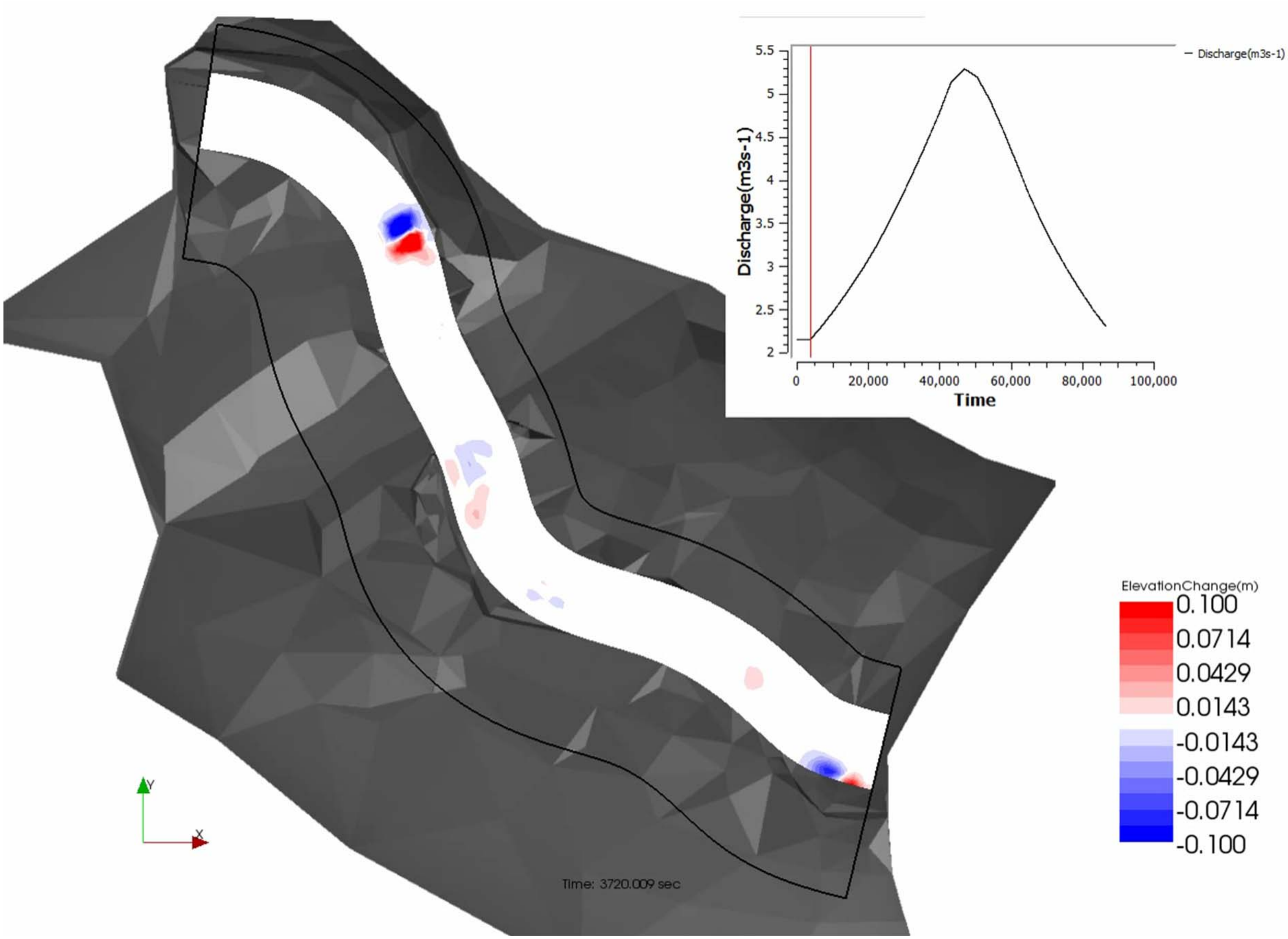
Blue = Scour

Red = Deposition



Video URL 0.8 BFW

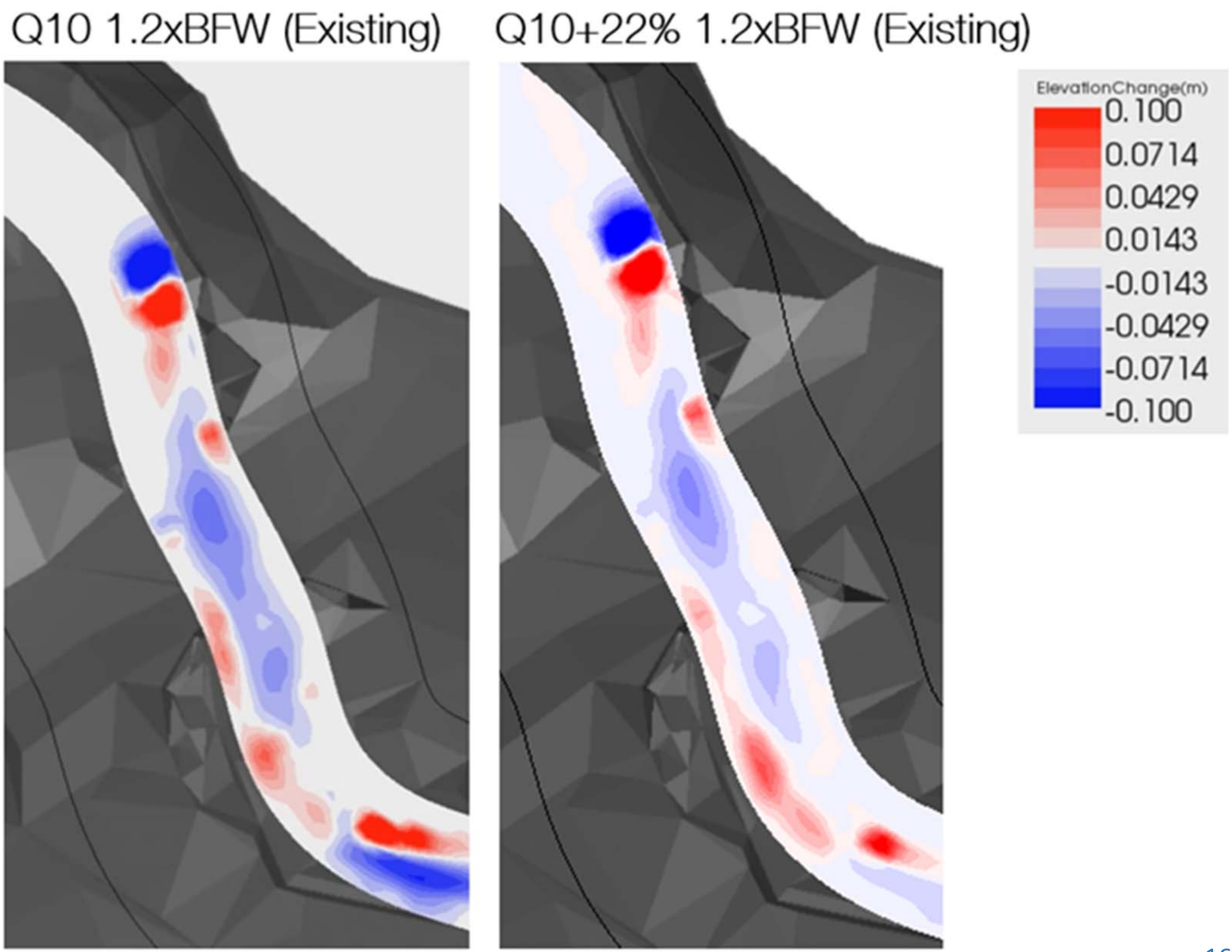
Video URL 1.5BFW



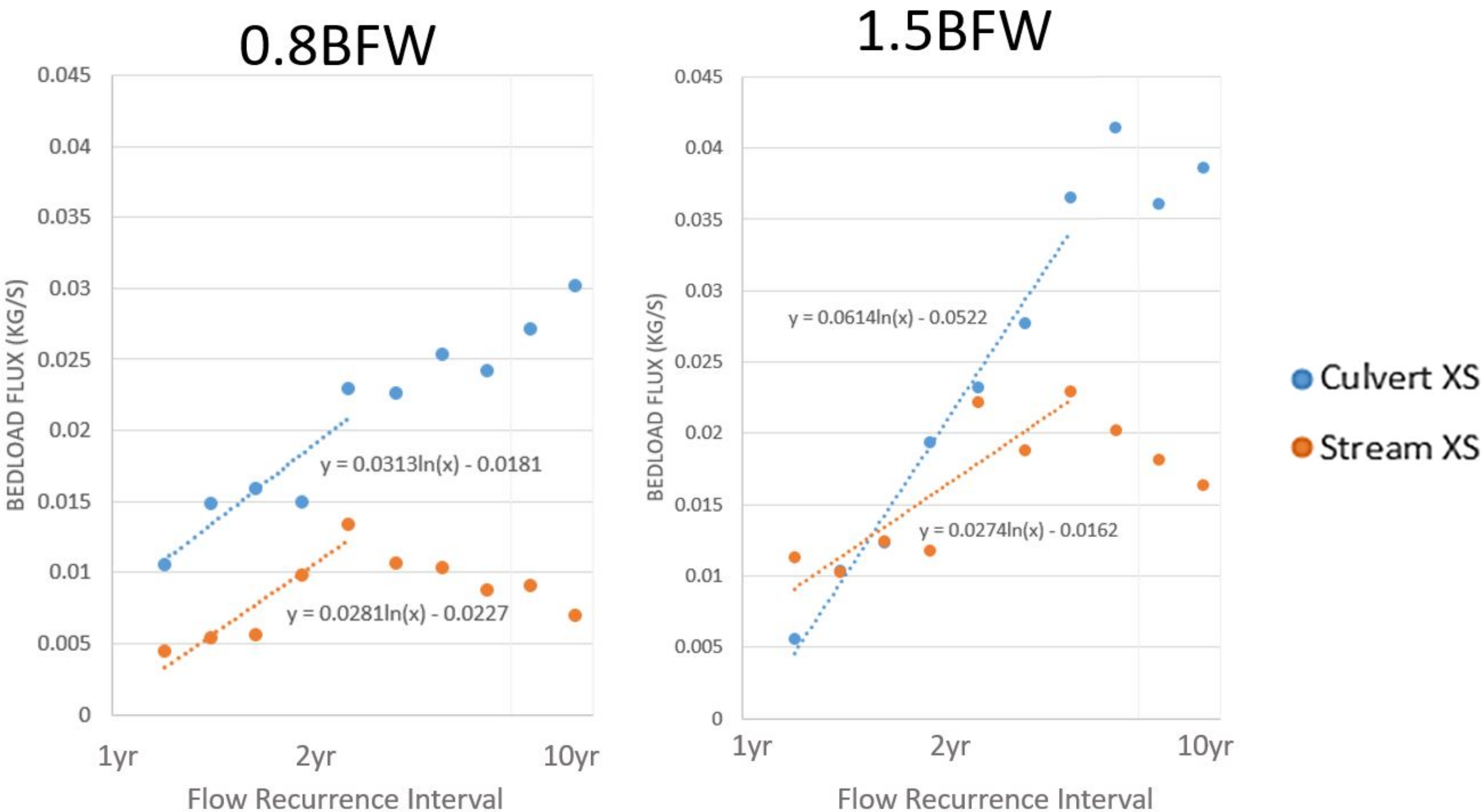
Discharge(m3s-1)
5.5
5
4.5
4
3.5
3
2.5
2
0
20,000
40,000
60,000
80,000
100,000
Time
Discharge(m3s-1)
ElevationChange(m)
0.100
0.0714
0.0429
0.0143
-0.0143
-0.0429
-0.0714
-0.100
Y
X
Time: 3720.009 sec

Climate Change

Velocity, mean diameter of the bed and scour increases were tolerable



Bedload vs. Discharge



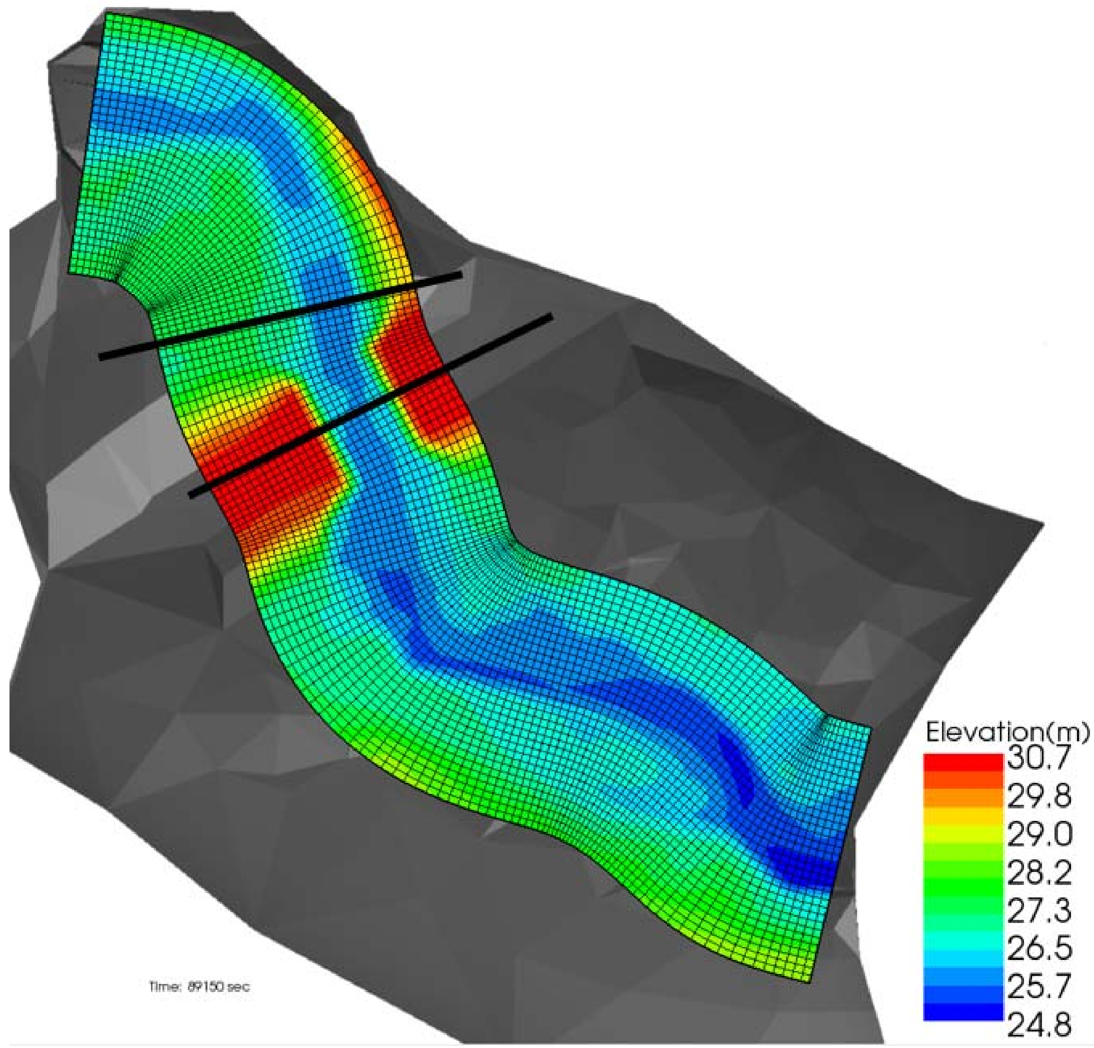
Culvert Performance Metrics

No.	Stream Simulation Metric	Input parameters			
		Stream	Value	Culvert	Value
1	Average Velocity	V_{stream}		$V_{culvert}$	
2	Headroom	WSE_{stream}		$CrownElev_{culvert}$	
3	Bankfull Width	BFW_{stream}		$BFW_{culvert}$	
4	Long-stream continuity	$BedElev_{stream}$		$BedElev_{culvert}$	
5	Bed Character	$D50_{stream}$		$D50_{culvert}$	
		σ_{stream}		$\sigma_{culvert}$	
6	Bed Mobility	$Qcrit_{stream}$		$Qcrit_{culvert}$	
7	Sediment Conectivity and Continuity	$(\delta Q_s/\delta Q)_{stream}$		$(\delta Q_s/\delta Q)_{culvert}$	
8	Channel Scour (All culverts)			$W_{culvert}$	
				$BedElev_{culvert}$	
				$FloorElev_{culvert}$	
				$FootElev_{culvert}$	
9	Lateral Dynamics (Long culverts)			N_{wall}	

Data Sources

<u>Cross section locations:</u>
Stream - upstream of the culvert
Midline of the culvert

Input from field data collection
and both 2D modeling efforts



Performance Evaluation Tool

COMFORT CREEK

1.5 X BFW WITH BENCH

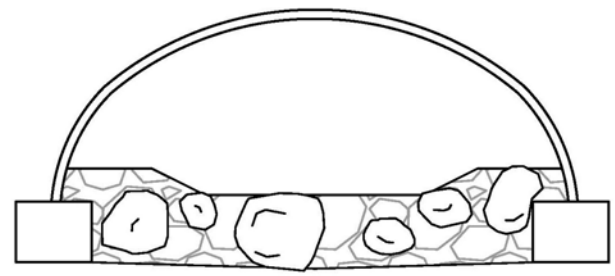
FLOW = Q10 HYDROGRAPH

MODEL = NAYS2DH

Stream Simulation Metric Identity	Metric Value	Stream Simulation Match	Comments
$V_{match} = V_c / V_s$	1.09	✓	Culvert velocity acceptable
$WSE_{stream} < CrownElev_{culvert}$	8.44	✓	Culvert headroom acceptable
BFW_{match} = BFWc/BFWs	1.00	✓	Culvert BFW acceptable
$Bed_{change} = (BedElev_c - BedELev_s) < 0.8$ ft	0.04	✓	Bedchange is acceptable
$D50_{match} = D50_c / D50_s$	0.98	✓	Median grain size is acceptable
$\sigma_{match} = \sigma_c / \sigma_s$	--		Not enough data
$Qcrit_{match} = Qcrit_c / Qcrit_s$	0.89	○	Bed mobility tolerable
$(\delta Q_s / \delta Q)_{match} = (\delta Q_s / \delta Q)_c / (\delta Q_s / \delta Q)_s$	3.95	✗	Sediment connectivity and continuity is too high
$BFW_{culvert} < W_{culvert}$	0.66	✓	Width of culvert is acceptable
$FloorElev_{culvert} < BedElev_{culvert}$	3.96	✓	Culvert bed elevation is acceptable
$FootElev_{culvert} < BedElev_{culvert}$	3.96	✓	Culvert foot elevation is acceptable
$N_{wall} < 3$	--		Not enough data

Conclusions and Recommendations

- Bankfull benches improve stream simulation performance
- Culvert width = BFW + stable bench width
- Skew effect needs further investigation
- Continue WDFW data collection
- Develop empirical relationships between performance metrics
- Utilize performance tool to ensure stream simulation compliance



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Thank You. Questions?

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