SKOKOMISH RIVER GI ECOSYSTEM RESTORATION HABITAT DESIGN AND HEC-RAS MODELING

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USACE Seattle District

June 24, 2020

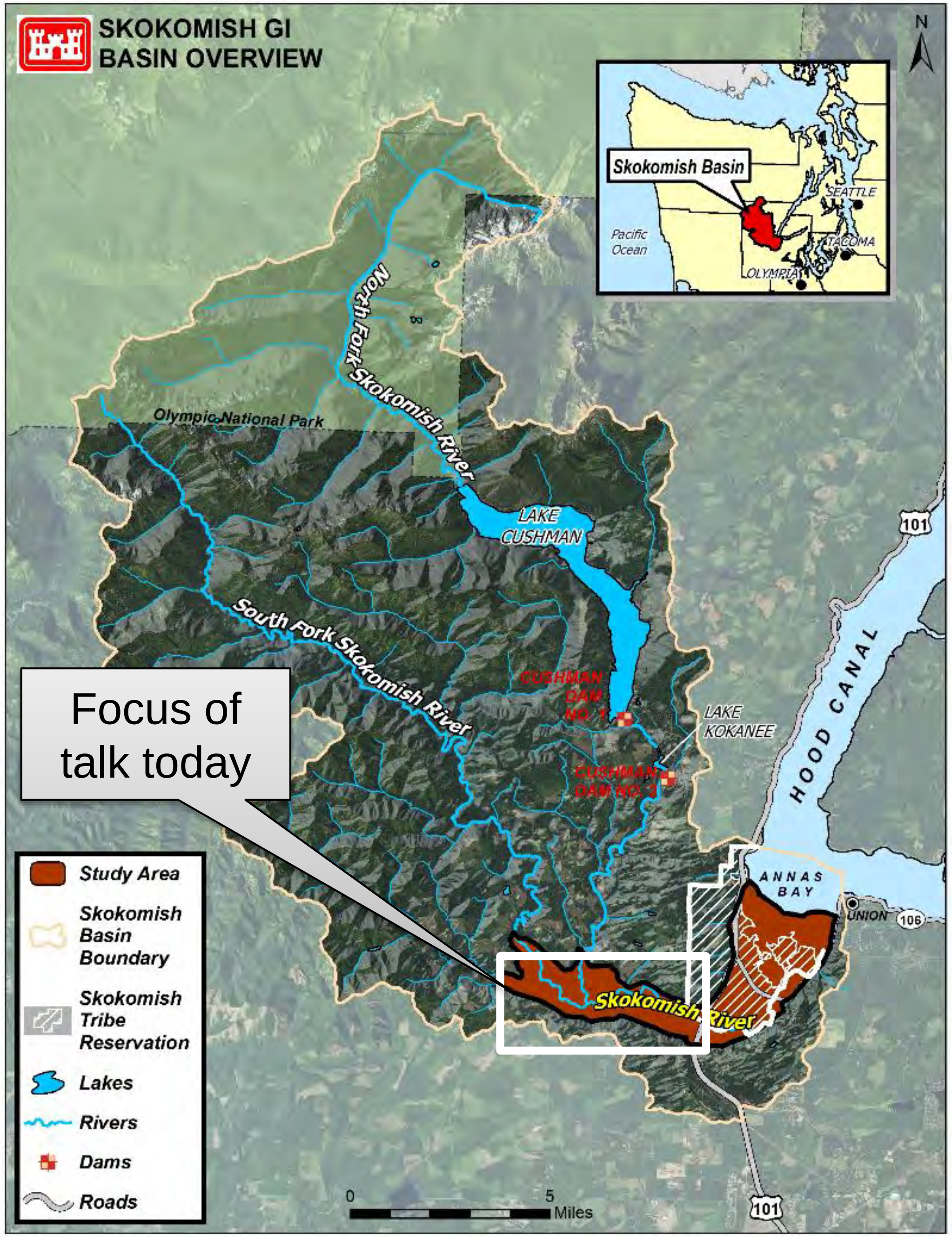
US Army Corps of Engineers ®

WHERE ARE WE?

South Fork and Mainstem Skokomish River, Olympic Peninsula, Tributary to Puget Sound (670 sq. mi.)

Status: Project design complete, permitting complete. Fully funded. Waiting on real estate to award & construct.

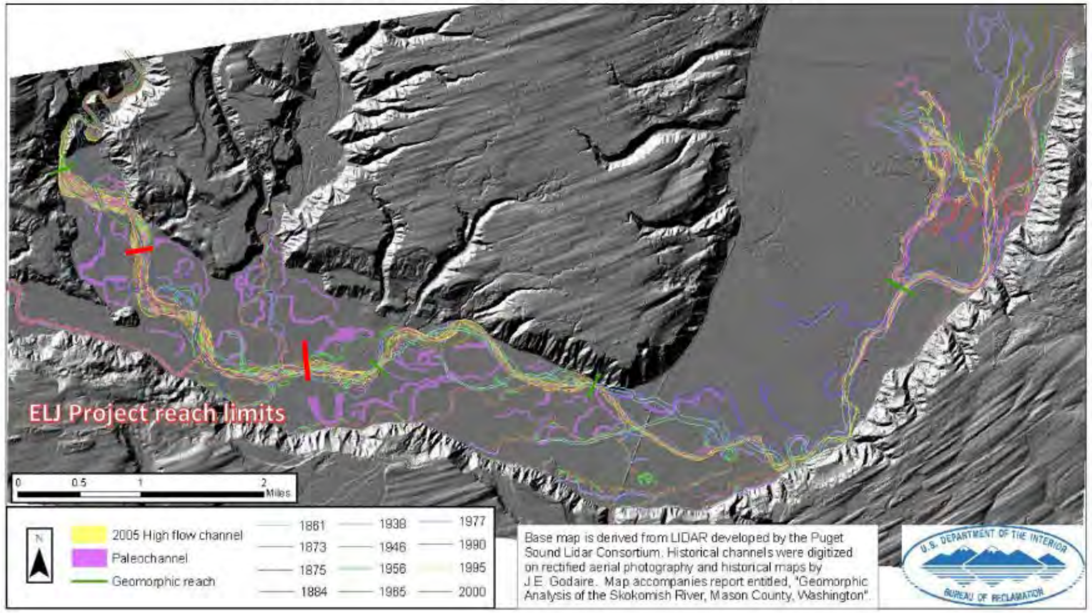
Cushman Dam on North Fork Skokomish built in 1920s affects peak flows and sediment transport



OUTLINE

- Problems
- Restoration Approach
- Hydraulic Modeling
- ELJ Design Guidance
- ELJ Design Process
- River Mile 9-11 ELJ Project Design
- Lessons Learned & Best Practices

Skokomish River Historical Channel Overlays



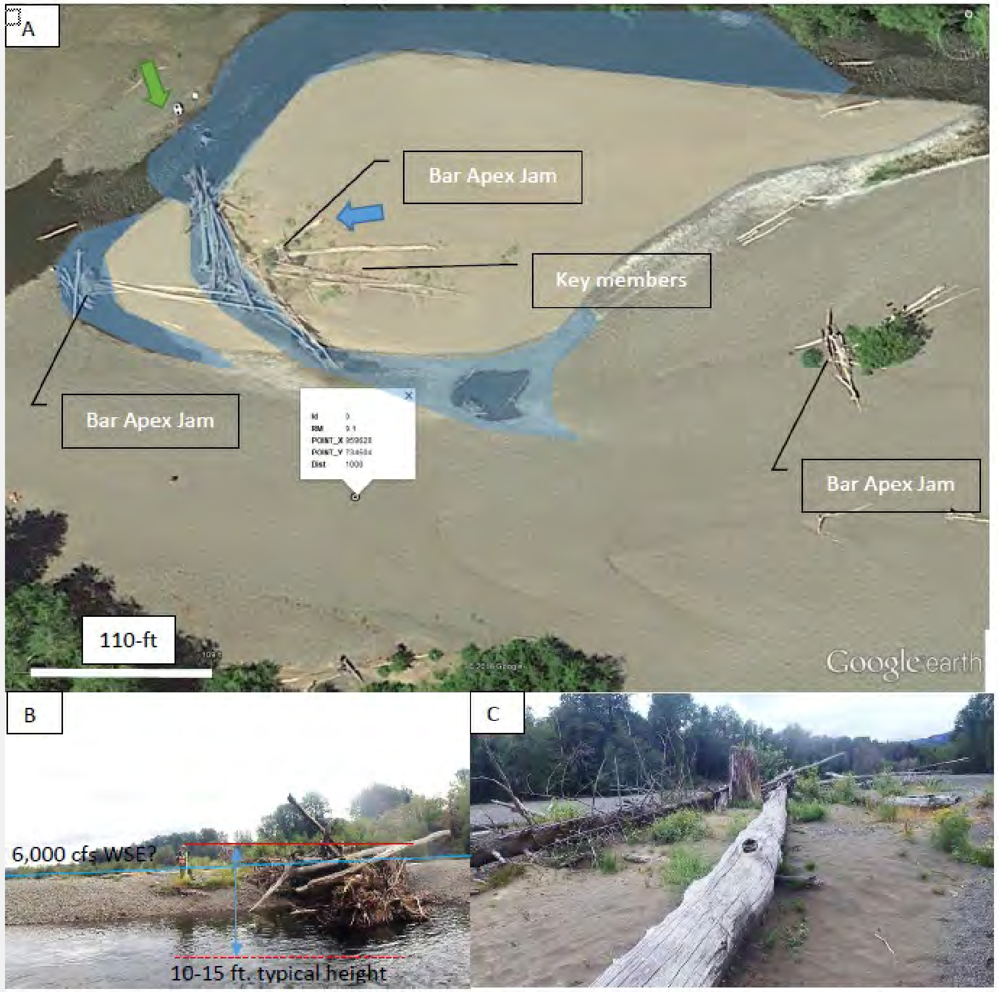
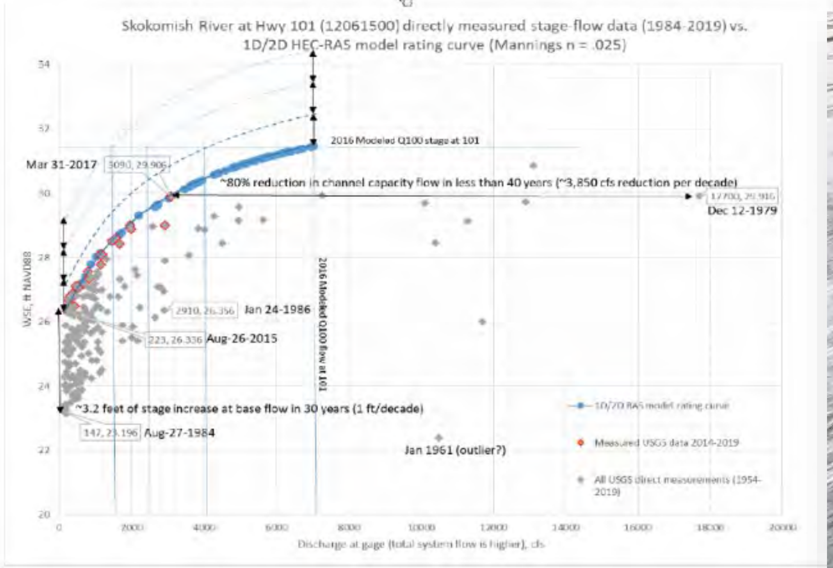


Figure A- 8. Bar apex jam at RM 9.1. July 2018 plan view (A). Tan areas are recruited sediment, blue areas are jam forced pools. Flow direction left to right. Photos from Aug. 2018 recon, looking at north side of jam (B, green arrow) and looking upstream at key piece (stump, fir trees) (C, blue arrow). Jam first appeared at this location after 2012 and has persisted since then. Note sediment and vegetation recruitment. Note the effective width of the jam (normal to flow) is about 125 feet. The outer extents (laterally) of the side channels/pools around the outside of the jam is 250 feet, about twice the width. The downstream extent of the bar is 400 feet, about 4 times the jam width. The upstream extent of the jam, inclusive of the upstream bar, is about 1 times the jam width. This is the only bar apex jam where the low-flow channel was in contact with the jam and a large, deep pool was present. All other jams were on dry gravel bars. Pool depth was approximately 4-6 feet based on a visual inspection.

PROBLEMS

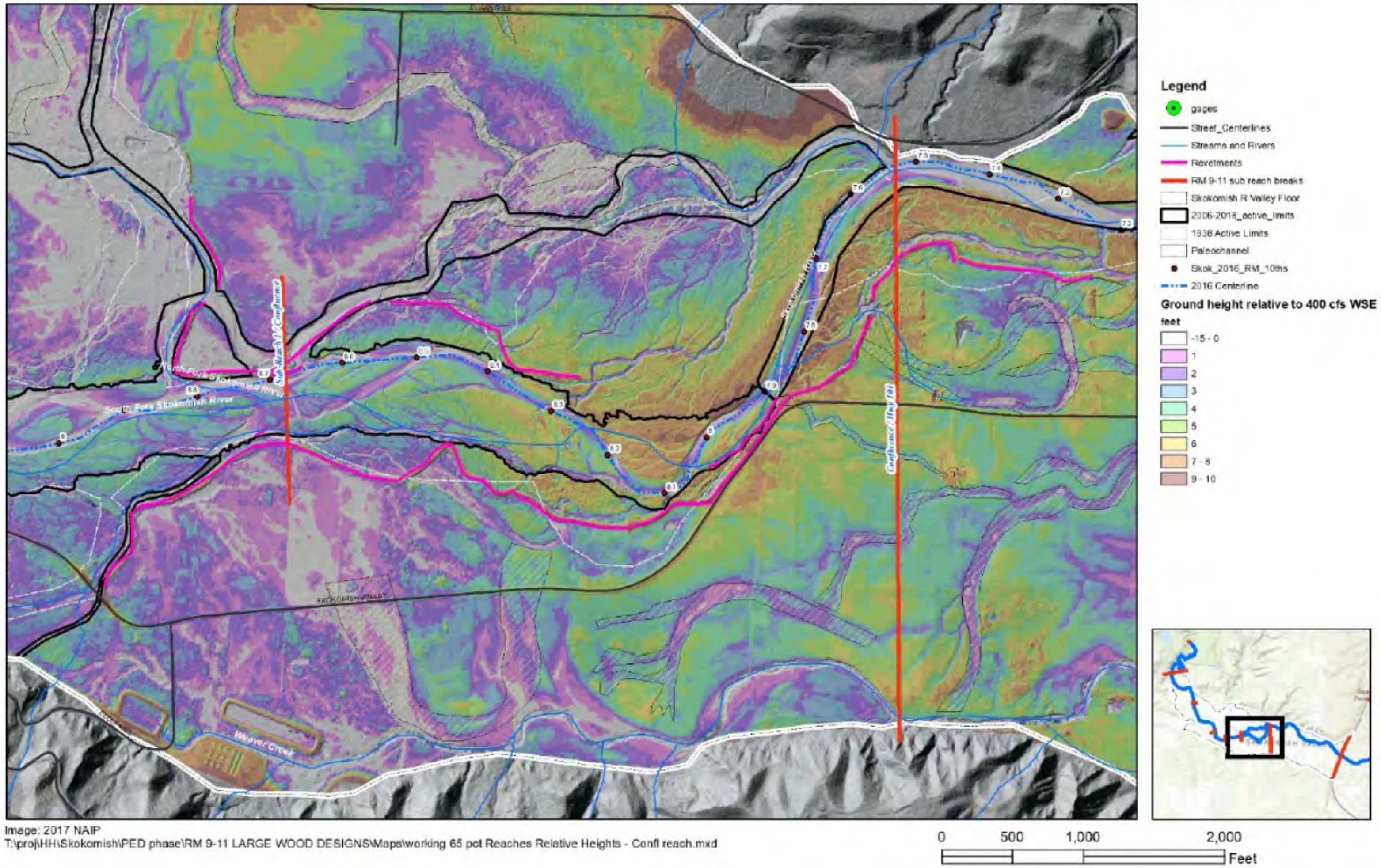
- **Watershed scale**: Land use changes (60% watershed clear cut by 1920s), sedimentation (1960s-present), frequent flooding
- **Localized**: Fish stranding due to sub-surface flows between South Fork and mainstem Skokomish River during low flows; Avulsion risks
- **Habitat**: Braided channel (formerly anabranched), infrequent jams, mobile wood, disconnected and degraded habitat



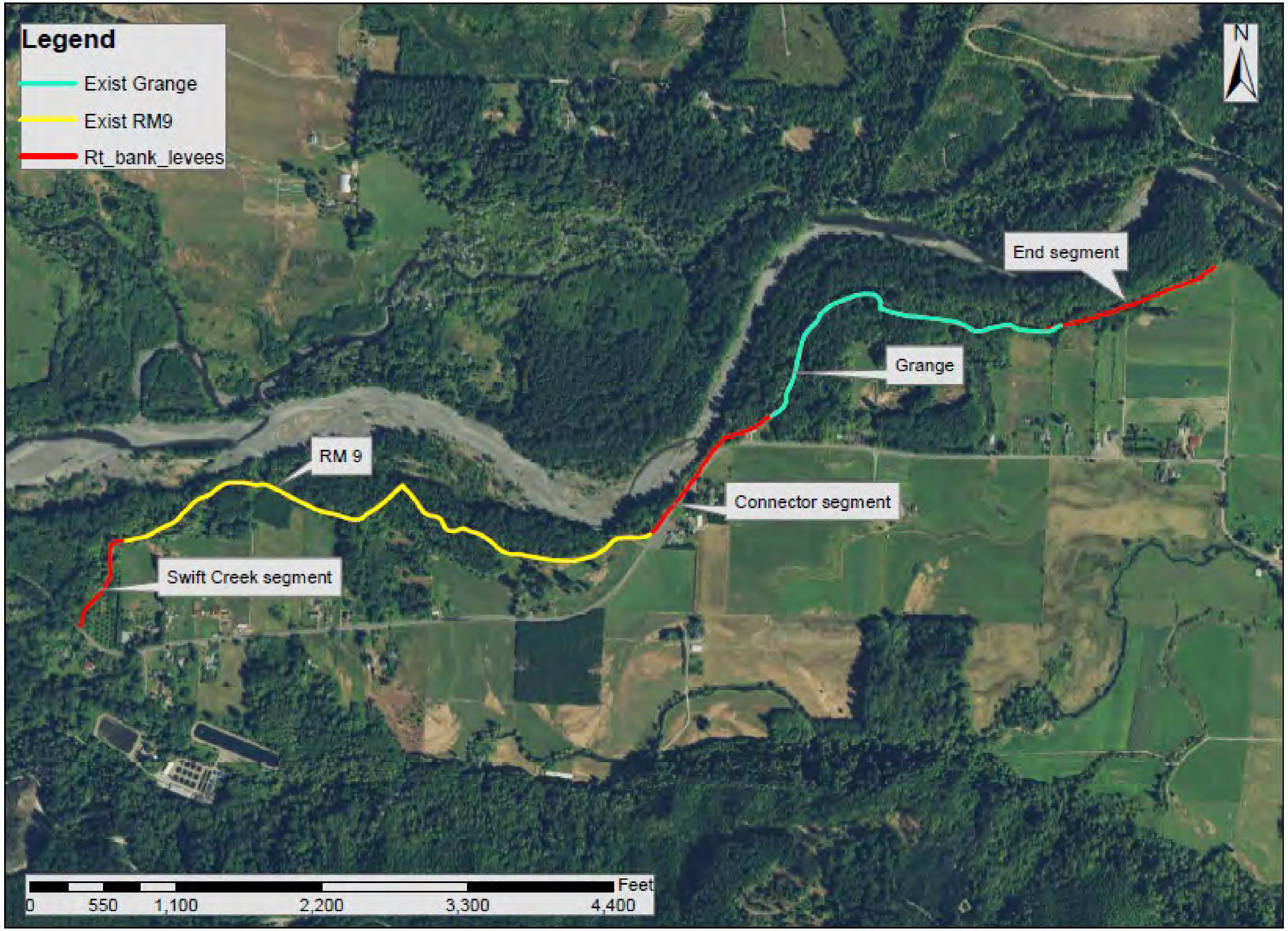
PROBLEMS

Aggradation→ Perched and Disconnected Channels→ Fish Passage Issues

Skokomish River GI - PED Phase - Geomorphic Analysis
Ground Height Above or Below 400 cfs Water Surface Elevation & Historical Channel Locations - Confluence Reach

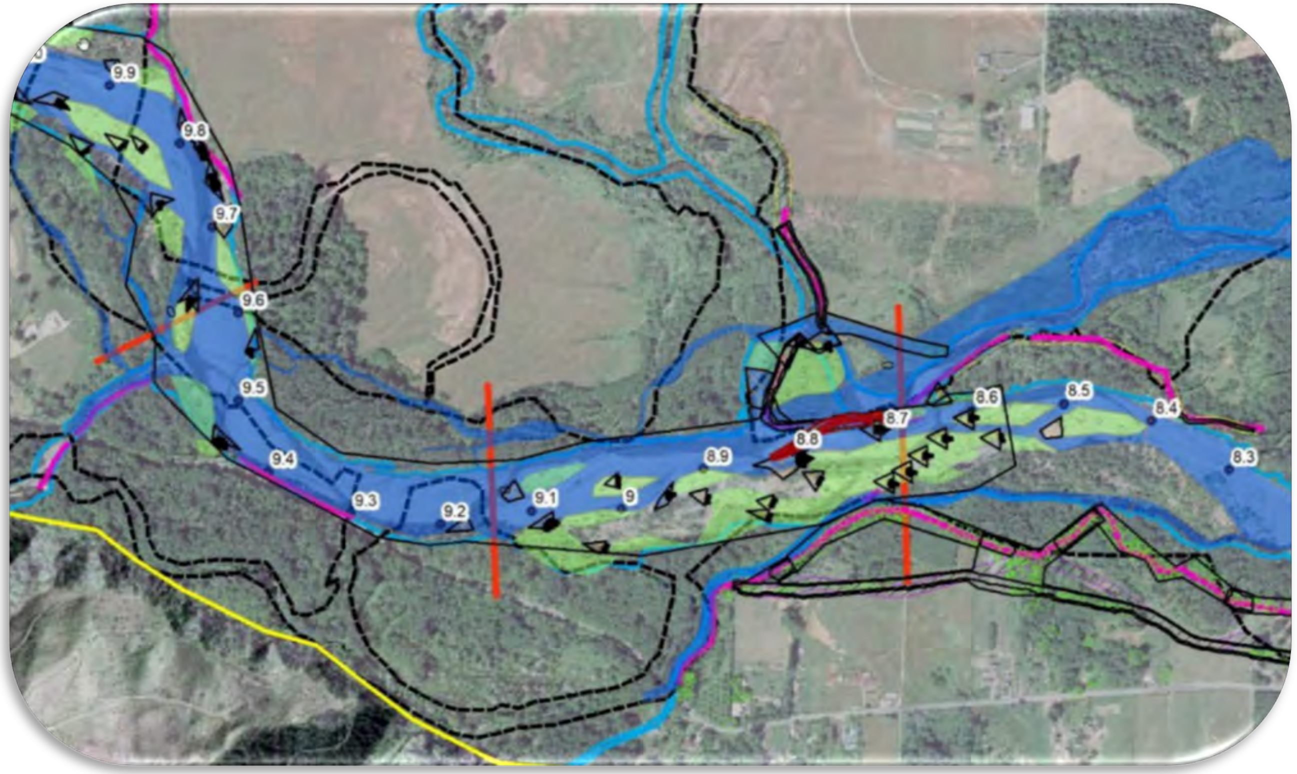


EXISTING LEVEE SYSTEM

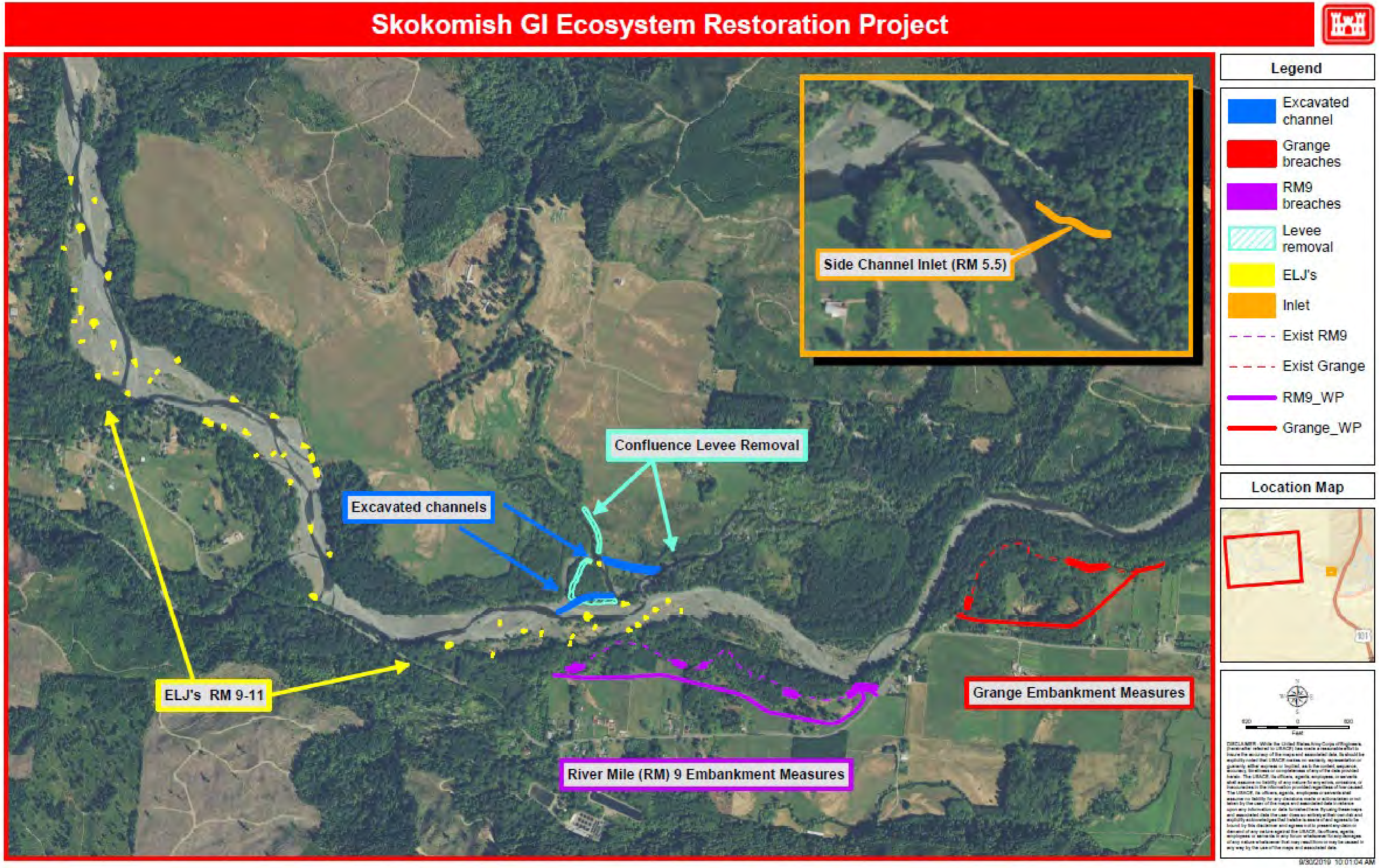


RESTORATION APPROACH

- **Promote anabranching planform that existed in early 20th century**
  - Add stable woody hard points (ELJs) that emulate existing natural jams
  - Promote vegetation growth on bars
  - Narrow active width, increase depth to maintain conveyance, increase sinuosity of low flow channel
- **Forced avulsion between South Fork, North Fork and mainstem**
  - Levee removal
  - Breach channel
  - ELJs + bar roughening
  - Setback levees
  - New North Fork to Mainstem connection
- **Route sediment through reach** to low lying disconnected floodplain to rebalance topography and bring water table up to reduce perched channel conditions

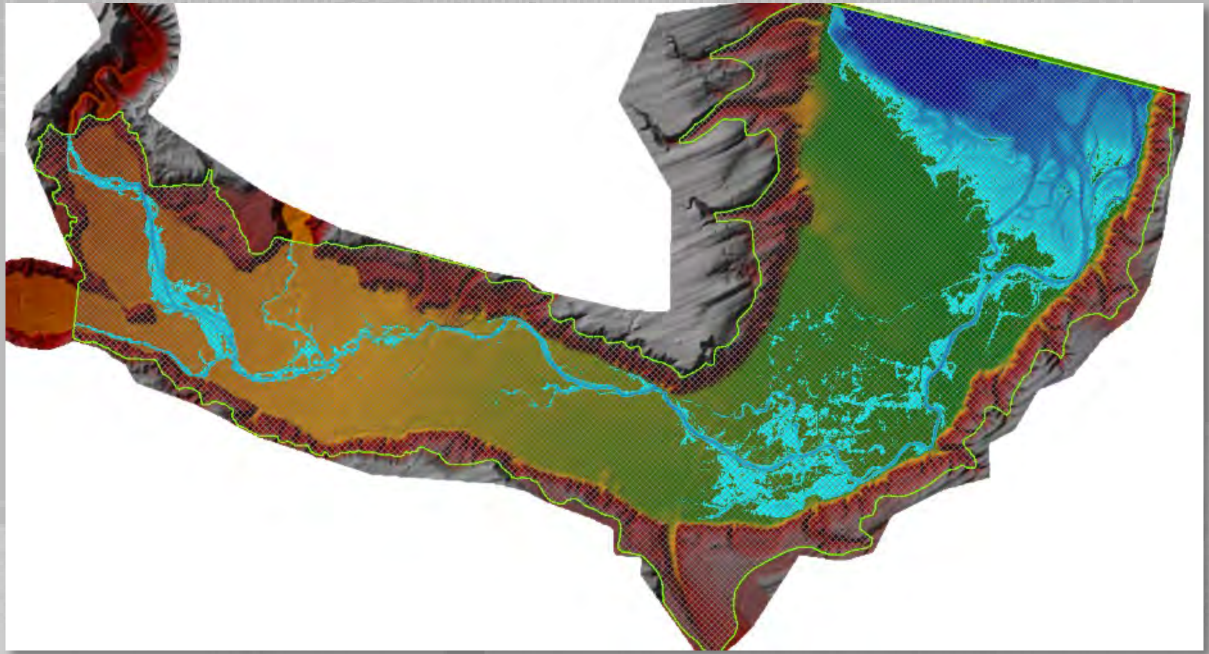


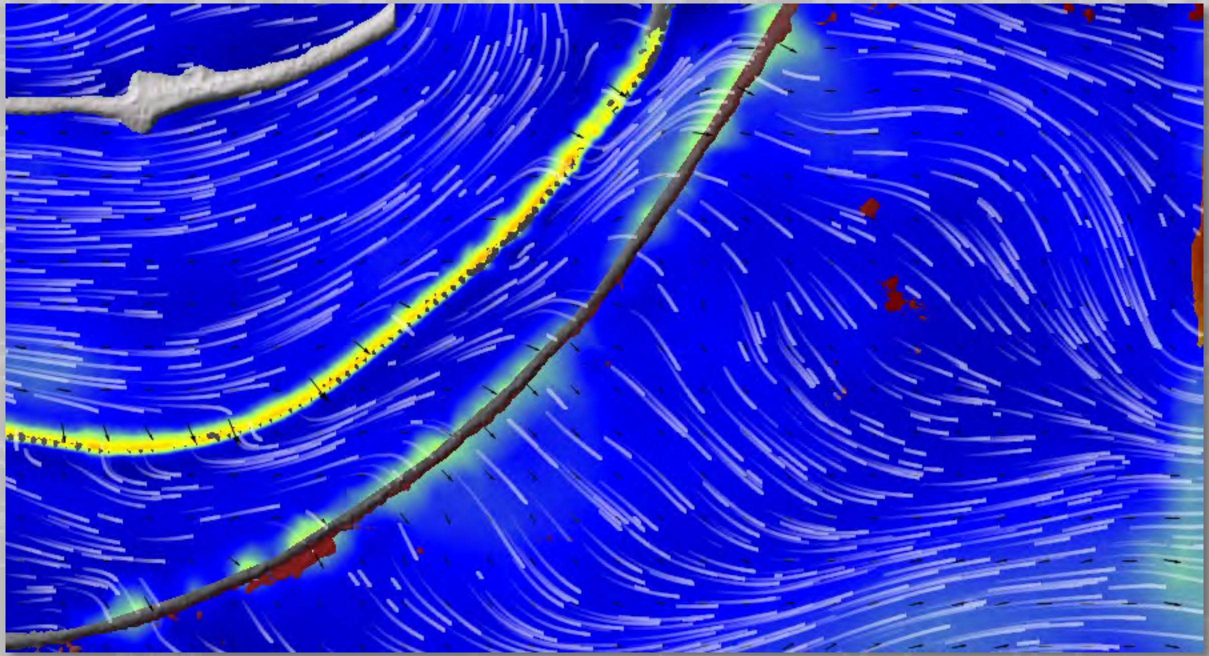
PROJECT MEASURES



HYDRAULIC MODELING

Brendan Comport, PE





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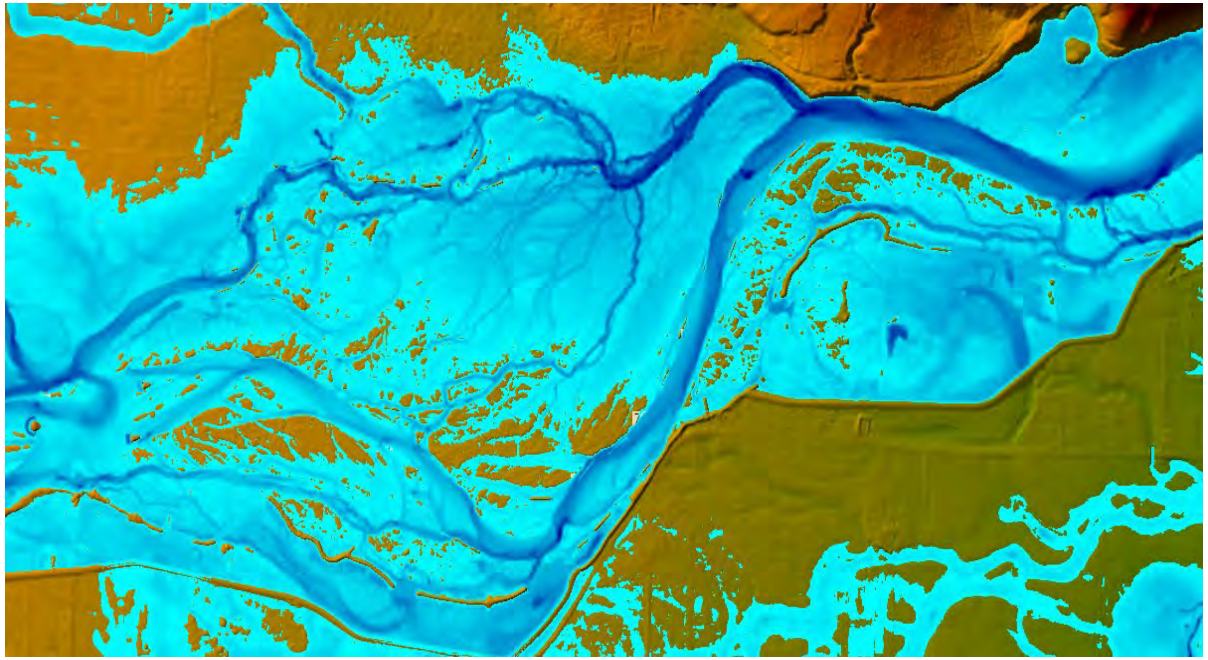
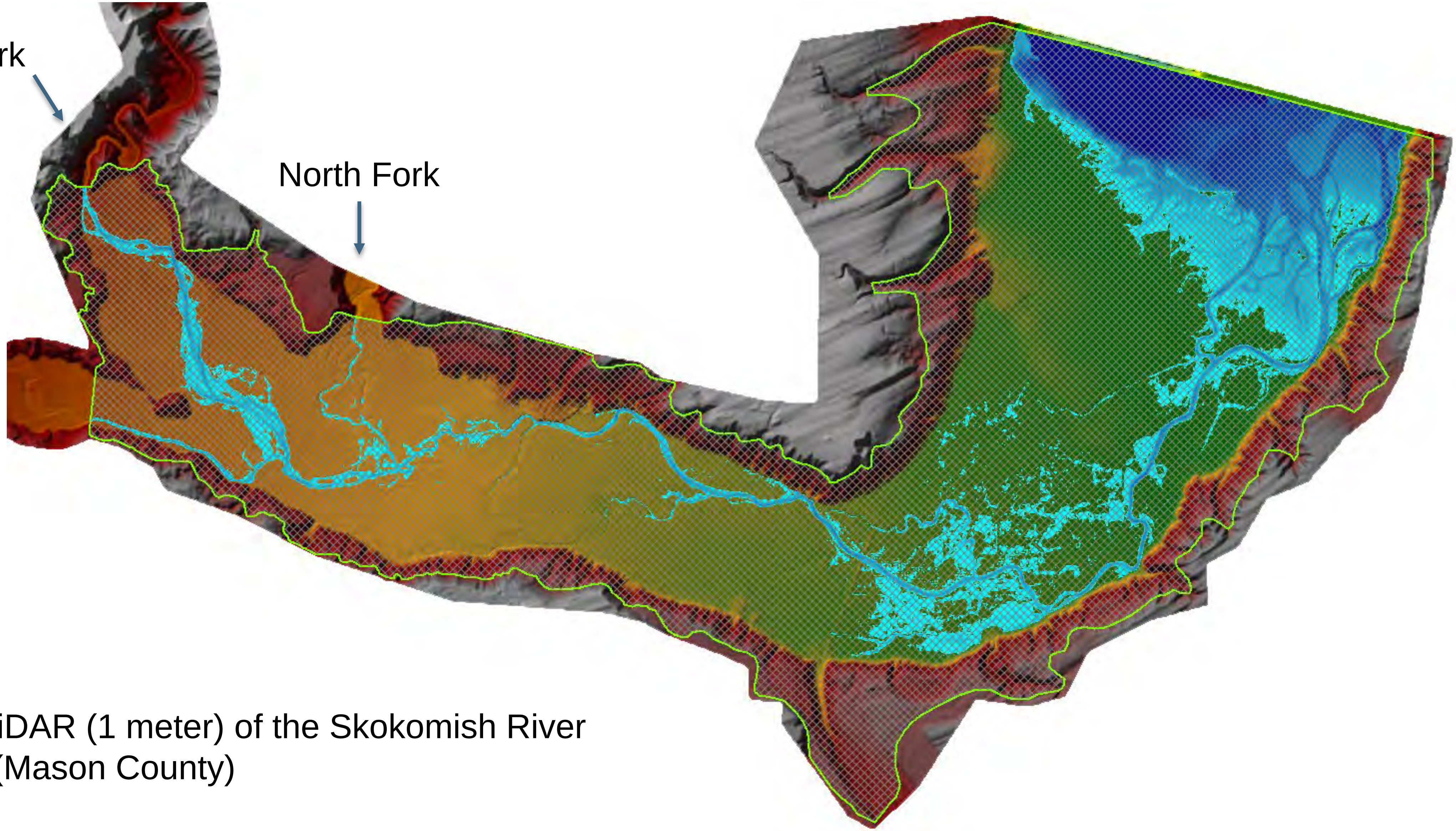
MODELING PROCESS

- Team building site visits to recon the project reach and survey
- Clarify and finalize design criteria with sponsors PRIOR to modeling
- Develop HEC RAS 2D hydraulic model
- Calibrate existing conditions model (without project)
- Develop (and iterate) with-project conditions model
  - ✓ Design of embankments
  - ✓ Hydraulic effects at ELJ’s
  - ✓ Erosion and scour protection design
- Flood impacts comparison
- Final design documentation



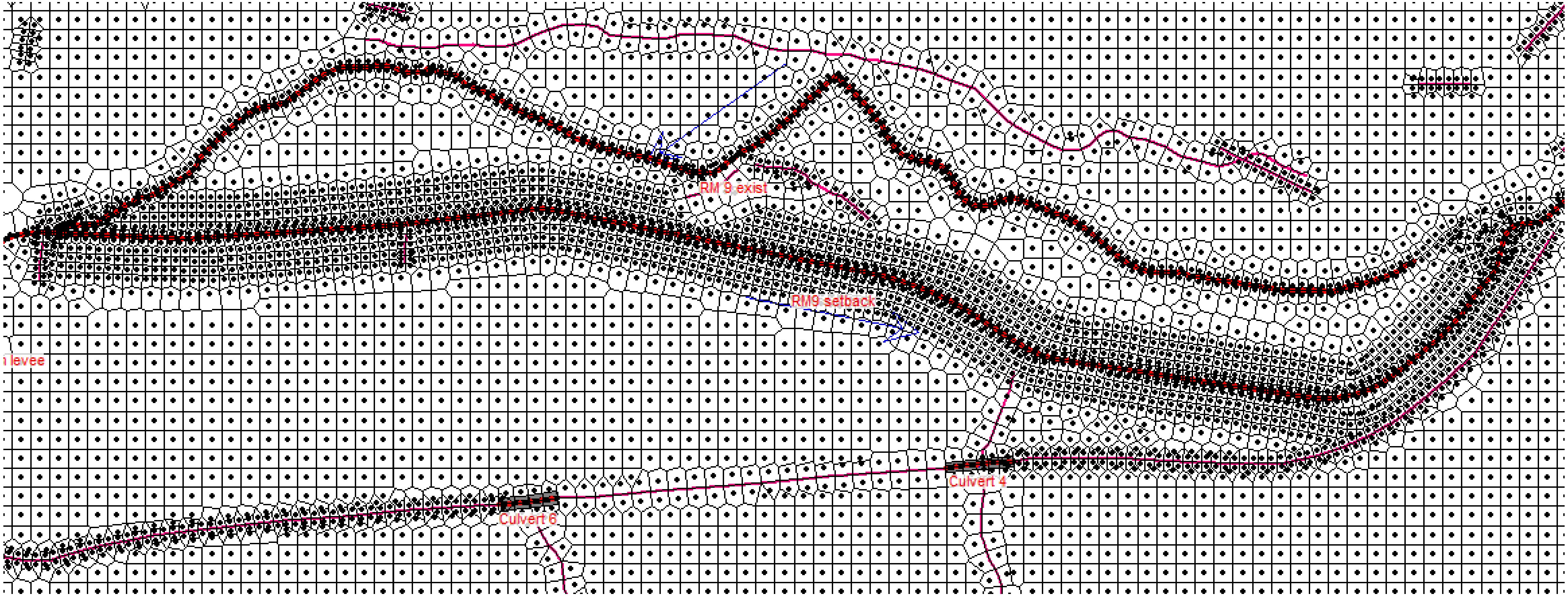
TERRAIN



2016 LiDAR (1 meter) of the Skokomish River Valley (Mason County)

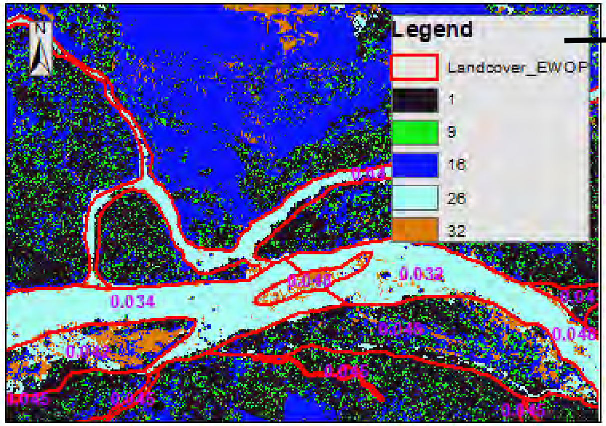
HYDRAULIC MODEL: GRID

- HEC RAS version 5.0.7 allows for varying cell size (through Mapper)
- Two-dimensional (2D), full momentum, implicit finite-volume modeling
- Model's 2D grid cell size varies from 10-100 feet, and contains roughly 80,000 cells



HYDRAULIC MODEL: LANDUSE

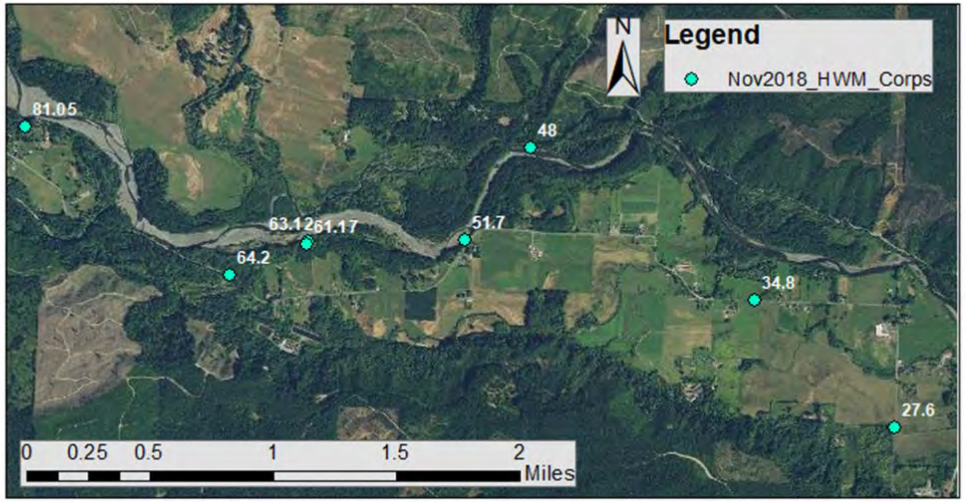
- Model requires either a single roughness value or a grid of spatially varying values, we used 5 categories
- Landuse (i.e. roughness) grid of Manning's n-values created from the 2017 Washington NAIP orthographic imagery dataset

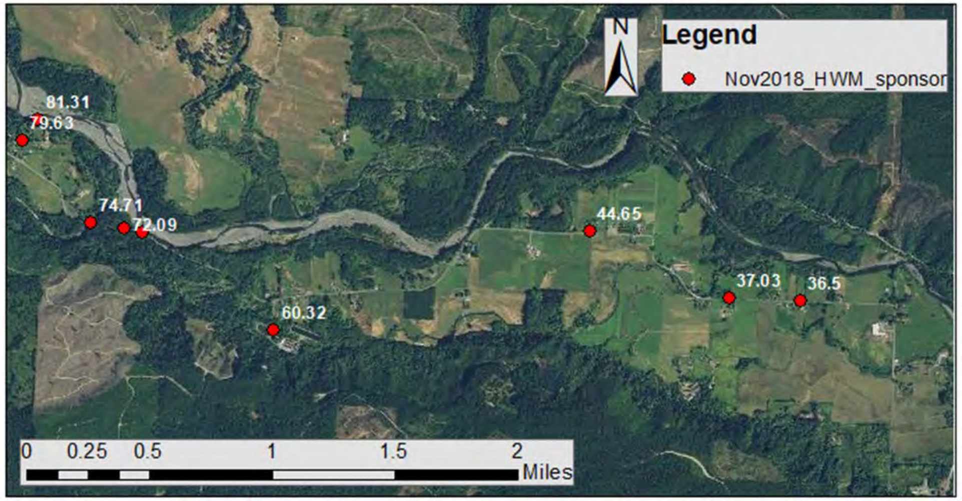


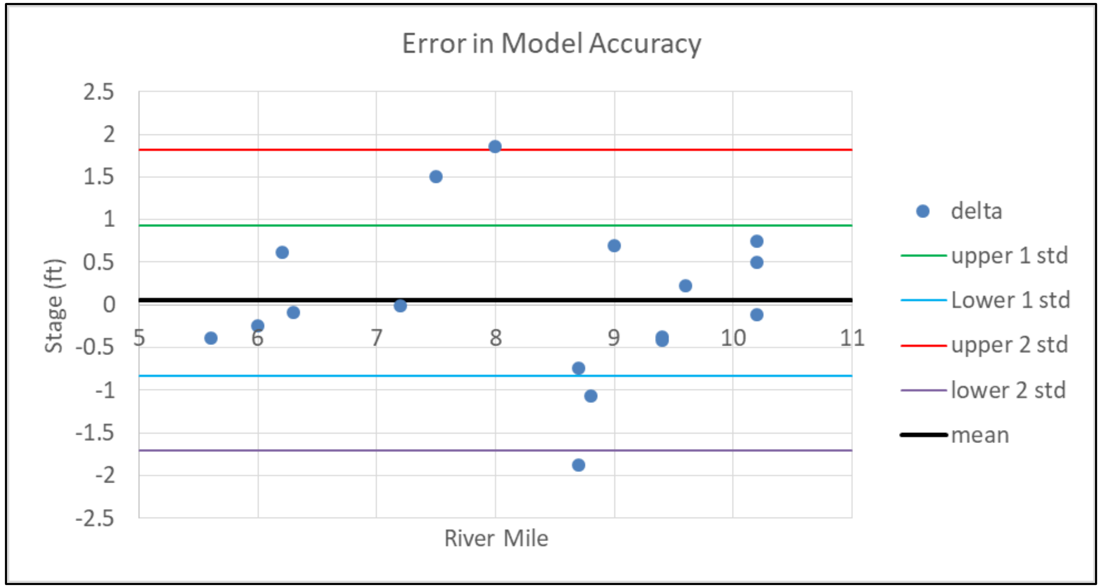
OID	Value	Count	Desc_	n_value
0	1	110330752	Mixed forest, most dense, shade	0.08
1	9	87785598	Coniferous, less dense forest	0.065
2	16	64060790	Scattered brush, pasture, agricultural	0.045
3	26	30987776	roads, gravel, sand, shade	0.03
4	32	18046379	clear cut, dirt, very short grass	0.035

HYDRAULIC MODEL: CALIBRATION

- Calibrated existing conditions model to Nov 2018 flood event (6,340 cfs SF flow)

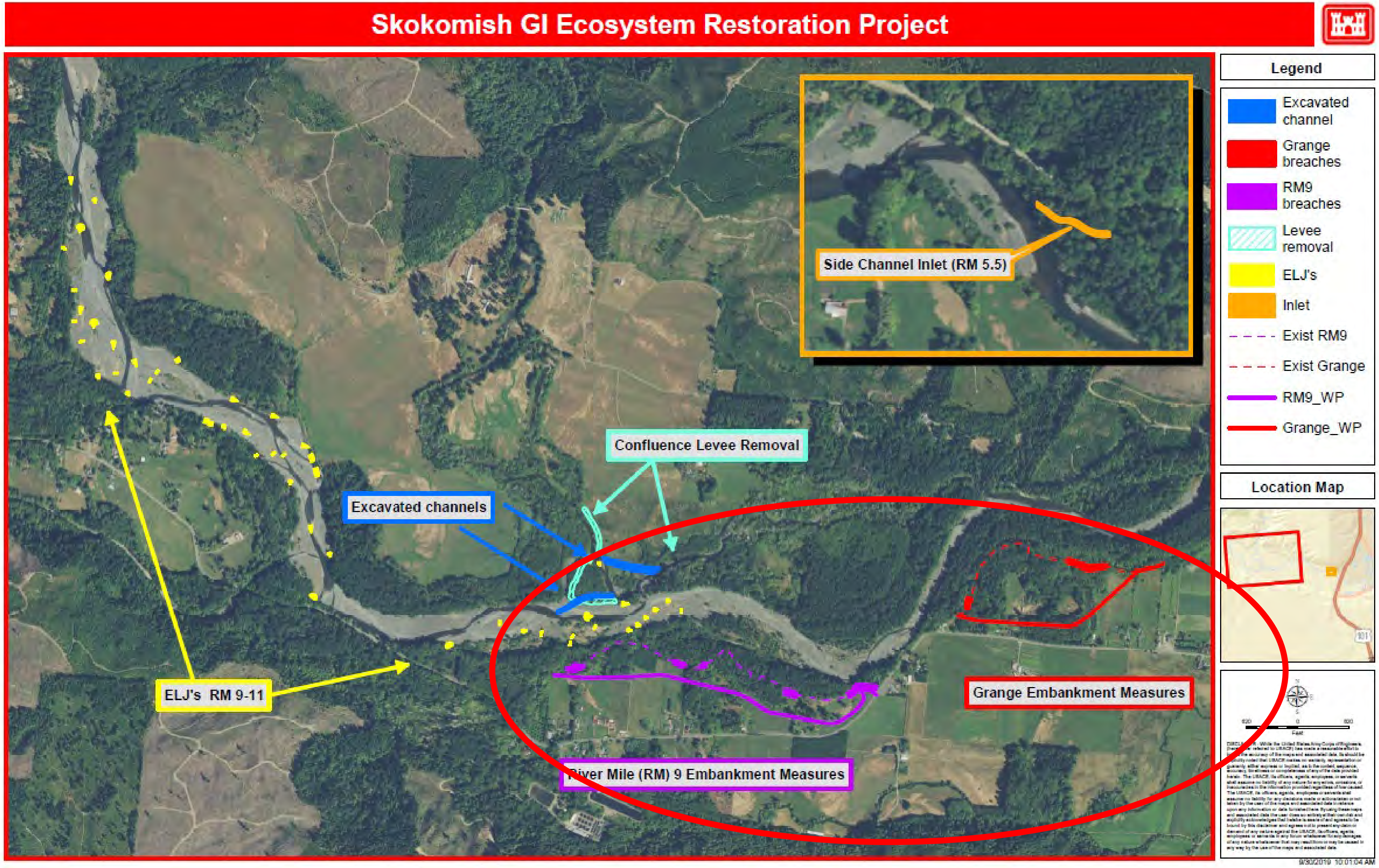






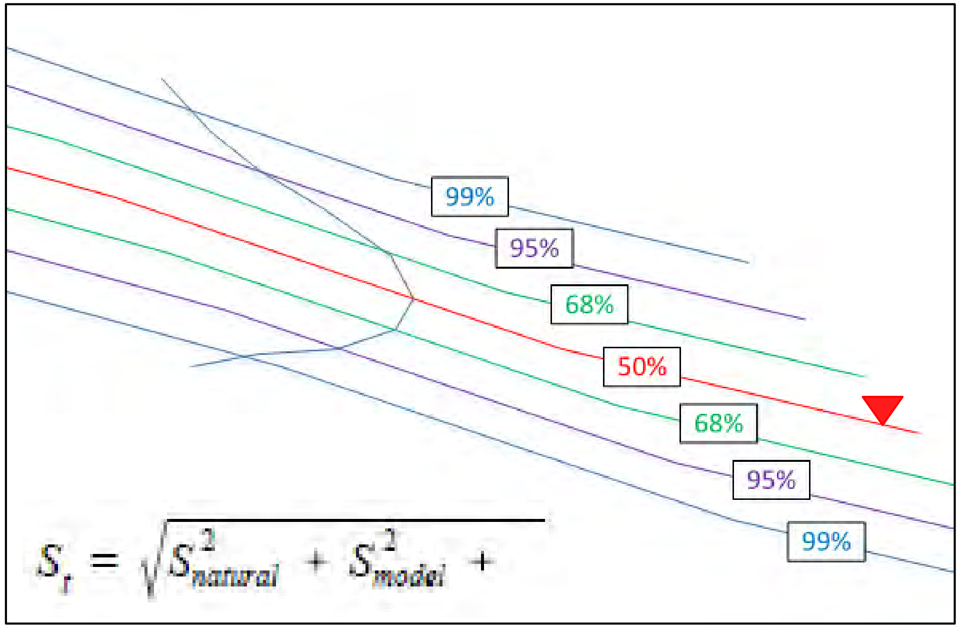
Mean calibration error was 0.05 feet, and the standard deviation 0.88 feet

PROJECT MEASURES: EMBANKMENTS

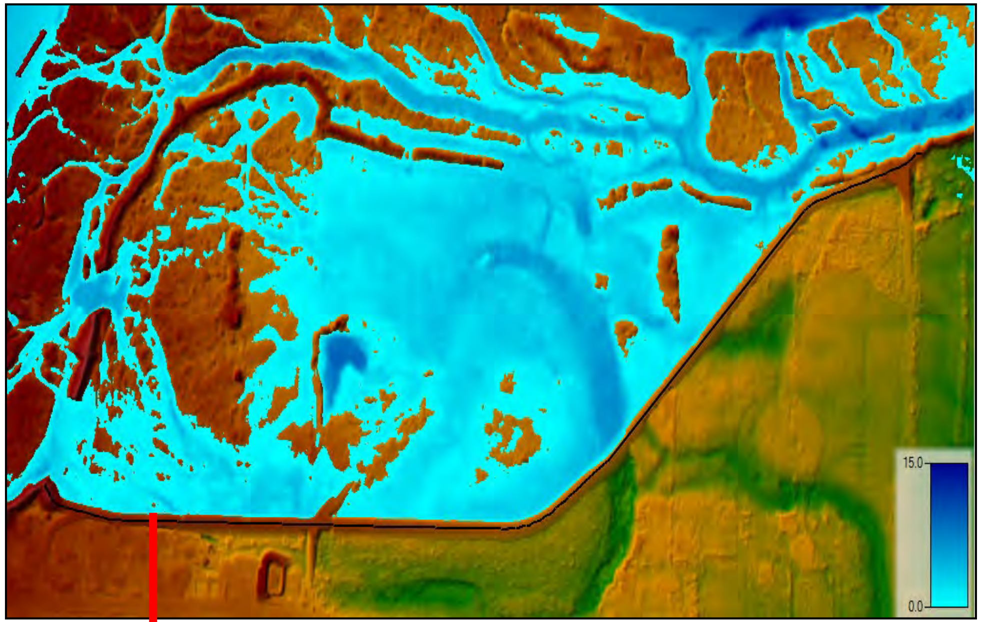


HYDRAULIC MODEL: EMBANKMENTS

- Embankment capacity was developed to satisfy three factors:
  - ✓ Provide desired habitat benefits
  - ✓ Approximate existing flood patterns
  - ✓ Account for uncertainty in model accuracy (i.e. stage error)
- Capacity of the new embankments is ~6000 cfs (South Fork flow) plus 30% for Vance Creek; (slightly less than an annual event)
- Following EM 1110-2-1619, added 1 standard deviation (0.85 feet) in total stage error to the embankment height to give 68% assurance



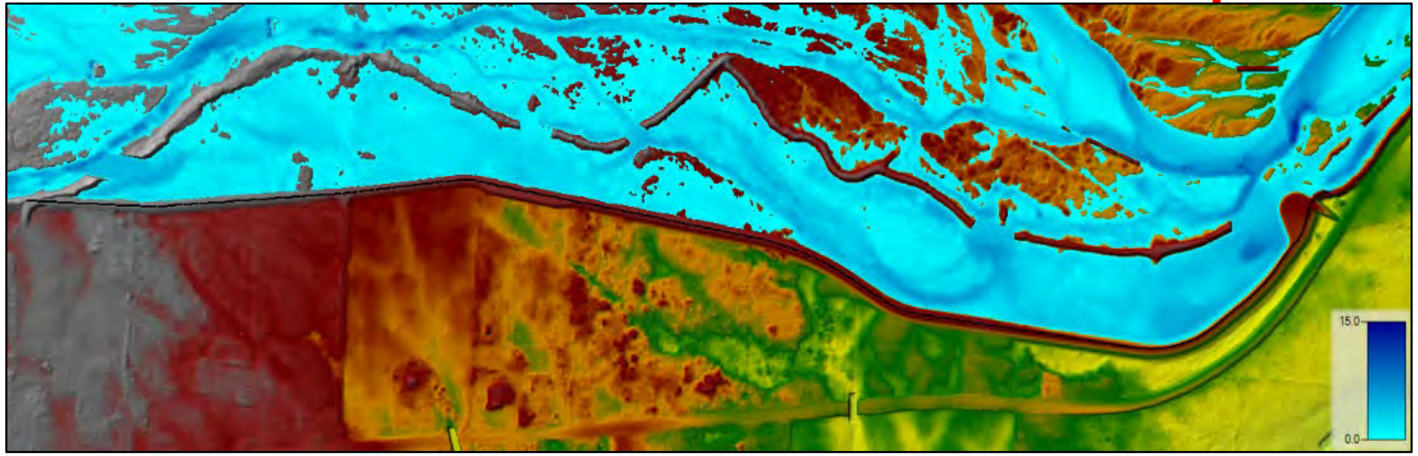
HYDRAULIC MODEL: EMBANKMENTS



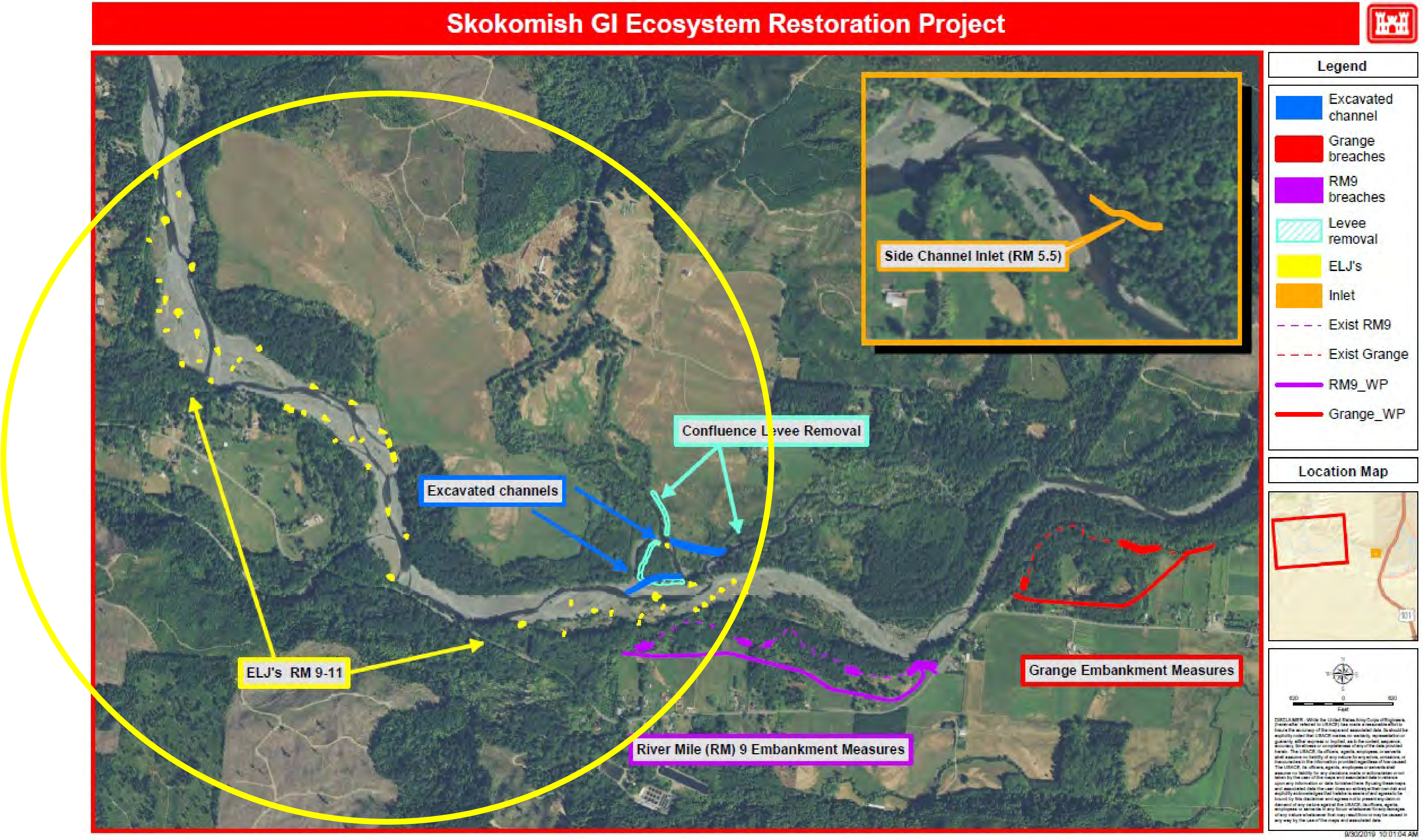
- Approximately 7000 feet of setback embankments
- Average height of 4.5 feet

Grange embankment

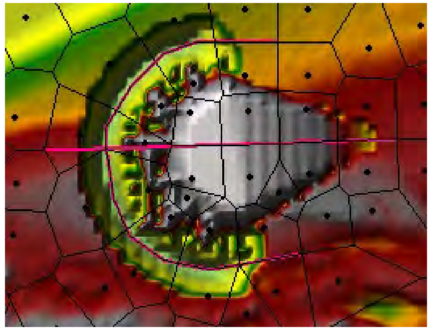
River Mile 9 embankment



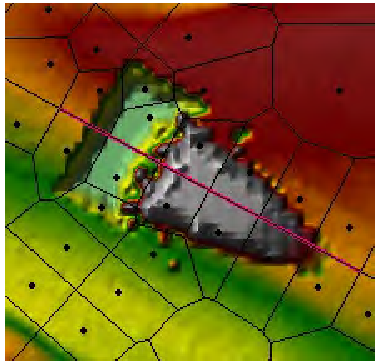
PROJECT MEASURES: ELJ'S



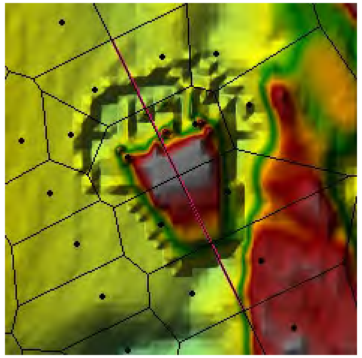
TERRAIN: ELJ FEATURES



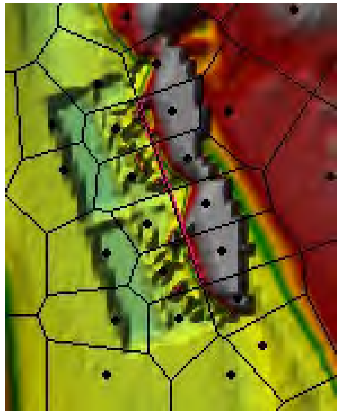
Large Bar Apex



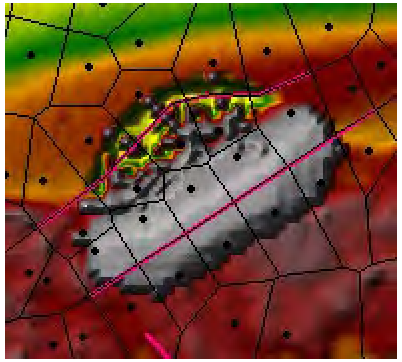
Medium Bar Apex



Small Bar Apex

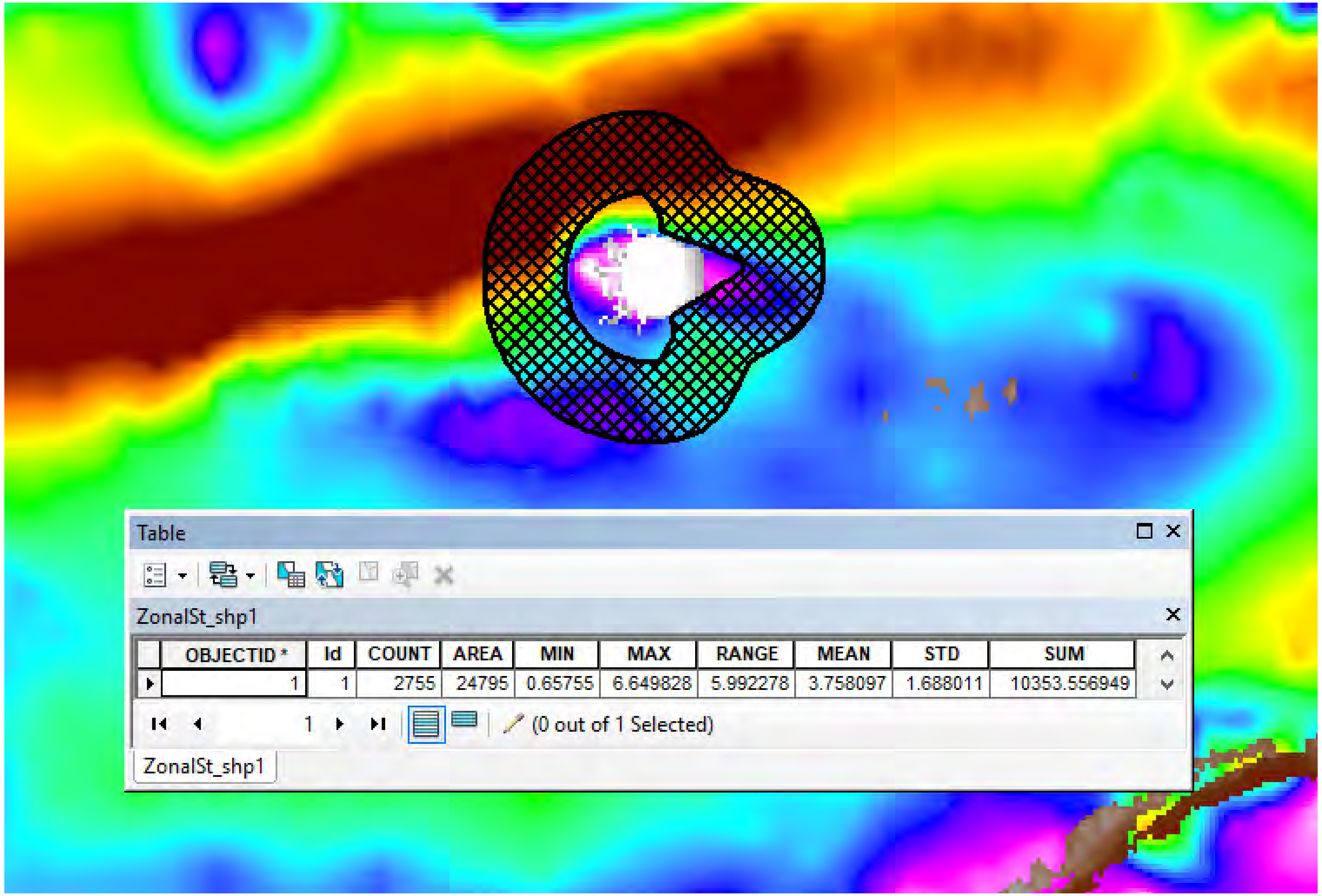


Bank Roughening Jam



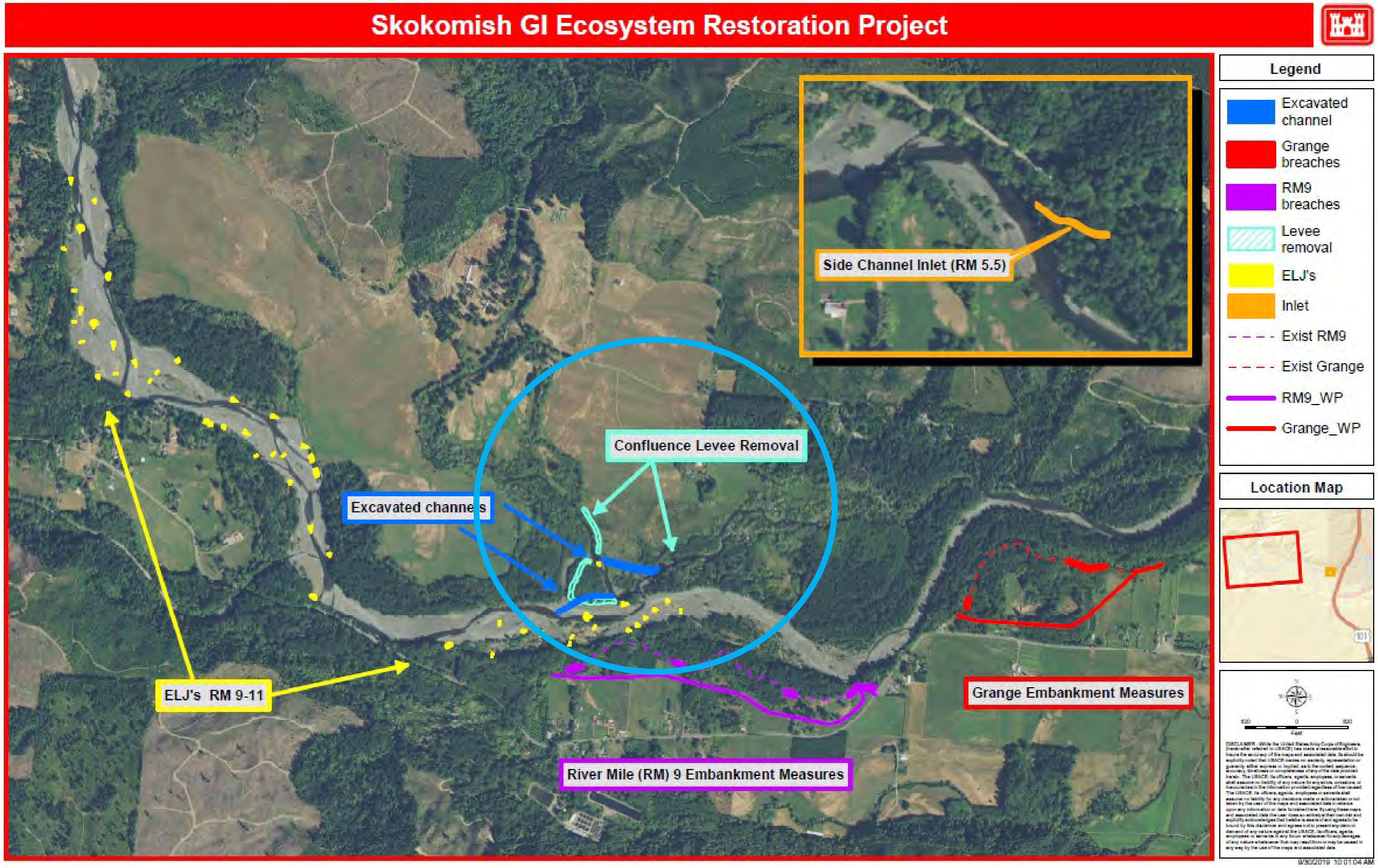
Large Deflector Jam

HYDRAULIC PROPERTIES AT ELJ'S



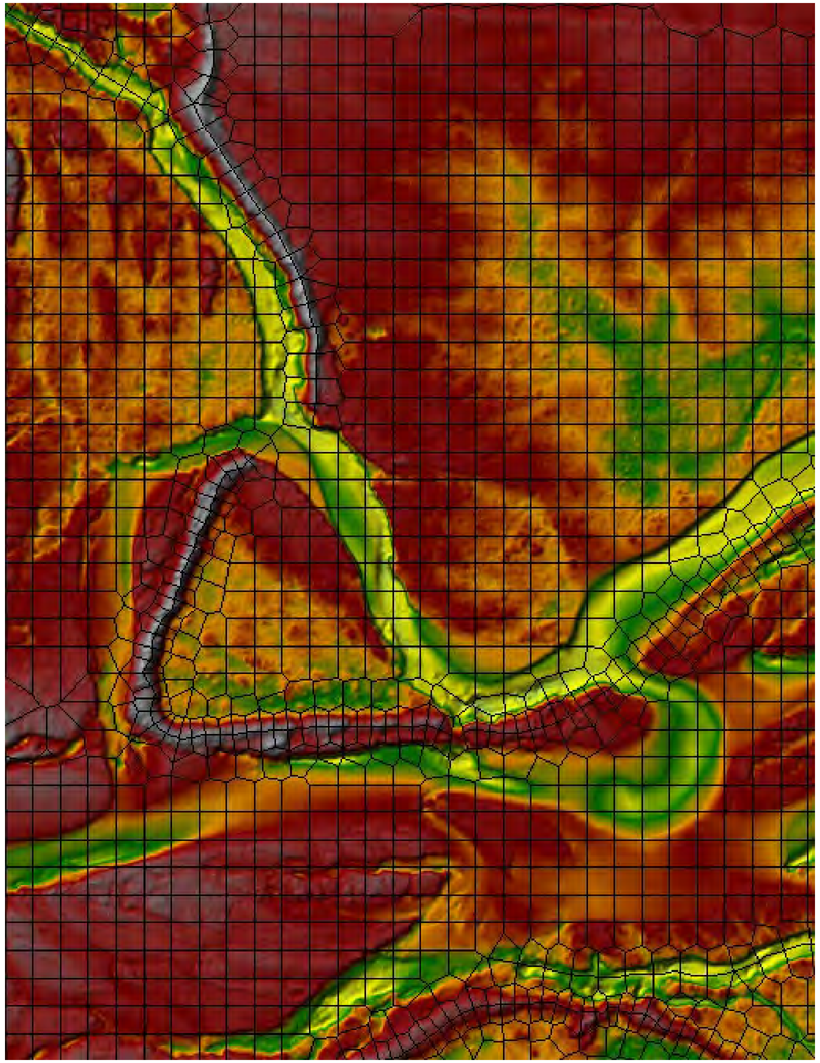
Used Zonal Statistics in ArcMap to extract velocity, depth, shear, etc.

PROJECT MEASURES: LEVEE REMOVAL

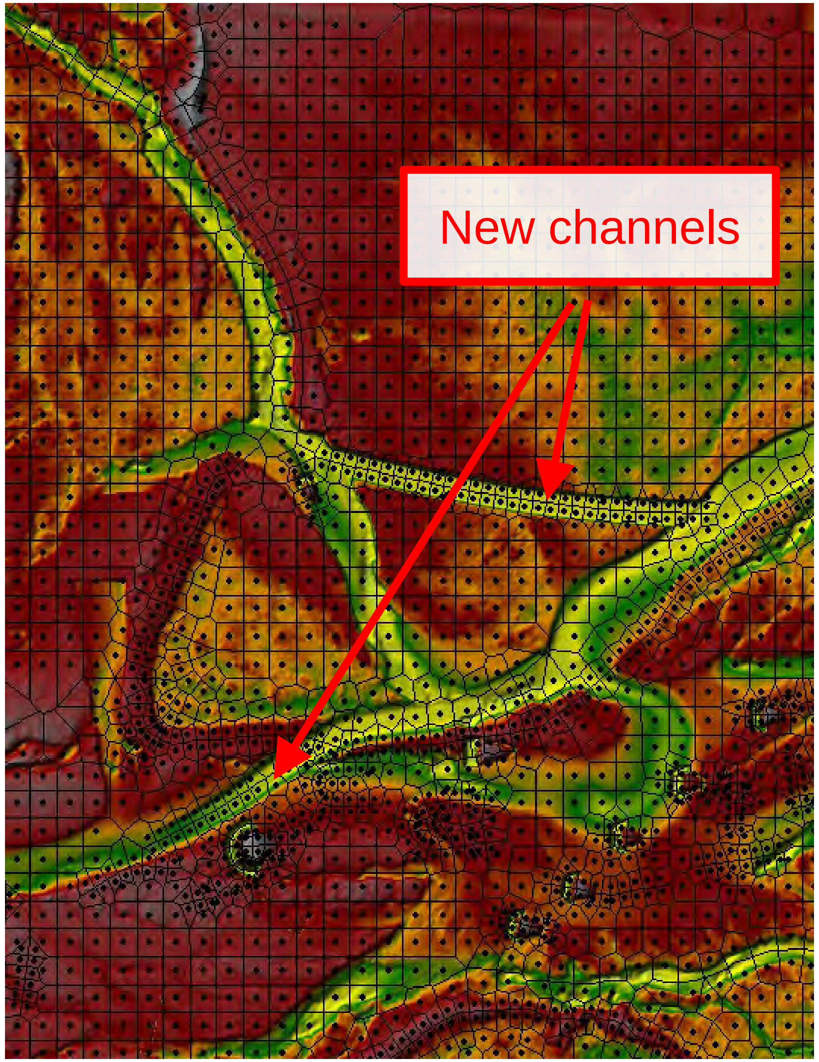


TERRAIN: CONFLUENCE AREA

Existing conditions

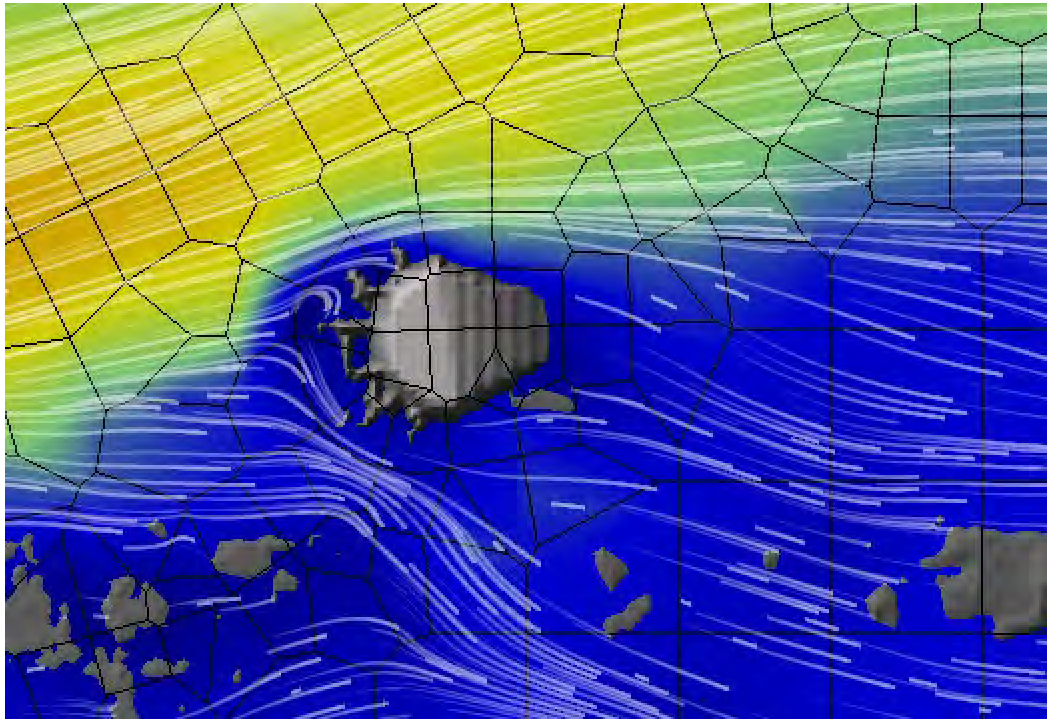


With-project conditions

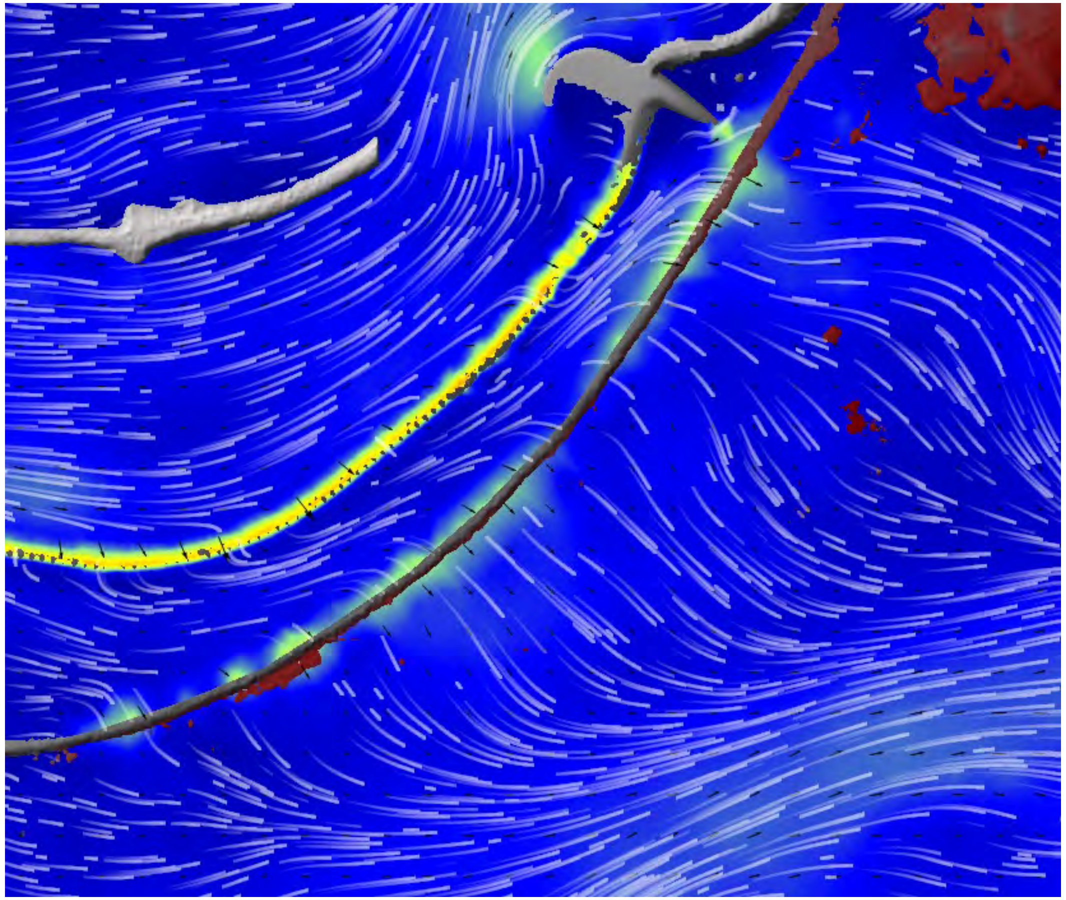


HYDRAULIC MODEL: FLOW DIRECTION

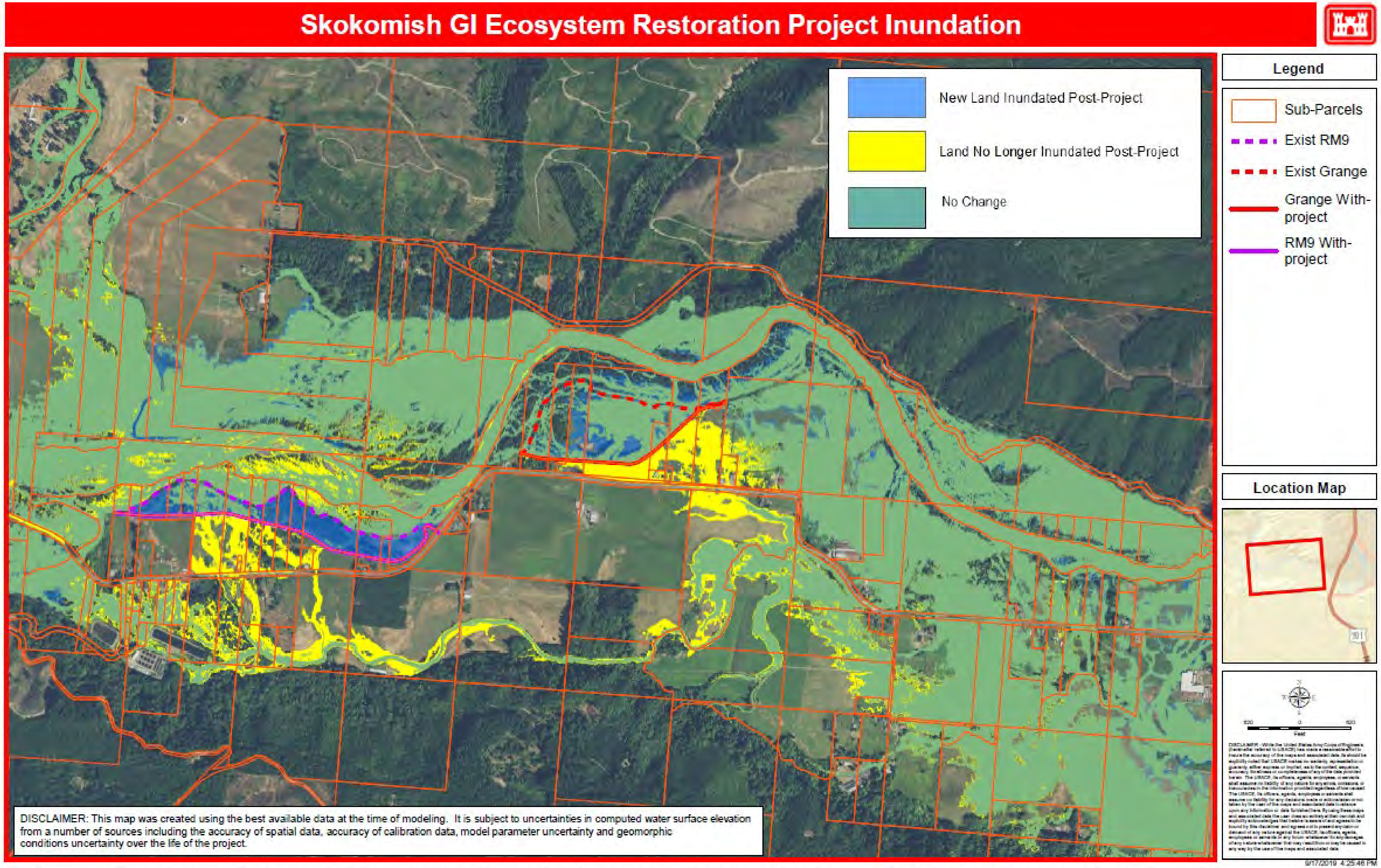
10-year event ELJ



10-year event embankment



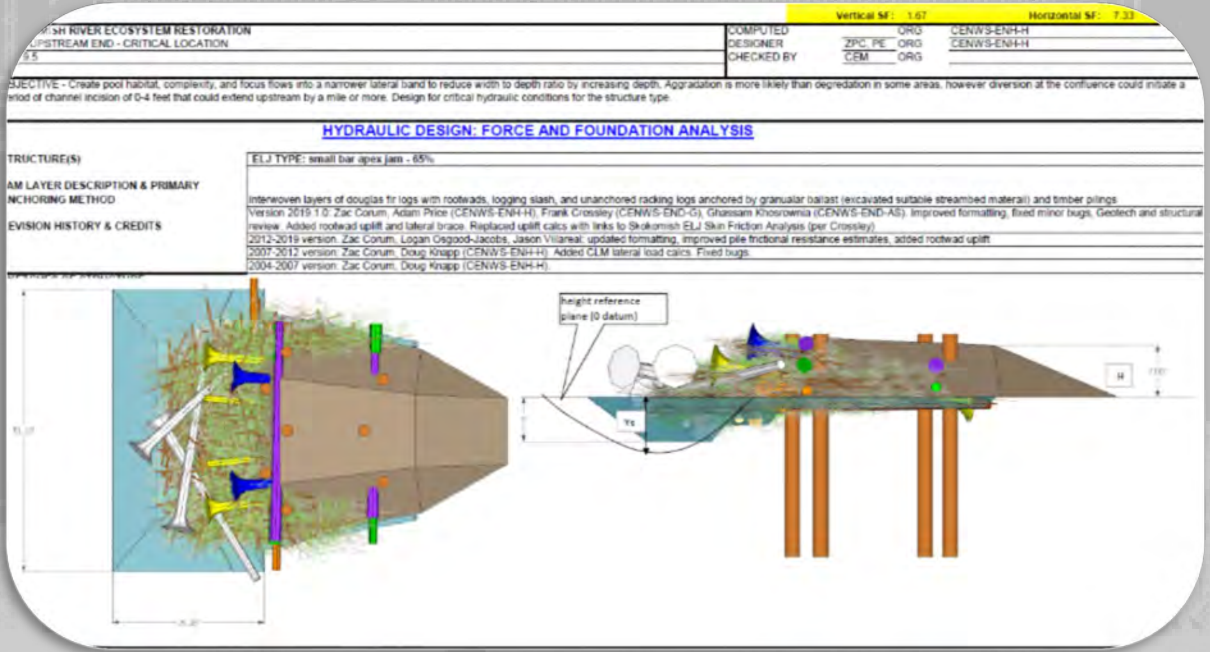
INUNDATION AT DESIGN CAPACITY

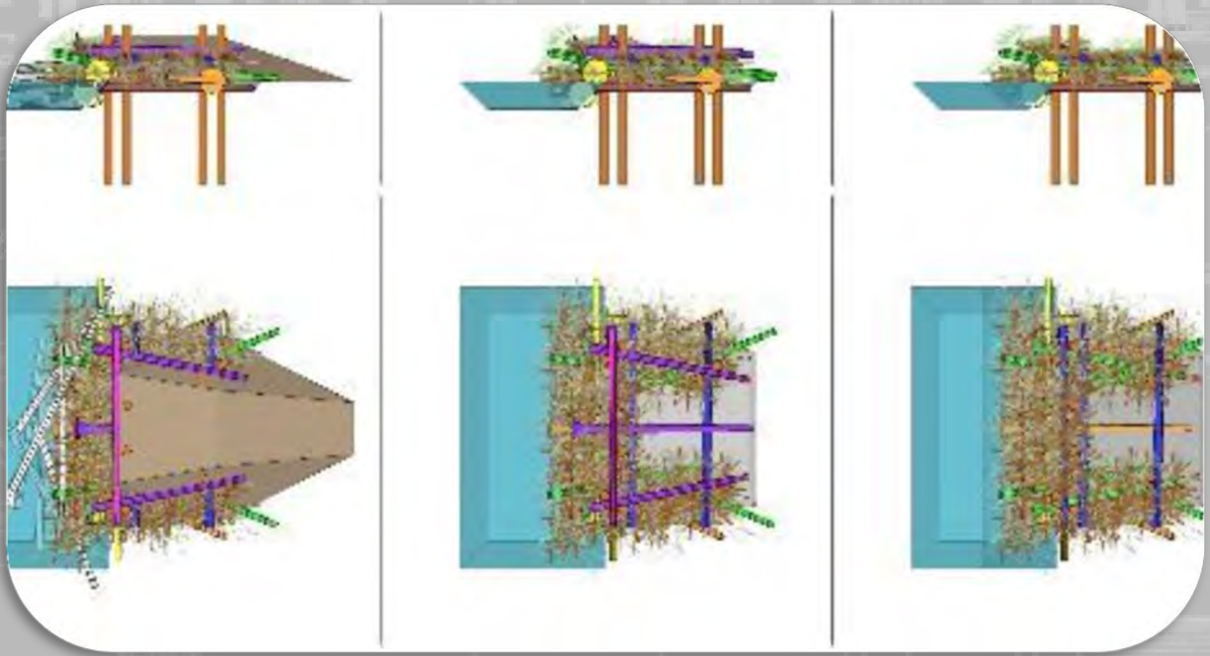


Maximum containment by new embankments at total flow= 8,000 cfs (South Fork+Vance Creek); At USGS Gage 12060500 on the South Fork stage= 5.26 ft for 6285 cfs.

RIVER MILE 9-11 REACH ENGINEERED LOGJAM (ELJ) DESIGN OVERVIEW

Zac Corum, PE





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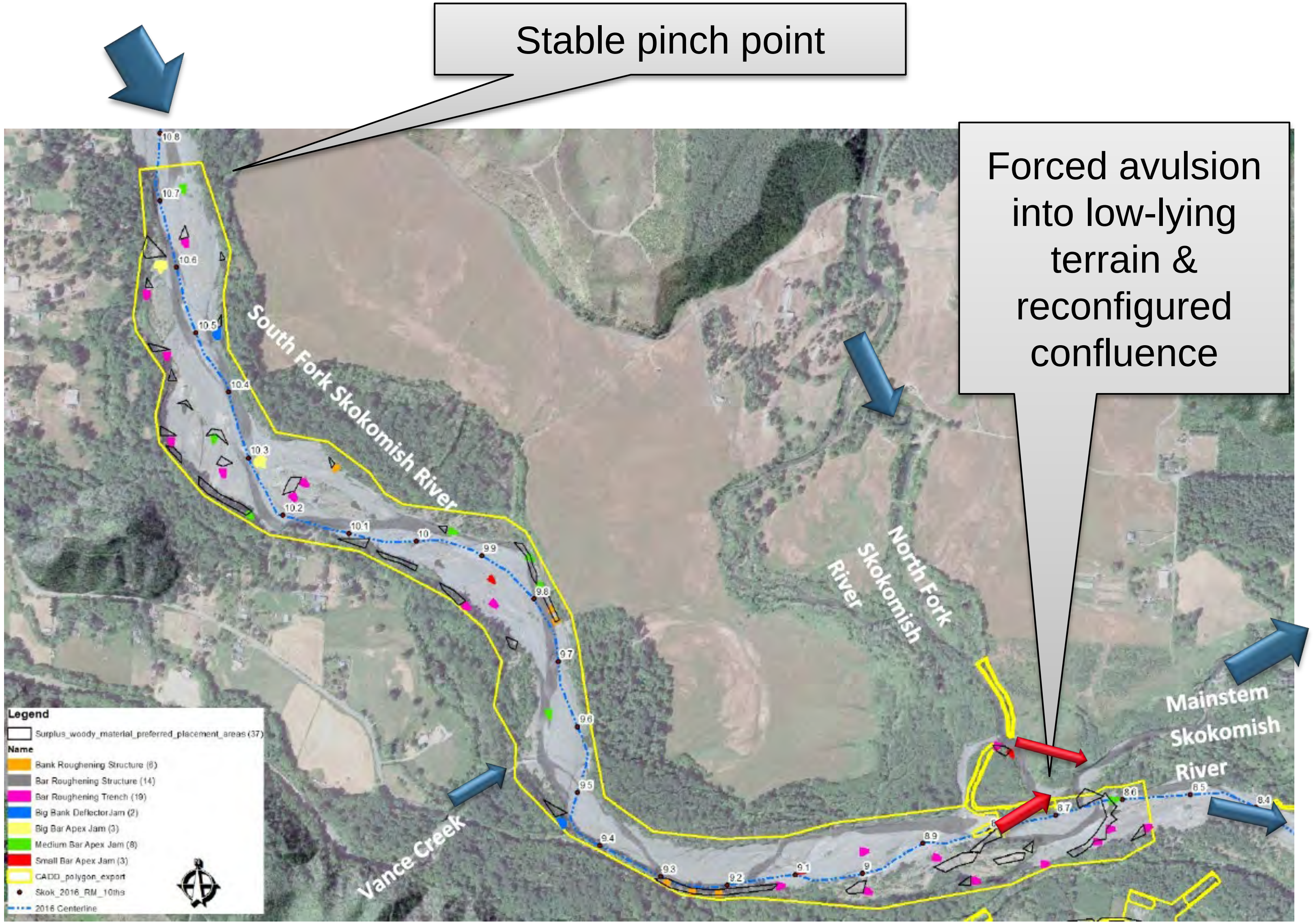
RIVER MILE 9-11 ELJ DESIGN OVERVIEW

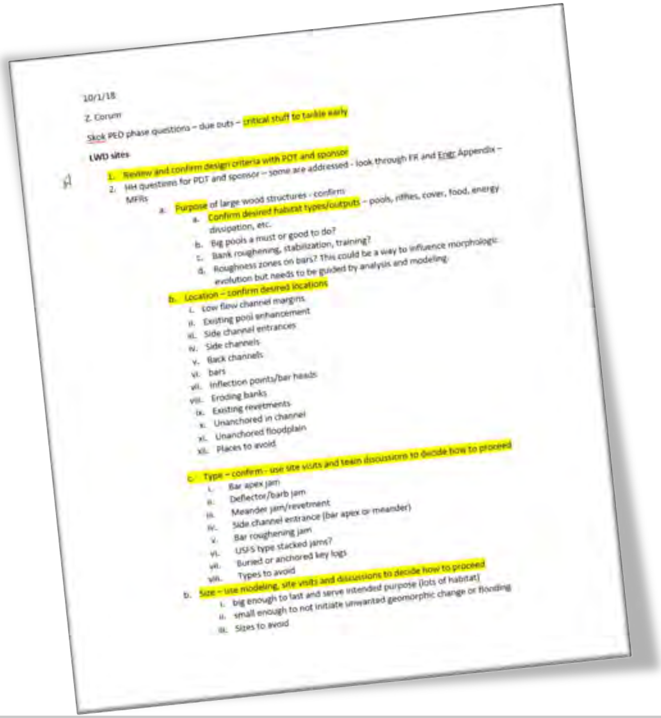


South Fork and Mainstem confluence (RM 9 to 11)

- 55 ELJs, 3 major structure types, construction start in 2021
  - (3) Small, (8) medium and (3) large **bar apex jams** → split and deflect flow, pool+island creation
  - (14) **Bar roughening structures** and (19) bar roughening trenches → trap mobile wood, roughen bars, promote vegetation growth, form bar apex jams in event of channel migration
  - (2) large **bank deflector** and (6) bank roughening jams → enhance habitat, stabilize bank line
- 930 pieces LW
- 2,100 CY logging slash
- 546 timber piles and 23,500 cy gravel ballast for stability
- Chain used to hold upper log layers to piles
- ELJs stable with scour for Q100

DESIGN PROCESS ELJ'S (35% → 100%)

- Project Kickoff: Team building site visits (visit completed projects, interview designers)
- Design charette –clarify and finalize design criteria with sponsors PRIOR to design



10/1/18

Z. Corum

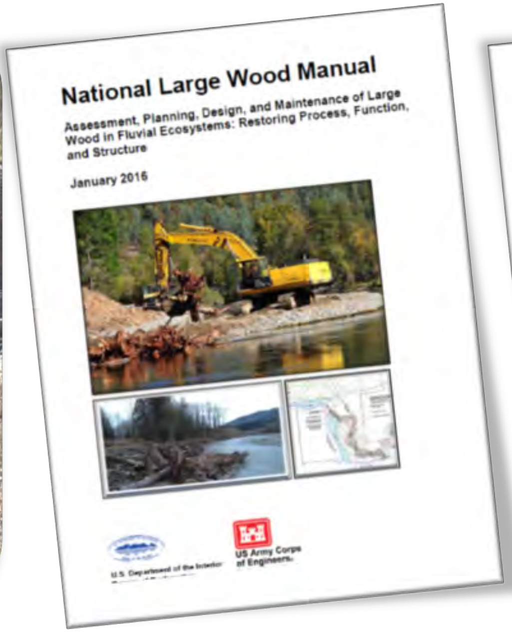
Skok PED phase questions – due outs – critical stuff to tackle early

LWD sites

1. Review and confirm design criteria with PDT and sponsor
2. HH questions for PDT and sponsor – some are addressed - look through FR and Engr Appendix – MFRs
   a. Purpose of large wood structures - confirm
      a. Confirm desired habitat types/outputs – pools, riffles, cover, food, energy dissipation, etc.
      b. Big pools a must or good to do?
      c. Bank roughening, stabilization, training?
      d. Roughness zones on bars? This could be a way to influence morphologic evolution but needs to be guided by analysis and modeling
   b. Location – confirm desired locations
      i. Low flow channel margins
      ii. Existing pool enhancement
      iii. Side channel entrances
      iv. Side channels
      v. Back channels
      vi. bars
      vii. Inflection points/bar heads
      viii. Eroding banks
      ix. Existing revetments
      x. Unanchored in channel
      xi. Unanchored floodplain
      xii. Places to avoid
   c. Type – confirm - use site visits and team discussions to decide how to proceed
      i. Bar apex jam
      ii. Deflector/barb jam
      iii. Meander jam/revetment
      iv. Side channel entrance (bar apex or meander)
      v. Bar roughening jam
      vi. USFS type stacked jams?
      vii. Buried or anchored key logs
      viii. Types to avoid
   b. Size – use modeling, site visits and discussions to decide how to proceed
      i. big enough to last and serve intended purpose (lots of habitat)
      ii. small enough to not initiate unwanted geomorphic change or flooding
      iii. Sizes to avoid

DESIGN GUIDANCE & CRITERIA

- Technical references: Fox & Bolton (2007); Eaton et al. (2010); Collins et al. (2012); NRCS National Engineering Handbook, Part 654, chapter 9; National Large Wood Manual (Reclamation and USACE, 2016)
- Institutional Knowledge: USACE Seattle District design procedures and spreadsheet
- General Design Criteria: Increase low flow channel sinuosity; Increase pool habitat; promote bar vegetation growth, deepen dominant channel thread and reduce width to depth ratio; structures stable during Q100; minimize flooding and bank erosion


National Large Wood Manual

Assessment, Planning, Design, and Maintenance of Large Wood in Fluvial Ecosystems: Restoring Process, Function, and Structure

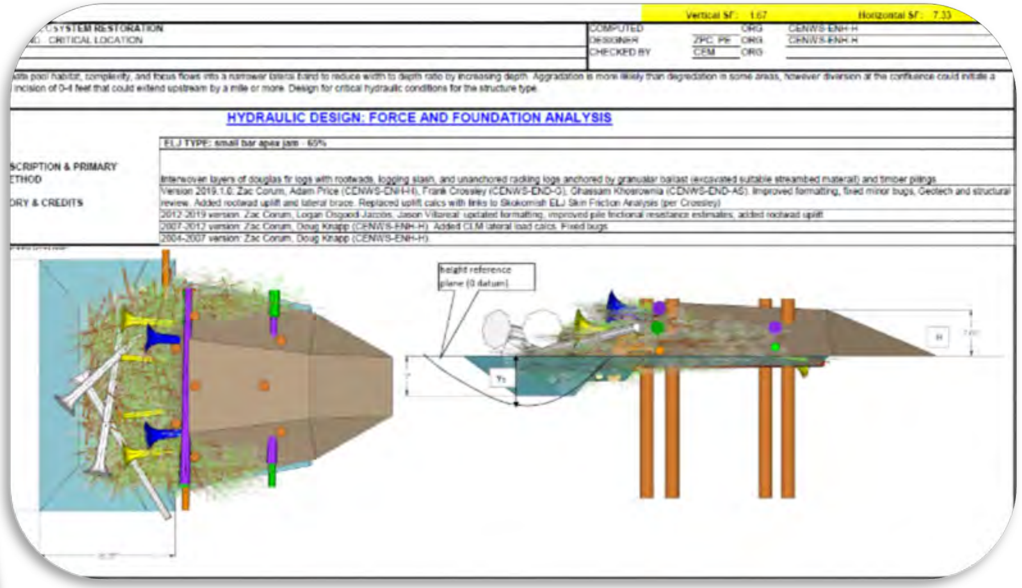
January 2016

U.S. Department of the Interior

US Army Corps of Engineers


Geomorphology

The floodplain large-wood cycle hypothesis: A mechanism for the physical and biotic structuring of temperate forested alluvial valleys in the North Pacific coastal ecoregion



DESIGN PROCESS ELJ’S (35% → 100%)

- Geomorphic recon and baseline trends
  - Lit review, pebble counts, sinuosity, width/depth, large wood and jam counts, natural design templates (jam size, frequency, pool depth, bar extents, active width)
- Wood volume estimates, trends, loading targets
- Riverbed borings for pile suitability
- Reach analysis
- Effective discharge & RAS 1D Copeland channel stability analysis
  - Determine target active width, slope, depth and allowable obstruction width

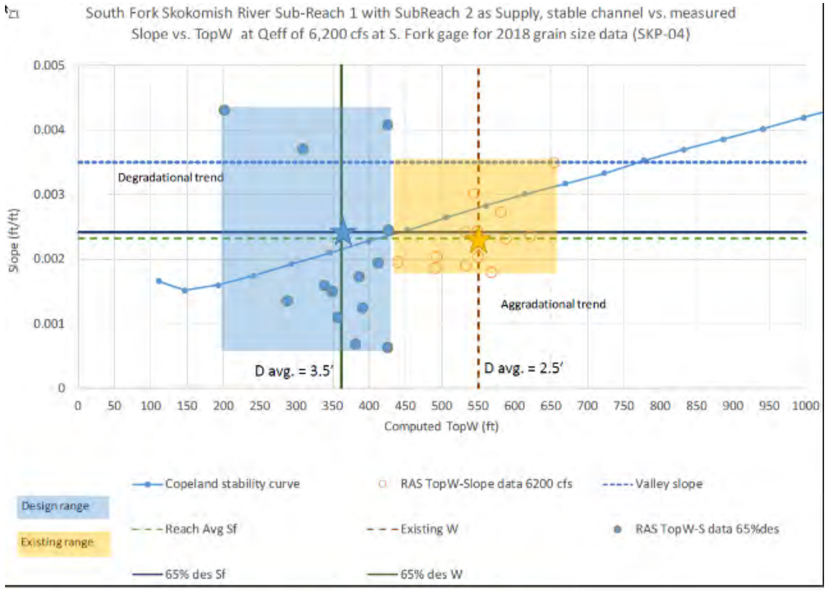
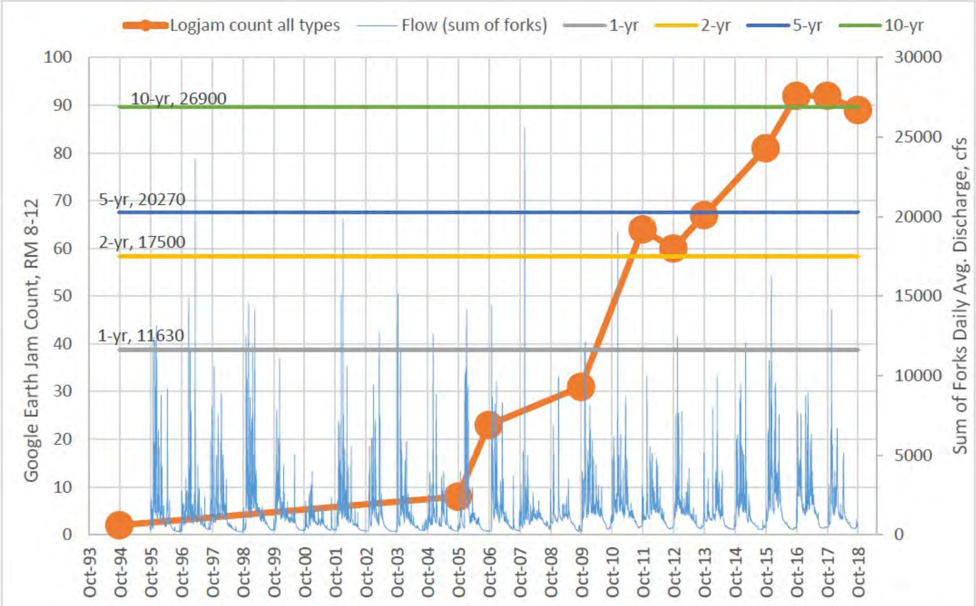
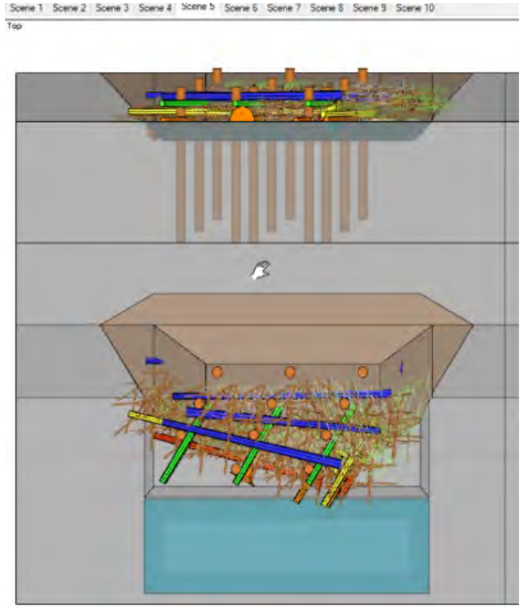


Figure 51. Analysis of stable channel conditions, sub-reach 1 (project near confluence with North Fork)



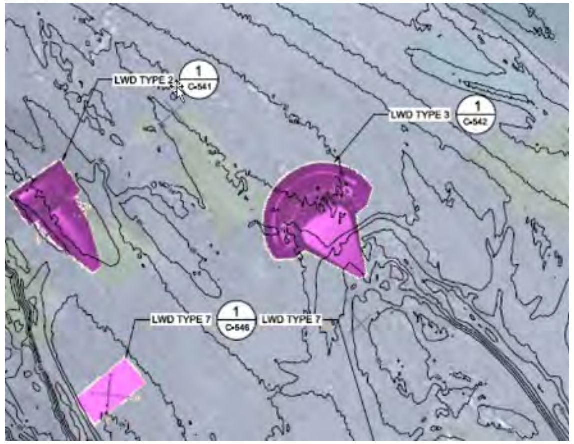
DESIGN PROCESS ELJ'S (35% → 100%)

- Initial structure design (Sketchup, Microstation) and bid quantities
- Initial structure layout and design (ArGIS Pro, Microstation), build terrains and roughness patches for RAS, compute depth and velocity statistics for stability analysis
- Refine type/size/location based on cost constraints

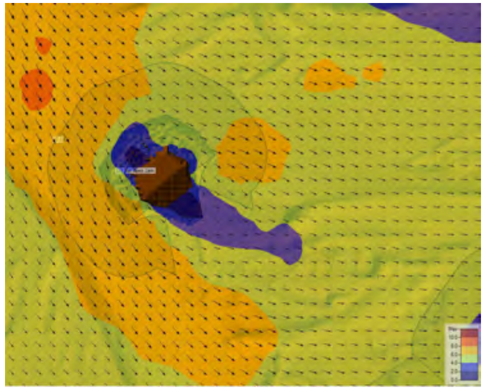


Sketchup: Structure design, assembly plan, QTO

ArcGIS Pro: 3D layout, terrain generation, roughness patches and D/V stats



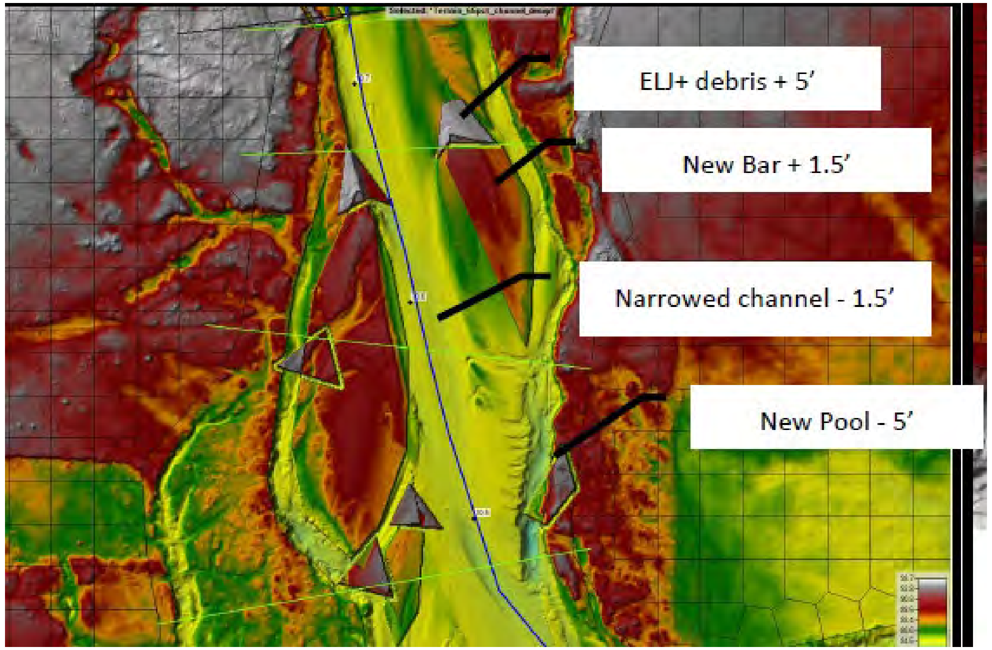
Microstation construction ready DWG



HEC-RAS 2D

DESIGN PROCESS ELJ'S (35% → 100%)

- Verify sediment routing with 1D HEC-RAS, flood impacts with 2D HEC-RAS
- Finalize scour and stability calculations
- Final design documentation



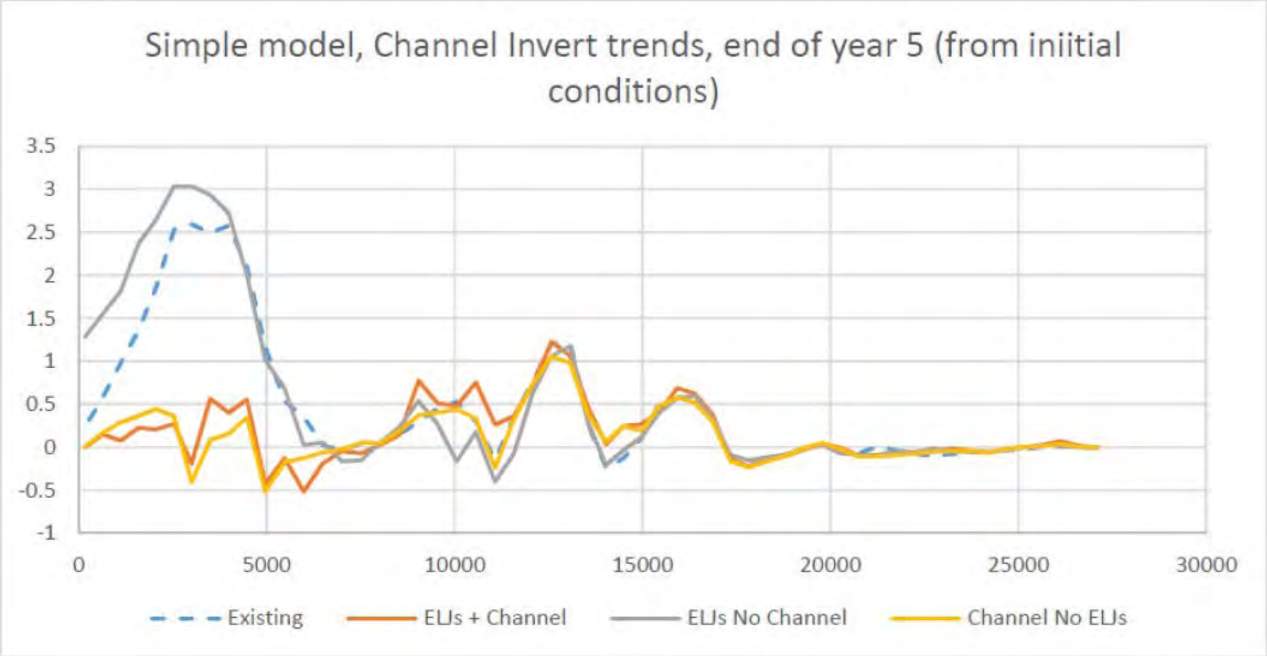


Figure 56. Comparison of predicted changes in channel invert elevations after 5 years on the South Fork upstream of the confluence

ELJ PLACEMENTS

Work downstream of stable pinch point, upstream of forced avulsion

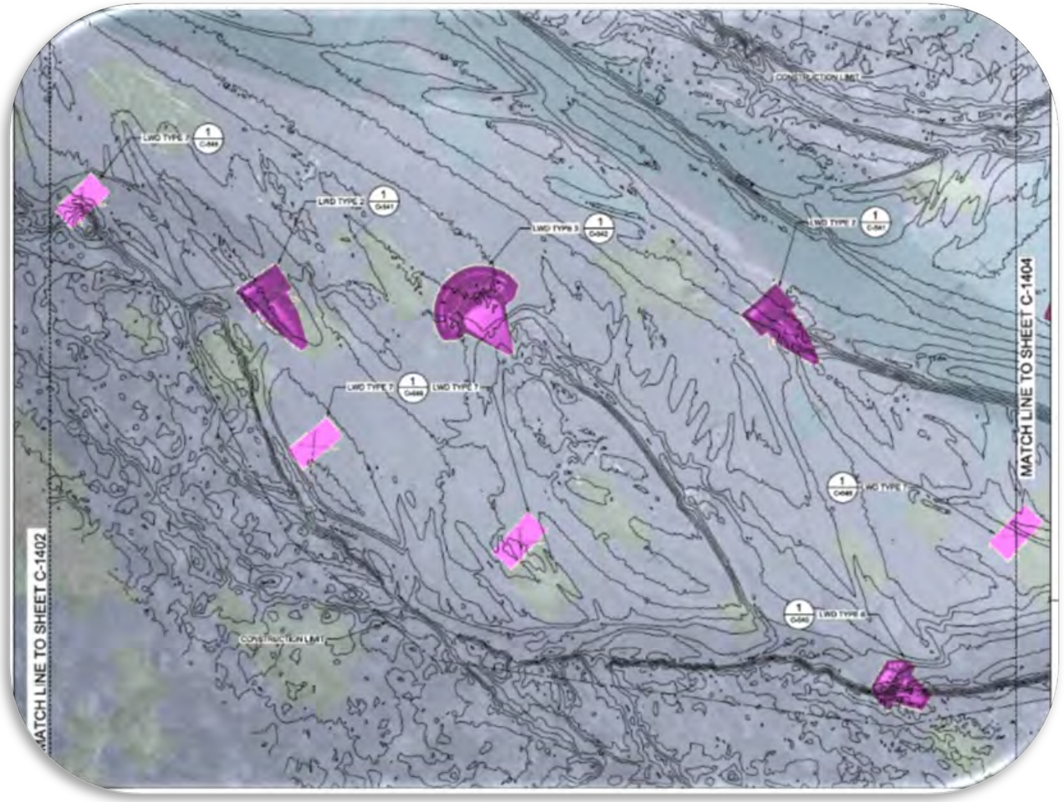
Dynamic conditions expected

Structures work in groups, anticipating future pool formation, debris recruitment, bar growth, and channel migration

Size is dependent on location (degree of expected engagement with river over time) and relative importance for achieving project objectives

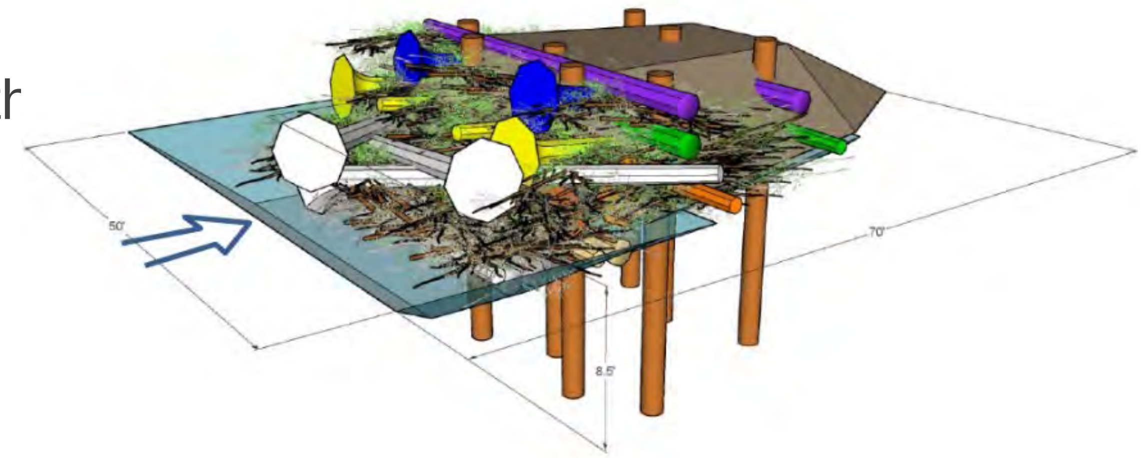
- 25 of these (46%) are intended to immediately engage with the low-flow channel and create pool habitat, deflect flows, and increase sinuosity and depth

- 29 of these (54%) are intended to complement the low flow channel jams by promoting bar and island formation during high flows.

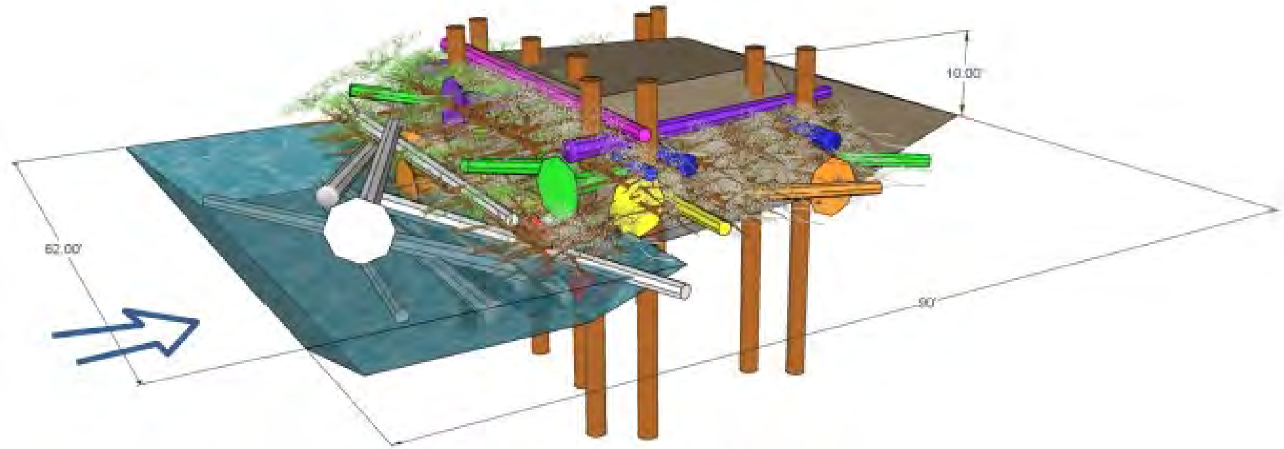


3 ELJ TYPES: BAR APEX, DEFLECTOR, ROUGHNESS

1. **Small bar apex jams** are located in the middle of the river and are associated with pool formation and mid-channel bar and island development

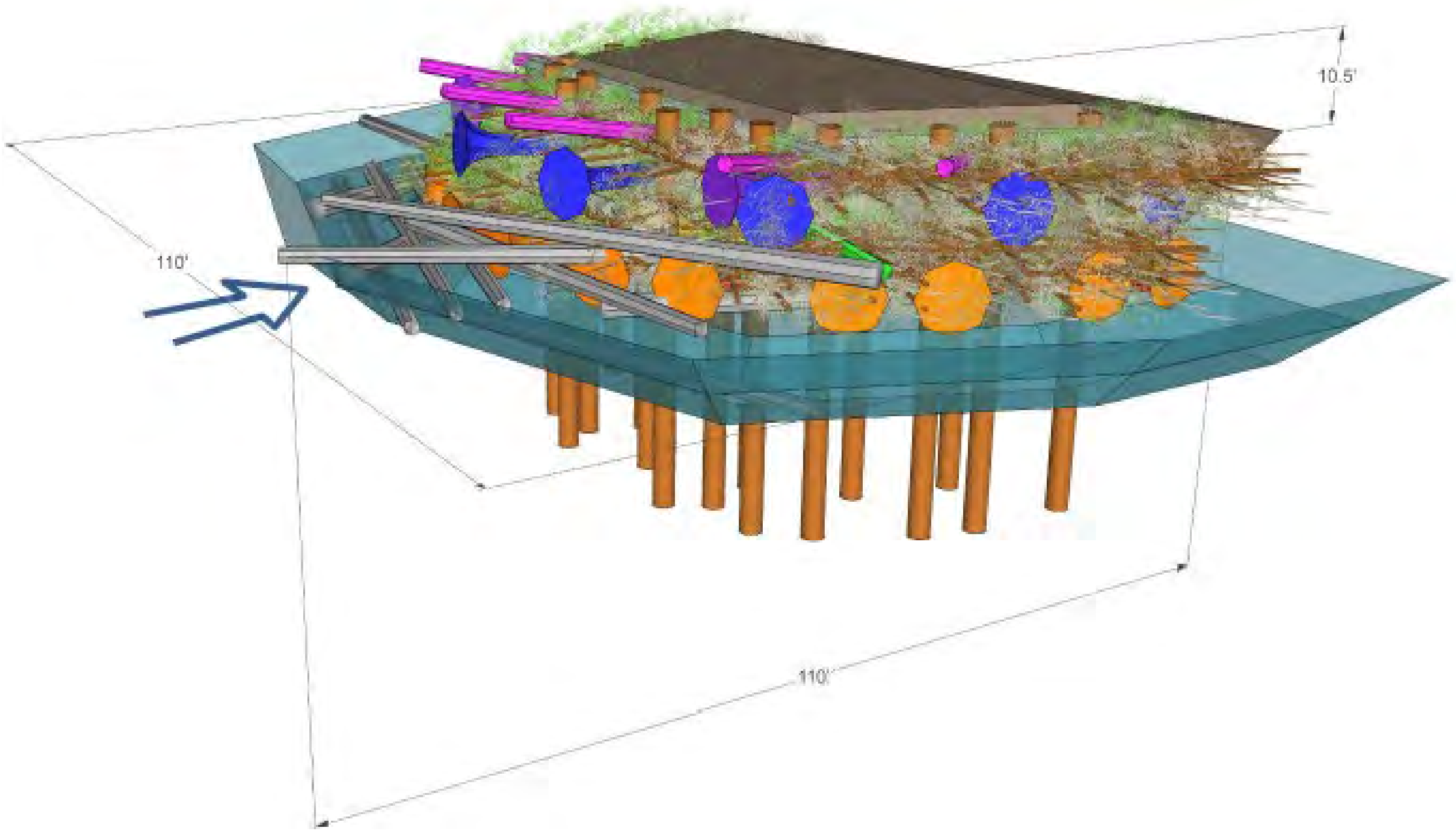


2. **Medium bar apex jams** are intended to provide a robust, cost effective engineered jam that can be installed efficiently in a wide range of locations where bar apex or flow deflection functions are desired



ELJ TYPES

3. **Large bar apex jams** are intended to provide robust performance in critical locations where reliable bar apex or flow deflection functions are required to achieve project success



ELJ TYPES

4. **Large bank deflector jams** are intended to provide robust performance in critical locations where reliable low deflection function and pool formation are required to achieve project success

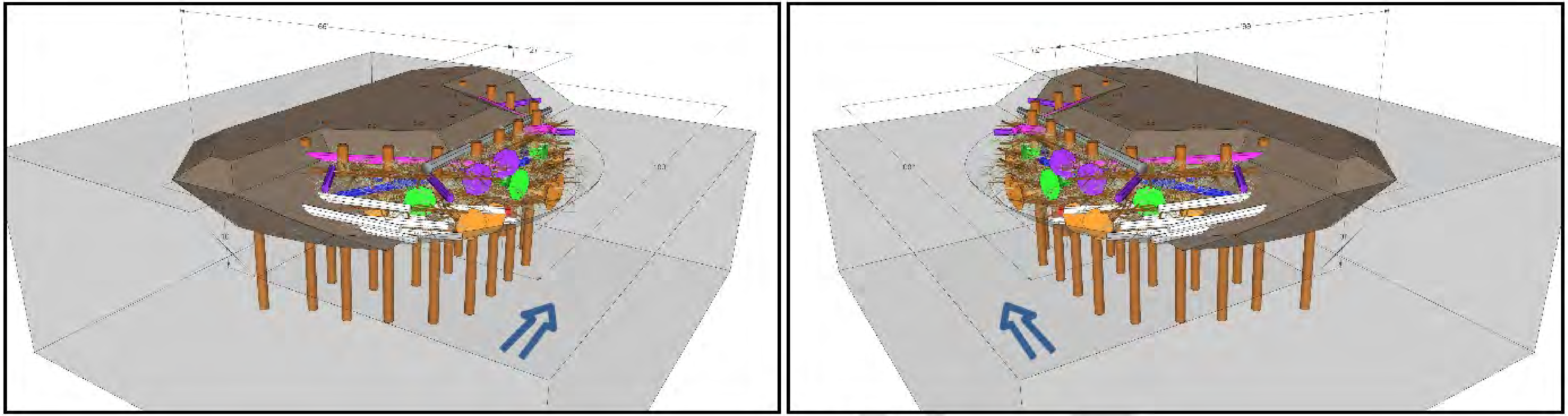


Figure 15. Type 3 ELJ: large bank deflector jam (shown on left and right banks)

ELJ TYPES

5. **Bank roughening structures** are intended to provide complex overhanging habitat along the toes of outer bends, where deeper, more complex pool habitat is desired

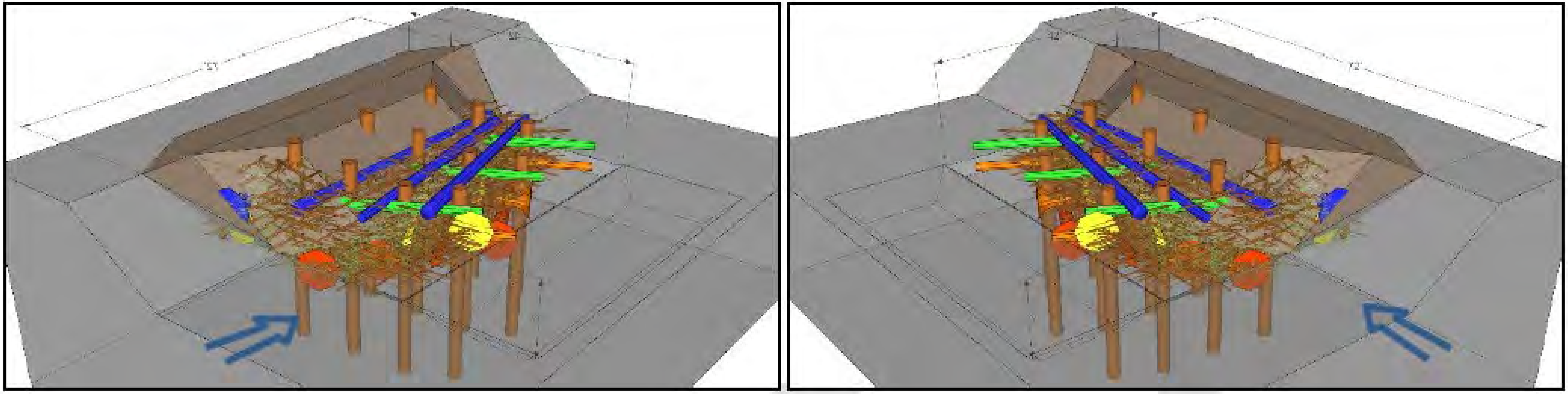
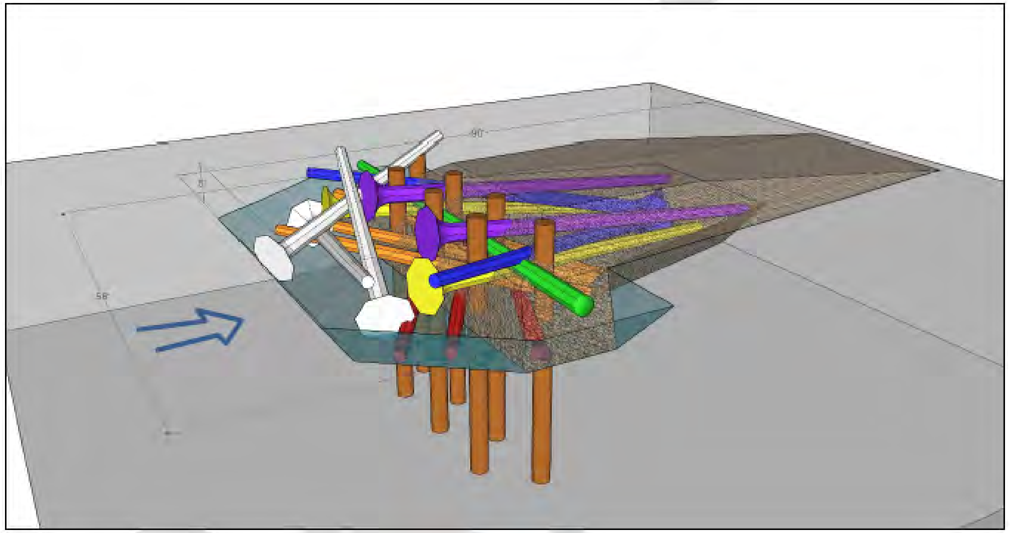


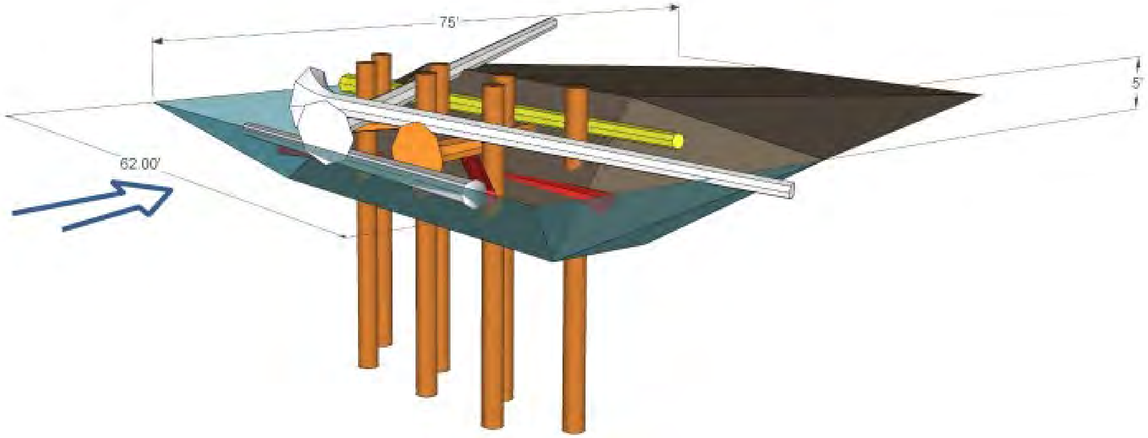
Figure 16. Type 5 ELJ: bank roughening structure (shown on left and right banks)

ELJ TYPES

6. **Bar roughening structures** are intended to function as sediment- and debris-trapping structures in locations that are intermediate between bar tops and the low-flow channel



7. **Bar roughening trenches** are the most common proposed jam type. They are intended to function as economical and dynamic sediment- and debris-trapping structures

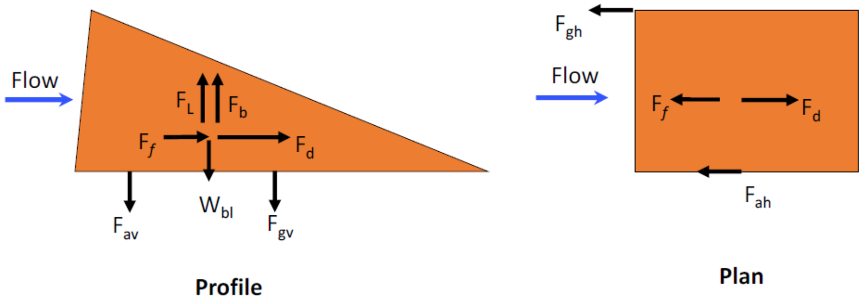


STABILITY ANALYSIS

Spreadsheet used to determine safety factors (ratio of resisting to applied forces in horizontal and vertical directions). See Large Wood National Manual for examples

Safety factors are sensitive to the input data and assumptions

Figure 6-13. Typical Free Body Diagram for a Large Wood Structure



Forces may be determined as follows. F_{av} = restraining force due to anchors or other restraints in vertical direction, W_{bl} = weight of ballast, F_{gv} = geotechnical forces in vertical direction, F_f = force of friction between LW and stream boundary, F_d = drag force, F_L = lift force, F_b = buoyant force, F_{gh} = geotechnical force in horizontal direction, F_{ah} = force due to anchors or other restraints in horizontal direction. Points of application for force vectors shown are arbitrary.

Relative importance of input parameters (at this site) to structure stability

Design parameter	Wood Volume Restrained	Gravel ballast volume	Velocity	% Submerged	Frontal Area (including recruited material)	Scour Depth	Pile Quantity	Pile Depth	Pile Diameter
Lateral Stability	Medium	**High**	**High**	Medium	**High**	Medium	**High**	Medium	**High**
Vertical Stability	**High**	**High**	Low	**High**	Low	Medium/ High	Medium/ High	Medium/ High	Medium/ High

SAFETY FACTORS

Safety factors for the design condition are within desired range, > 1.6 for design condition, > 1 for worst case loading

Vertical loading (buoyancy) controls stability when ballast present, horizontal loading (fluid drag) when ballast lost

Table 12. ELJ safety factors by type, allowable pile pullout resistance design method – 95% design

ELJ	95% Design Update Data						
	Q100 Design Condition Velocity (ft/s)	Q100 Worst Case Condition Velocity (ft/s)	Pile Embedment below streambed elev. (ft)	Design Condition Total Scour (ft)	Worst Case Total Scour (ft)	Design Condition Minimum SF	Worst Case Minimum SF
Type 1	4.6	6.9	25	11.8	17.5	1.7 v	1.0 v
Type 2	4.4	8.4	25	14.2	17.2	1.6 v	1.0 v
Type 3	5.6	8.7	25	16.8	18.1	1.7 v	1.0 v
Type 4	4.4	8.7	25	20.6	20.6	1.8 v	1.0 v
Type 5	5.1	8.2	25	15.4	15.4	1.6 v	1.0 v
Type 6	4.2	8.5	20	11.2	16.1	1.9 v	1.0 v
Type 7	4.1	8.8	20	12.6	17.3	1.9 v	1.0 h

Notes: h = horizontal (lateral) loading controls, v = vertical (buoyancy) loading controls

Table 13. 95% ELJ safety factors by structure type, ultimate pile pullout resistance design method

Type	Design Condition		Worst Case	
	Lateral SF	Vertical SF	Lateral SF	Vertical SF
1	7.3	2.4	1.2	1.6
2	5.7	2	1.1	1.3
3	23.6	2	1.4	1.2
4	46.5	2	1.6	1.2
5	17	1.9	1.8	1.4
6	21.4	2.1	1.3	1.2
7	26.4	2.2	1	1.3

Equation 6-12:

$$F_{sv} = \frac{\vec{W}_{bl} + \vec{F}_{gv} + \vec{F}_{av}}{\vec{F}_b + \vec{F}_L}$$

Equation 6-13:

$$F_{sh} = \frac{\vec{F}_f + \vec{F}_{gh} + \vec{F}_{ah}}{\vec{F}_d}$$

STABILITY ANALYSIS SUMMARY

Stability analysis shows that **submergence** is a key factor

- full submergence of the structure means that a portion of the ballast does not utilize its full weight against the constructed logs

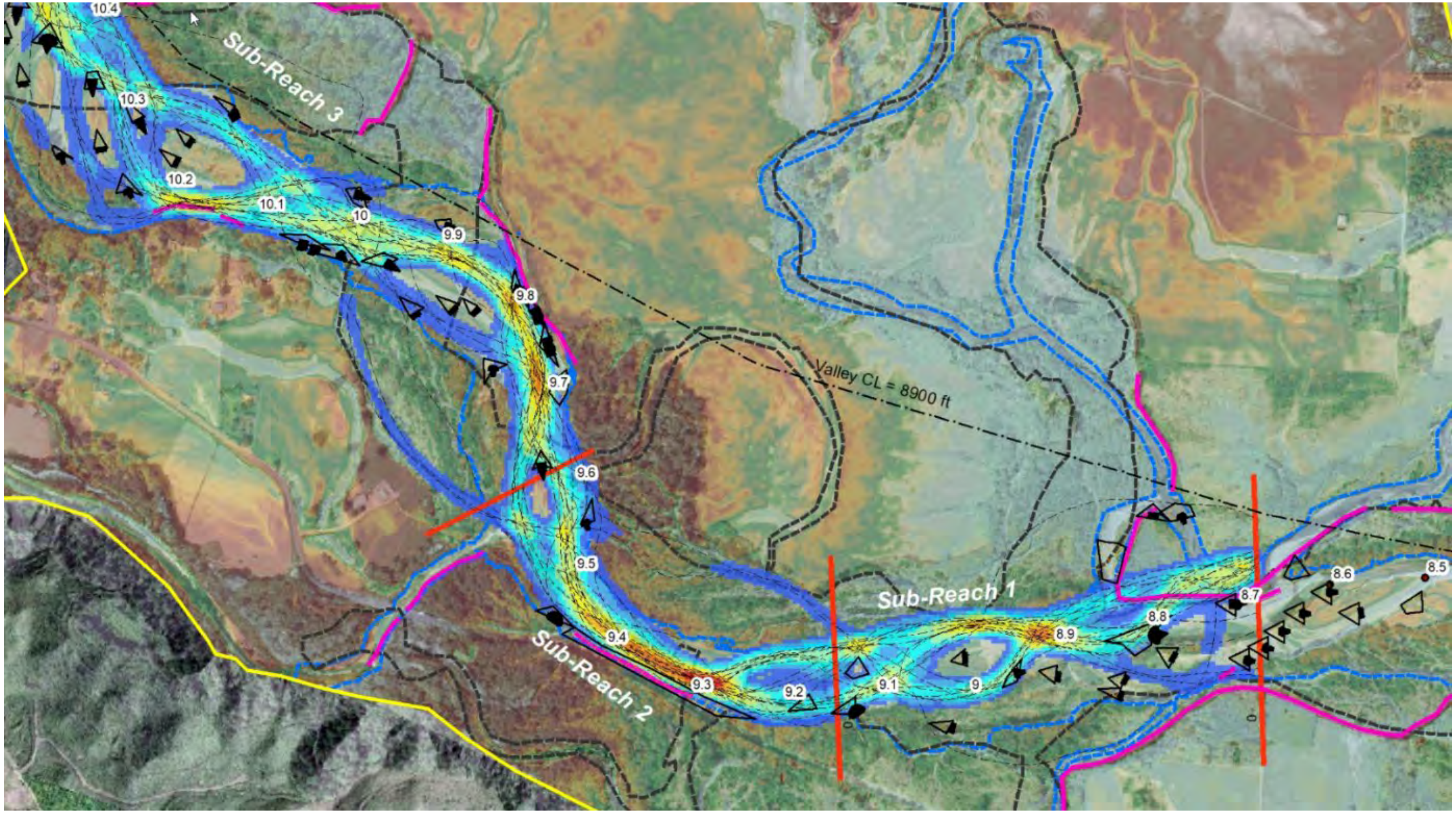
Key stability factors in each type of engineered log jam are identified:

- Location (depth, velocity)
- The volume of wood restrained
- The volume of ballast present/eroded
- Obstruction area and drag coefficient
- Piles (diameter, depth, number, ultimate or allowable strength assumptions)


Snoqualmie River ELJ (King County)

RISK MANAGEMENT

- These are experimental interventions: be prepared to test your restoration hypothesis
- Include monitoring and adaptive management to address residual risks
- Consider range of outcomes→ acquire project lands accordingly and communicate risks openly and honestly



GIS Density analysis of 20 potential dominant channel threads

LESSONS LEARNED & BEST PRACTICES

- Leverage regional SME expertise and successful project examples
- Define design criteria, project examples early on and get project team buy-in before initiating design
- Leverage existing habitat and natural processes to reduce costs
- Consider range of outcomes, acquire project lands accordingly and communicate risks
- 3D models of log structures + ArcGIS Pro + 2D HEC-RAS is relatively efficient and physically accurate workflow
- Coordinate with local landowners early (through sponsor)
- Include monitoring and adaptive management to address residual risks

Snoqualmie River restoration project under construction (King County)

THANKS!

USBR TSC: Jennifer Bountry
Corps PDT: Christine Ceragnioli, David Cook, Nancy Gleason, Glenn Kato, Ethan Cheng, Courtney Moore, Chad Zagar, Frank Crossley, Brendan Comport, Zac Corum
Mason County: Loretta Swanson, Evan Bauder
Skokomish Indian Tribe: Joseph Pavel, Alex Gouley
USFS: Brian Bair, Marc McHenry
King County: Chris Brummer, Chase Barton, Craig Garric, Jen Rice
Tacoma Public Utilities: Tyler Patterson, Greg Volkhardt