How physical monitoring informs restoration progress on the Trinity River

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Past and present physical monitoring

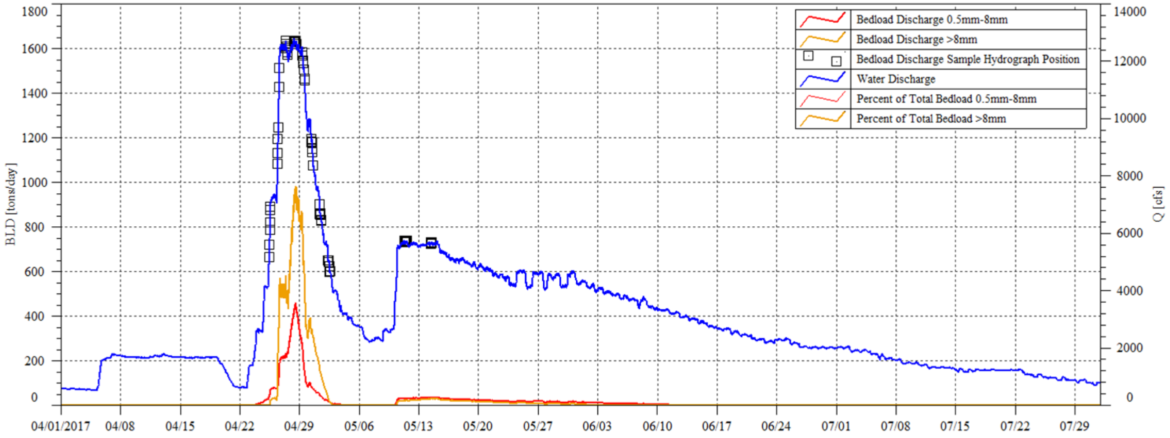
- Sediment transport monitoring (WYs 2004-2019) at TRAL, TRGV, TRLG, TRDC.
  - Bed load and suspended sediment transport sampling and turbidity measurements
  - Cross section surveys, Wolman (1954) samples, water surface slopes
- Bed material sampling at repeat stations (about every 5 years since WY 2000).
  - Bulk sampling surface and subsurface sediments

Surveys and remote sensing

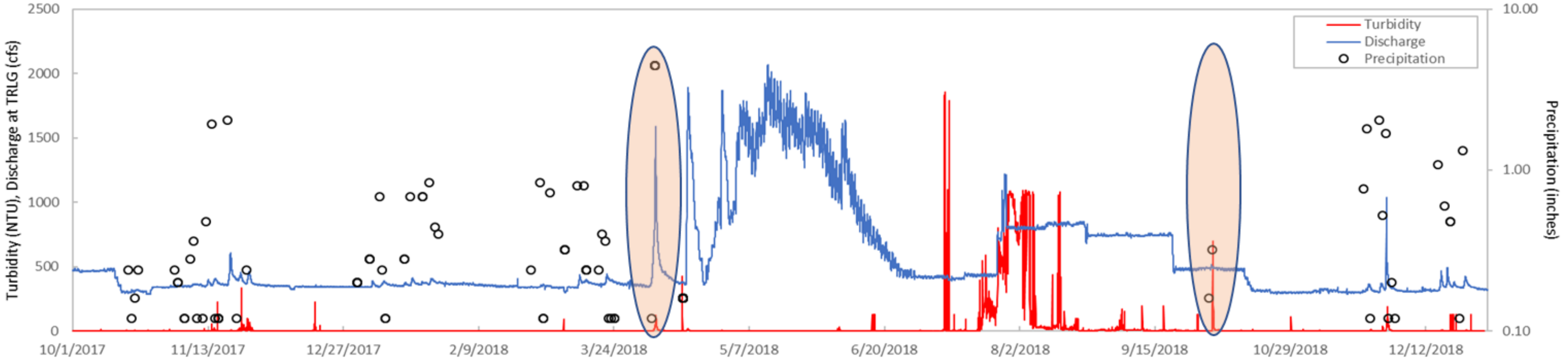
- Topographic surveys of river bed and floodplain (various periodicity for hydraulic modeling, gravel augmentation, delta sediments, and others).
- Aerial photography of restoration reach (annually in summer).

What are the physical measurements used for?

- Bed load and suspended sediment transport sampling
  - Used to derive transport relationships to discharge for computing annual total and fractional loads.
  - Total loads track bulk sediment and fractional loads indicate masses of different sized grains exchanged as bedload during spring flows between budget cells on the river.
  - Sediment budgeting informs flow scheduling, coarse sediment augmentations, tributary sediment management, and channel designs.



- Turbidity measurements
  - Turbidity correlates with measured suspended sediment concentrations and is an alternate to sedigraph method for computing suspended loads.
  - Provides early ID of watershed disturbance that can impact salmonids. The early detection results from small sediments having low transport thresholds and long travel distances once mobile.

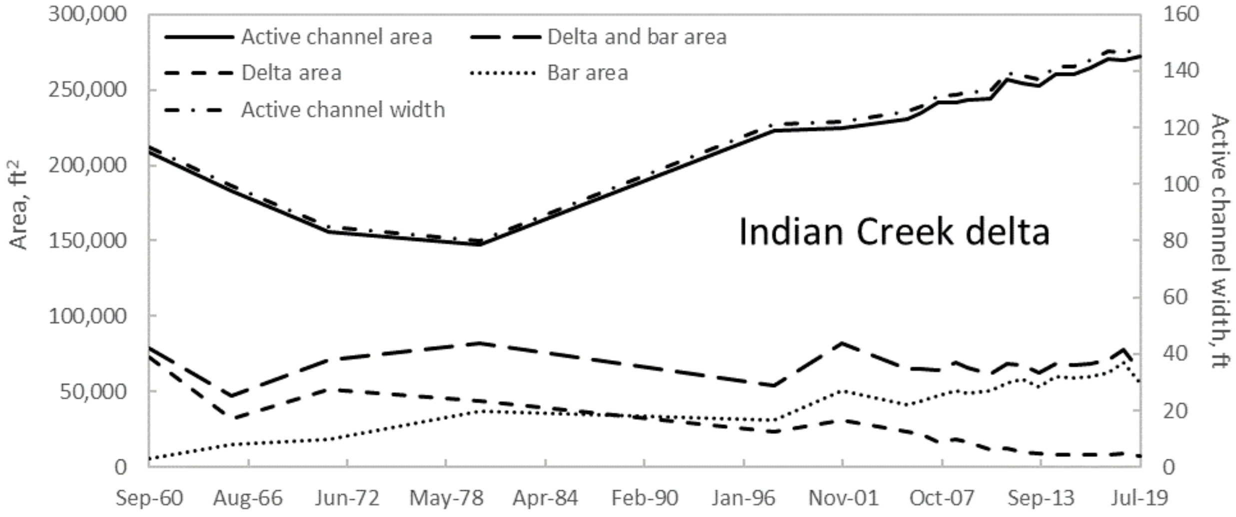


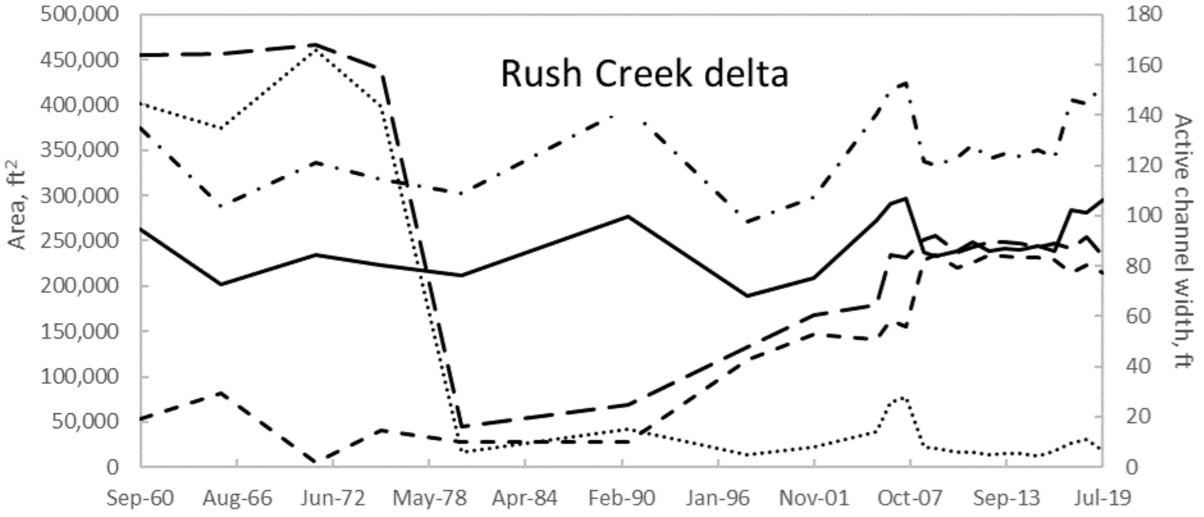
What are the physical measurements used for?

- Cross section surveys, Wolman (1954) samples, water surface slopes
  - Suite of measurements enables computation of thresholds of entrainment, relative mobility of particle sizes, and annual sediment loads.
- Bed material sampling at repeat stations
  - Bulk samples are used to monitor spawning gravel quality for estimating egg to fry survival, track percentages of fines in and on the river bed, and determine the relative availability of different sized grains for storage and transport.
- Topographic surveys of river bed and floodplain
  - The surveys enable hydraulic modeling the restoration reach (~every 5 years), gravel augmentation monitoring (annually), tributary delta tracking (up to twice annually), computation of Chinook production capacity and bed complexity (as needed), and other analyses.
    - Provides no information on bed conditions for physical and biological functioning, only morphology (shape) of features in river corridor.
- Aerial photography of restoration reach
  - Allows measurements of channel migration rates and exposed bar areas, visualization of study areas and before/after effects of restoration actions, et al.

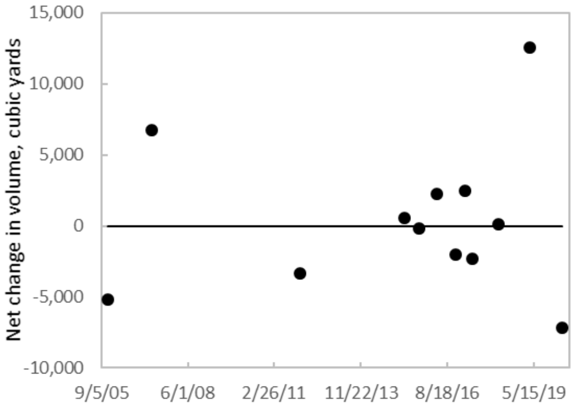
What are surveys and remote sensing telling us?

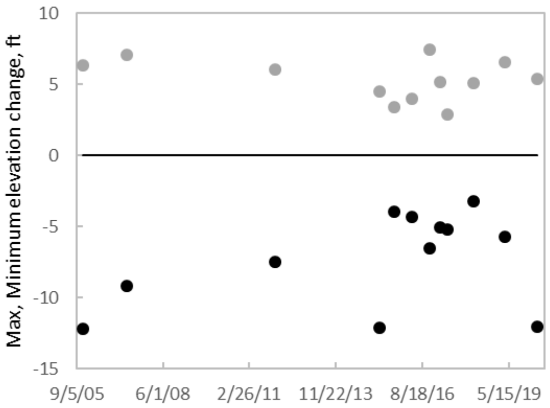
- Aerial photo analyses indicate Rush and Indian Creek deltas are progressively returning (or have returned) their dimensions to values present before dam closure.

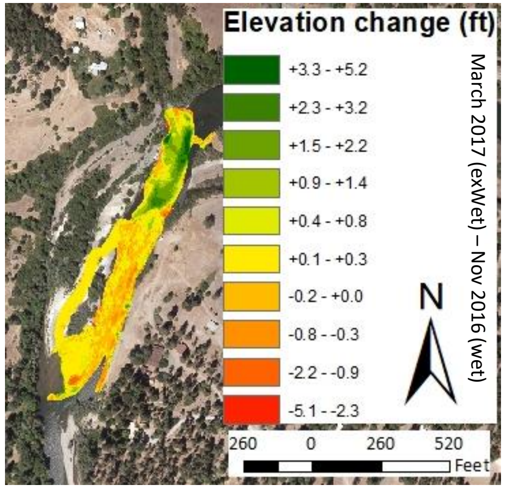




- Spring flow releases generally accomplish the goal of mobilizing deltas, which are large sediment sources/sinks that can be accounted for in sediment budgeting with biannual surveys of topography.

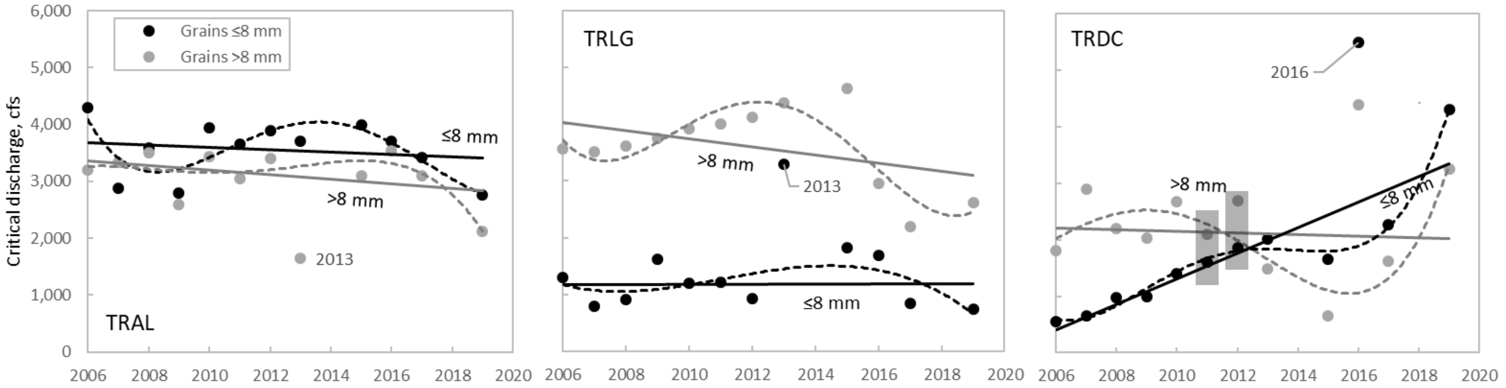






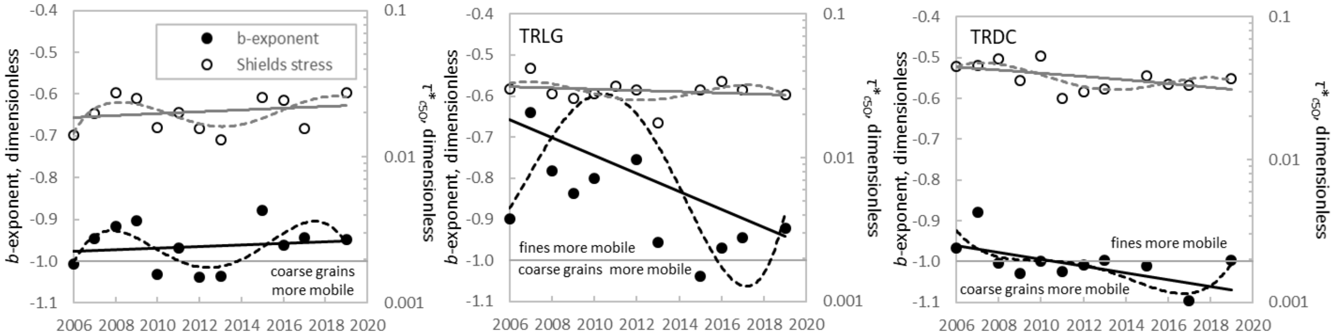
What are the physical measurements telling us?

- Discharges needed to entrain fine sediment are increasing at TRLG and TRDC and are slightly decreasing at TRAL; coarse sediments are becoming more easily mobilized at all stations.



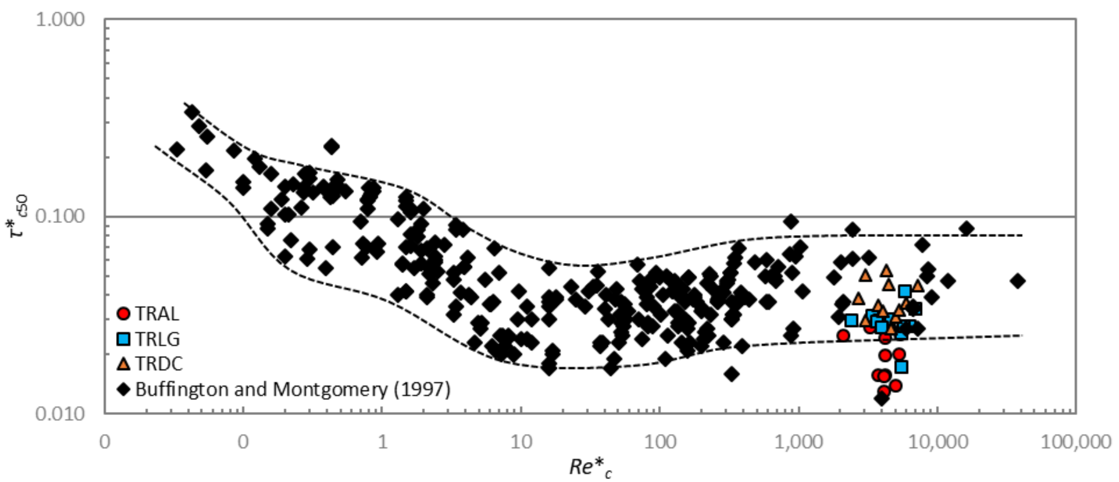
  - Informs flow scheduling objective to mobilize, transport sediment and flush the bed for egg incubation.

- Higher flows are often required to mobilize fine grains than large sediments at TRDC and the same dynamic is forming at TRLG. Coarse and fine grains at TRAL have remained approximately equally mobile through time.

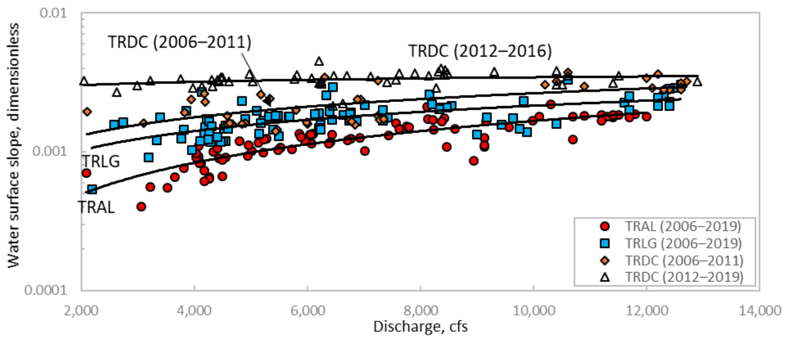


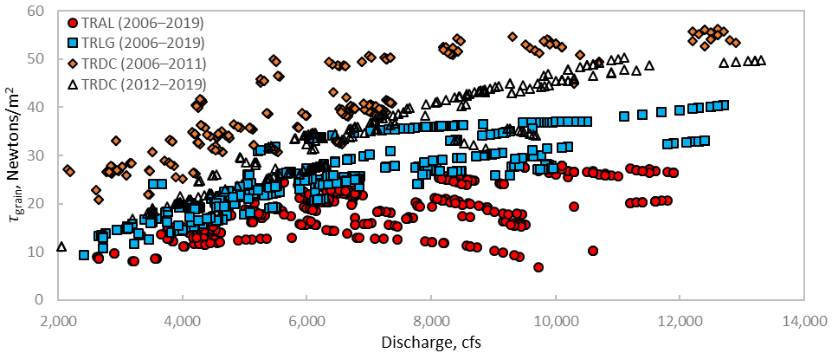
  - Indicates how flow management and the availability of different sized particles is influencing bed dynamics and sediment transport. Indicates a limitation of fine sediments is (or has) developing on the Trinity River.

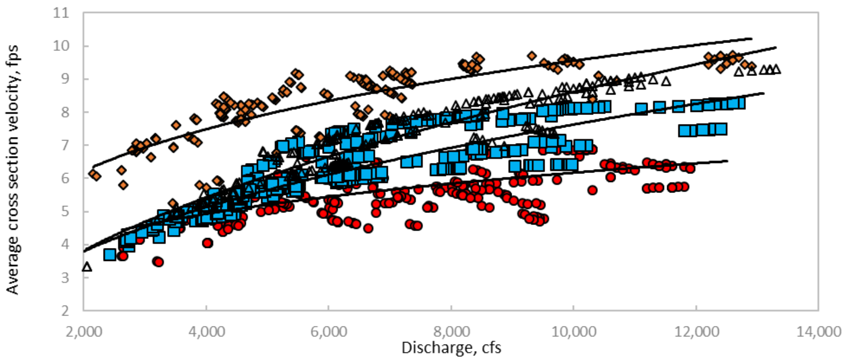
What are the physical measurements telling us?



- Shields stresses at a given particle Reynolds number are within expected ranges at TRLG and TRDC but often lower than normal at TRAL. This may seem to contradict that generally higher flows are required to mobilize sediment at this station, which occurs because energy (i.e., water surface) slopes are relatively low, so higher discharges are required to generate levels of shear stress or flow velocity that are required to mobilize the bed and transport sediment.
  - Guides hydrograph development, informs decisions made to disburse sediment additions downstream.

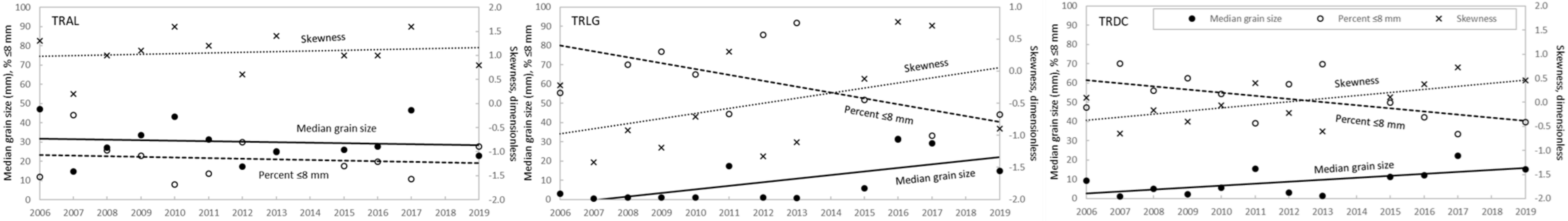




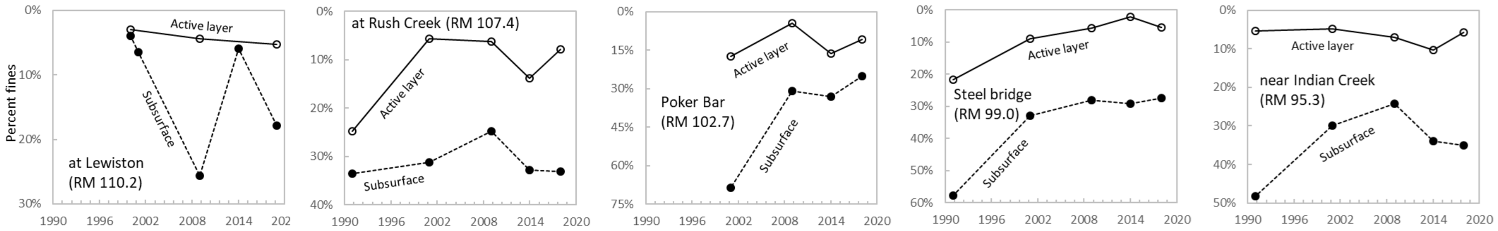


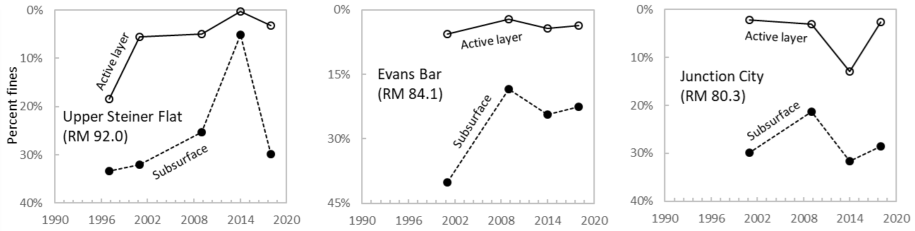
What are the physical measurements telling us?

- Median grain sizes, skewness, and percentages of fines in bedload indicate a largely static composition at TRAL and increasingly coarse bedload with fewer fines at TRLG and TRDC.



- Bed material sampling shows substantial decreases in fines have occurred at most stations on the Trinity River, notably accepting TRAL, which exhibits large variations due to availability of open pore spaces for storing and then evacuating fines delivered by channel reconstruction activities (2008) and wildfire (2018).

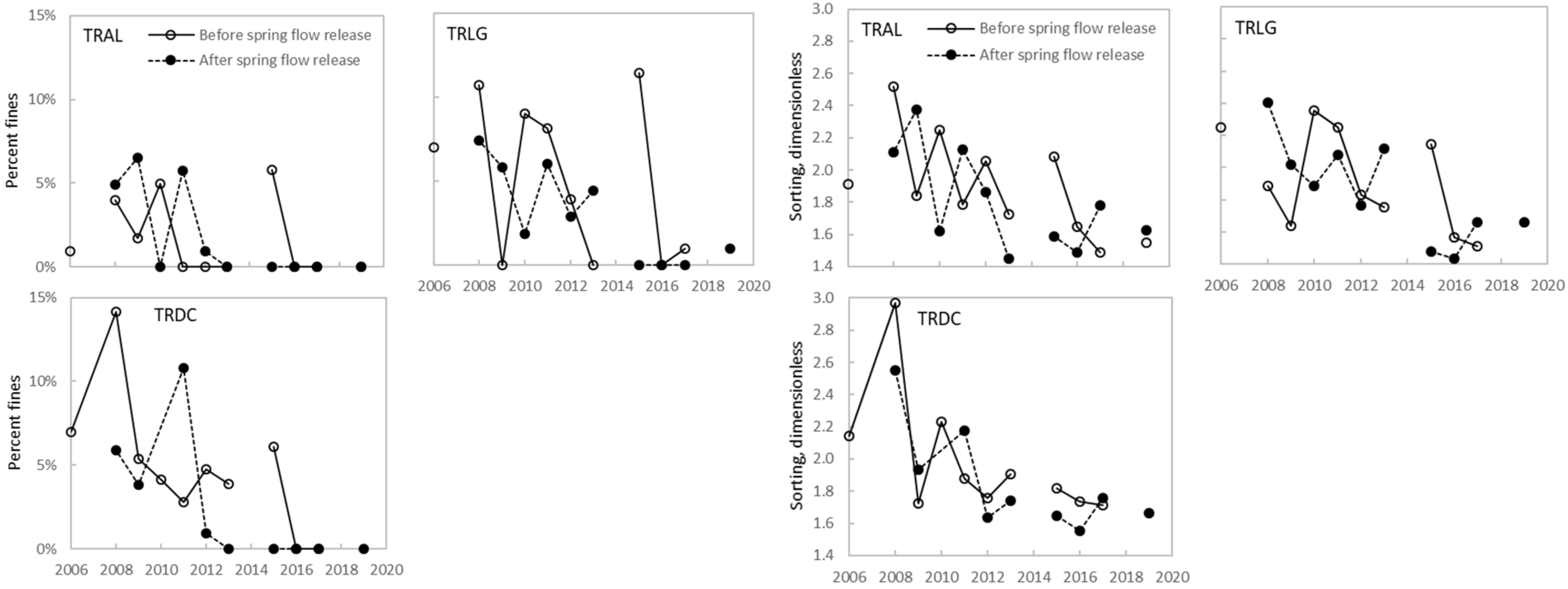




  - These data with load estimates guides sediment management (how much and what sizes of grains to augment where)

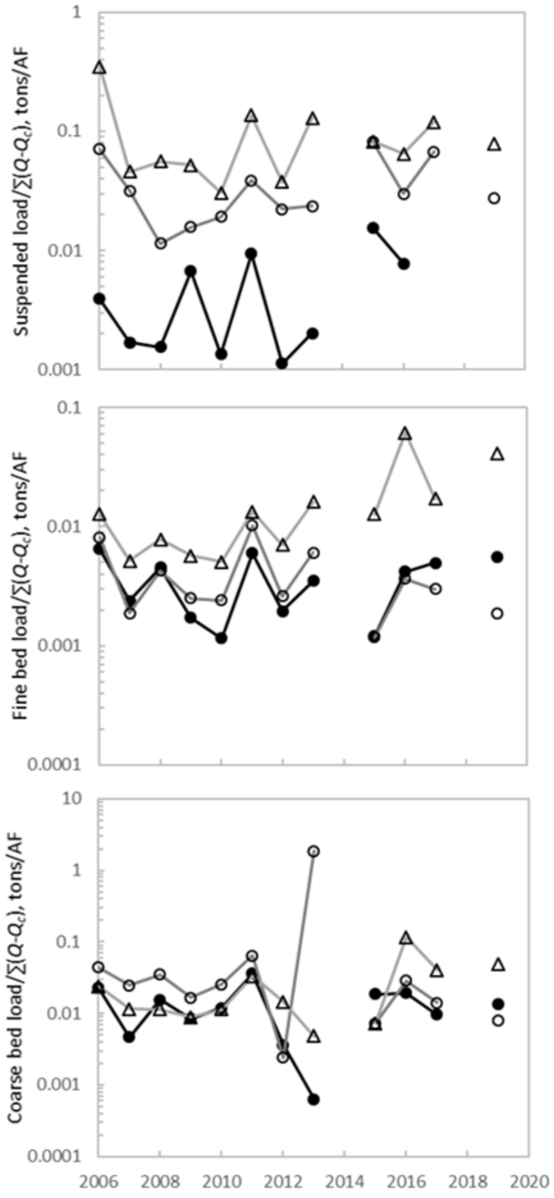
What are the physical measurements telling us?

- Spring flow releases annually deplete the river’s supply of fine sediment and the depletions are cumulative = progressively fewer fines through time.
  - Tributaries are contributing fewer fines than river flows are transporting from the restoration reach.



Focusing on the fine sediment component of the Trinity River ecosystem, why are fines important?

Indicator	Target
Spawning gravel quality and incubation success	Fines ≤2 mm <15% in subsurface bulk samples in spawning areas Chinook egg-to-fry survival ≥80% estimated with equation (1) $\sum Q_s / \sum Q$ ≤0.05 tons/cfs in the Chinook egg incubation period (October – March)
Juvenile rearing	Turbidity <30 NTU for >80% of the juvenile rearing period (January – July) z ≤5 for >80% of the rearing period (January – July)
Adult holding and spawning	V* for pools <0.10 z ≤5 for ≥80% of the spawning period (September – January)
Benthic macroinvertebrates	Fines ≤2 mm <30% in subsurface bulk samples on riffles, runs, and glides Embeddedness ≤33% outside of pools
Ammocoete rearing	Fines ≤2 mm >28% in composite bulk samples from slack water areas Presence of fine sediment deposits in lee areas of the winter baseflow channel
Nutrient storage	Presence of fines <0.5 mm in suspended sediment samples
Floodplains	Fines ≤2 mm >15% in Wolman (1954) samples Fines ≤2 mm 20% in subsurface bulk samples
Coarse sediment mobility	Fines ≤2 mm 5-12% on the bed in Wolman (1954) and bulk surface samples Fines ≤2 mm 16-24% in subsurface bulk samples
Channel meandering	Deposit fines ≤2 mm on the upper surface and in cut-off channels on bars at RM 73.1, 79.4, 82.0, 104.2, 106.1 to the depth of the local surface D_{84}



What are the physical measurements telling us?

Fine sediment targets for stream biology are being (sometimes overly) met in the Trinity River.

Water year	Station		
	TRAL	TRLG	TRDC
2006	0.003	0.089	0.078
2007	<0.001	0.018	0.016
2008	<0.001	0.007	0.080
2009	<0.001	0.006	0.021
2010	<0.001	0.006	0.037
2011	<0.001	0.014	0.056
2012	<0.001	0.011	0.006
2013	<0.001	0.007	0.037
2014	—	—	—
2015	<0.001	0.024	0.069
2016	<0.001	0.033	0.061
2017	<0.001	0.084	0.068
2018	—	—	—
2019	<0.001	0.007	0.029
Average	<0.001	0.025	0.046
High value	0.003	0.089	0.080

Suspended loads normalized by the sum of discharges (tons/cfs) during the egg incubation period (October-March) on the Trinity River. The target is ≤0.05 tons/cfs; shaded cells indicate years when the target was not met.

Percent of time in the juvenile rearing period (January–July) that turbidity was measured at stations on the Trinity River and percent of the available data that values were <30 NTU for >85% of the rearing period. The target was met in all cases except those indicated by shaded cells.

Water year	TRLG (GMA[4])		TRLG (USBR[3])		TRDC (GMA)		TRNF (USBR[4])	
	% time[1]	% data[2]	% time[1]	% data[2]	% time[1]	% data[2]	% time[1]	% data[2]
2001	—	—	61%	90%	—	—	—	—
2002	—	—	100%	83%	—	—	—	—
2003	—	—	95%	85%	—	—	—	—
2004	13%	100%	100%	98%	—	—	—	—
2005	8%	100%	99%	80%	—	—	—	—
2006	30%	100%	100%	77%	89%	94%	—	—
2007	43%	100%	100%	95%	43%	100%	—	—
2008	48%	100%	99%	91%	26%	100%	—	—
2009	57%	100%	99%	95%	20%	100%	—	—
2010	27%	100%	100%	98%	45%	100%	—	—
2011	45%	100%	100%	92%	44%	94%	64%	97%
2012	40%	100%	100%	94%	33%	100%	100%	98%
2013	48%	100%	100%	100%	25%	100%	100%	100%
2014	32%	100%	100%	98%	20%	100%	100%	98%
2015	31%	100%	100%	94%	15%	100%	100%	98%
2016	53%	100%	100%	96%	42%	100%	100%	96%
2017	52%	100%	100%	89%	56%	100%	100%	95%
2018	—	—	100%	92%	—	—	100%	100%
2019	53%	99%	84%	93%	22%	96%	100%	94%

What are the physical measurements telling us?

Percent egg-to-fry survival estimated for Chinook with equation (1) by Tappel and Bjornn (1983). The target is ≥80%; shaded cells indicate years when the target was not met.

Station	Water year								
	2001-2019 average	2019	2018	2014	2009	2001	2000	1997	1991
Lewiston (RM 111.5)	96%	100%	—	95%	92%	97%	94%	—	---
at Rush Creek (RM 107.4)	90%	—	84%	99%	90%	85%	—	—	76%
Poker Bar (RM 102.7)	64%	—	92%	75%	81%	7%	—	—	—
Steel Bridge (RM 99.0)	86%	—	89%	87%	88%	78%	—	—	0%
Indian Creek (RM 95.3)	83%	—	87%	75%	90%	80%	—	—	85%
Upper Steiner Flat (RM 92.0)	87%	—	89%	100%	84%	73%	—	90%	—
Evans Bar (RM 84.1)	84%	—	92%	90%	95%	59%	—	—	—
Junction City (RM 80.3)	85%	—	88%	78%	93%	82%	—	—	—

BUT fine sediment targets for physical processes are being missed by quite a long shot.

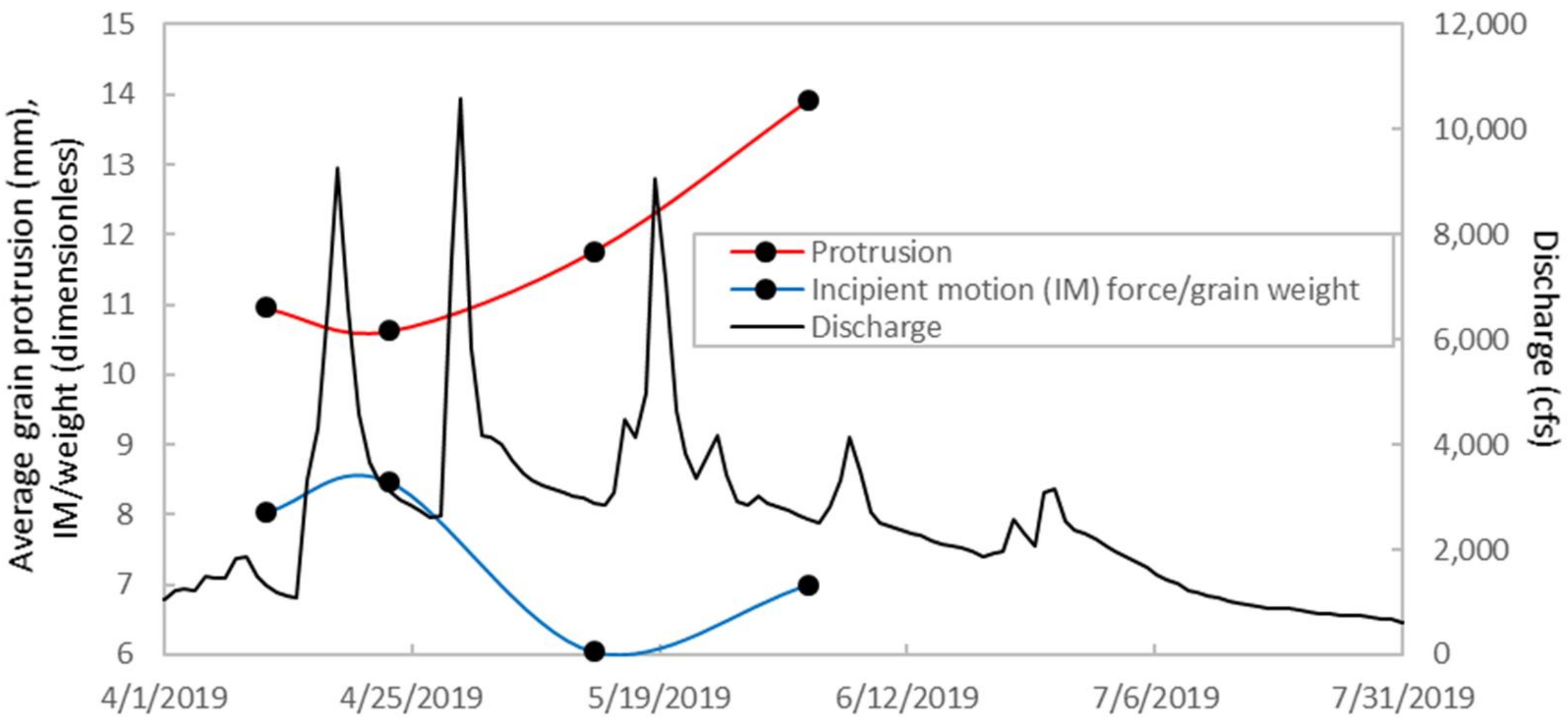
Station	Water year							
	2019	2018	2014	2009	2001	2000	1997	1991
Lewiston (RM 111.5)	**1.8%**	—	—	**1.0%**	—	**0.7%**	—	—
at Rush Creek (RM 107.4)	—	**1.7%**	**4.6%**	**2.0%**	**1.8%**	—	—	9.5%
Poker Bar (RM 102.7)	—	**4.1%**	7.5%	**1.9%**	6.9%	—	—	—
Steel Bridge (RM 99.0)	—	**1.5%**	**0.4%**	**1.6%**	**4.3%**	—	—	21.7%
Indian Creek (RM 95.3)	—	**2.3%**	**3.9%**	**3.6%**	**1.8%**	—	—	**1.8%**
Upper Steiner Flat (RM 92.0)	—	**1.9%**	**0.2%**	**2.0%**	**2.1%**	—	10.3%	—
Evans Bar (RM 84.1)	—	**1.6%**	**1.5%**	**0.8%**	**2.5%**	—	—	—
Junction City (RM 80.3)	—	**0.9%**	6.9%	**0.8%**	**1.0%**	—	—	—

Percentages of grains ≤2 mm in bulk surface samples at stations on the Trinity River. Bold values are below the target range and shaded cells indicate values that are above the target range (5-12%) for gravel mobility. Underlined values are within range.

Station	Water year							
	2019	2018	2014	2009	2001	2000	1997	1991
Lewiston (RM 111.5)	**15.5%**	—	**1.1%**	**6.6%**	**2.5%**	**0.4%**	—	—
at Rush Creek (RM 107.4)	—	**14.7%**	**14.9%**	**9.9%**	**13.1%**	—	—	16.0%
Poker Bar (RM 102.7)	—	**9.5%**	16.4%	**14.5%**	30.0%	—	—	—
Steel Bridge (RM 99.0)	—	**10.1%**	**10.1%**	**10.0%**	**15.7%**	—	—	45.8%
Indian Creek (RM 95.3)	—	19.1%	**15.8%**	**13.0%**	**14.7%**	—	—	23.1%
Upper Steiner Flat (RM 92.0)	—	**15.1%**	**2.5%**	**11.6%**	**15.7%**	—	**8.6%**	—
Evans Bar (RM 84.1)	—	**13.8%**	**8.3%**	**8.6%**	20.1%	—	—	—
Junction City (RM 80.3)	—	17.3%	16.0%	**8.8%**	16.6%	—	—	—

Percentages of grains ≤2 mm in bulk subsurface samples used to evaluate the target range for gravel mobility (16-24%).

What are the physical measurements telling us?



Buxton, T.H. and E.M. Yager (in prep) Selective mobility and hysteresis effects on bed arrangement and bar entrainment on a regulated river.

Recommendations in fine sediment synthesis report (draft) derived from physical measurements

Release flows for sediment routing and salmonid protection

- Replicate the natural timing of flows during sediment transport events in tributaries to avoid smothering salmon eggs in bed

Add fine sediment to the channel between Lewiston Dam and Rush Creek

- Restore the fine sediment component of the river ecosystem in this river reach

Undertake analyses to remove Trinity River listing as sediment impaired

- Eliminate turbidity restrictions on channel construction and sediment augmentation to help restore the fine sediment component of the river

Cease dredging Hamilton Ponds

- To restore and maintain fine sediment dynamics in the Trinity River below Grass Valley Creek

Monitor sediment transport and storage in the Trinity River

- To monitor effects of these changes in sediment management and continue to adapt the physical habitat restoration approach to conditions in the river corridor.

Consequences of not having a physical sampling program on the Trinity River

Contemporary information would not be available to design and adapt sediment augmentations to changing conditions in the channel, and sediment budgets would be based on old data and assumptions.

- Potential implications: no impact; loss of habitat from channel degradation resulting from too little sediment being added; increased flood risk and damage to infrastructure from too much sediment being added.

Lack of information for adjusting flow releases to exceed current mobility thresholds.

- Likely to cause “wasted flow” – water released for a purpose that is inefficiently met by releasing more water than is required.

Data to assess the effectiveness of flow releases meeting geomorphic objectives will not be available (excepting those topographically based).

- Trajectory of channel and floodplain evolution will be unclear, potentially resulting in unwanted outcomes imperiling restoration progress.

River ecosystem components that enable salmon production and FY 2021 allocation of science budget

Flow/water temperature
FY21 budgeted: $262,100

Physical processes/channel morphology
FY21 budgeted: $0

Riparian plants/substrate/floodplain structure
FY21 budgeted: $0

Primary production (benthic plants and invertebrates)
FY21 budgeted: $0

Outmigrant monitoring/adult salmon returns and catch
FY21 budgeted: $2,403,752

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Science Plan drafting committee (refinements)

Elizabeth Hadley or Paul Zedonis, Bureau of Reclamation (flow, temperature)
Seth Naman, National Marine Fisheries Service (fisheries)
Nick Som, U.S. Fish and Wildlife Service (fisheries)
George Kautsky, Hoopa Valley Tribe (fisheries)
Kyle DeJuilio, Yurok Tribe (fisheries)
Ken Lindke, California Department of Fish and Wildlife (fisheries)
James Lee, Science Coordinator (riparian)