# History of fine sediment and its impacts on physical processes and biologic populations in the Trinity River

Todd H. Buxton

Buxton, T. H. 2021. History of fine sediment and its impacts on physical processes and biological populations in the restoration reach of the Trinity River, CA. Report TRRP-2021-1 for the Trinity River Restoration Program (TRRP). Trinity River Restoration Program, Weaverville, California.
Available: https://www.trrp.net/library/document?id=2483.

# Fine sediment to streams is like porridge to goldilocks

Detrimental conditions when fines are in deficit (cold porridge)

- Over-coarsened bed difficult to mobilize
- Shortage of fine sediment deposits that are habitat for lamprey rearing
- Salmon egg damage from large void spaces between coarse grains enabling egg jiggling and abrasion
- River meandering inhibited from lack of fine sediment deposition, riparian generation on inside of bends
- Decreased water storage and riparian germination from high hydraulic conductivity of substrate on floodplains

Benefits when fines are not overly abundant or in deficit (just right)

- Promotes bed surface mobility
- Can benefit salmon egg incubation by formation of sand seals and prevent egg mortality from jiggling
- Supports nutrient cycling, biofilm, and macroinvertebrates (food base)
- Aids juvenile rearing by providing cover (turbidity) from predators
- Supports riparian germination and water retention in floodplains

Damaging effects when fines are overly abundant (hot porridge)

- Overly mobile bed more likely to scour salmon redds and expose eggs to predation and mechanical crushing
- Suffocation of salmon eggs in redds and pool filling decreasing rearing habitat
- Excessive turbidity suppressing prey food base and juvenile fish growth
- Accelerated meandering affecting maturation of riparian plants and input of large wood to the channel

# Historic impacts to the Trinity River

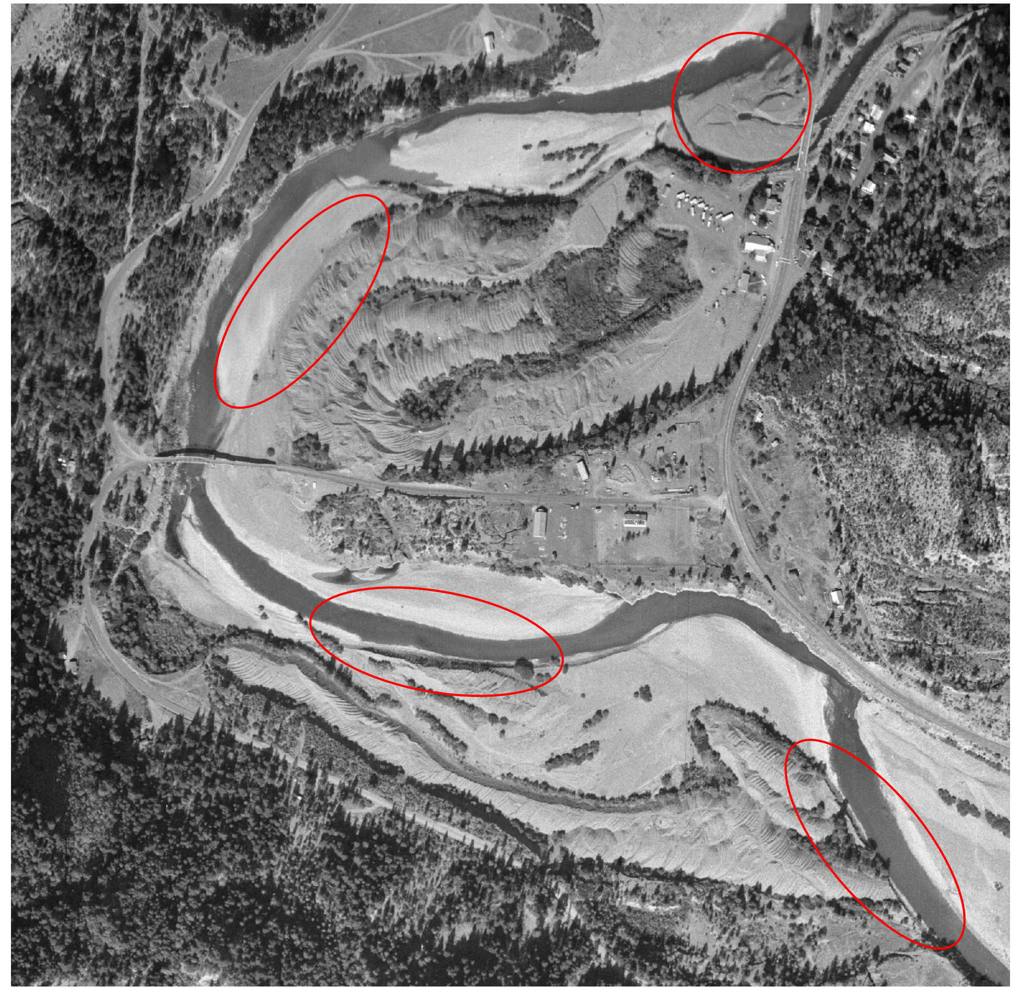

Dredger Mining


Hydraulic Mining

Logging and roads

# Restoration by full natural flows

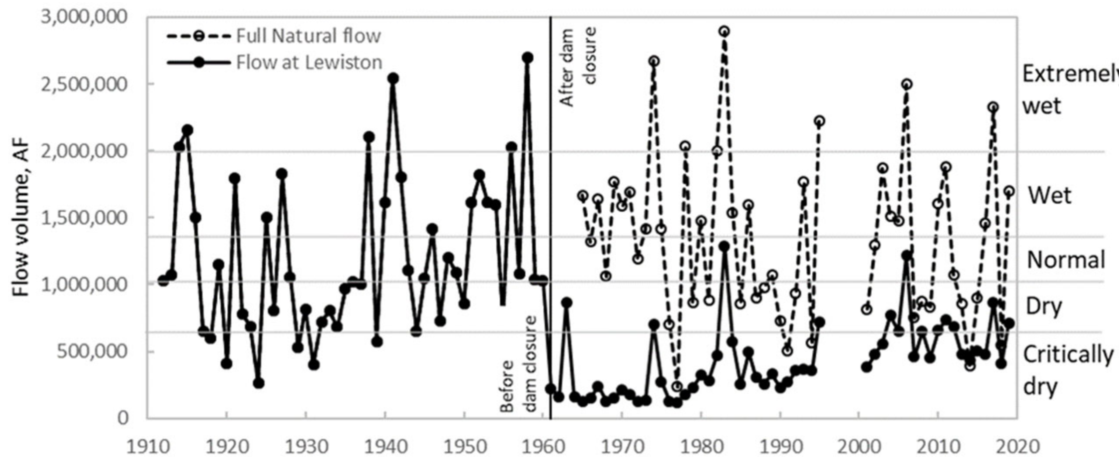
Trinity River at Junction City (1944)



Trinity River at Junction City (1960)

# Trinity and Lewiston dams

Trinity Dam closure November 1960

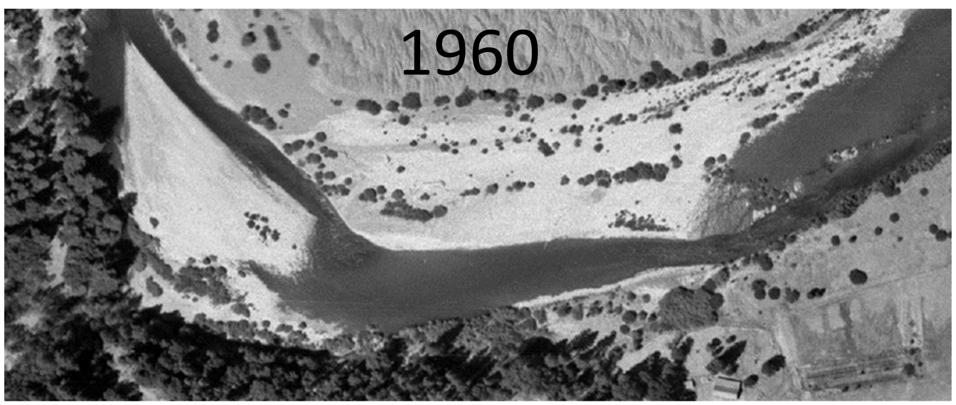



Lewiston Dam closure and flow diversions began April 1963

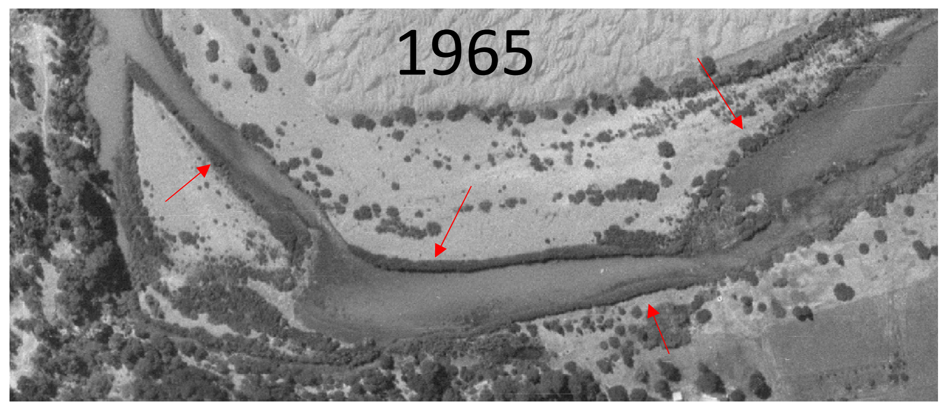
# Impacts to the Trinity River

Transformed gravel bed to a sand-bed river near Lewiston

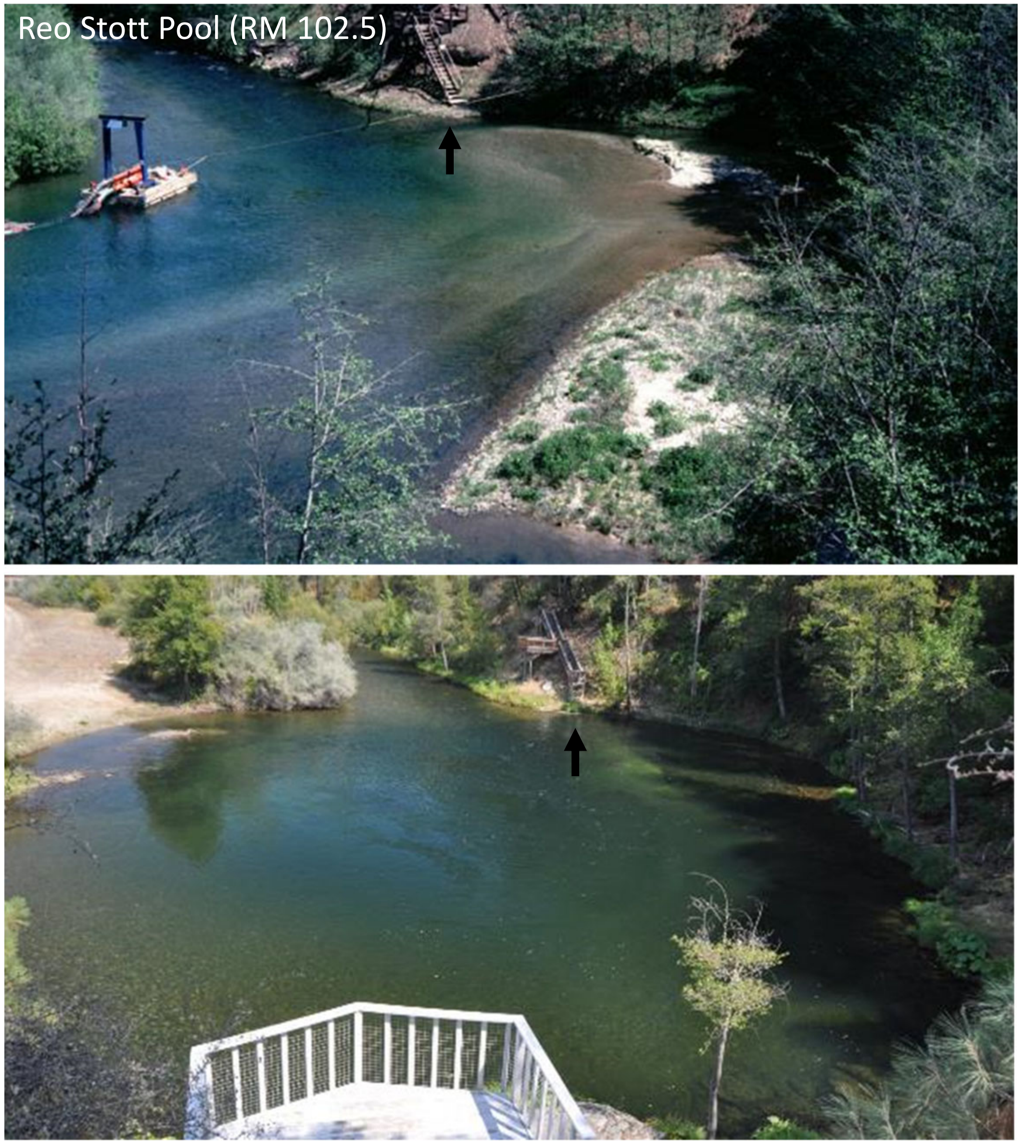
Pools filled with fine sediment




Dark Gulch near Rush Creek



# Reversing fine sedimentation of the river…some approaches were effective, some not so much.





Visual results of restoration actions

# Fine sediment targets on the Trinity River

| Indicator | Target |
| --- | --- |
| Spawning gravel quality and incubation success | Fines ≤2 mm <15% in subsurface bulk samples in spawning areas<br>Chinook egg-to-fry survival ≥80% from equation by Tappel and Bjornn (1983)<br>$\sum Q_s / \sum Q$ ≤0.05 tons/cfs in the Chinook egg incubation period (Meyer et al., 2005) |
| Juvenile rearing | Turbidity <30 NTU for >80% of the juvenile rearing period (January – July)<br>$z$ ≤5 for >80% of the rearing period (Newcombe and Jensen, 1996) |
| Adult holding and spawning | $V^*$ for pools <0.10<br>$z$ ≤5 for ≥80% of the spawning period (Newcombe and Jensen, 1996) |
| Benthic macroinvertebrates | Fines ≤2 mm <30% in subsurface bulk samples on riffles, runs, and glides<br>Embeddedness ≤33% outside of pools |
| Ammocoete rearing | Fines ≤2 mm >28% in composite bulk samples from slack water areas<br>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<br>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<br>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 $D_{84}$ |

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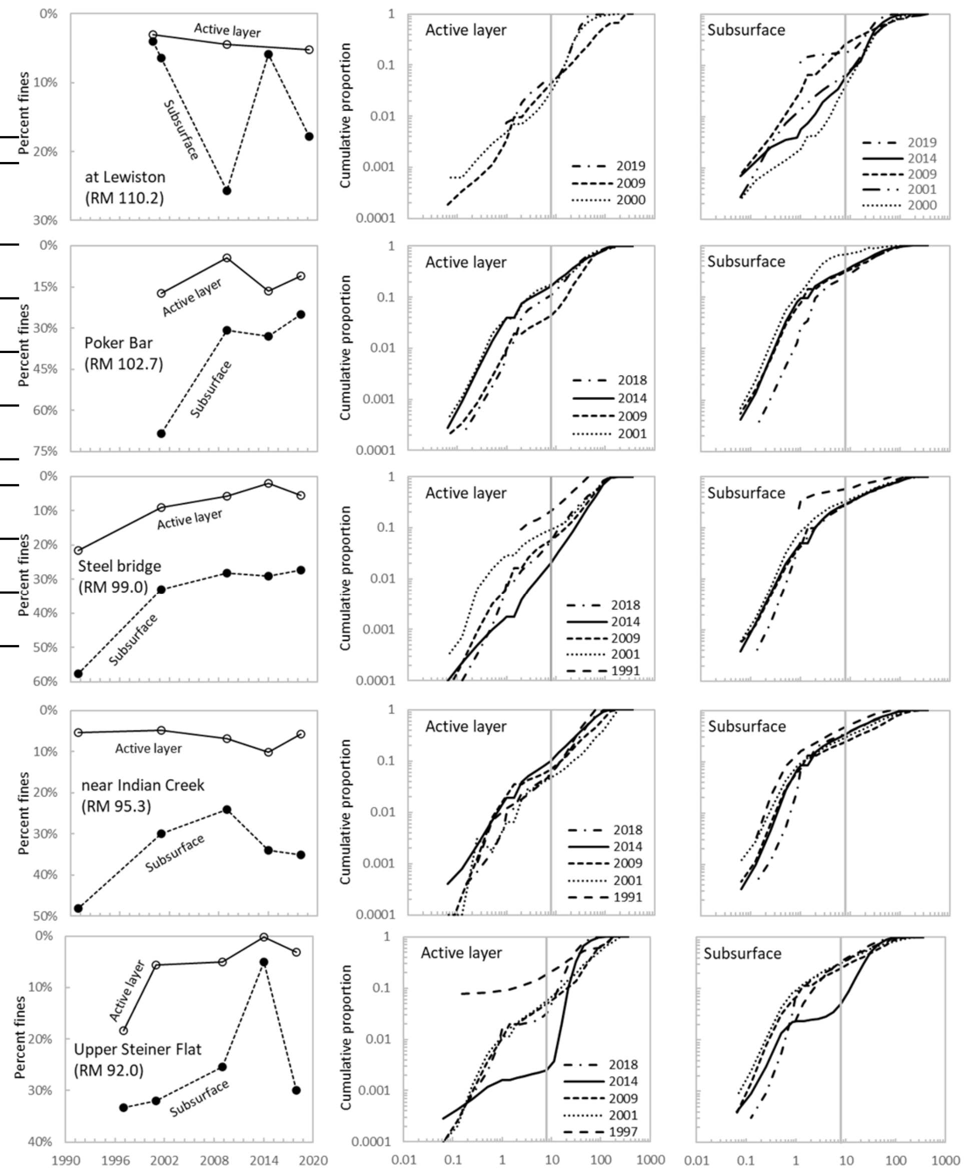
| KEY | Missed target for substrate quality for spawning and macroinvertebrates | Missed target for macroinvertebrates only |
|---|---|---|

| 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% | — | — | — |



# Fine sediment targets

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|---|---|
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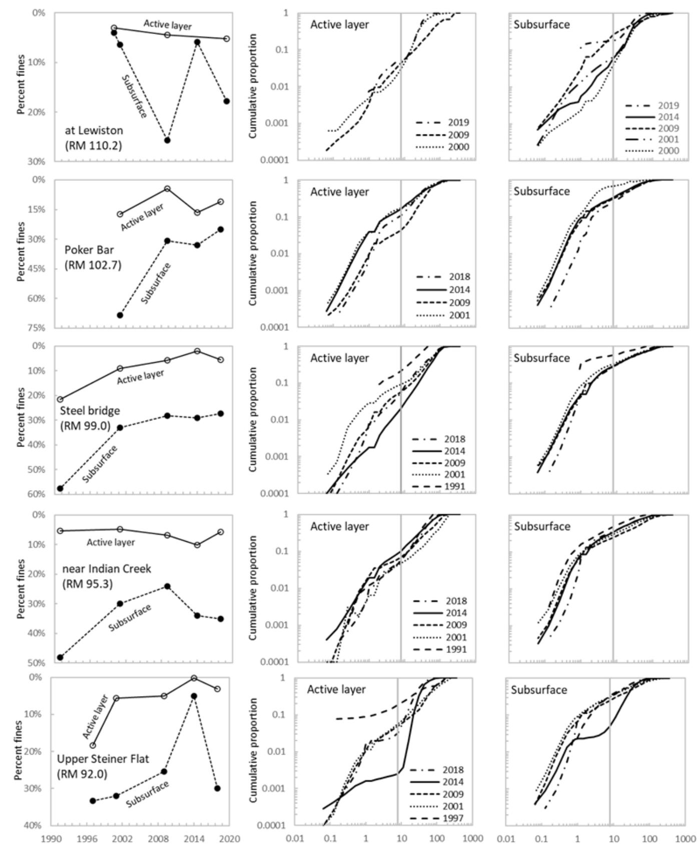
KEY

Missed target

| 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% | — | — | — |




Tappel and Bjornn (1983)

$$S = 93.4 - 0.171 s_{9.5} s_{0.85} + 3.87 s_{0.85}$$

where S is the percent survival of Chinook embryos and $s_{9.5}$ and $s_{0.85}$ are percentages of subsurface bulk samples that are respectively smaller than 9.5 mm and 0.85 mm.

# Fine sediment targets

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|---|---|
| Spawning gravel quality and incubation success | Fines ≤2 mm <15% in subsurface bulk samples in spawning areas<br>Chinook egg-to-fry survival ≥80% from equation by Tappel and Bjornn (1983)<br>$\sum Q_s/\sum Q \leq 0.05$ tons/cfs in the Chinook egg incubation period (Meyer et al., 2005) |
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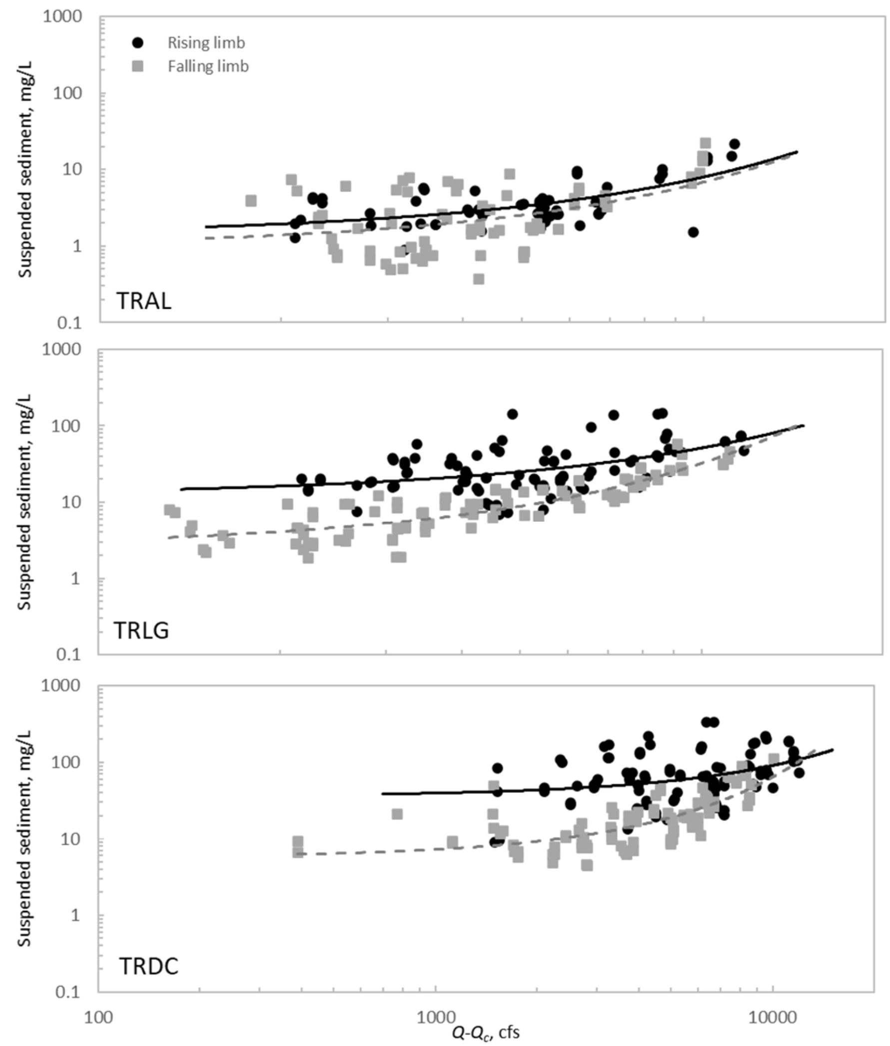
| KEY |
|---|
| Missed target |

| 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 |

*$\sum Q_s/\sum Q$ = sum mass of suspended sediment/sum discharge →*



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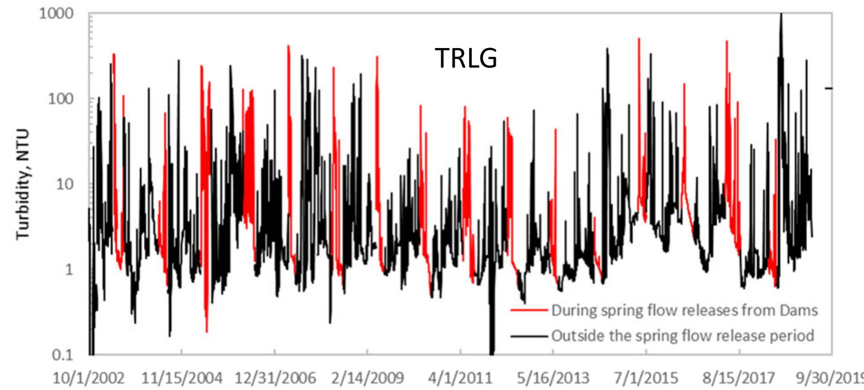
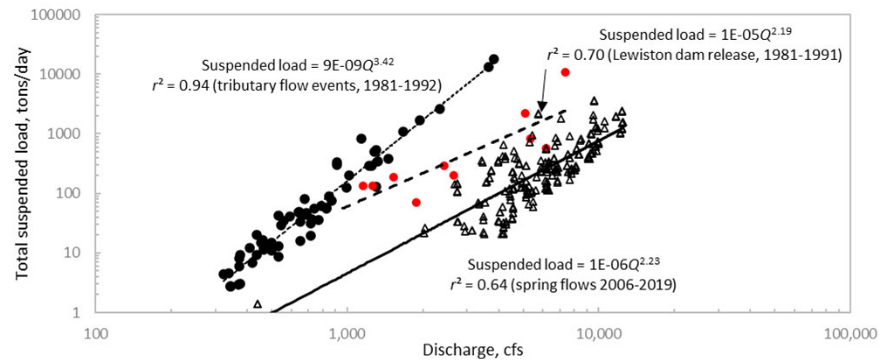
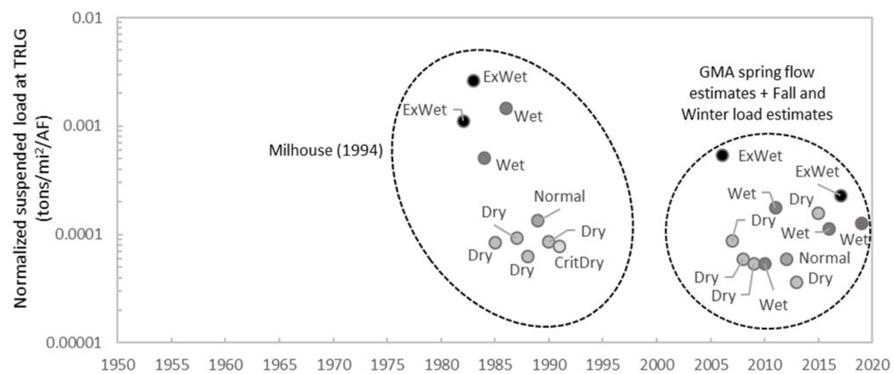
KEY

Missed target

| Water year | TRLG (GMA[3]) | | TRLG (USBR[4]) | | TRDC (GMA[3]) | | TRNF (USBR[5]) | |
|---|---|---|---|---|---|---|---|---|
| | % 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% |



# Fine sediment targets

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KEY

Missed target

| Water year | Juvenile Chinook (January – July) | | | Adult Chinook (September – January) | | |
|---|---|---|---|---|---|---|
| | TRAL | TRLG | TRDC | TRAL | TRLG | TRDC |
| 2006 | 100% | 81% | 58% | 100% | 89% | 78% |
| 2007 | 100% | 92% | 92% | 100% | 94% | 97% |
| 2008 | 100% | 93% | 83% | 100% | 99% | 90% |
| 2009 | 100% | 96% | 91% | 100% | 100% | 100% |
| 2010 | 100% | 97% | 85% | 100% | 99% | 94% |
| 2011 | 100% | 91% | 85% | 100% | 99% | 94% |
| 2012 | 100% | 95% | 96% | 100% | 98% | 100% |
| 2013 | 100% | 97% | 90% | 100% | 99% | 91% |
| 2014 | — | — | — | — | — | — |
| 2015 | 100% | 92% | 93% | 100% | 93% | 95% |
| 2016 | 100% | 86% | 82% | 100% | 99% | 95% |
| 2017 | — | 81% | 71% | — | 93% | 93% |
| 2018 | — | — | — | — | — | — |
| 2019 | — | 91% | 90% | — | 100% | 100% |
| Average | 100% | 91% | 85% | 100% | 97% | 94% |
| High value | 100% | 97% | 96% | 100% | 100% | 100% |
| Low value | 100% | 81% | 58% | 100% | 89% | 78% |

Newcombe and Jenson (1996)

$$z = 1.0642 + 0.6068\log_e x + 0.7384\log_e y$$

where $x$ is the duration of exposure (hrs) and $y$ is the concentration of suspended sediment ≤0.25 mm in mg/L.

| $z$ value | Description of effects | Class of effects |
|---|---|---|
| 0 | No behavior effects | Nil effect |
| 1 | Alarm reaction | Behavioral effects |
| 2 | Abandonment of cover | |
| 3 | Avoidance response | |
| 4 | Short term reduction in feeding success | Sub-lethal effects |
| 5 | Minor physiological stress and increased rates of coughing and respiration | |
| 6 | Moderate physiological stress | |
| 7 | Moderate habitat degradation and impaired homing | |
| 8 | Indications of major physiological stress and reductions in feeding rate and success | |

# Fine sediment targets

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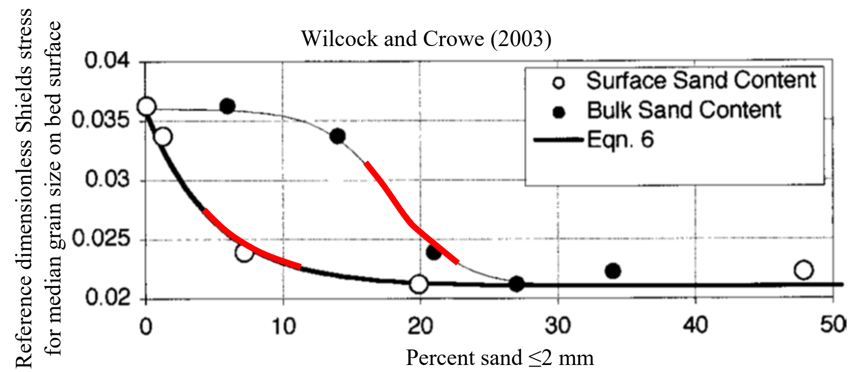


KEY

Met target

Missed target

Fines ≤2 mm 5-12% on the bed in Wolman (1954) taken before/after spring flow releases

| Water year | TRAL | TRLG | TRDC |
|---|---|---|---|
| 2006 | —/0% | —/0% | —/4% |
| 2007 | — | — | — |
| 2008 | 1%/1% | 2%/4% | 8%/4% |
| 2009 | 0%/0% | 0%/0% | 1%/0% |
| 2010 | 0%/0% | 1%/2% | 0%/— |
| 2011 | 0%/1% | 1%/4% | 2%/0% |
| 2012 | 0%/1% | 3%/3% | 2%/1% |
| 2013 | 0%/0% | 0%/0% | 4%/0% |
| 2014 | — | — | — |
| 2015 | 0%/0% | 0%/0% | 0%/0% |
| 2016 | 0%/0% | 0%/0% | 0%/0% |
| 2017 | 0%/0% | 0%/0% | 0%/0% |
| 2018 | — | — | — |
| 2019 | 0%/0% | 0%/0% | 0%/0% |

| | Station | Water year | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2019 | 2018 | 2014 | 2009 | 2001 | 2000 | 1997 | 1991 |
| Fines ≤2 mm 5-12% in bulk surface samples | 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% | — | — | — |
| Fines ≤2 mm 16-24% in subsurface bulk samples | 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% | — | — | — |

# Fine sediment to streams is like porridge to goldilocks

Detrimental conditions when fines are in deficit (cold porridge) - Lewiston Dam to Rush Creek (at least).

- Over-coarsened bed difficult to mobilize
- Shortage of fine sediment deposits that are habitat for lamprey rearing
- Salmon egg damage from large void spaces between coarse grains enabling egg jiggling and abrasion
- River meandering inhibited from lack of fine sediment deposition, riparian generation on inside of bends
- Decreased water storage and riparian germination from high hydraulic conductivity of substrate on floodplains

Benefits when fines are not overly abundant or in deficit (just right) - Limekiln Reach, below Douglas City.

- Promotes coarse sediment transport
- Can benefits salmon egg incubation by formation of sand seals and prevents egg mortality by jiggling
- Supports nutrient cycling, biofilm, and macroinvertebrates (food base)
- Aids juvenile rearing by providing cover (turbidity) from predators
- Supports riparian germination and water retention in floodplains

Damaging effects when fines are overly abundant (hot porridge) – nowhere in the Trinity River restoration reach?

- Overly mobile bed more likely to scour salmon redds and expose eggs to predation and mechanical crushing
- Suffocation of salmon eggs in redds and pool filling decreasing rearing habitat
- Excessive turbidity suppressing prey food base and juvenile fish growth
- Accelerated meandering affecting maturation of riparian plants and input of large wood to the channel

# Major findings

- The abundant fine sediments in the restoration reach of the Trinity River after dam closure has been reversed principally by watershed restoration/stabilization/road work in major tributaries, sediment capture in Grass Valley Creek, and spring flow releases.
- A strong deficit in fine sediment now exists between Lewiston Dam and Rush Creek and may extend downstream to Douglas City, excepting Limekiln area and perhaps other areas where data is unavailable.
- Fine sediment targets for biological populations are now overwhelmingly met where data are available but targets for coarse sediment transport have rarely been met since around the start of ROD flow releases.
- Funding is needed for physical monitoring to adaptively implement sediment additions to the river.
- There exists a disjunction in size-specific transport and storage of sediment in the restoration reach of the Trinity River. Short, moderate spring flow peaks that are mistimed with creek flows for routing and sorting tributary sediments may be one cause for this.



# Recommendations

- Release flows in winter for sediment routing and salmonid protection
  - Route tributary delta sediments, improve fish access into creeks, and help prevent siltation of redds.
- Add fine sediment to the channel between Lewiston Dam and Rush Creek
  - Restore the beneficial effects of fines missing from this reach and in downstream areas.
- Refine Trinity River TMDL to allow addition of fines and higher turbidity
  - Would simplify sediment augmentations and channel reconstruction by relaxing turbidity constraints and save funds by not having to screen fines from gravel augmentation.
- Monitor sediment transport and storage in the Trinity River
  - A monitoring schedule should be funded to enable adaptive management of coarse and fine sediment additions to the river.
- Cease dredging Hamilton Ponds
  - Allow Grass Valley Creek to contribute sediment to the river. A plan for restoration of lower Grass Valley Creek is needed (upper Hamilton Pond and downstream).
- Reevaluate the need for Buckhorn Dam
  - Sediment capture by the dam in the 31 years since its construction appears low, even after 78% of its drainage area was burned in the Carr Fire in 2018.