Modeling Chinook Salmon Spawning Habitat Decay

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Spawning Habitat in the DSM

- Females create redds in available spawning habitat
- DSM accounts for redd capacity
  - If exceeded, late arriving females destroy earlier redds
- Juvenile production is a function of:
  - Number of intact redds
  - Female fecundity
  - Egg-to-fry Survival

Previous Approach to Spawning Habitat Decay

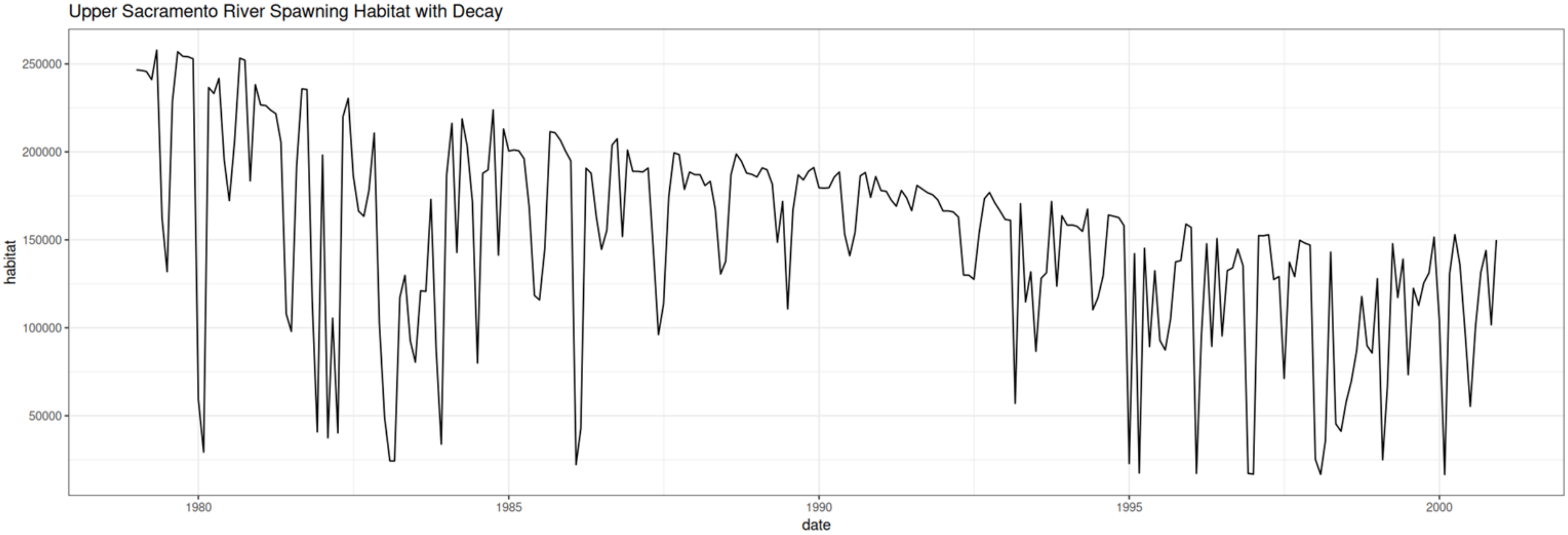
- Probabilistic model
  - Random decay rate between 0-5% annually
- Disconnected from hydrology and sediment transport
- Applied uniformly across all areas

Spawning Decay Rates	
watershed	decay rate
Upper Sacramento River	0.9472944
Antelope Creek	0.9898985
Battle Creek	0.9898985
Bear Creek	0.9898985
Big Chico Creek	0.9898985
Butte Creek	0.9898985
Clear Creek	0.9472944
... and 26 more rows	

Previous Approach to Spawning Habitat Decay

```
spawn_decay_amount <- t(sapply(1:31, function(index) {
  if (stochastic) {
    runif(spawn_years, min = spawn_decay_rate[index], max = 1)
  } else {
    rep(mean(c(spawn_decay_rate[index], 1)), spawn_years)
  }
}))
```

Previous Approach to Spawning Habitat Decay



Limitations

- Did not accurately represent real-world dynamics
- Failed to show large losses of spawning habitat during high flow years
- Lacked link to sediment transport processes
- Did not account for watershed-specific characteristics
- Unable to reflect the impact of extreme hydrological events

Need for a New Approach

A new approach should:

- Be Linked to hydrology
- Be Linked to sediment transport
- Better represent unique characteristics at watershed level
- Be easily updated when new data becomes available

Methods Overview

Sacramento River Model Augmentation Study

- Based on Sacramento River Gravel Augmentation Study (2020)
- Worked with CDFW and Reclamation experts
- Used general sediment transport rates for Sacramento River
  - Reclamation's Sacramento River Bedload Analysis of NODOS Alternatives (2011)
  - Empirical spawning habitat data and observations
- Overall approach is to take a raw transport curve and perform a series reductions based on observed events and watershed characteristics

Sediment Transport Capacity

- Data source: Reclamation's Sacramento River Gravel Augmentation Study
    - (2020)Used SRH-2D hydraulic and sediment transport model
- Created generalized transport capacity rating curves:
    - Based on four different models (Parker, Wilcock, Gaeuman)
- Selected minimum transport capacity curve for further analysis after discussions with Reclamation and CDFW experts

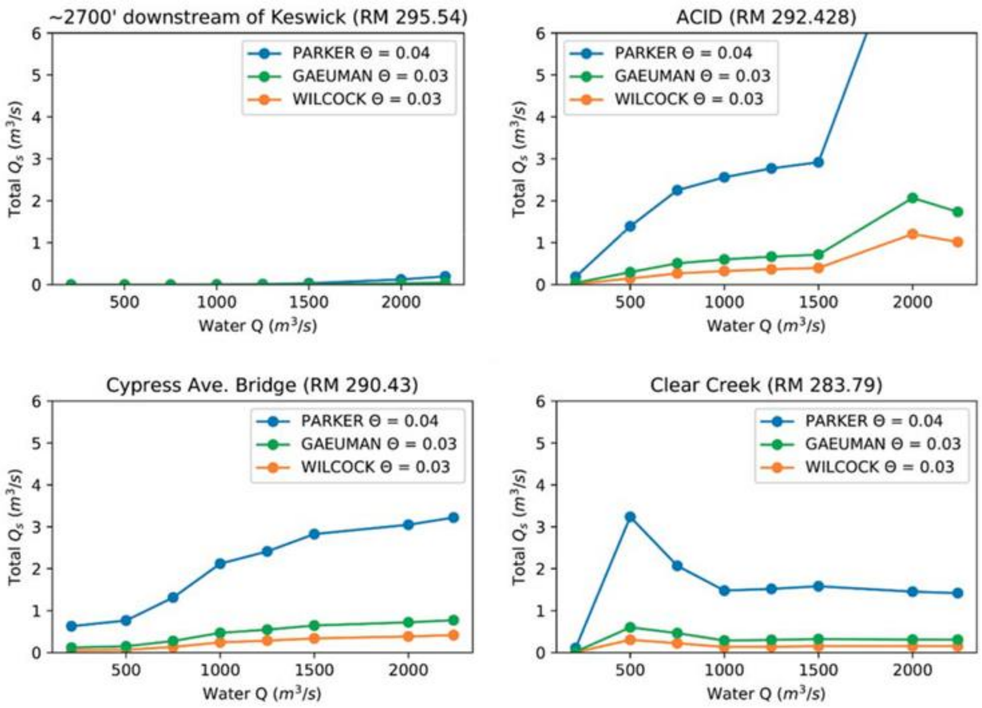
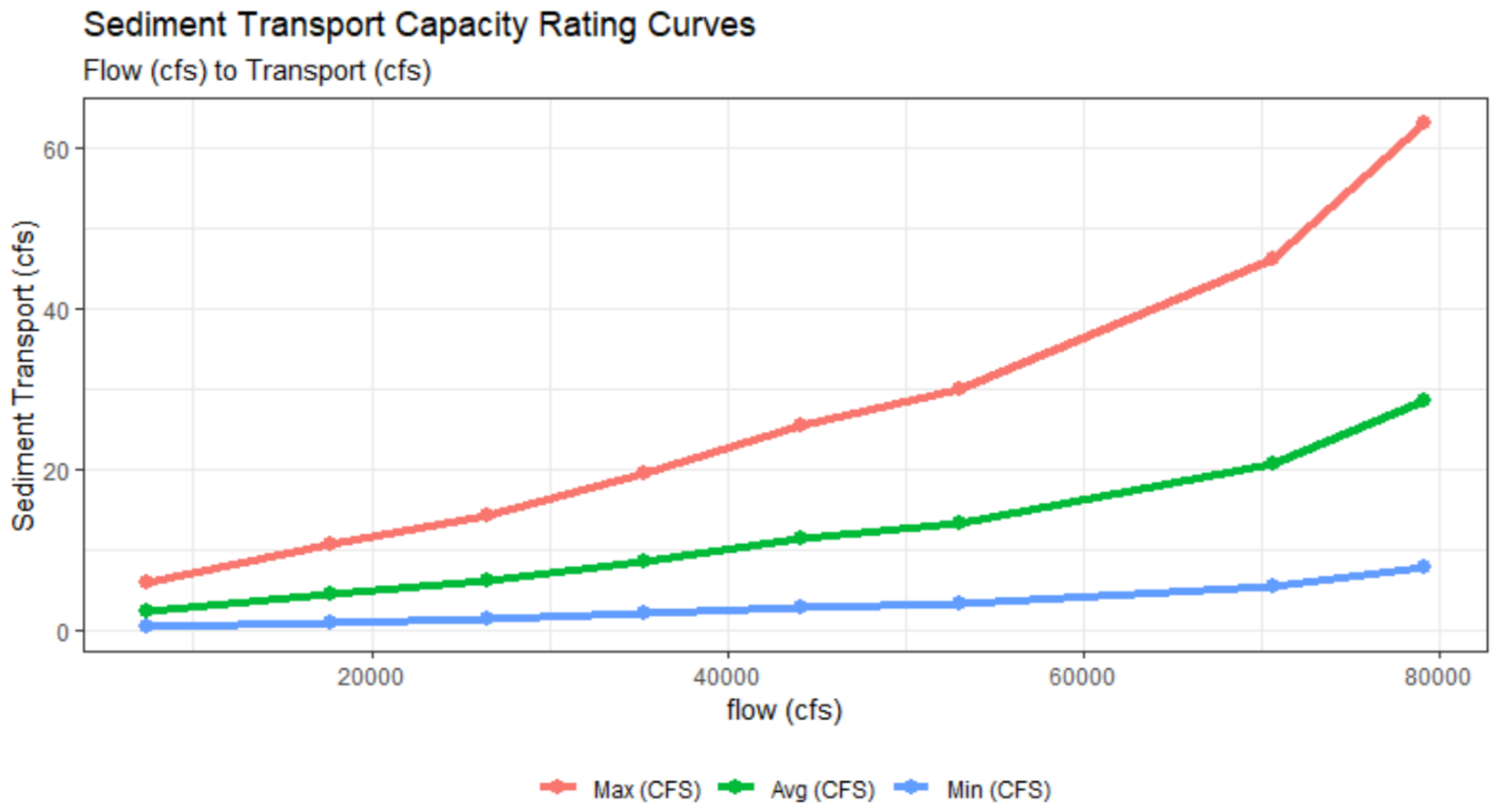


Figure 30. Sediment transport capacity rating curves at selected cross sections.

Sediment Transport Capacity

Flow (cfs)	Parker	Wilcock	Gaeuman	River Mile
210	0.000071	0.000096	0.000246	283.33
500	0.004994	0.001350	0.003240	283.33
750	0.036029	0.005301	0.013065	283.33
1000	0.150990	0.016174	0.039437	283.33
1250	0.368879	0.036586	0.085184	283.33
355 additional rows not shown				

```
flow_cfs_to_sed_transport_cfs <- approxfun(
  x = rating_curve$flow_cfs,
  y = rating_curve$sed_ft3_per_second_min
)

flow_cfs_to_sed_transport_cfd <- approxfun(
  x = rating_curve$flow_cfs,
  y = rating_curve$sed_ft3_per_day_min
)
```


Sediment Transport Capacity Rating Curves
Flow (cfs) to Transport (cfs)
Sediment Transport (cfs)
60
40
20
0
20000
40000
60000
80000
flow (cfs)
Max (CFS)
Avg (CFS)
Min (CFS)

First Scaledown: Sediment Particle Size

- Quantify the fraction of different sediment size classes expected to be mobile across a range of flows in four study reaches
  - Obtained from Sacramento River Gravel Augmentation Study (2020)
- 40mm sediment particles was selected as the best representative of salmonid spawning gravel size.

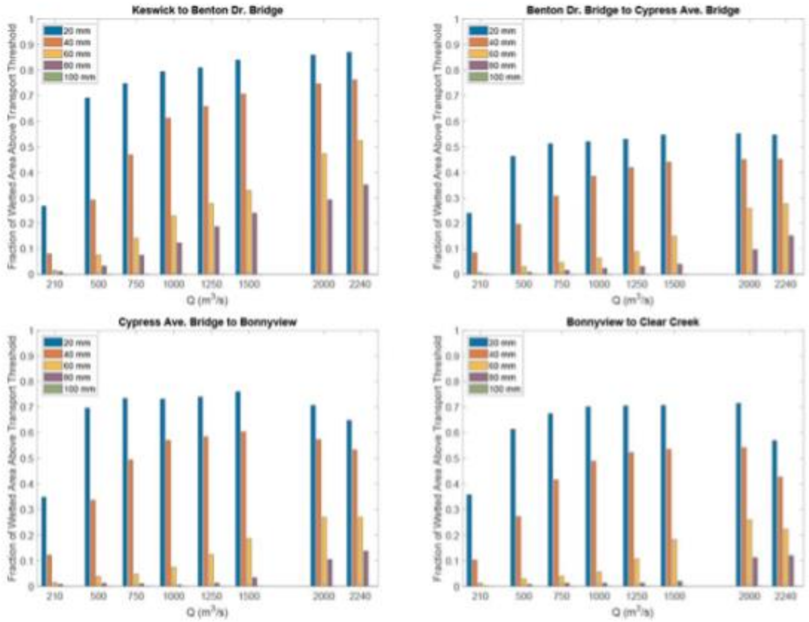


Figure 29. The fraction of each reach that exceeds a threshold Shields stress of $\theta_r = 0.04$ for a range of grain sizes and flows. Finer gravel is mobile over much of the river at flows of 500 m^3/s and above. The least mobile reach is Benton Dr. to Cypress Avenue which includes Turtle Bay and Park Marina.

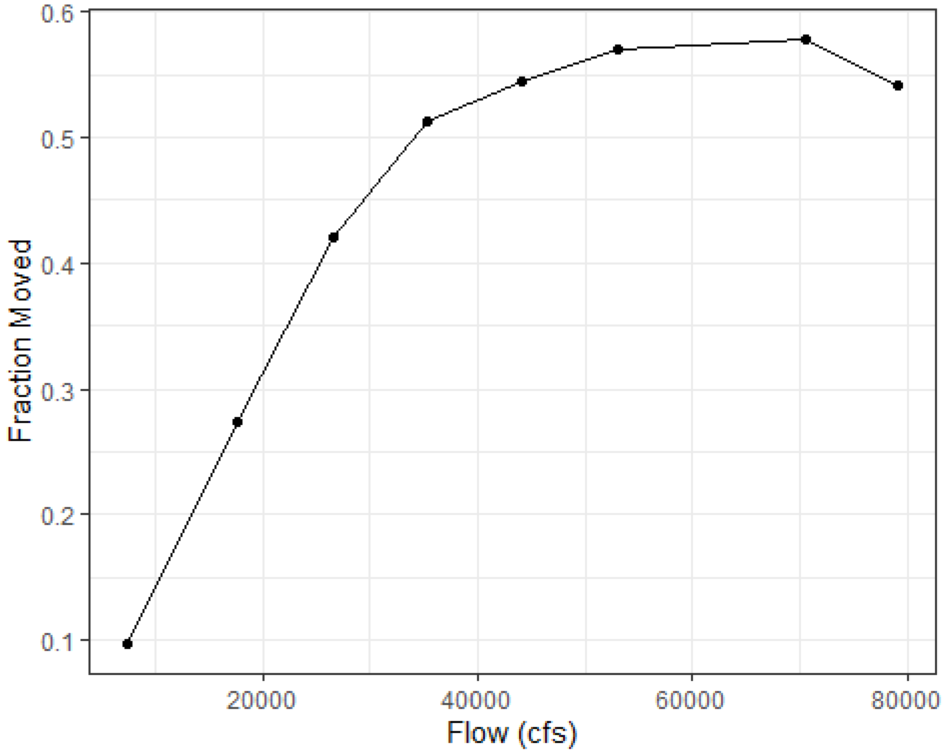
Spawning Habitat Sediment Particle Size

- Digitized plots to obtain tabular data
- Relationships between flow and proportion of sediment mobilized were generalized
- Summarized by selecting the minimum, average, and maximum values for each flow across all four relationships

Flow (m3s)	Fraction	Reach
210	0.08060183	kes_to_ben
500	0.28909189	kes_to_ben
750	0.46587856	kes_to_ben
1000	0.60881247	kes_to_ben
1250	0.65502418	kes_to_ben
1500	0.70445997	kes_to_ben

Spawning Habitat Sediment Particle Size

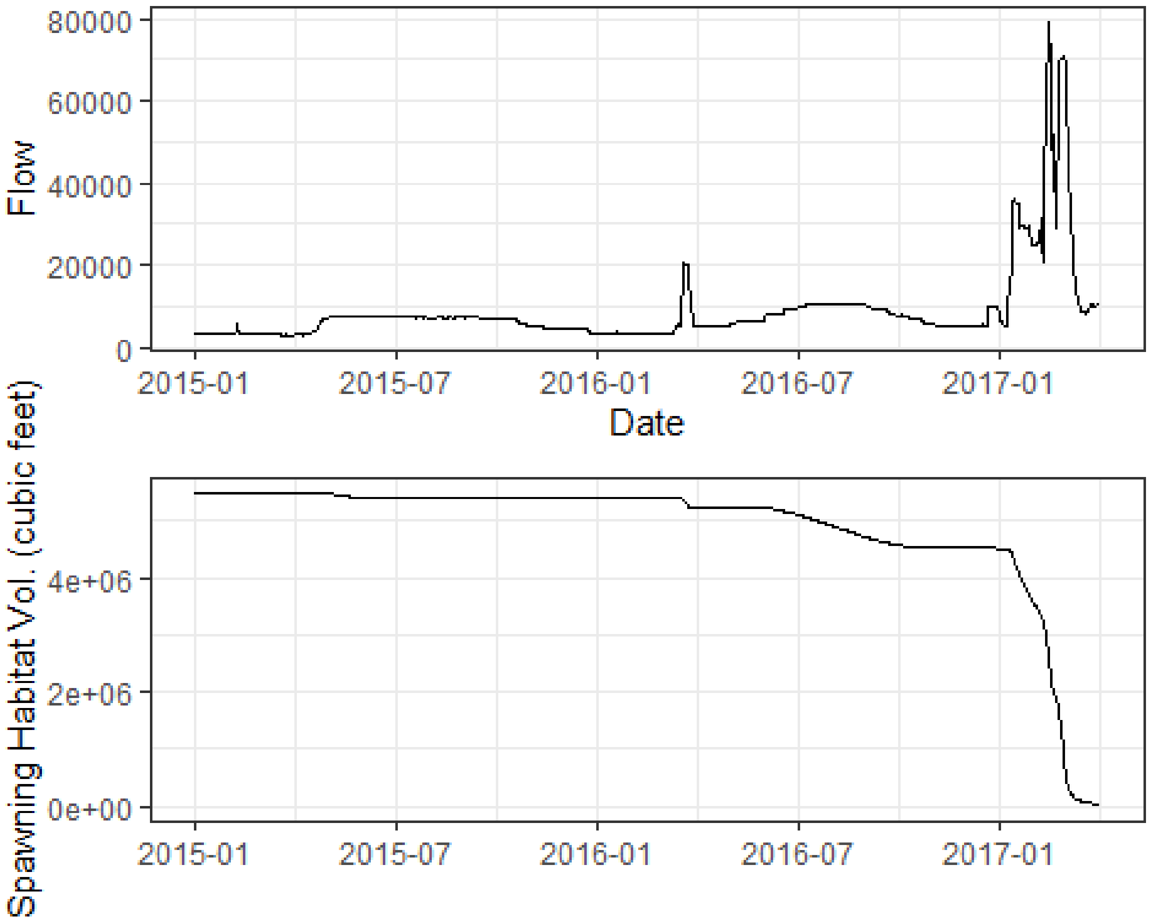
flow_cfs	min_fraction	avg_fraction	max_fraction
7416.15	0.08060183	0.09683229	0.1217712
17657.50	0.19411461	0.27333493	0.3368477
26486.25	0.30252969	0.41972416	0.4928835
35315.00	0.38306660	0.51274475	0.6088125



Observed Sediment Transport

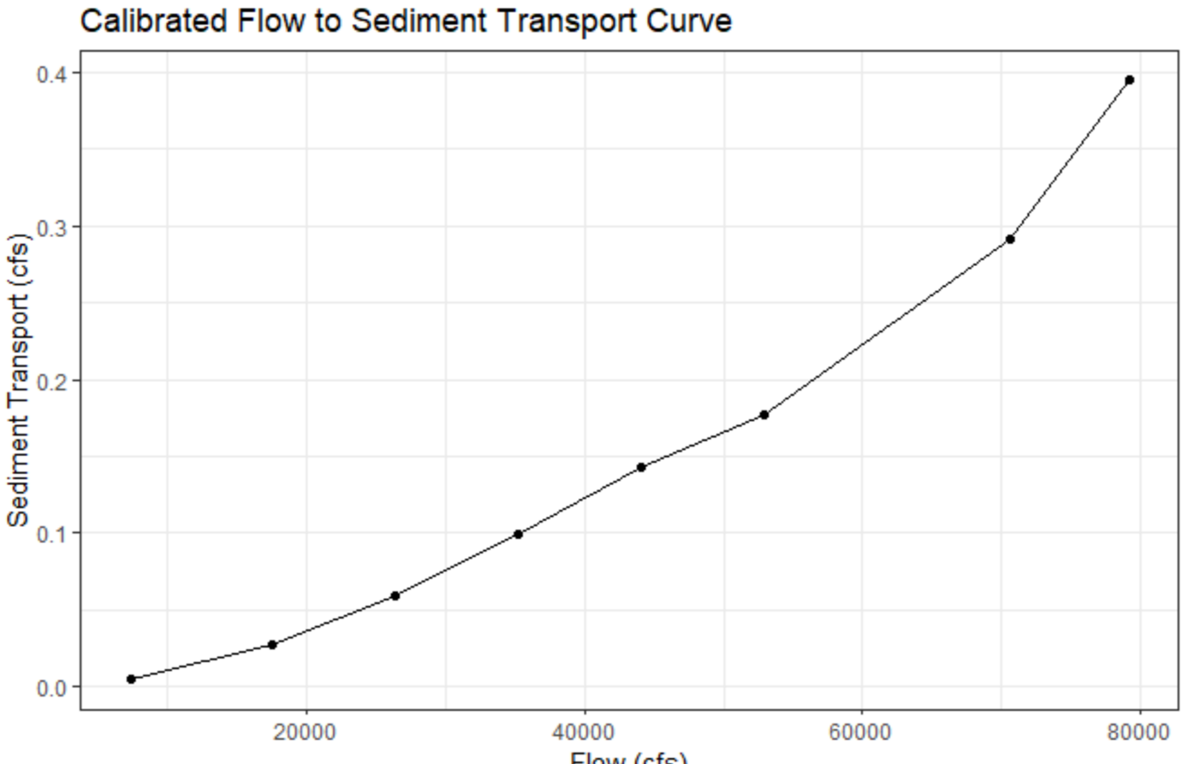
- Evaluated known spawning gravel augmentation event
  - Market Street, Sacramento River
  - 254,690 square meters of spawning-sized sediment added in 2015
  - Completely removed by April 2017
- Used to calibrate sediment transport model:
  - Developed function to determine scaling factor
  - Adjusted sediment transport capacity for fraction of sediment mobilized
  - Aimed for complete transport of augmented sediment (2015-2017)

```
objective_func <- function(threshold) {

  # scale down the tranport curves to just the d50mm threshold of movement
  scaled_sed_transport <- rating_curve$sed_ft3_per_day_min *
    gravel_size_scaledown_summarized$avg_fraction

  # create an approxfun given a threshold of movement (this value will be searched by the optim
function)
  calib_sed_curve <- approxfun(rating_curve$flow_cfs,
                               scaled_sed_transport *
                                 rep(threshold,
                                     length(rating_curve$flow_cfs)))

  # convert square meters to cubic feet, assume 2ft depth
  starting_volume <- (254690.3 * 10.764) * 2

  calib_kwk_sed_transport <- tibble(
    date = kwk_usgs$Date,
    flow = kwk_usgs$Flow,
    sediment_transport_f3_day = calib_sed_curve(flow)
  ) |>
    mutate(sediment_transport_f3_day = ifelse(is.na(sediment_transport_f3_day), 0,
sediment_transport_f3_day))


  calib_kwk_sed_transport_sim <- calib_kwk_sed_transport |>
    filter(date >= "2015-01-01", date <= "2017-04-01") |>
    mutate(sediment_transport_f3_day = ifelse(is.na(sediment_transport_f3_day), 0,
sediment_transport_f3_day),
           sediment_transport_f3_day_accum = cumsum(sediment_transport_f3_day),
           current_vol = starting_volume - sediment_transport_f3_day_accum)

  last_volume <- calib_kwk_sed_transport_sim |> tail(1) |> pull(current_vol)

  # return absolute distance to zero
  return(abs(last_volume - 0))
}


# We want to optimize the function by the threshold value that results
# in the volumne nearest zero.
result <- optimise(objective_func, interval = c(0, 1), maximum = FALSE)
```

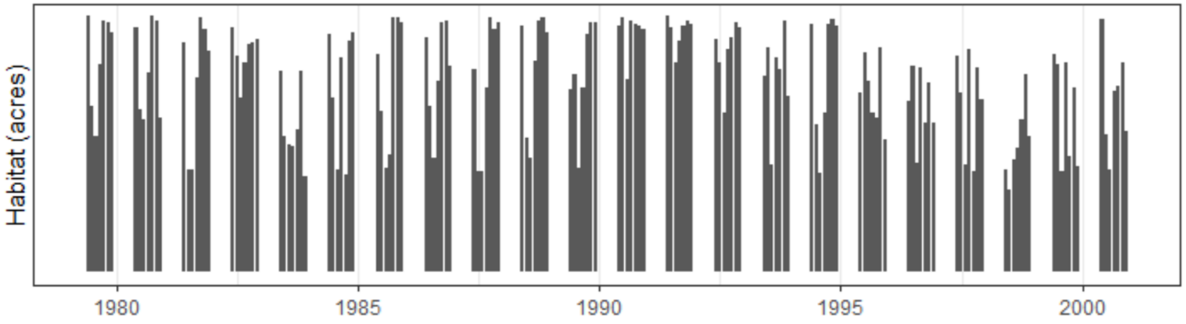


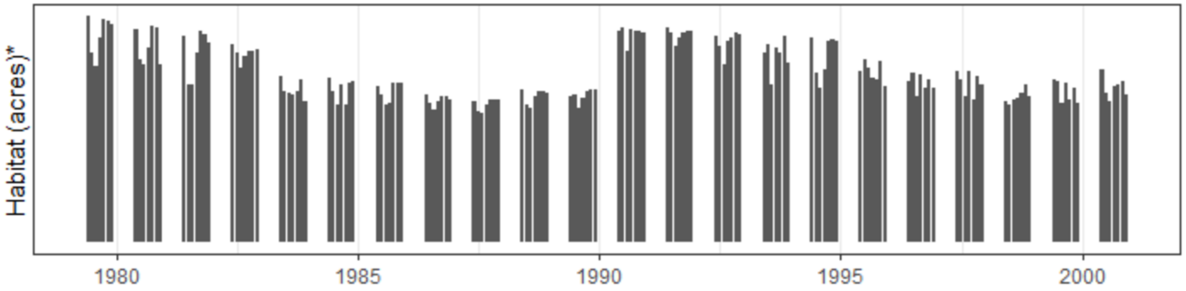
Flow
80000
60000
40000
20000
0
2015-01
2015-07
2016-01
2016-07
2017-01
Date
Spawning Habitat Vol. (cubic feet)
4e+06
2e+06
0e+00
2015-01
2015-07
2016-01
2016-07
2017-01

Final Sediment Transport Model



New Spawning Habitat Decay Pattern





*offset to account for non-zero end

Translating to Other Watersheds

- Goal: Apply flow-driven decay approach consistently across DSM watersheds
- Translation method:
  - Calculate flow at incipient motion for Sacramento River 5.7% exceedance probability (18,000 cfs at Keswick)
  - Determine equivalent 5.7% exceedance flow for each watershed
  - Shift sediment transport rate curve accordingly

Watershed	Estimated Flow at Incipient Motion (5.7% exceedance) (cfs)	Minimum Average Annual Decay (acres)	Average Average Annual Decay (acres)	Maximum Average Annual Decay (acres)
Clear Creek	297	0.00	0.00	0.01
Stony Creek	2019	0.03	0.16	0.37
Feather River	10445	0.47	1.97	4.48
Yuba River	6783	0.13	0.58	1.34
American River	9680	0.26	1.11	2.53
Calaveras River	844	0.02	0.08	0.19
Mokelumne River	1999	0.02	0.10	0.23

Implementation in DSM

- Pre-computed decay
  - Stored as Matrix and looked up at runtime for fast model runs
- Expandable, easily updated
- Parameterized for sensitivity analysis needs

Long-term Spawning Sediment Augmentation