What Dimensional and Lagrangian Analyses tell us about Flow Regimes, Flow Indices and Fish Salvage at the Export Facilities

Greg Gartrell, PhD, PE

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Dimensionless Parameters and Order of Magnitude

- Buckingham Pi Theorem (1914)
- Dimensionless parameters allow adjustments with changing conditions:
  - Climate change
  - Habitat Restoration
- Allows characterization of flow regimes

Order of Magnitude

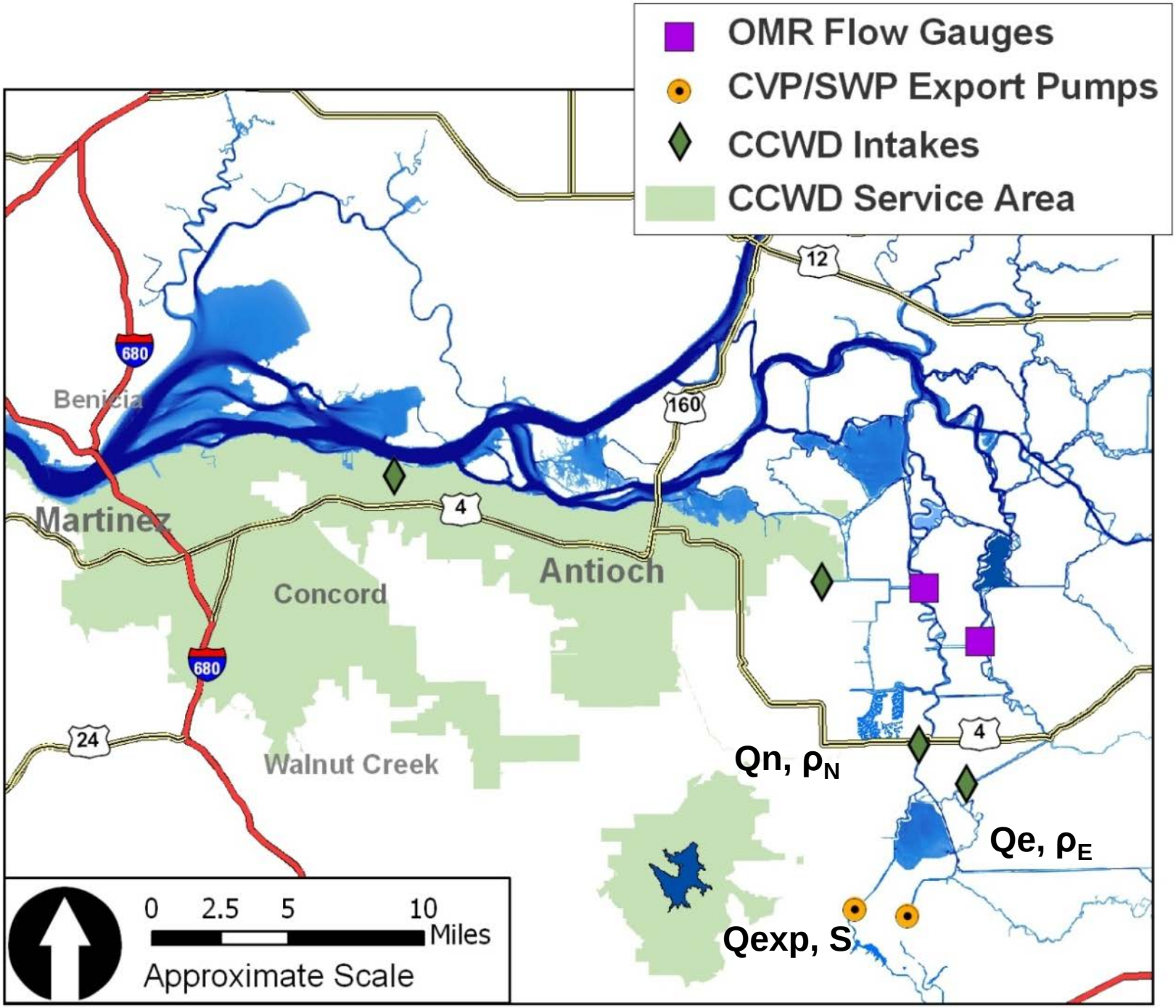
Factor	Designation	Order of Magnitude Range
Tides, weather in Delta channels (for example, Old River)	Qa	+/-400 m^3/s (+/-15,000 cfs) in any one channel
Export pumping	Qexp	30-400 m^3/s (1,000-15,000 cfs)
San Joaquin River inflow	Qsjr	15-300 m^3/s (500-10,000 cfs) Can be higher in flood conditions
Agricultural diversions, south Delta	Qag	-15 – 30 m^3/s (-500 to 1000 cfs) Can be negative during precipitation events, varies over irrigation season
Minor diversions (CCWD, ECCID)	Qm	0-7 m^3/s (0-300 cfs) (each), varies seasonally

Dimensionless Parameters

- Velocity, not flow, affects fish movement
- For a fixed system, flow and velocity related such that:

$$Qi/Qa = Vi/Va$$

- Choose Qa (Va) on the most significant parameter: tidal amplitude (always there)


OMR Flow Gauges
CVP/SWP Export Pumps
CCWD Intakes
CCWD Service Area
Benicia
Martinez
Concord
Antioch
Walnut Creek
680
680
24
4
4
12
160
Qn, ρN
Qe, ρE
Qexp, S
0 2.5 5 10
Miles
Approximate Scale

Important Parameters

Easily shown that:

$S = Q_{exp}\, \rho_N\, (1 + Qm/Qexp + a*Qsjr/Qexp\, (\rho_E / \rho_N - 1))$

S = normalized salvage

Q_{exp} = export flow

Qm = minor diversions

a * Qsjr = flow from San Joaquin River (adjusted for barriers and diversions)

ρ_N = normalized fish density from the north

ρ_E = normalized fish density from the east (SJR)

Important Parameters

$S = Q_{exp}\, \rho_N\, (1 + Qm/Qexp + a*Qsjr/Qexp\, (\rho_E / \rho_N - 1))$

→Reduce Qexp and reduce salvage

$Qm/Q_{exp} << 1$, so:

For San Joaquin salmon and steelhead, $\rho_E / \rho_N = O(1)$

→ $\mathbf{S \approx Q_{exp}\, \rho_E}$ (depends on Qexp, not Old/Middle River flow)

For smelt and Sacramento/Mokelumne salmon: $\rho_E \approx 0$

→ $\mathbf{S \approx Q_{exp}\, \rho_N\, (1 - a*Qsjr/Qexp)}$

Important Parameters

ρ_N ?

- Local value depends on ρ at another location at prior time ("Retarded time", or antecedent conditions)
- Depends on travel over a path, and condtions (turbidity, survival)
- Suggests Lagrangian frame, not Eulerian

Important Parameters

Start with the parameter

$$Qexp\ (1 - a^*\ Qsjr/Qexp)\ /\ Qa$$

or

$$Qi/Qa = A\ (Qexp - a^*\ Qsjr)/Qa$$

Then compare with <Qomr> (filtered Old and Middle River flow) to determine effects of parts left out

Regression:

A = -.87, a = 0.48 for no barriers

Important Parameters

$$Qi/Qa = 0.87(Qexp - .48 * Qsjr)/Qa$$

Allows direct comparison to <Qomr>

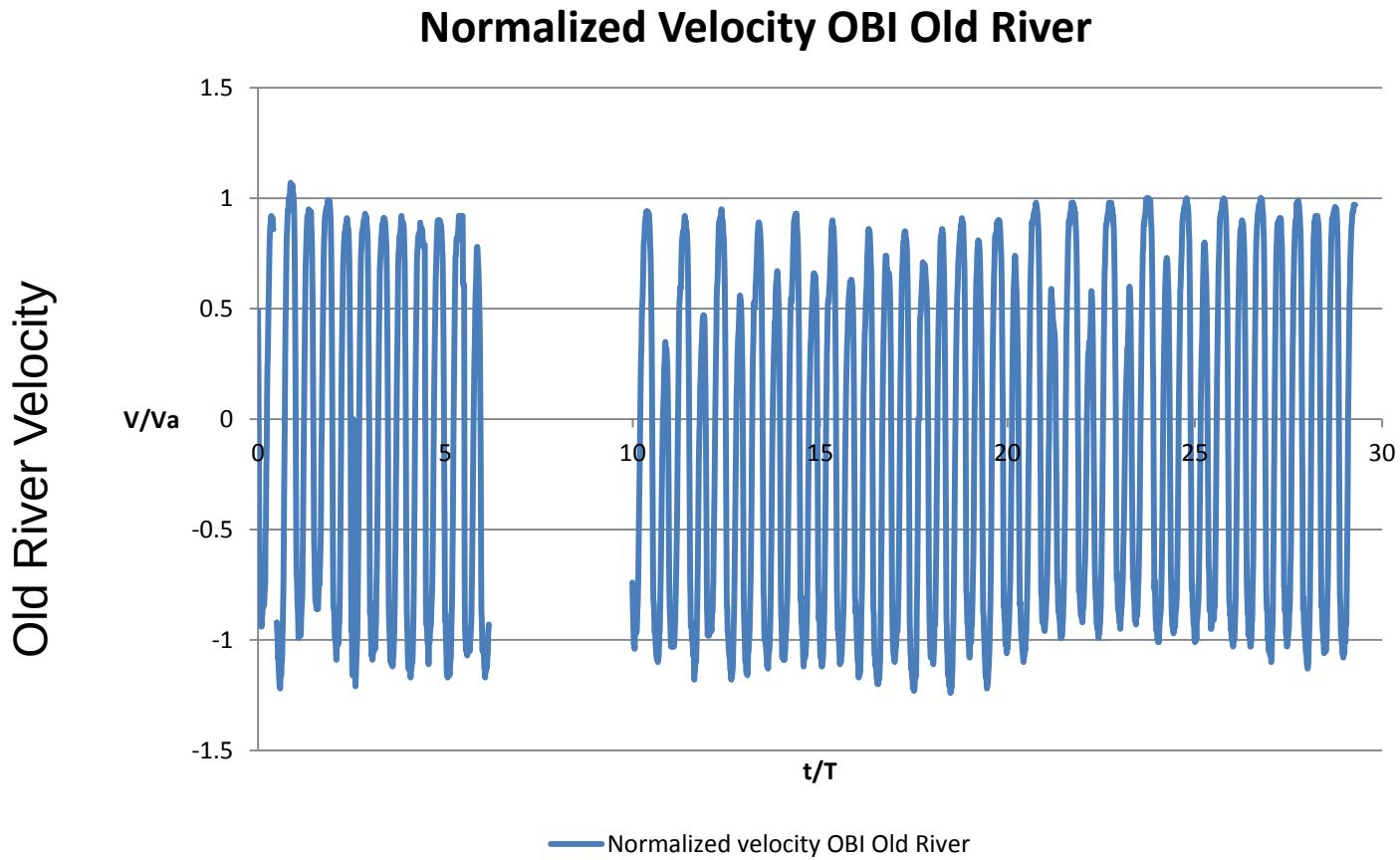
But 0.87??

When Qexp >> Qsjr, Qi as defined here (or <Qomr>, tidally measured flow) is 87% of the flow to the export pumps. The rest must come from Indian Slough (unmeasured).

Suggests correct parameter is Qexp – a* Qsjr

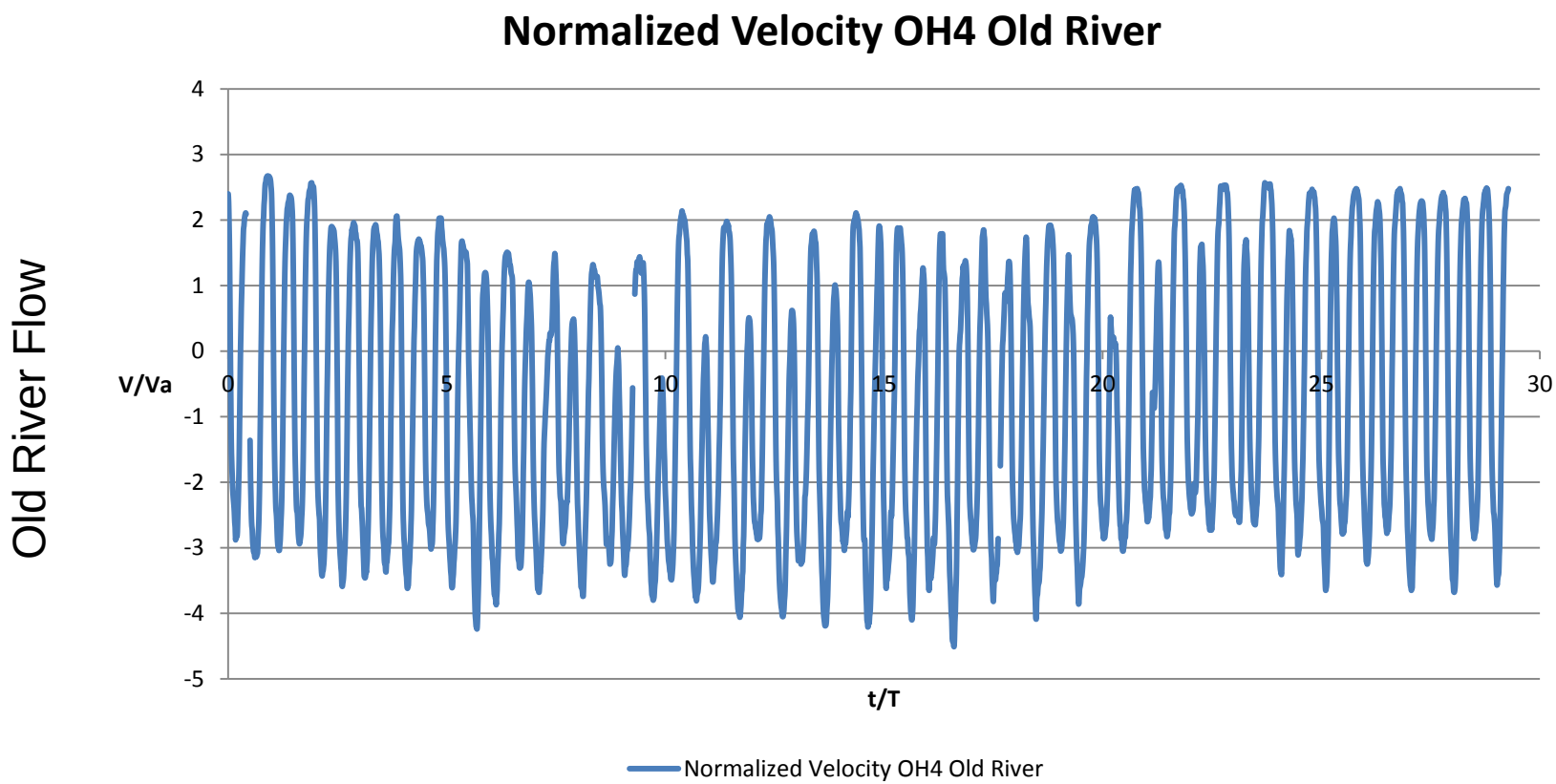
without the 0.87 (retained here to compare)

Normalized Velocity (Tidal amplitude)



Data source: USGS station Old River Bacon 11313405. March 2014

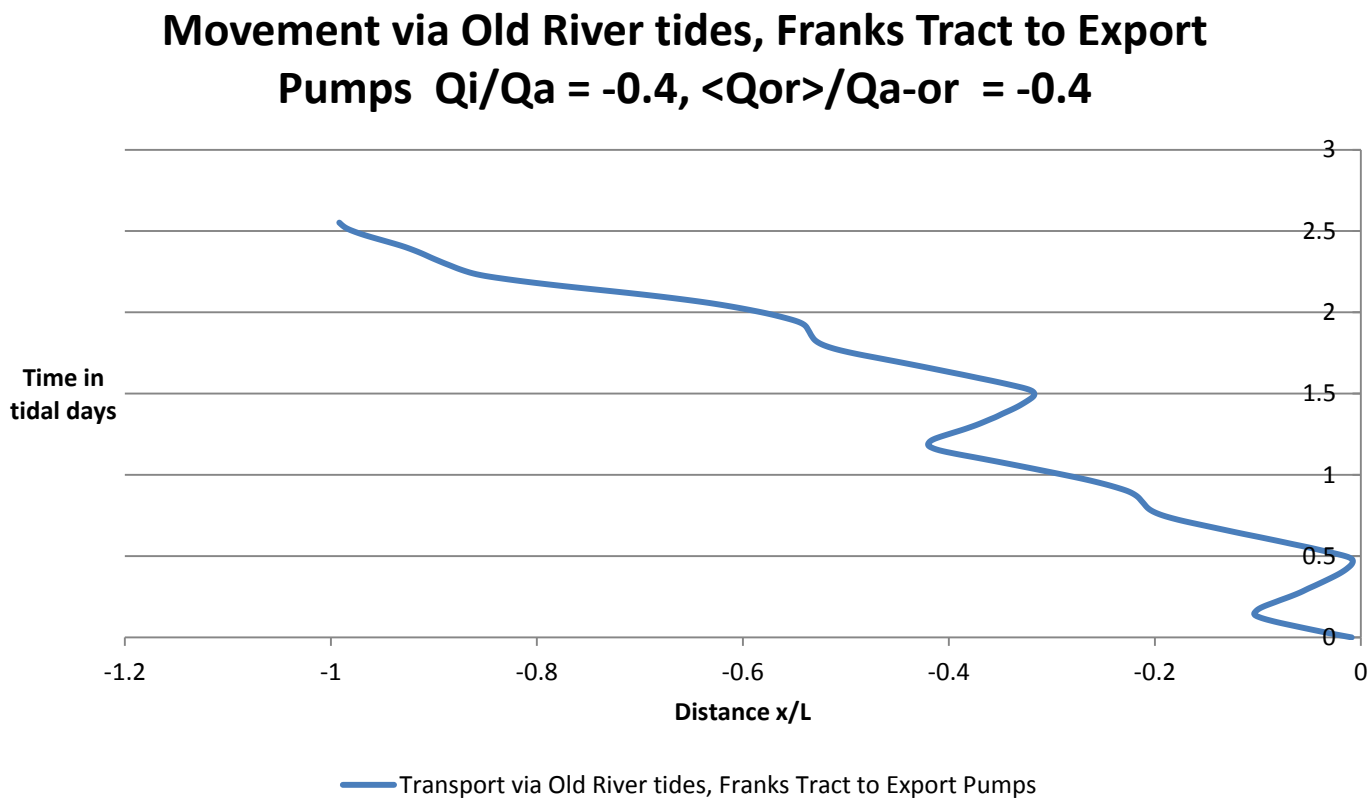
Normalized Velocity (Tidal amplitude)



Data source: USGS station Old River Bacon 11313405, March 2104

Quasi-Lagrangian movement

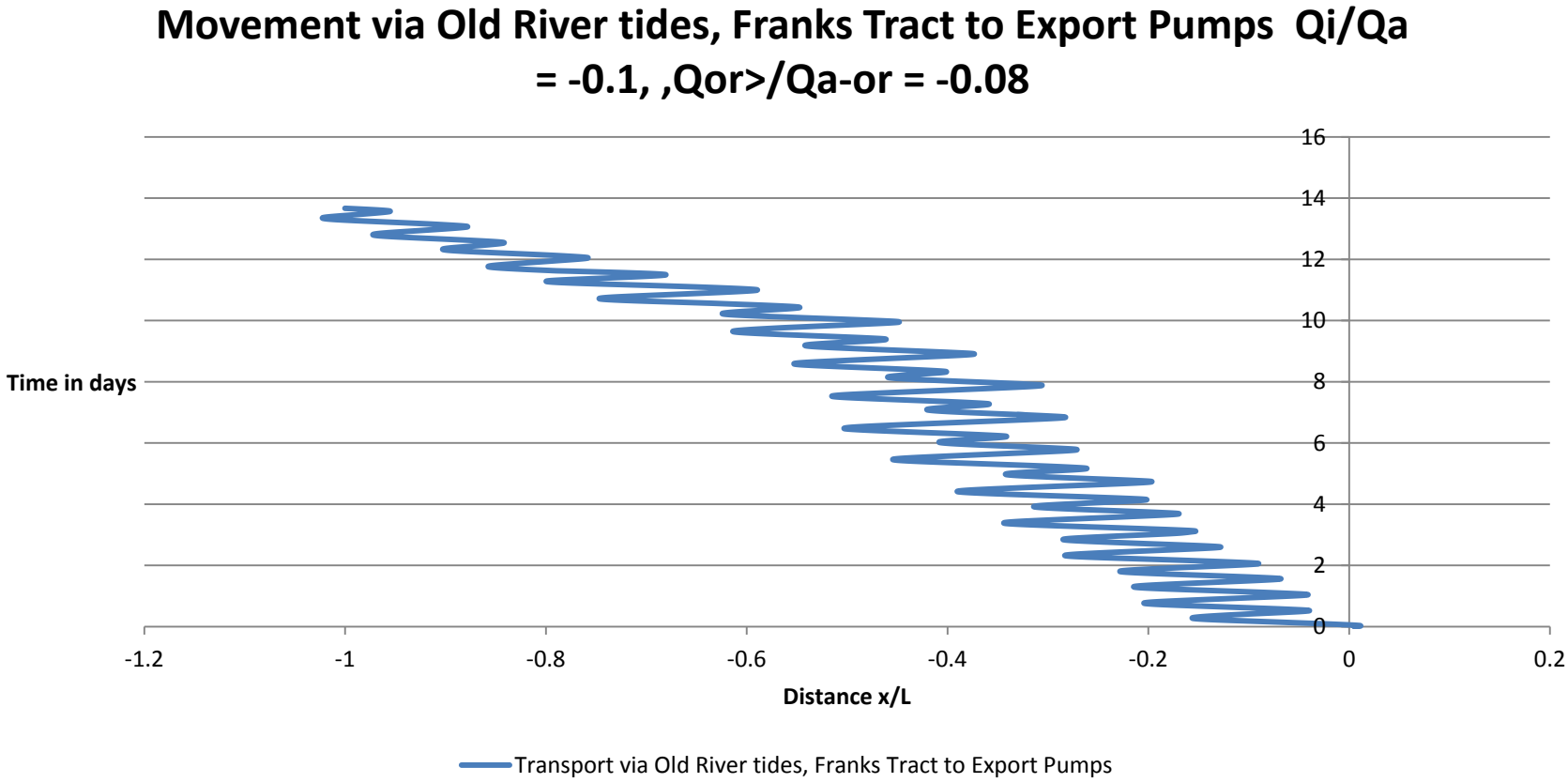
- Riverine



Data source: USGS station Old River OBI and OH4, 11313405, 11213315, July 2102

Quasi-Lagrangian movement

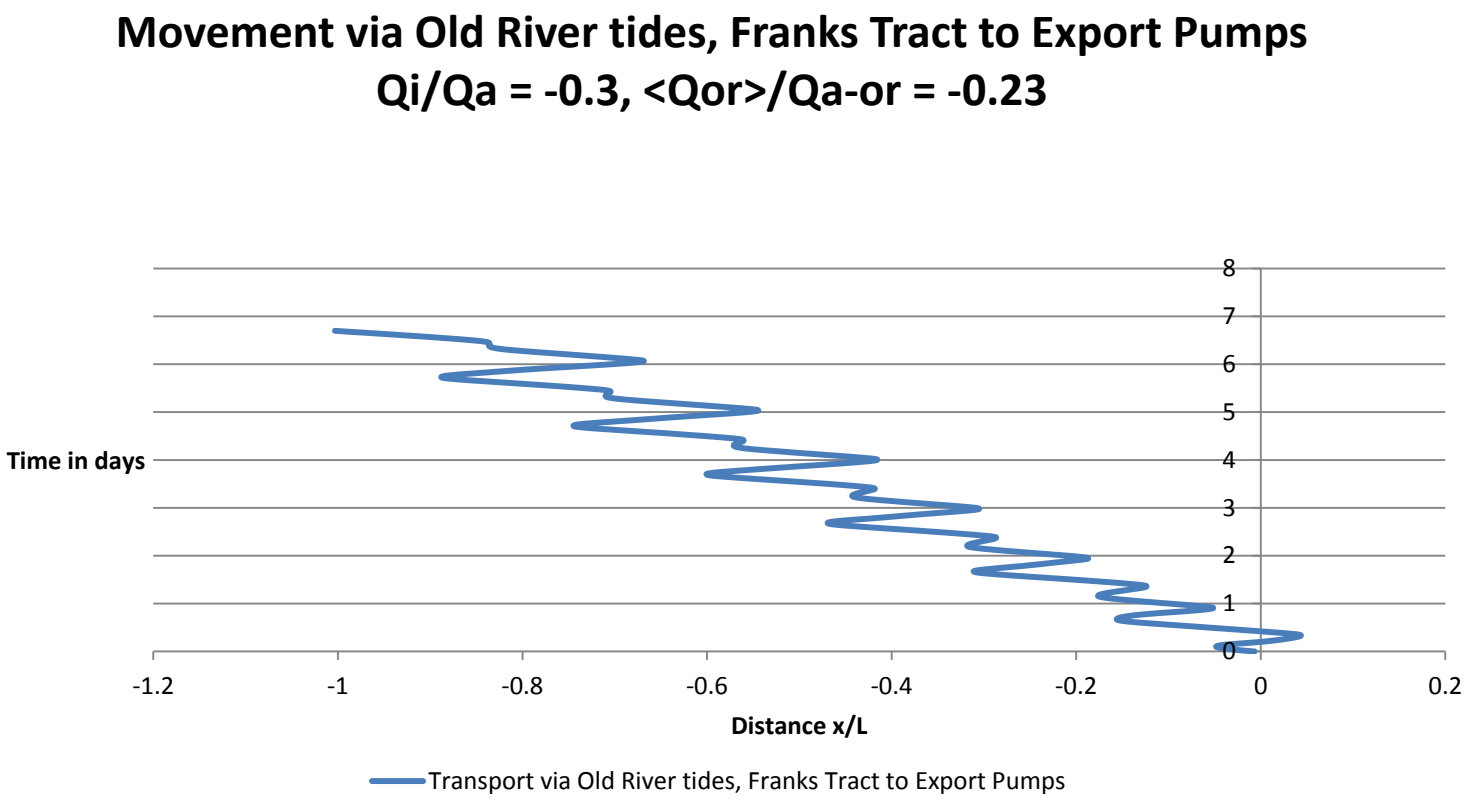
- Tidal



Data source: USGS station Old River OBI and OH4, March 2012

Quasi-Lagrangian movement

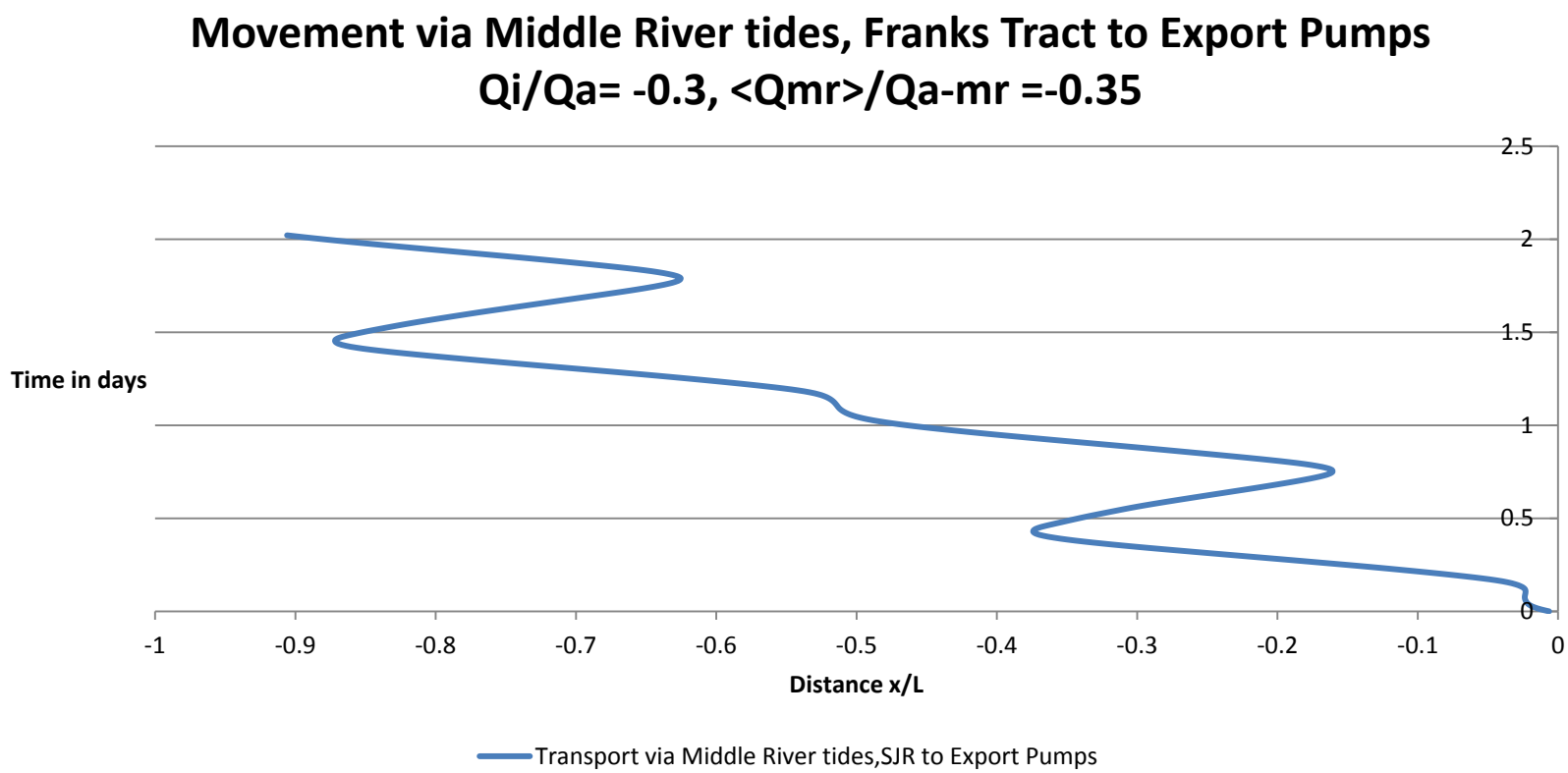
- Transitional (tidal local)



Data source: USGS station Old River Bacon November 2006

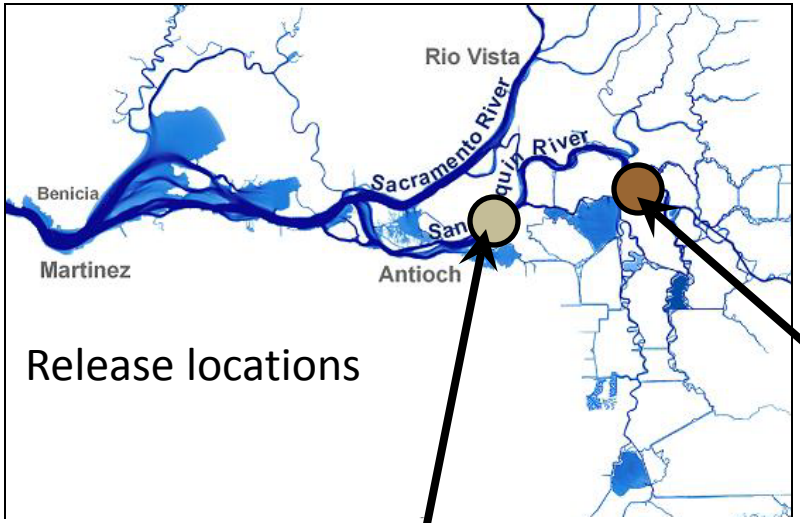
Quasi-Lagrangian movement

- Transitional (Riverine local)

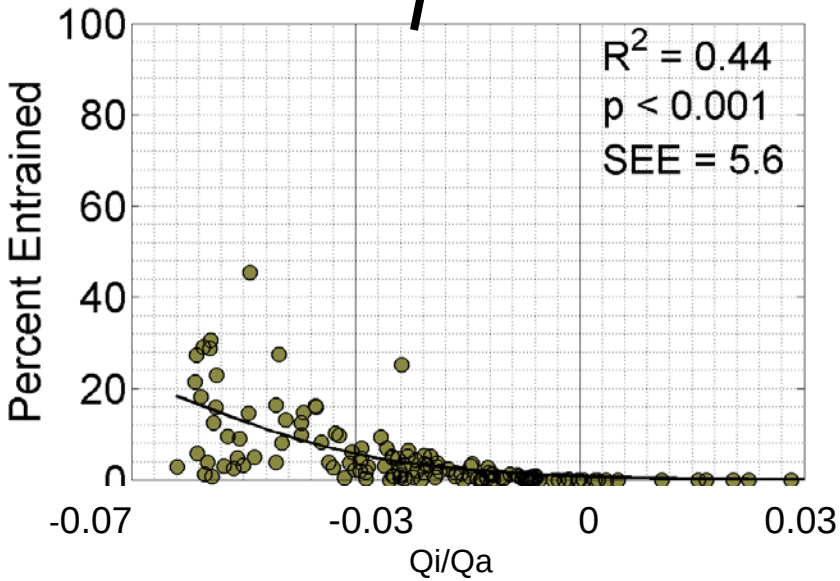


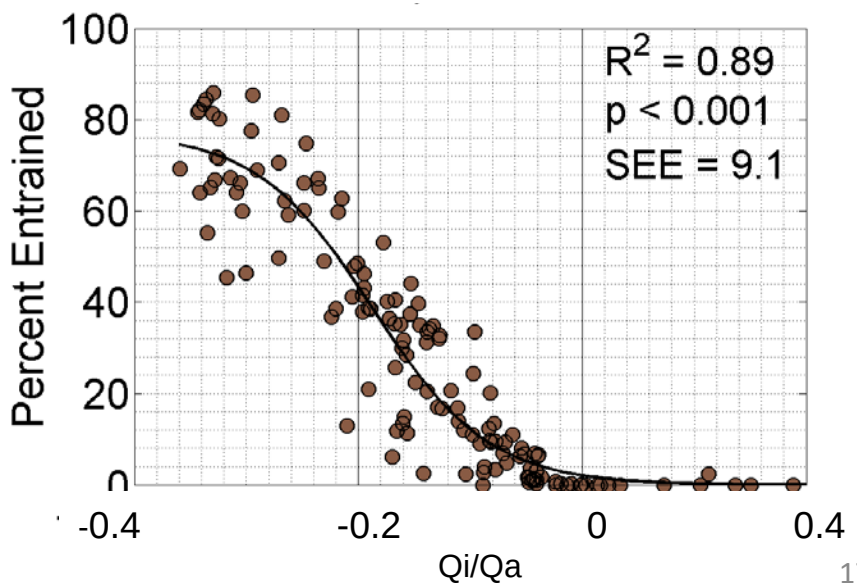
Data source: USGS station Middle River 11312676, November 2006

Qi/Qa reflects flow regimes



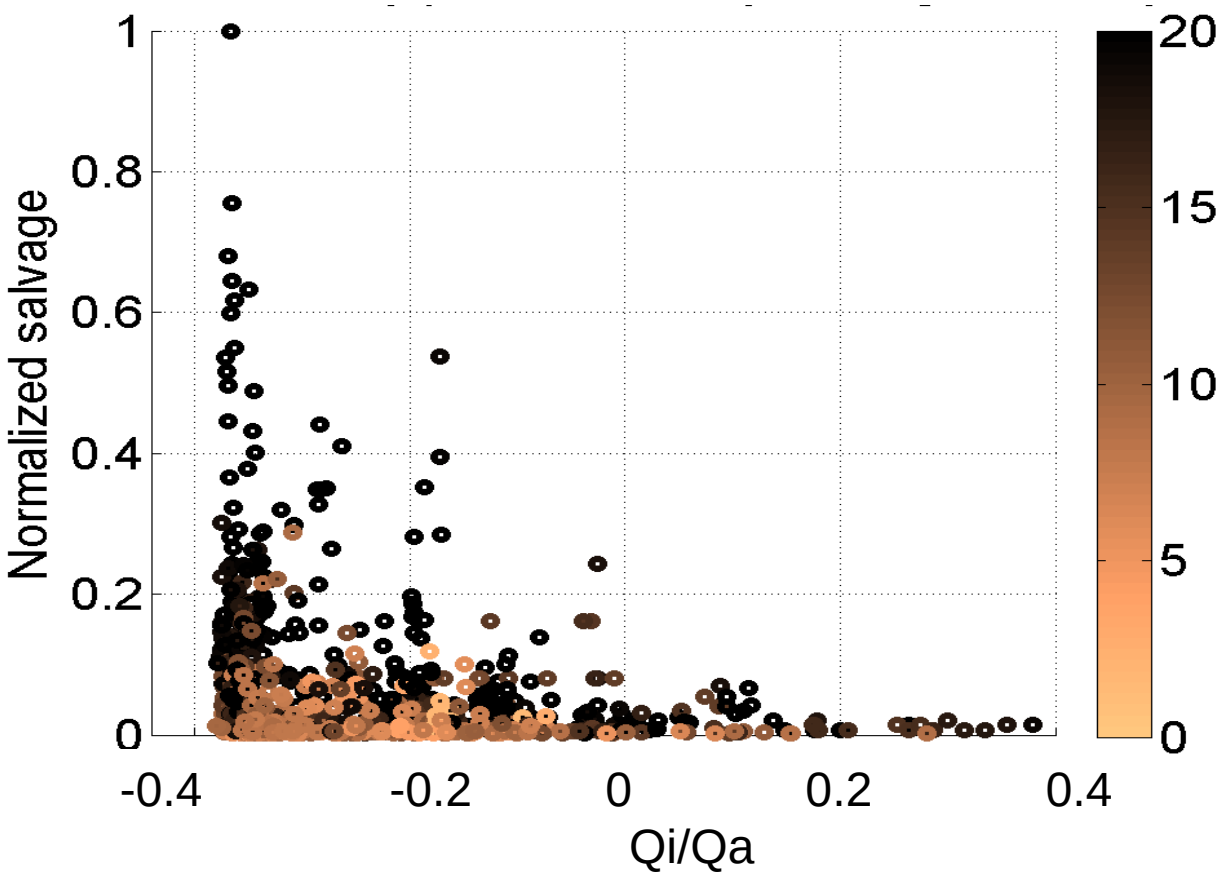
- Entrainment increases as Qi/Qa becomes more negative (riverine)
- Considerable scatter such that a given Qi/Qa does not precisely predict entrainment





Riverine: high salvage; tidal: low

Normalized salvage as a function of flow and turbidity
Data colored by prior 3-day average turbidity (NTU)

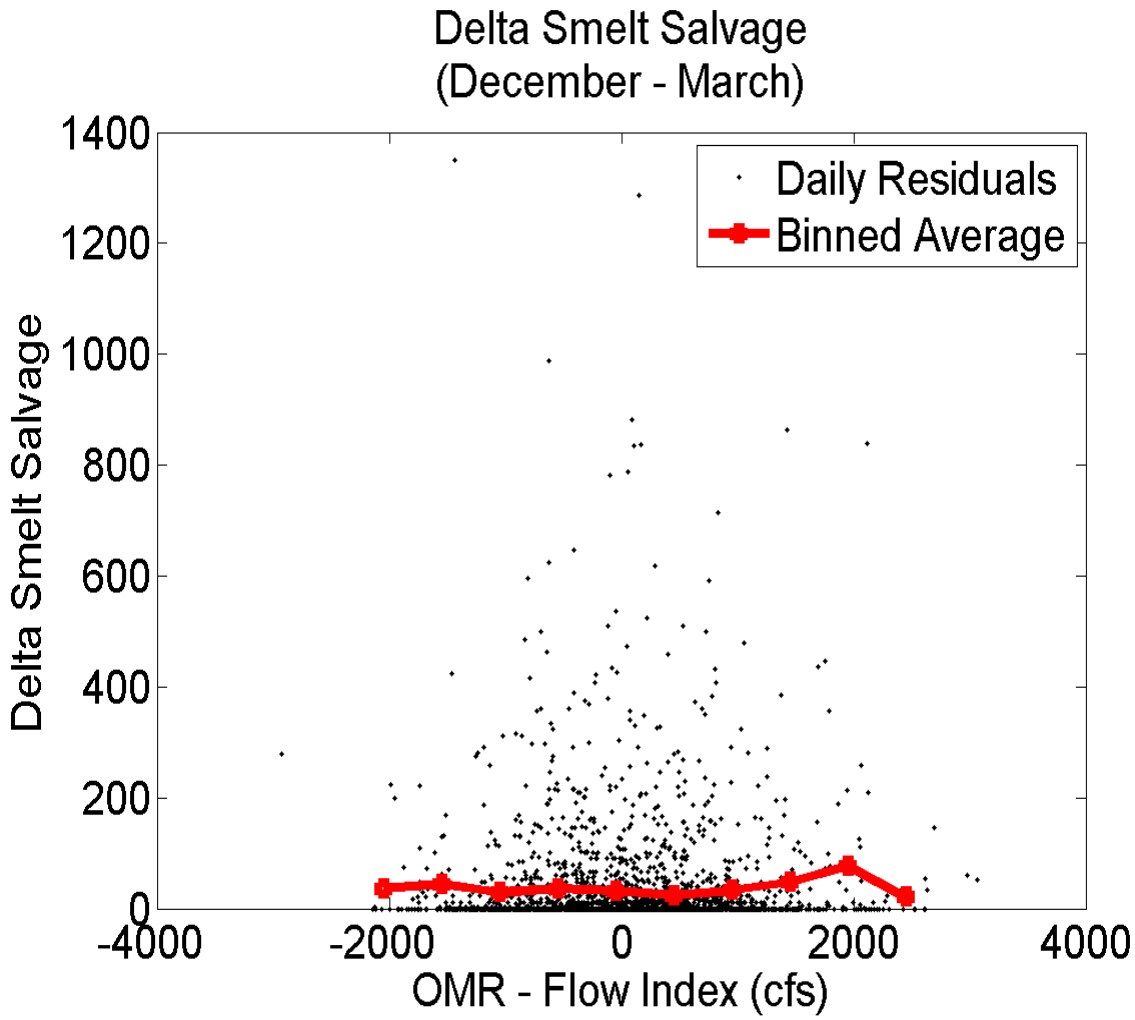


Flow Index appears to reduce scatter.

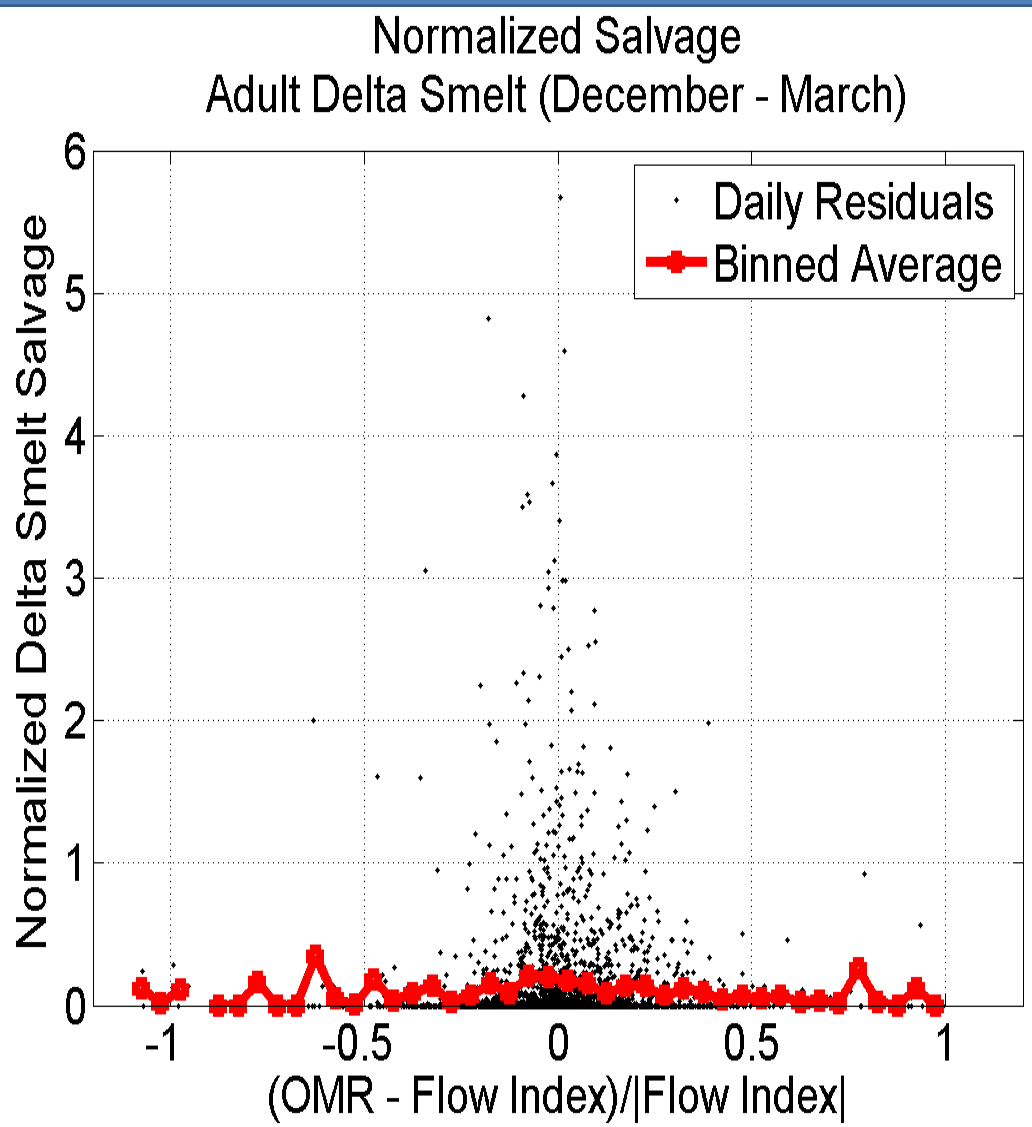
Test Qi and <Qomr>

- Qi includes only Qexp and Qsjr
- <Qomr>, tidally filtered flow, does not include Indian Slough but does include low frequency tidal effects and minor flows
- Examine trend of salvage with <Qomr> - Qi and (<Qomr> - Qi)/|Qi|
- Might expect more salvage when <Qomr> - Qi is negative

Comparison of Qi with <Qomr> no trend



Comparison of Qi with <Qomr> no trend when normalized

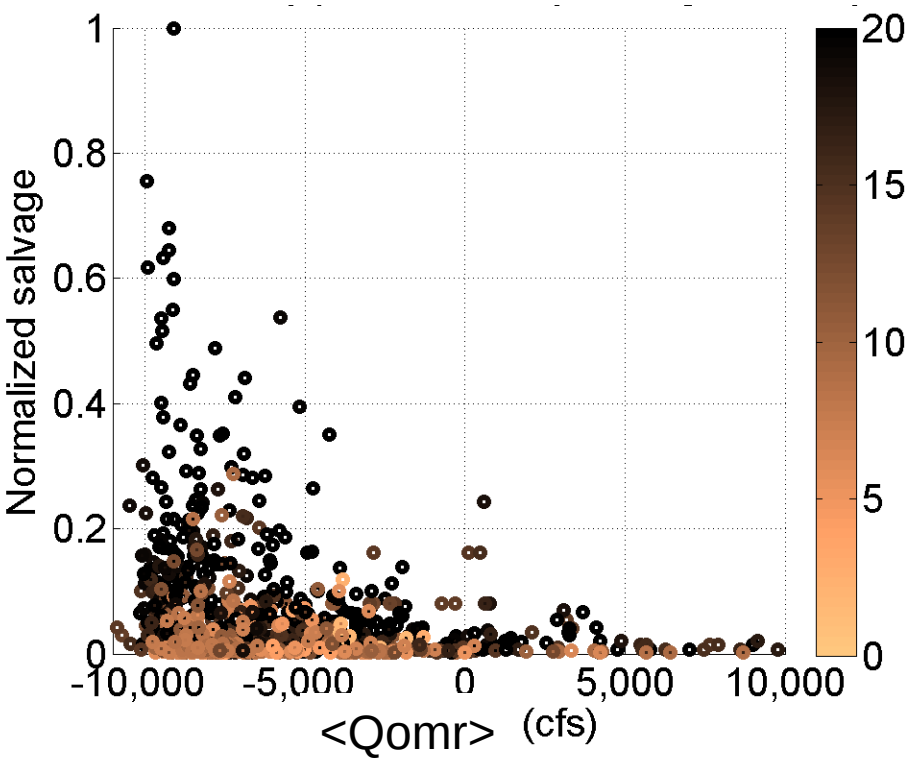


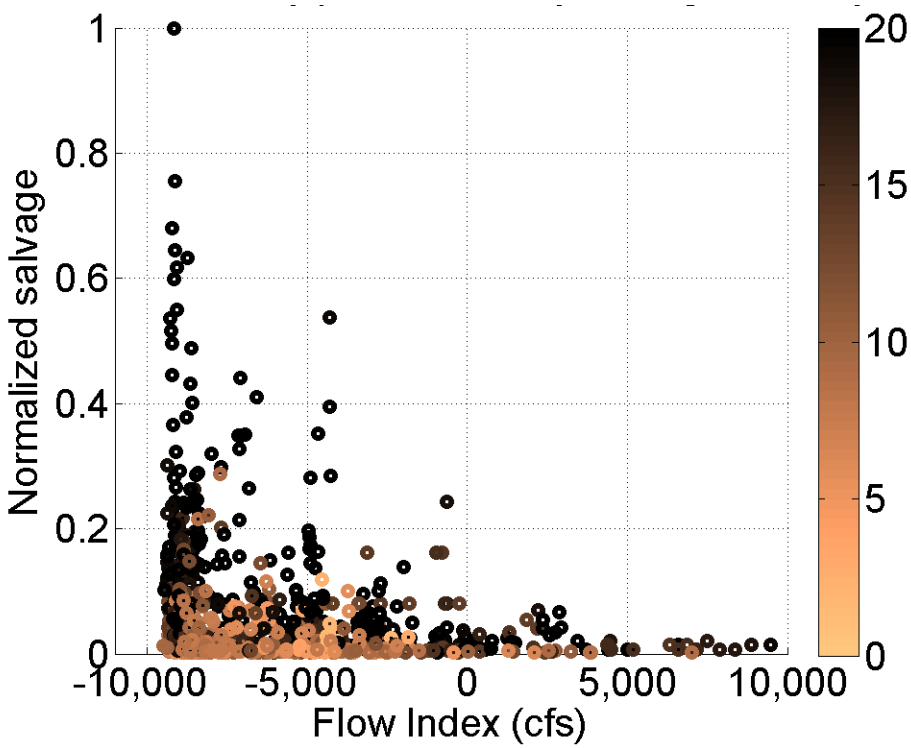
Information from <Qomr> compared to Qi?

- When |Qi| large, <Qomr>-Qi has little effect (few hours of travel time)
- When <Qomr>-Qi large compared to Qi, long travel time averages variations
- Suggests noise, rather than trend
- Compare salvage trends

Qi and <Qomr> compared for adult delta smelt

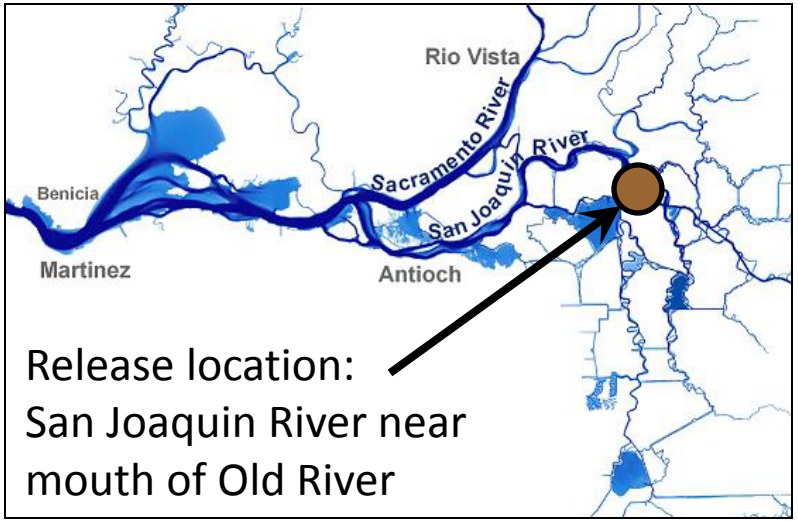
Normalized salvage as a function of flow and turbidity
Data colored by prior 3-day average turbidity (NTU)



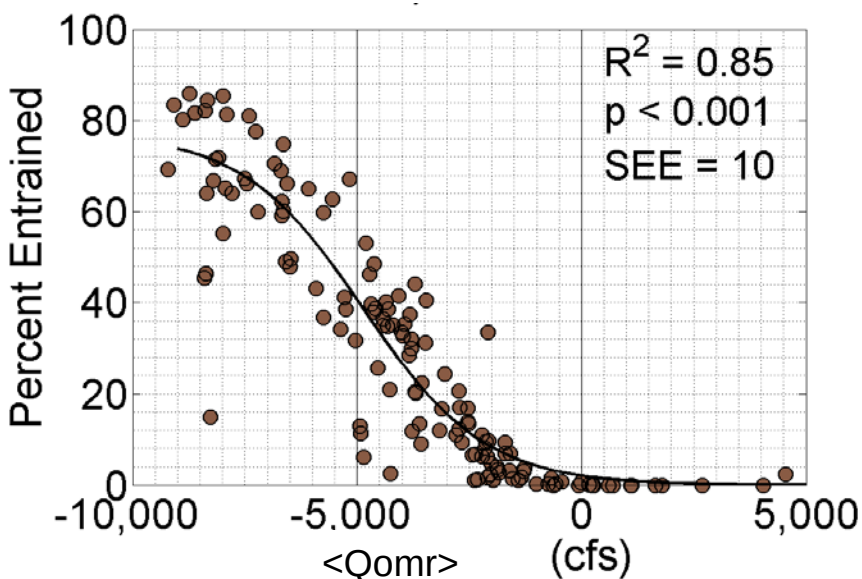


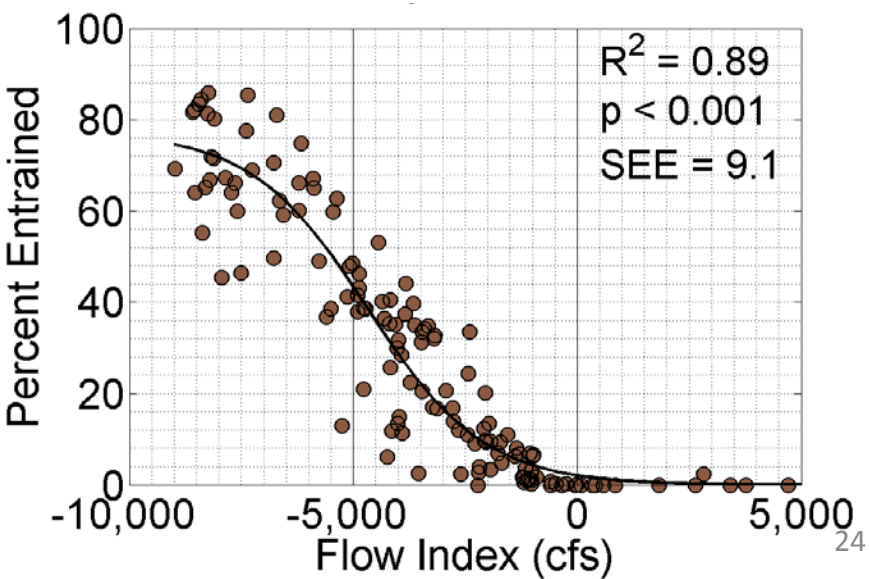
Flow Index Qi appears to reduce scatter.

Flow Index reflects regional hydrodynamics



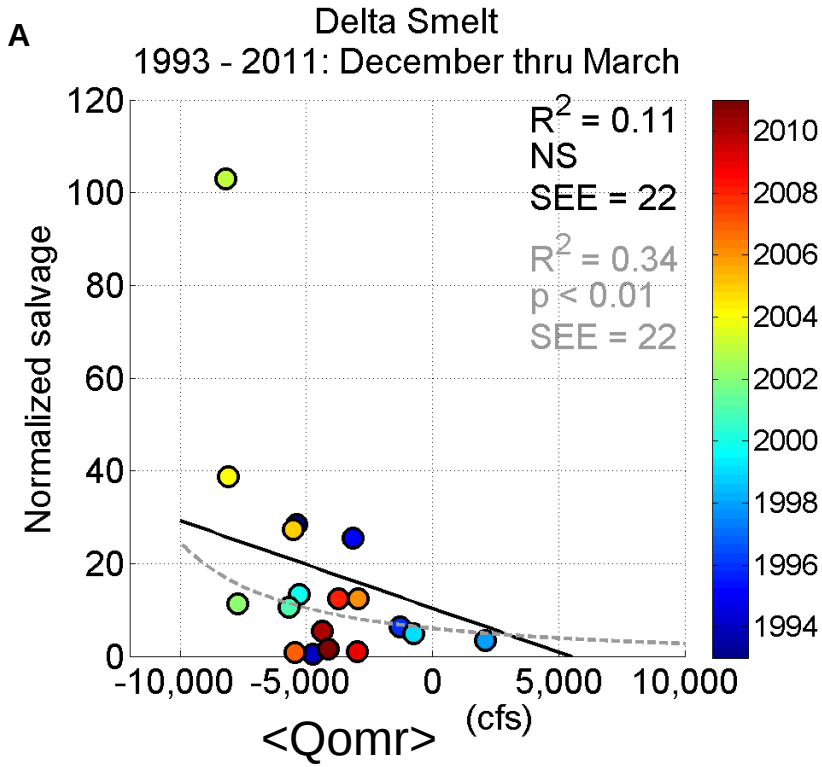
- Entrainment increases as <Qomr> and Qi become more negative
- Considerable scatter such that a given Qomr or Qi Flow Index does not precisely predict entrainment

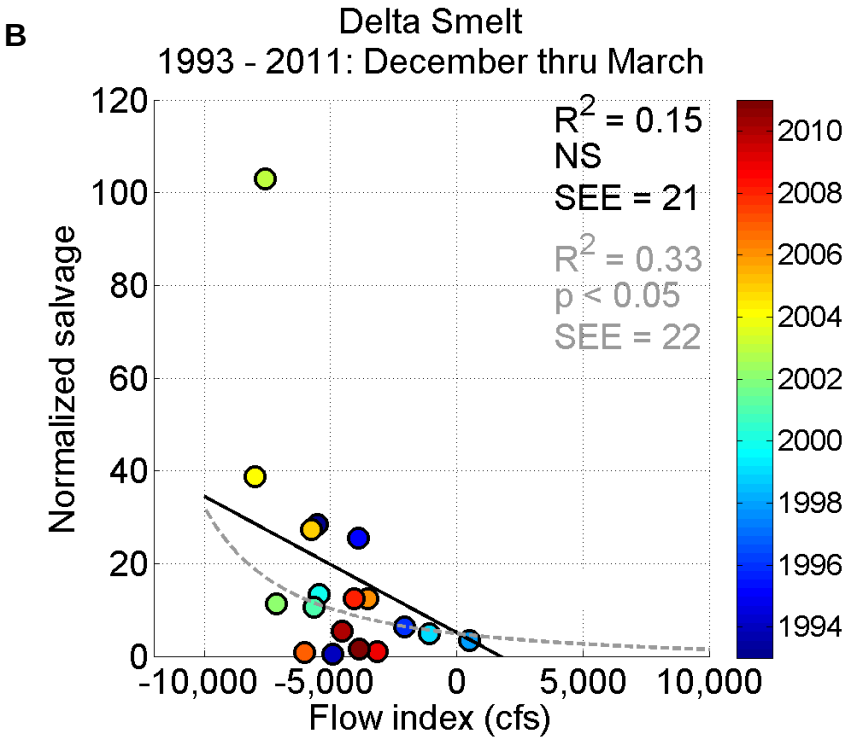




Qi and <Qomr> compared for adult delta smelt

Salvage as a function of flow



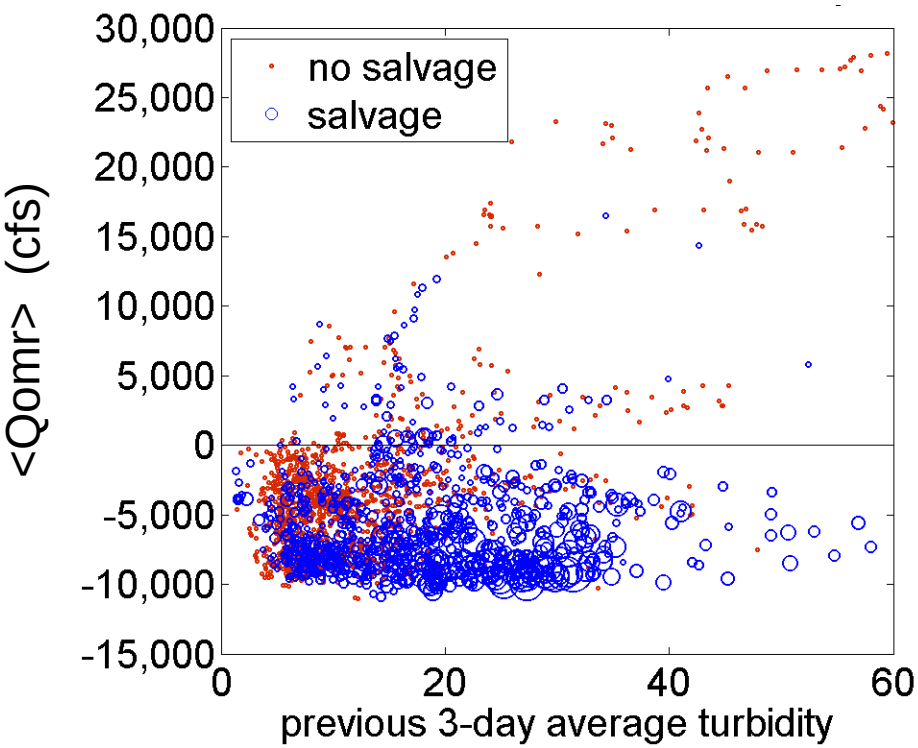


Based on Figure S-8 from 2008 USFWS BiOp
Years colored by percent estimated (Dec-Mar)

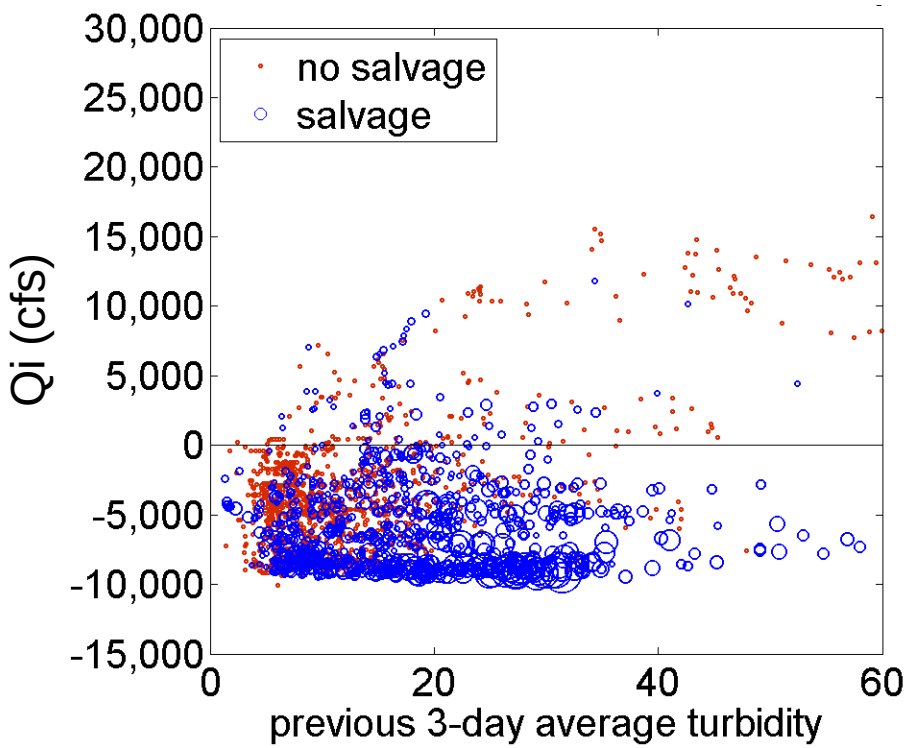
Statistical relationship with the Index Qi is as good as or better than <Qomr>.

Qi and <Qomr> compared for adult delta smelt

Normalized salvage (shown as size of bubble) as a function of flow and turbidity



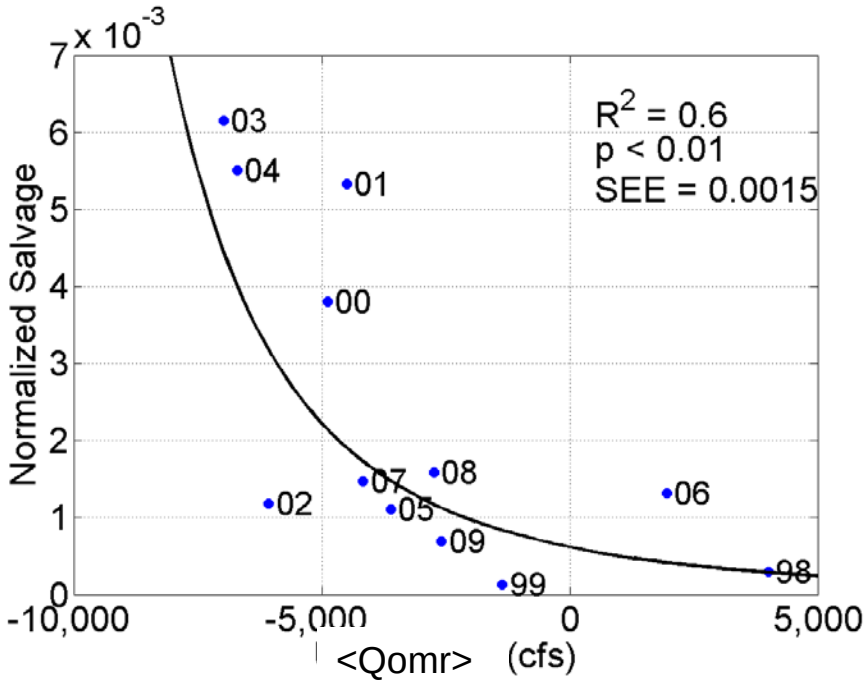
Recreation of Figure 45 from 2011 USFWS BiOp

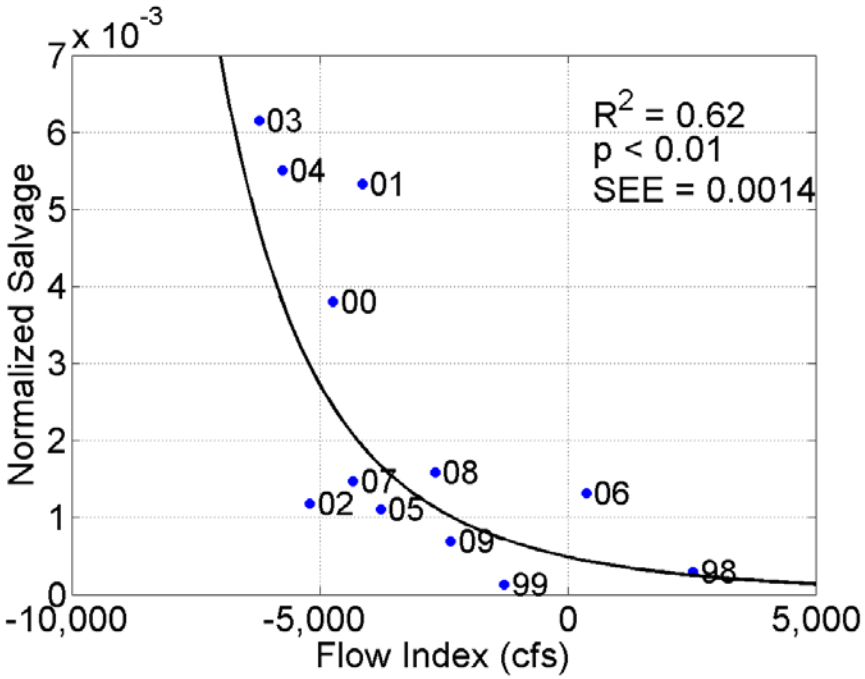


Flow Index Qi appears to reduce scatter.

Qi and <Qomr> compared for Steelhead

Seasonal aggregate of normalized hatchery steelhead salvage as a function of flows



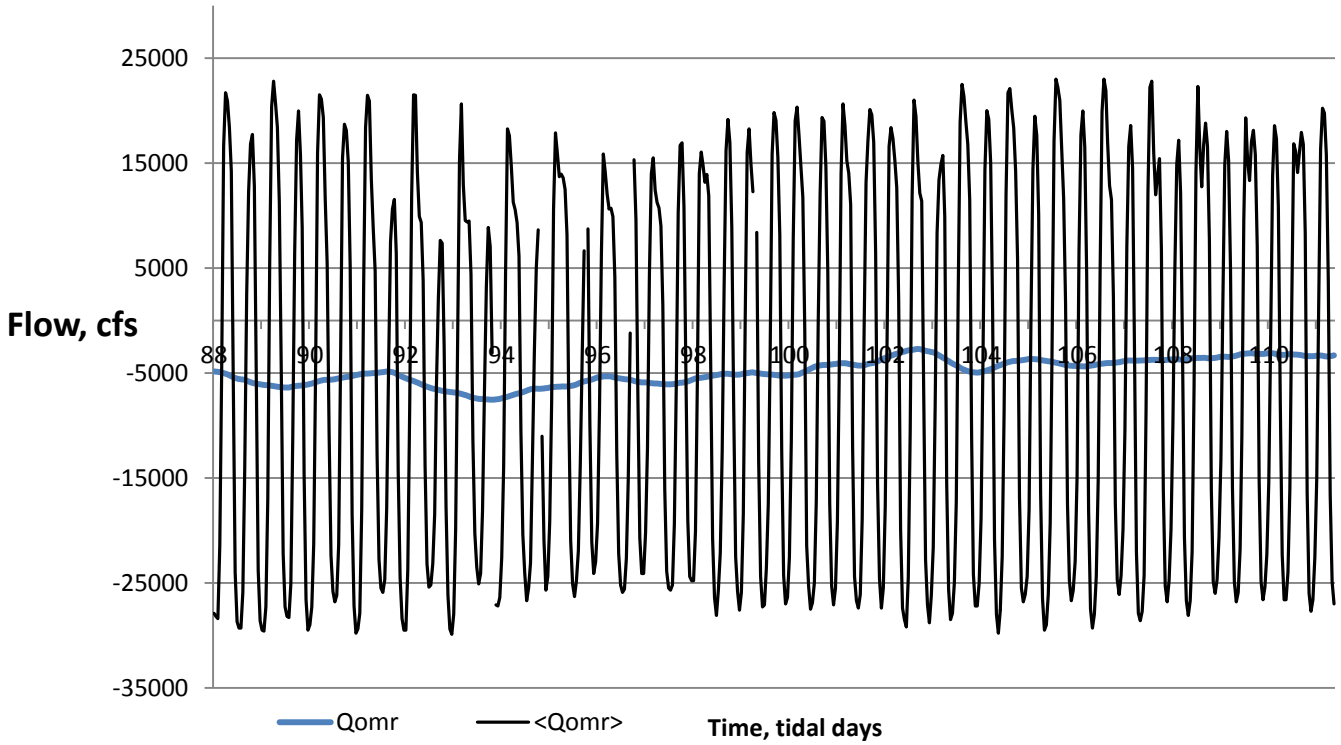


Analysis based on Grimaldo (2012)

Flow Index Qi is just as predictive as <Qomr>, but Qexp possibly better

Tidal and filtered flow

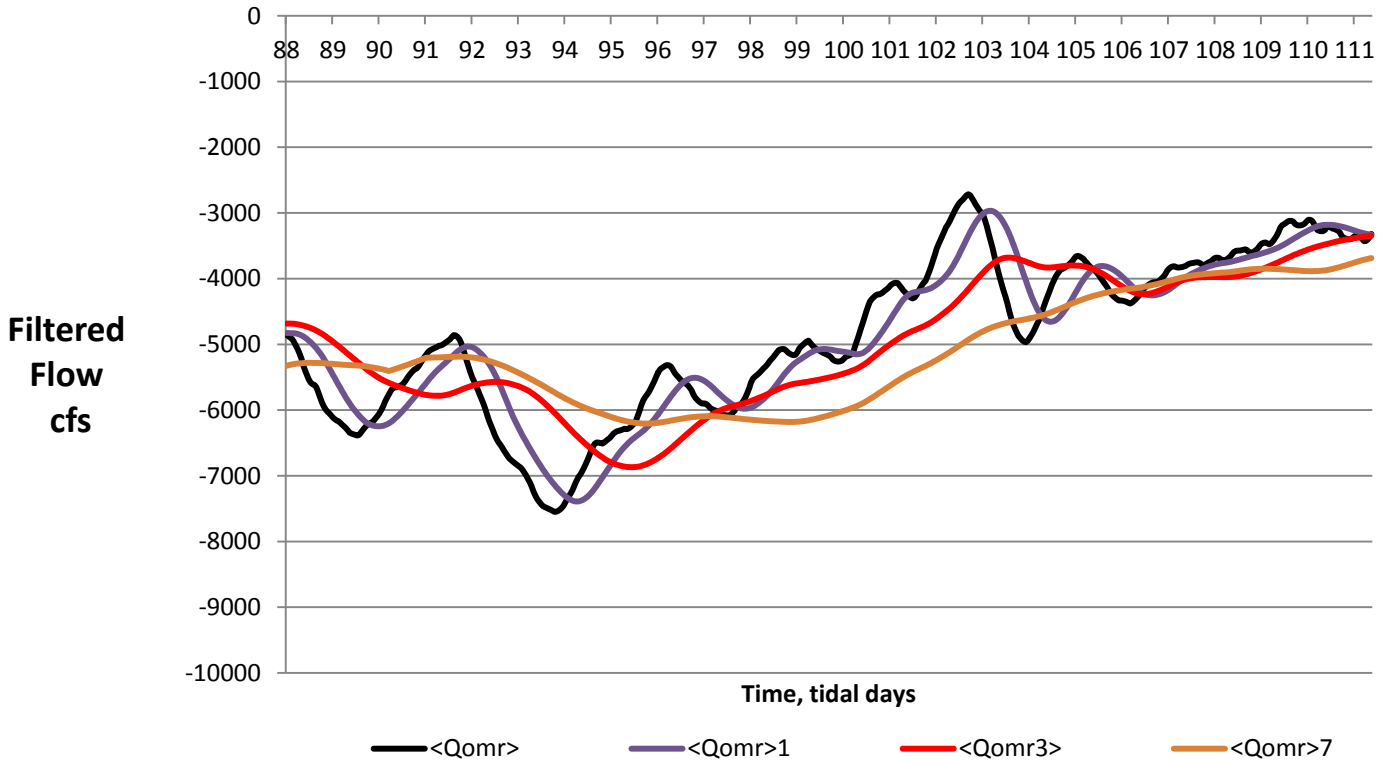
Old and Middle River Flow



Data source: USGS station Old River Bacon OBI, Middle River MDM, fall 2103

Filtered flow, effect of averaging

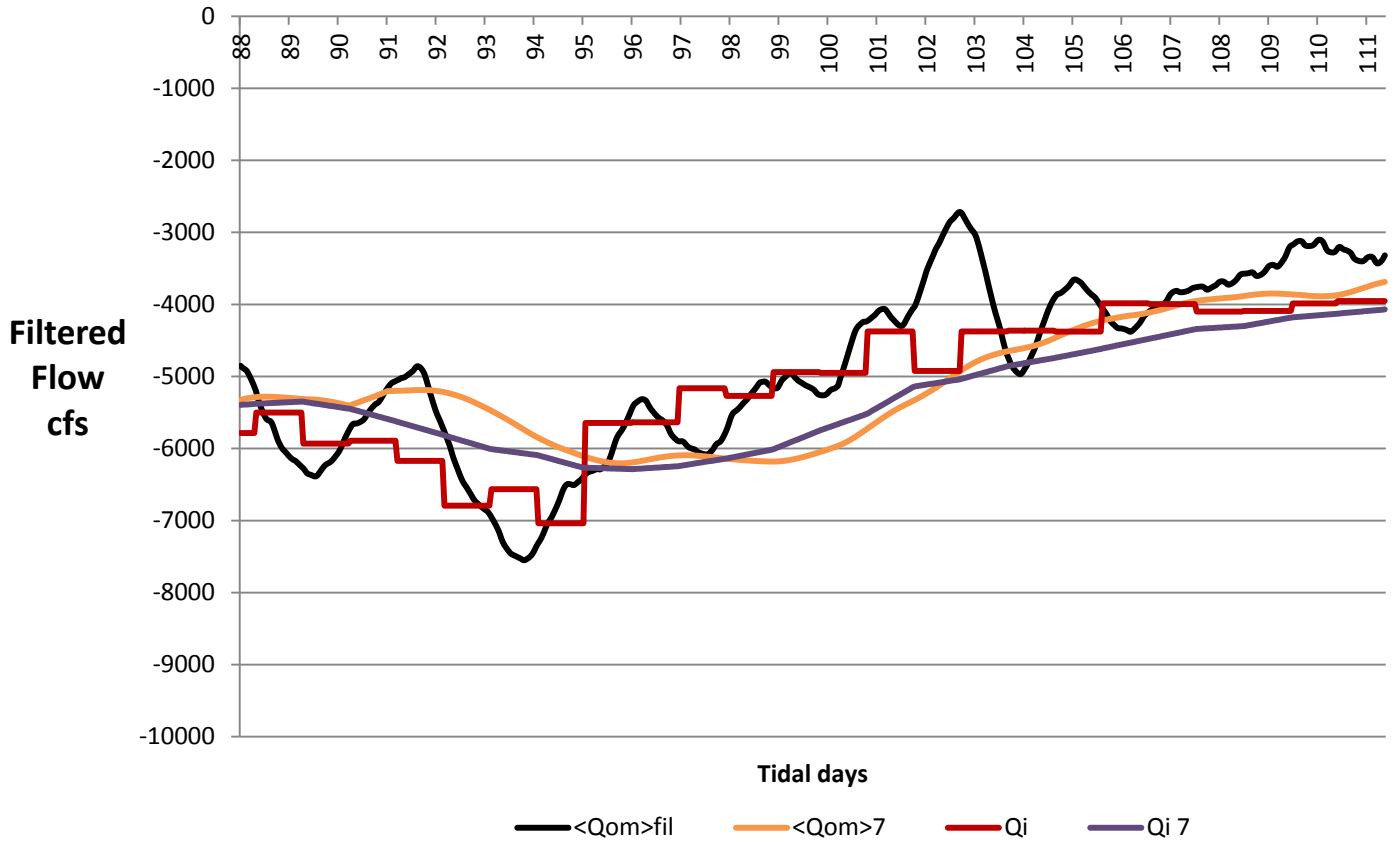
Old River Flow



Data source: USGS station Old River Bacon, Middle River MDM, fall 2013

Qi and <Qomr> compared without and with averaging

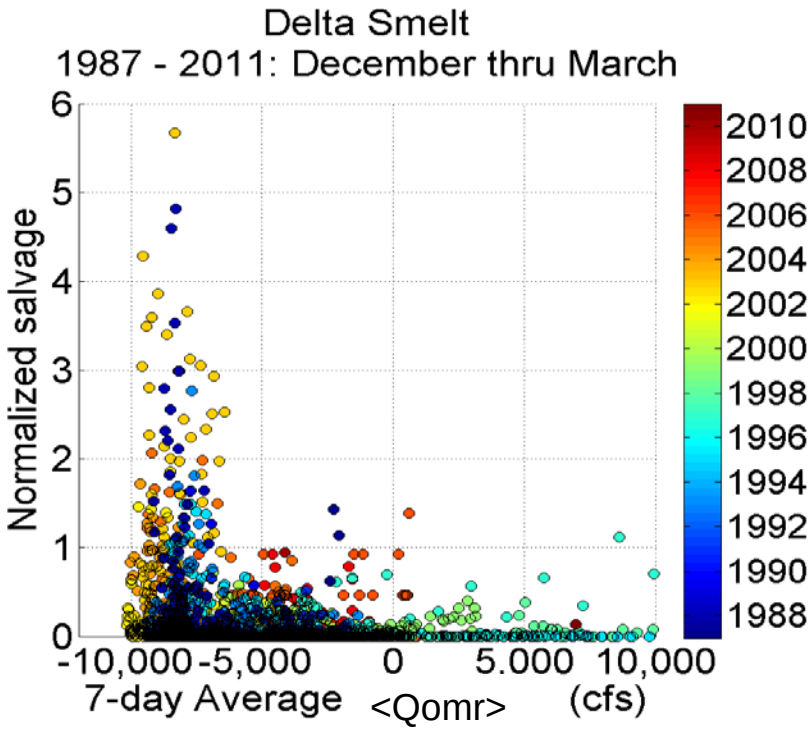
Old River Flow

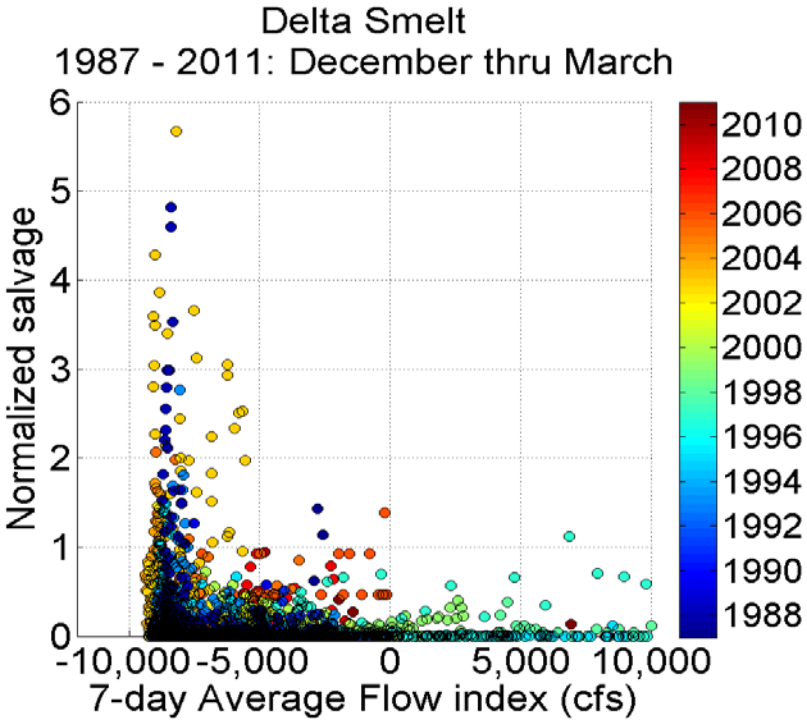


Data source: USGS station Old River Bacon and Middle River MDM, fall 2013

Seven day averaged Qi and <Qomr> compared for adult delta smelt

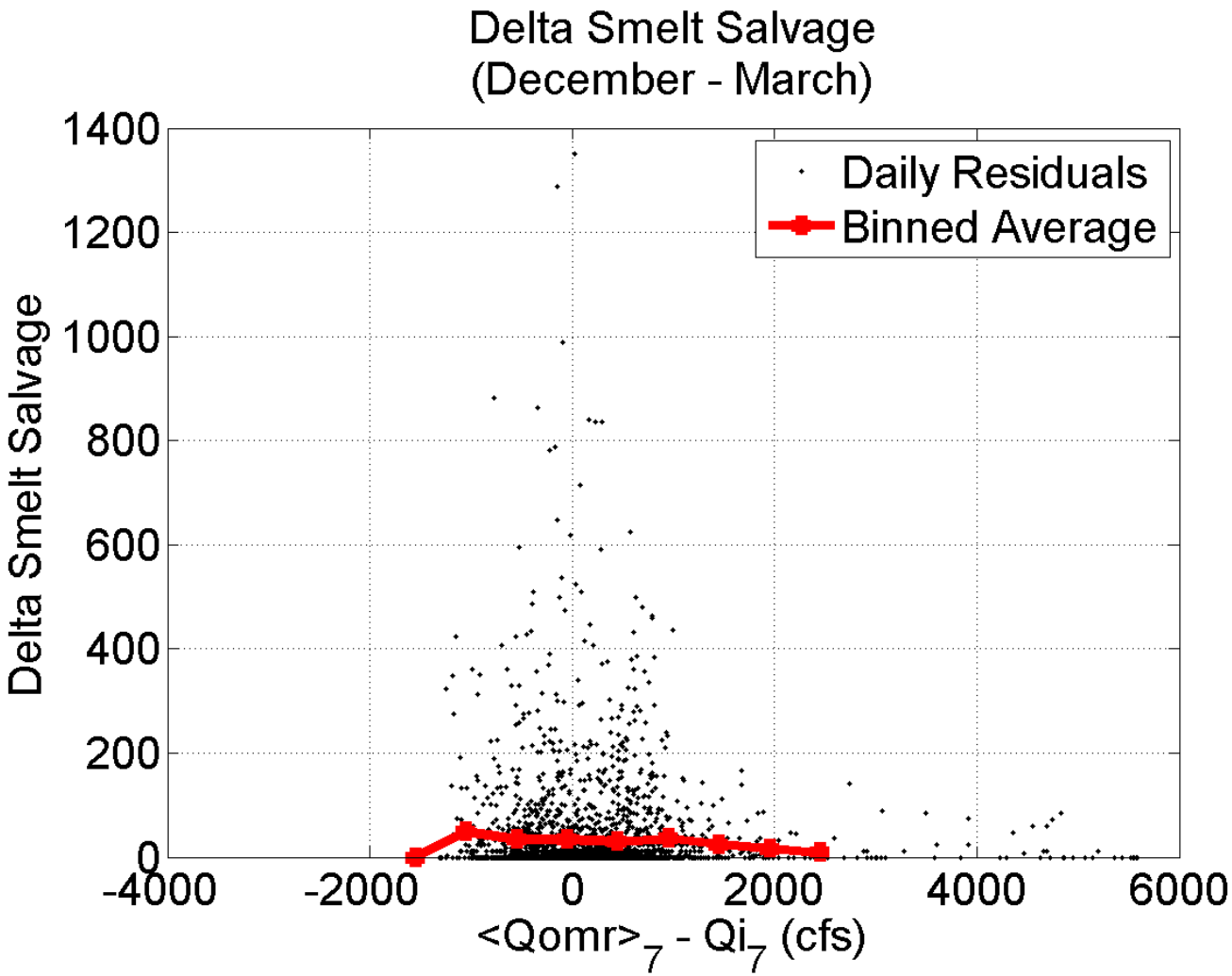
Salvage as a function of seven day average of flow



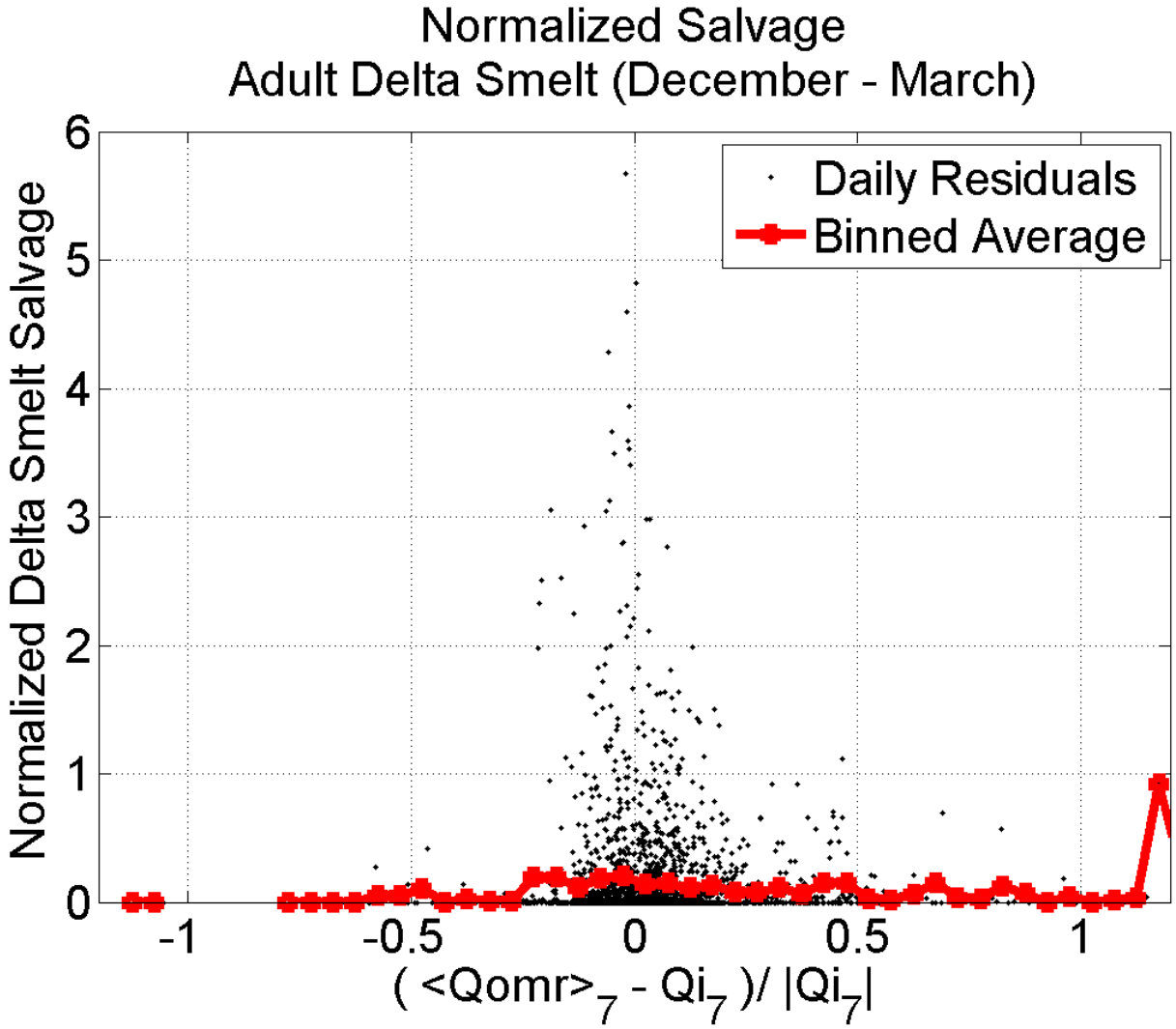


Based on Figure S-8 from 2008 USFWS BiOp
Years colored by percent estimated (Dec-Mar)

Comparison of Qi with <Qomr> 7-day averages: no trend



Comparison of Qi with <Qomr> 7 day normalized: no trend



Conclusions

- Normalize velocity (flow) for regimes and for future changes
- Important are tidal amplitude, exports, San Joaquin flows
- Avoid riverine conditions to avoid “large” salvage
- Qexp, not <Qomr> or Qi, probably appropriate for SJR salmon and steelhead
- Lagrangian frame suggests averaging over the transit time (which is a function of flow regime, Qexp and Qa)
- Comparison of <Qomr> with Qi reveals that <Qomr> provides no new information, adds noise
- Qi puts emphasis on factors that change flow regime, are directly related to salvage: dual goals