San Francisco Bay sediment transport: Comparison of sediment supply to San Francisco Bay from coastal and Sacramento-San Joaquin watersheds

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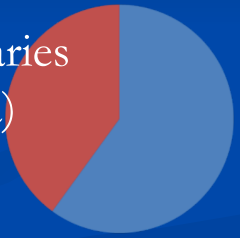
History of information development

- 1979: Ray B Krone: Roughly 80% of sediment enters the Bay system from the Central Valley
  - Sediment loads will diminish through time based on water development and demands

- As we have continued to refine estimates:
  - McKee et al., 2001; 2003 (RMP) (Rivers: 60%)



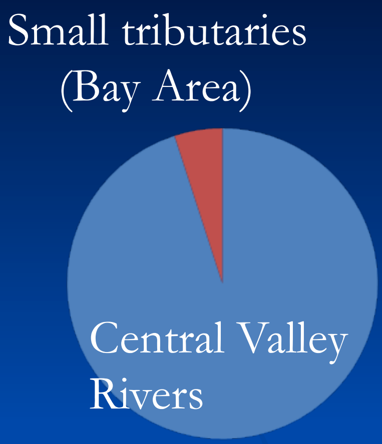
  - McKee et al., 2006 (J. Hydrol.) (Rivers: 56%)

  - Lewicki and McKee, 2010 (IAHS Pub.337) (Rivers: 44%)

Objective of this latest work

- Update the suspended sediment loads estimates
  - Provide a consistent treatment of climatic variation and non-stationarity
  - Provide spatially explicit data for use by modelers and managers

Physiography



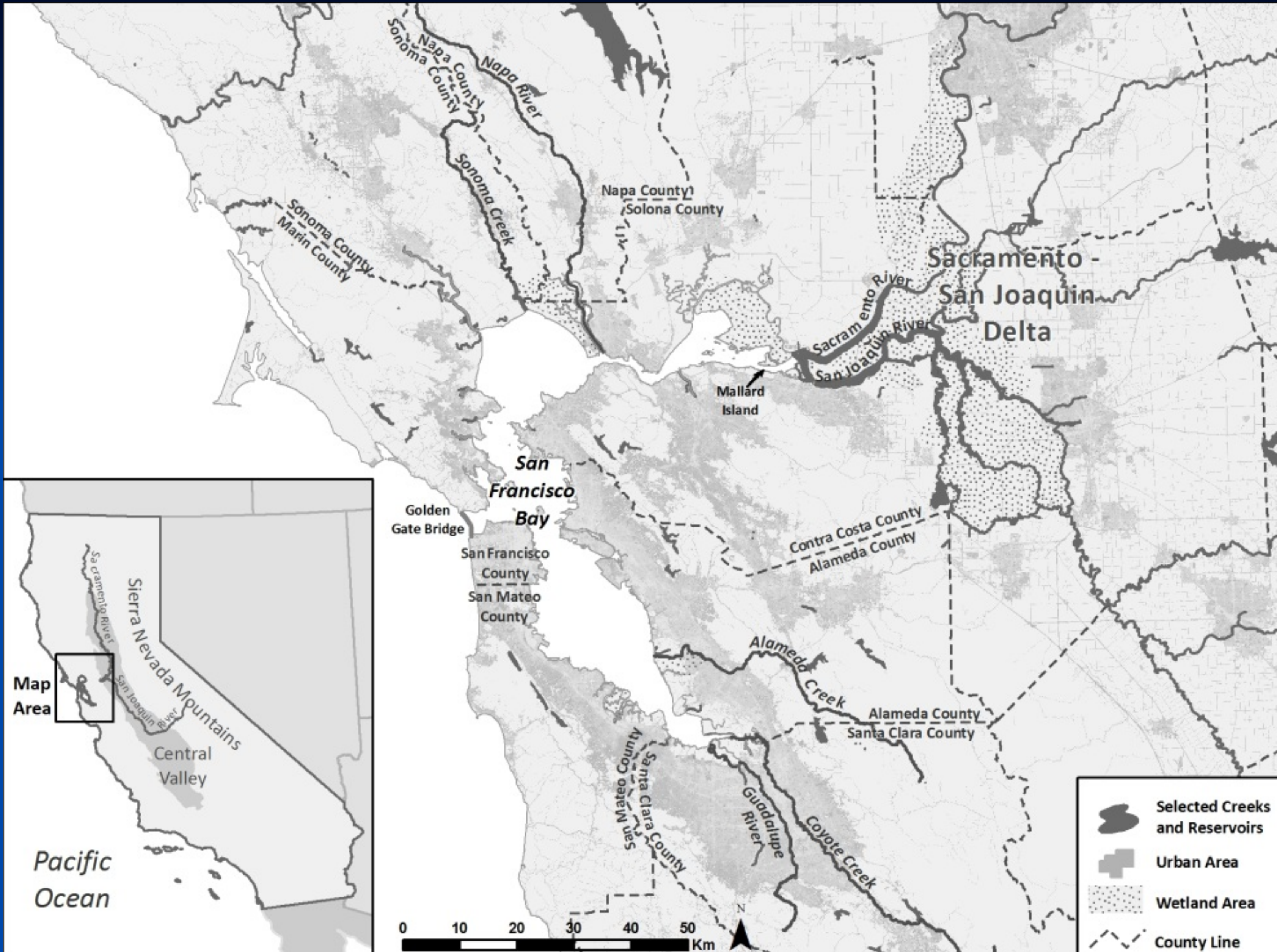
- Area
  - Golden gate watershed: 160,000 km^2
    - Central Valley: 154,000 km^2
    - Small tributaries (482 individual watersheds): 8,145 km^2

- Water flow
    - Central Valley: 25 km^3
    - Small tributaries: 1.5 km^3
- Geology
    - Central Valley: Granite
    - Small tributaries: Weak sedimentary and volcanics

Data available for loads computations

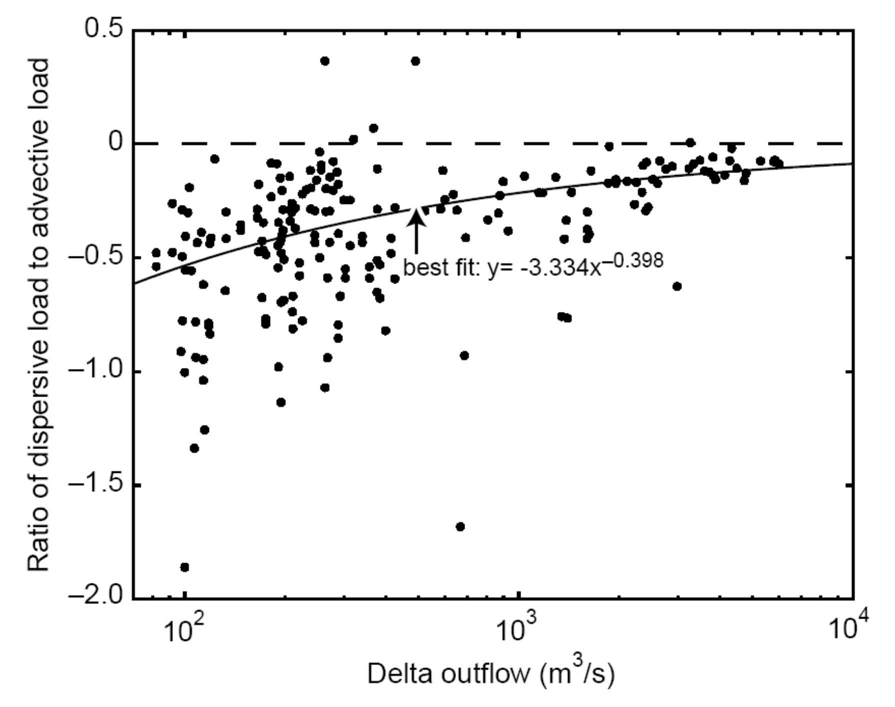
- Central Valley
  - Day flow – delta outflow (1 day time step)
  - USGS suspended sediment record at Mallard Island (15 minute)
  - Acoustic Doppler Current Profiler (ADCP) data:
    - WY 1994 near surface and mid depth
    - WY 1996 near surface

- Small tributaries surrounding the Bay
  - GIS watershed boundary shape file (incl. storm-drain-sheds)
  - GIS land use data
  - Peak annual flow data
  - 235 station years from 38 locations (51% of the area)
  - Suspended sediment mostly <63 microns


Napa County
Sonoma County
Napa River
Sonoma Creek
Napa County
Solona County
Sonoma County
Marin County
Sacramento River
San Joaquin River
Sacramento - San Joaquin Delta
Mallard Island
San Francisco Bay
Golden Gate Bridge
San Francisco County
San Mateo County
Contra Costa County
Alameda County
Alameda Creek
Alameda County
Santa Clara County
San Mateo County
Santa Clara County
Guadalupe River
Coyote Creek
0 10 20 30 40 50 Km
N
Selected Creeks and Reservoirs
Urban Area
Wetland Area
County Line
Sacramento River
Sierra Nevada Mountains
San Joaquin River
Map Area
Central Valley
Pacific Ocean

Computation methods – Central Valley

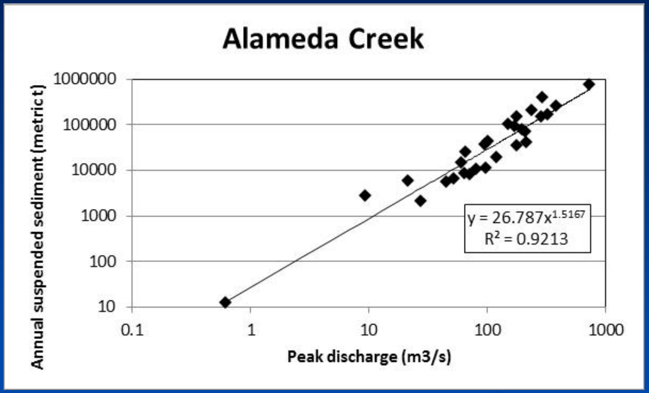
- Followed published methods (McKee et al., 2006, J. Hydrol.)
- A correction factor (Ratio of dispersive to advective flux in relation to flow) was calculated
  - CF (7%-82%, average = 20%)



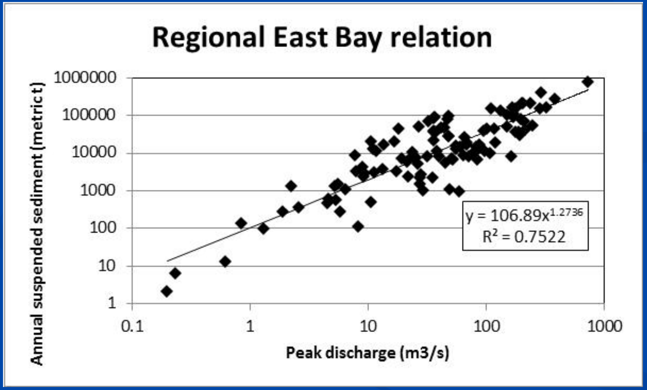
- Suspended sediment load = SSC 24 hr average x Delta outflow * CF

Computation methods – Small tributaries

- Watersheds with empirical field data
  - Watershed specific regression



- Without empirical field data dominated by non-urban land use
  - Regional regression specific to three provinces



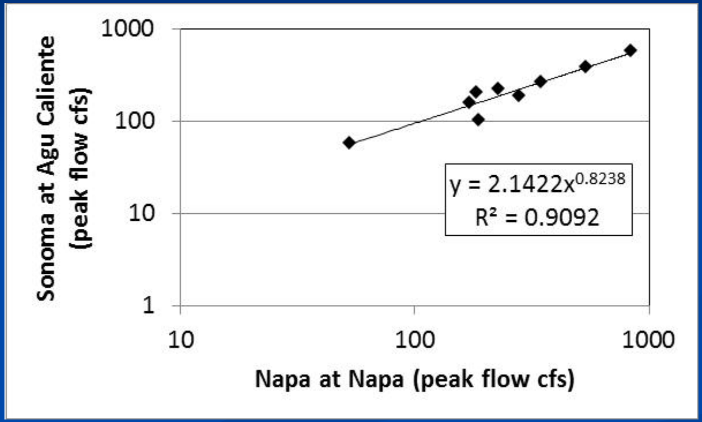
- Without empirical field data dominated by urban land use
  - Land use based method

Donigian and Love (2003) and EPA (2008).

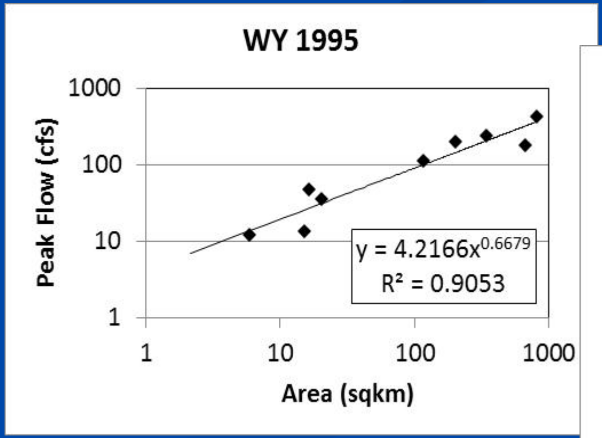
	Natural	Agriculture	Low Density Urban	High Density Urban	Industrial
Sediment production (metric t/km2/year)	72	2,461	450	996	1,836

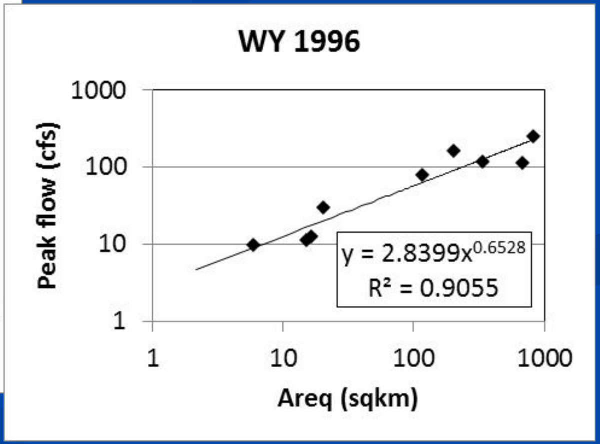
Computation methods – Small tributaries

- Estimating instantaneous peak flow in the absence of a USGS data record



  - Local regression
  - Regional water-year specific regressions



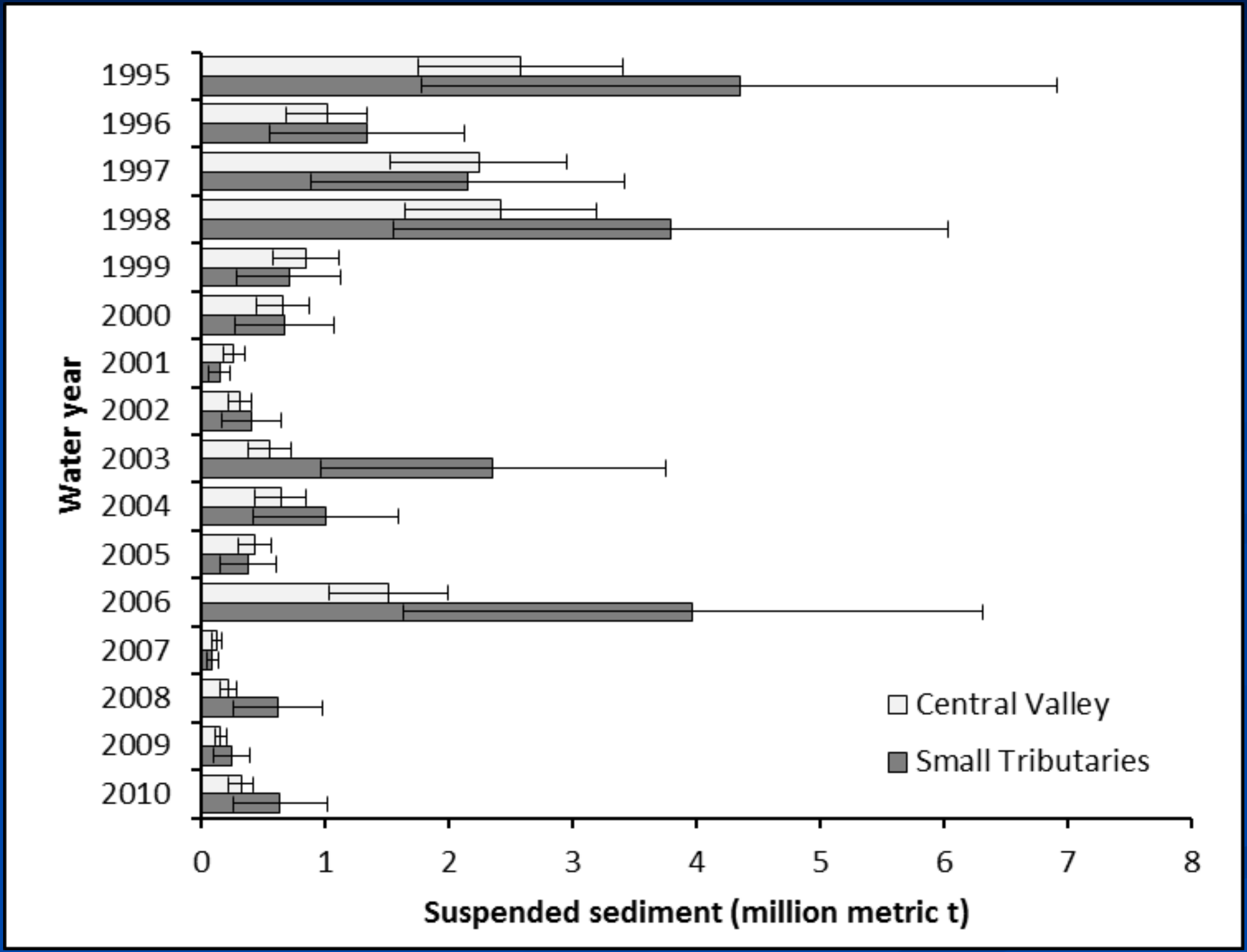


Results (WYs 1995 – 2010 (16 years))

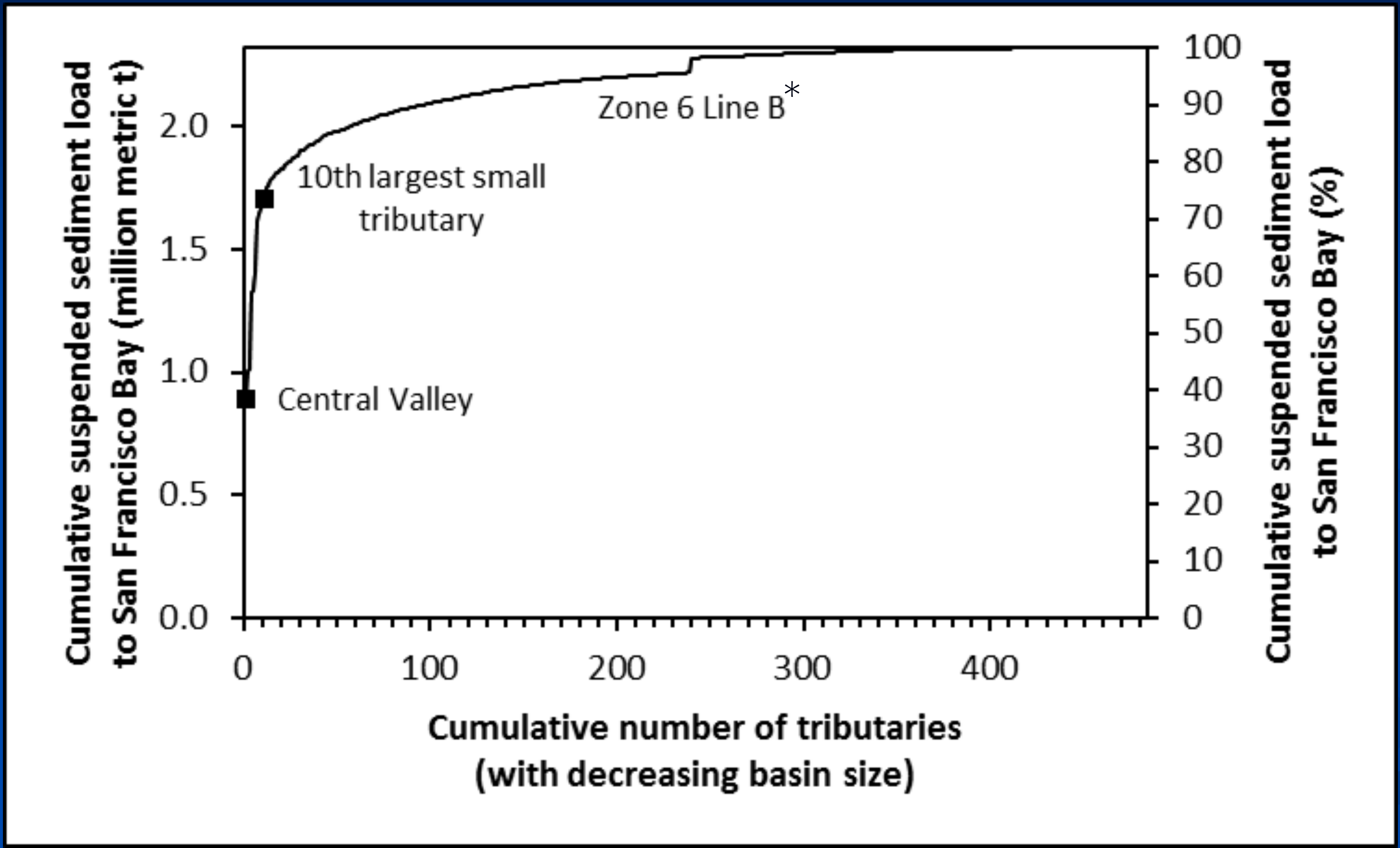
- Central Valley
  - MAR (1971-2010): 23 km^3
  - Flow 1995-2010: 25 km^3
    - 7-fold variation between years
  - SS load: 0.125 – 2.58 (0.89) Mt
    - 16-year total = 14.3 Mt
    - 21-fold variation
- Small tributaries
  - MAR (1971-2010): 1.54 km^3
  - Flow 1995-2010: 1.84 km^3
    - 8-fold variation between years
  - SS load: 0.089 – 4.35 (1.43) Mt
    - 16-year total = 22.8 Mt
    - 49-fold variation

	Central Valley			Small Tributaries		
Water Year	Runoff (km3)	Load (Million metric t)	Error (+/- Million metric t)	Runoff (km^3)	Load (Million metric t)	Error (+/- Million metric t)
1995	51.559	2.58	0.826	3.93	4.35	2.22
1996	31.436	1.01	0.324	2.31	1.33	0.679
1997	42.307	2.24	0.717	2.62	2.15	1.10
1998	53.639	2.42	0.774	3.94	3.79	1.93
1999	27.805	0.842	0.270	1.43	0.705	0.360
2000	22.394	0.659	0.211	1.33	0.673	0.343
2001	8.565	0.263	0.084	0.575	0.144	0.0737
2002	11.303	0.309	0.099	1.24	0.404	0.206
2003	17.330	0.546	0.175	1.80	2.36	1.20
2004	18.577	0.640	0.205	1.44	1.00	0.510
2005	19.000	0.428	0.137	1.94	0.379	0.193
2006	54.033	1.51	0.484	3.54	3.97	2.02
2007	7.668	0.125	0.0401	0.476	0.089	0.0454
2008	8.233	0.216	0.0692	0.906	0.612	0.312
2009	8.280	0.156	0.0498	0.683	0.249	0.127
2010	12.781	0.319	0.102	1.31	0.636	0.324
Total	394.909	14.3	4.565	29.5	22.8	11.6
Minimum	7.668	0.125	0.040	0.476	0.0890	0.0454
Maximum	54.033	2.58	0.826	3.94	4.35	2.22
Mean	24.682	0.892	0.285	1.841	1.43	0.73
Variation	7.0	21	-	8.3	49	-

Temporal variation

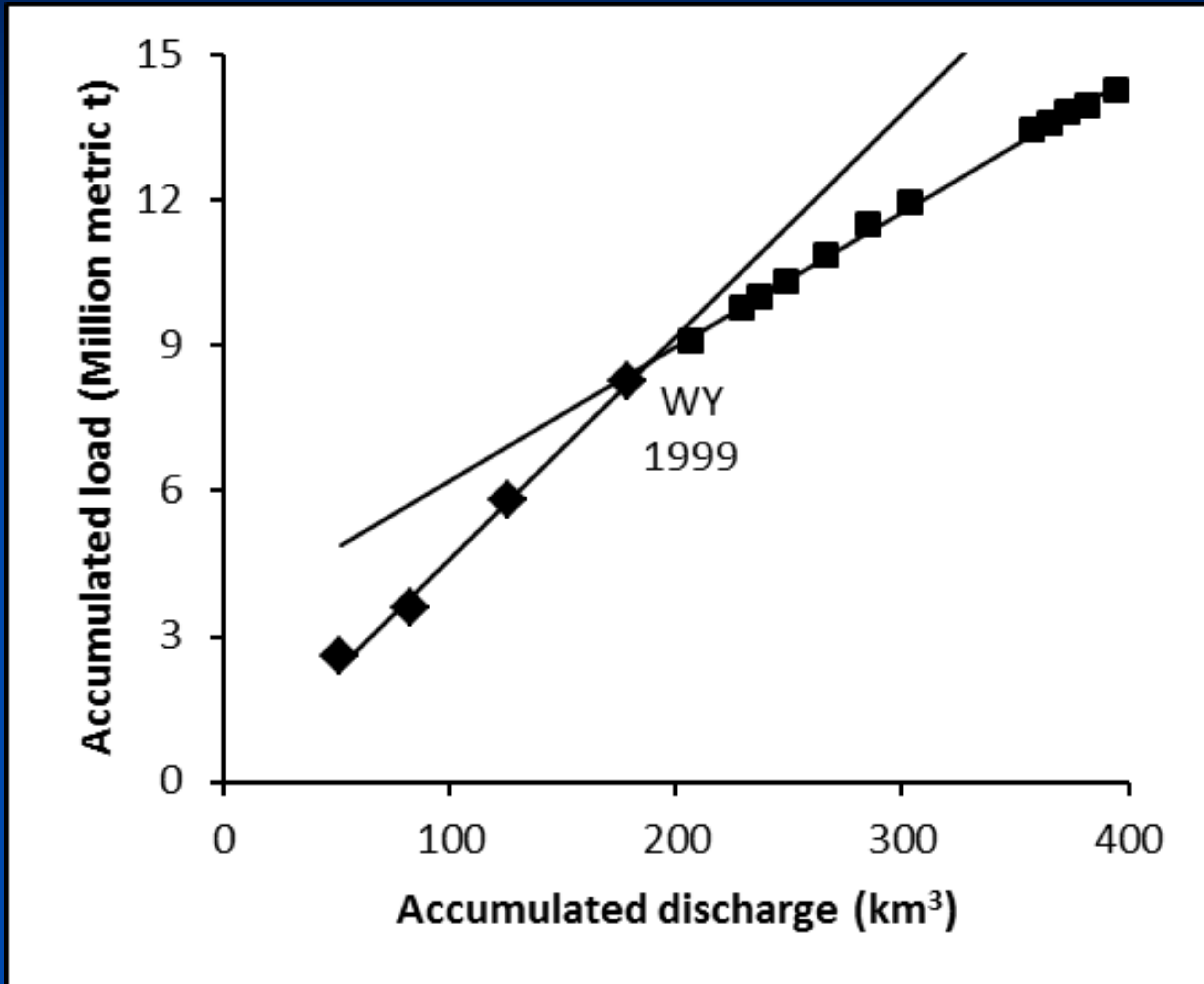


Cumulative area and loads plot

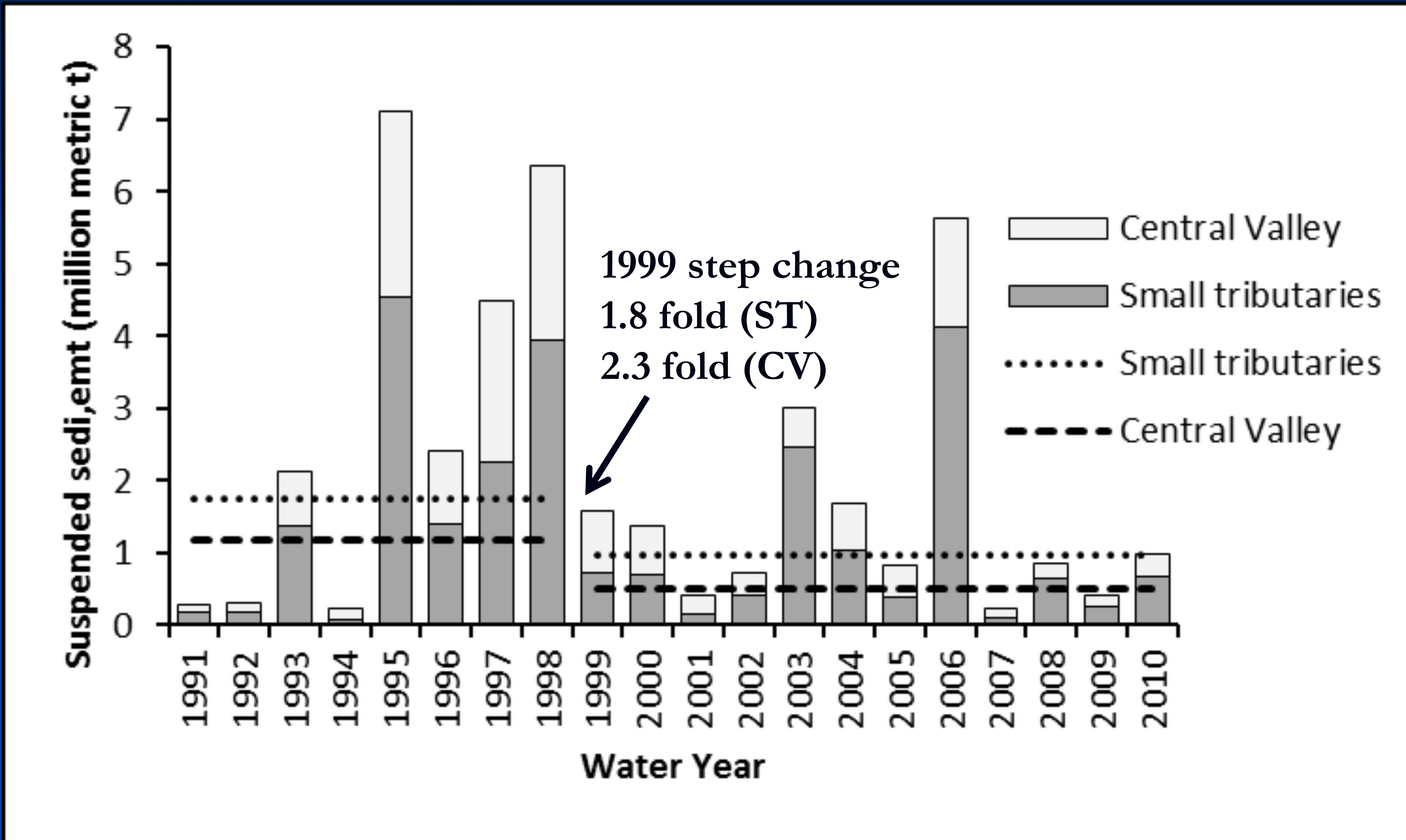


* Small urbanizing steep watershed with very high sediment production

Double mass plot (cumulative flow v cumulative load)



Step change (cf Schoellhamer, 2011



Summary

- Predictions of Ray Krone seem to have become reality
- Bay sediment supply has switched from **<u>Central Valley dominated</u>** to local small tributary dominated

<u>1960 average</u>
3 M t
76%

Summary

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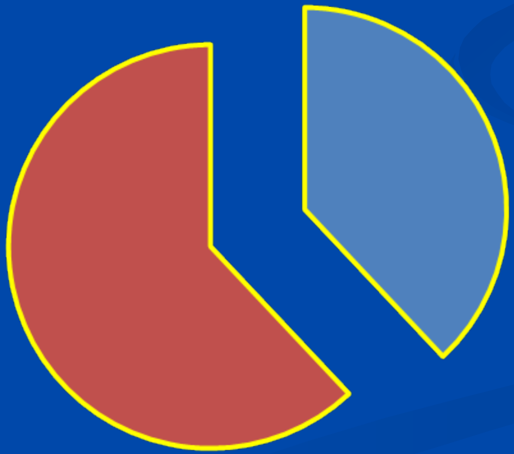

1995-2010 average
0.89 M t
38%

Conclusions

- Highly spatially and temporally resolved suspended sediment data is now available for modelers and managers
- Managers responsible for sediment accumulating in shipping channels and restoring wetlands may need to more carefully account for proximity to urban tributaries and contaminant sources
- Sediment loads can go through step changes in relation to supply and climate – during the next 5-10 years, a fuller understanding of the causes and management implications of the step changes will grow
- The lack of treatment of bedload data remains a weakness and is the subject of ongoing research by McKee and others

Acknowledgements

Funding: Regional Monitoring Program for Water Quality in San Francisco Bay (3 reports and 4 journal articles)

- McKee et al., 2002 (Technical Report)
- Leatherbarrow et al., 2005 (Technical Report)
- McKee et al., 2006 (Journal of Hydrology, v323)
- Lewicki and McKee, 2009 (Technical Report)
- David et al., 2009 (Environmental Toxicology and Chemistry, v28 no10)
- Lewicki and McKee, 2010 (IAHS Pub 337)
- David et al., in review (Water Environment Research)
- McKee et al., in review (Marine Geology)

Oversight: Sources Pathways and Loading Workgroup (1998- present)