

ANNUAL SEDIMENT LOAD IN SANTA CRUZ RIVER

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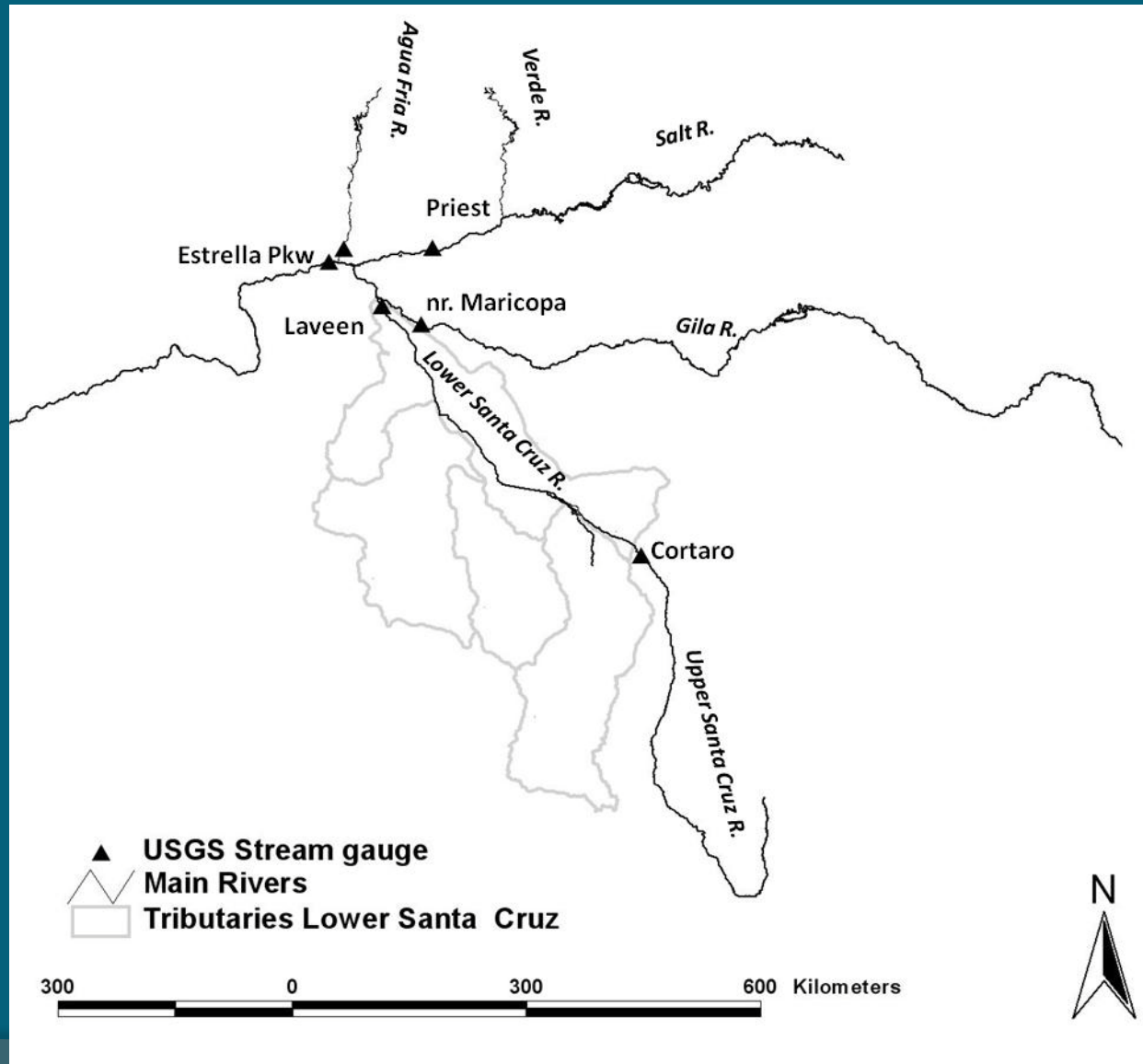
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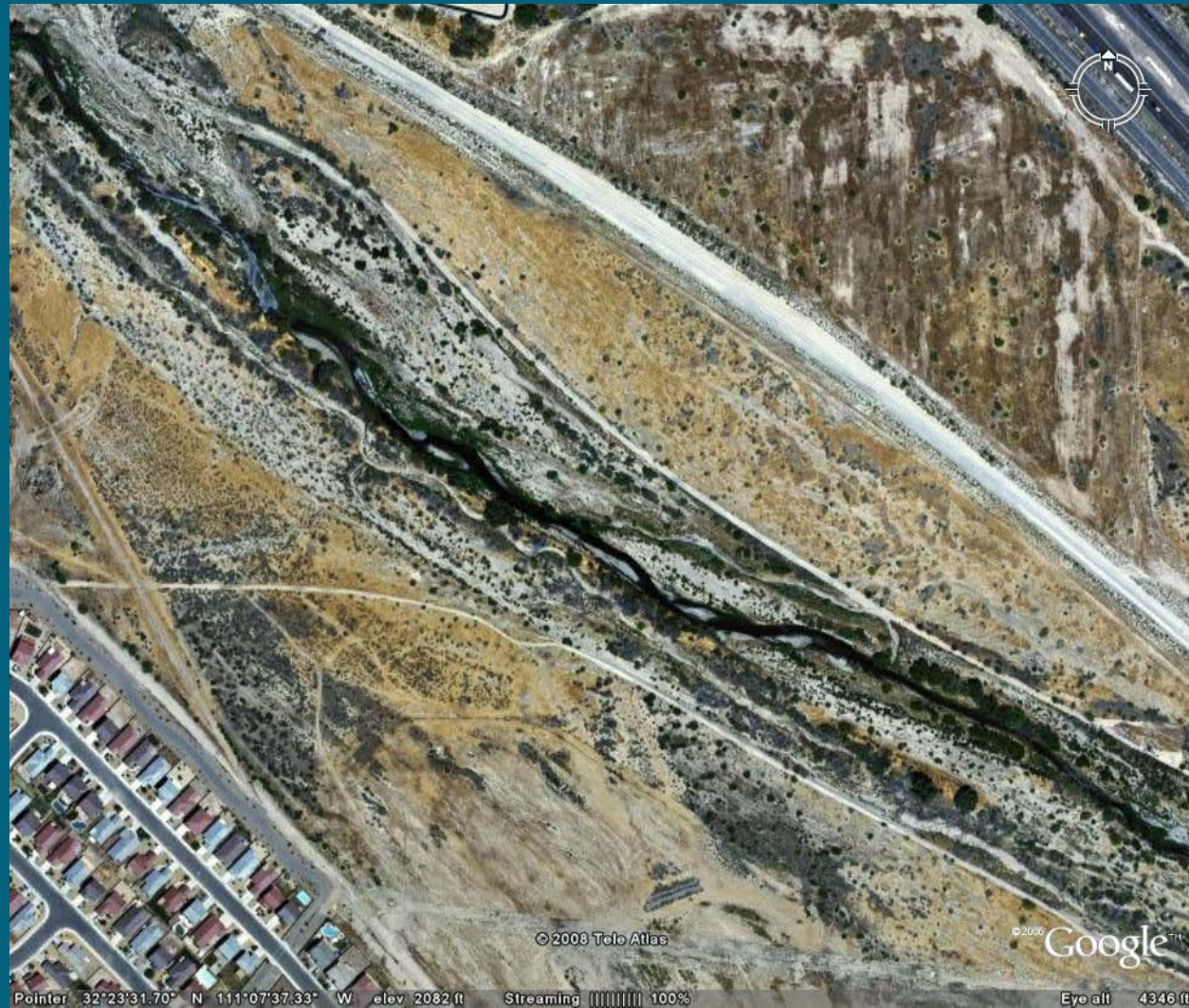
Project Background

- The project aims to determine the hydrologic connections between Santa Cruz River and Gila River
- Quantify annual sediment load from Santa Cruz River to Gila River from 1993-2008
- Determine the maximum daily sediment load occurred in Santa Cruz River
- Determine the contribution of sediment load from Santa Cruz to Gila River

Study Site



Santa Cruz River near Confluence



Flow Discharge Records

- The **Laveen Gage** is the last gage on the lower Santa Cruz River. It has recorded flow discharge nearly year-round since 1940.
- The calculation of sediment load requires the gage height data for determining stream power, and these data has also been recorded since 1993.
- Upstream of the Laveen Gage at **the Cortaro Gage**, the flow is perennial due to the discharge of sewage effluent from the sewage treatment plants. The Cortaro Gage has both gage height and discharge records since 1996.
- This study used daily discharges and daily averaged gage heights to calculate daily total sediment load. The annual sediment load through each gage is the summation of daily sediment load over an entire year.

Sediment Equations

- ◉ Among over 40 sediment load transport equations (Laursen 1958; Toffaleti 1966; Engelund and Hansen 1972; Yang 1973) Laursen (1958) and Yang (1973) are applicable to fine grain sized sediment having a size less than 0.0625mm.
- ◉ All of the equations have limited accuracies when applying to field sites, especially for dry-land rivers in the semi-arid region.
- ◉ This study first evaluated which sediment transport equation is applicable to the study site using limited measured data.
- ◉ Both the Laursen (1958) and Yang (1973) equations are used to estimate the total sediment load for those days having sediment load measurements.

Number	Sediment Function	Sediment size (mm)	Mean size (mm)	Specific gravity	Velocity (m/s)	Flow depth (m)	Channel slope (S x1000)	Channel width (m)	Water temperature (°F)
1	Ackers -White (1973)	0.040-7.00	NA	1.00-2.70	0.021-2.164	0.003-0.427	0.060-37.000	0.070-1.220	46-89
2	Engelund - Hansen (1967)	NA	0.19-0.93	2.65	0.198-1.933	0.058-0.405	0.055-0.019	2.44	45-93
3	Copeland - Lausen (1989)	0.011-290.000	NA	0.70-9.40	0.009-1.097	0.00007-0.008	0.250-25.000	0.076-1109.756	32-93
4	Tofaletti (1969)	0.062-4.000	0.09-0.91	2.65	0.213-2.378	0.021-17.287	0.140-19.000	0.244-1109.756	32-93
5	Yang (1972)	0.150-7.000	NA	2.65	0.243-1.951	0.012-15.244	0.043-29.000	0.134-533.537	32-94
6	Bagnold (1966)	0.120-200.000	NA	2.65	0.244-2.134	0.091-2.287	12.400-25.800	0.235-6.548	35-86
7	Bishop et al. (1965)	0.190-0.930	0.37	1.87-2.65	0.200-1.897	0.030-0.405	0.055-19.280	0.610-2.439	44-94
8	Brownlie (1981)	0.062-0-76.000	0.08-2.80	2.65	0.008-3.719	0.009-17.282	0.002-36.700	0.021-1109.000	32-146
9	Brownlie (1983)	0.062-76.000	0.08-2.80	2.65	0.008-3.719	0.009-17.282	0.0021-36.700	0.021-1109.000	32-146
10	Chang et al. (1965)	NA	0.19-0.93	2.65	0.091-0.305	0.019-0.488	1.000-15.000	2.439	34-100
11	Colby (1964)	0.100-0.800	0.20-0.30	2.65	0.030-3.049	0.030-30.488	0.010-18.000	0.267-2.439	40-80
12	Einstein (1950)	NA	0.06-8.00	2.65	0.020-0.063	0.152-3.049	1.000-1.050	1.524-198.171	32-95
13	Egiazaroff (1965)	0.050-20.000	0.07-0.77	2.65	NA	NA	0.900-11.000	NA	36-96
14	Karim-Kennedy (1981)	NA	0.13-28.65	2.65	0.300-2.700	0.030-5.900	0.080-24.300	0.610-2.440	33-100
15	Graf et al. (1968)	0.010-30.000	0.30-1.70	2.65	0.198-2.134	0.091-0.400	0.500-1.000	0.065-3.865	35-90
16	Graf et al. (1987)	0.010-28.000	0.30-1.70	2.65	0.152-2.350	0.065-0.500	0.300-1.900	0.700-5.090	35-90

17	Colby- Hembree (1955)	0.031-28.600	0.19-4.00	2.65	0.268-2.220		12.400-25.800	21.341-36.585	35-85
18	Vanoni -Raudkivi (1975,1976)	NA	0.19-0.93	2.65	0.198-1.933	0.058-0.405	0.055-19.000	2.439-2.500	45-93
19	Maddock (1976)	0.001-100.000	0.40-2.35	2.65	0.622-0.878	0.183-0.200	0.600-3.200	0.305-1.341	35-86
20	HR Wallingford (1990)	0.040-7.000	NA	1.00-2.70	0.021-2.165	0.003-0.427	0.060-37.000	0.070-1.220	46-89
21	Yang (1979)	0.062-2.000	0.15-1.71	2.65	0.230-1.970	0.010-15.198	0.043-27.900	0.116-532.012	32-94
22	Yang (1984)	3.170-7.010	NA	2.65	0.221-1.549	0.009-0.226	0.120-13.400	0.200-0.400	32-94
23	Yang et al. (1996)	0.007-0.091	NA	2.65	0.260-5.470	0.509-11.290	0.010-0.100	55.000-1500.000	87-88
24	Yang-Lim (2003)	0.400-7.650	0.83-3.54	2.65	0.150-0.733	0.020-0.220	0.500-1.000	0.061-1.000	34-111
25	Moore-Burch (1986)		0.06-2.00	2.65	0.183-2.134	0.010-16.250	1.000-40.000	0.105-4.000	50-69
26	Velikanov (1954)	0.033-3.250	NA	2.65	0.150-2.845	0.010-4.635	0.010-32.500	NA	NA
27	Vittal et al. (1973)	0.009-12.652	0.01-7.36	2.65	0.091-4.350	0.020-11.260	0.080-18.735	0.070-260.583	32-96
28	RangaRaju et al. (1981)	0.007-9.856	0.01-3.60	2.65	0.126-2.500	0.017-10.000	0.090-16.000	0.067-253.963	32-98
29	Wu et al. (2000)	0.010-128.000	0.06-2.37	2.65	0.140-2.800	0.030-4.400	0.110-16.200	0.204-558.130	42-96
30	Molinas-Wu (2001)	0.090-1.300	0.10-0.90	2.65	0.230-1.670	0.056-1.496	0.930-12.700	0.260-46.630	33-77
31	Rottner (1959)	0.150-7.000	NA	2.65	0.198-2.546	0.003-14.924	0.060-30.568	0.020-35.625	40-95

Yang (1972, 1973) Relation

Yang (1972, 1973) relation is based on the concept of unit stream power, which is defined as the power available per unit weight of fluid to transport sediment, which is written as VS/ω_f , where V = velocity, S = energy slope, ω_f = fall velocity.

Using the multiple regression analysis for 463 sets of laboratory data. Yang (1972, 1973) sediment transport equation is obtained as

$$\log C_t = 5.435 - 0.286 \log \frac{\omega_f d_{50}}{\nu} - 0.457 \log \frac{u_*}{\omega_f} + (1.799 - 0.409 \log \frac{\omega_f d_{50}}{\nu} - 0.314 \log \frac{u_*}{\omega_f}) \log \left(\frac{VS}{\omega_f} - \frac{V_c S}{\omega_f} \right)$$

in which C_t = total sediment concentration by weight in ppm, (or mg/l)

ω_f = sediment fall velocity

d_{50} = sediment mean size

ν = kinematic viscosity

u_* = friction velocity

V_c = critical velocity for sediment incipient motion

Yang (1972, 1973) Relation

The dimensionless critical velocity can be calculated as

$$\frac{V_c}{w_f} = \frac{2.5}{\log(u_* d_{50} / \nu) - 0.06} + 0.66 \quad \text{for} \quad 1.2 < \frac{u_* d_{50}}{\nu} < 70$$
$$\frac{V_c}{w_f} = 2.05 \quad \text{for} \quad \frac{u_* d_{50}}{\nu} \geq 70$$

Yang's (1973) laboratory data set on which Eq. 2.6.1 was based includes the data of Guy, Simons and Richardson (1966), Williams (1967), Vanoni and Brooks (1957), and Kennedy (1961) as well as others for which flow depths were from 0.03m to 0.3m.

The coefficients in Equations are obtained from the regression analysis. The correlation for determining the coefficients is 0.94.

Larsen (1958) relation

Larsen (1958) relation is valid for sediment ranging from 0.011mm to 29mm. The expression is below,

$$C_m = 0.01\gamma \left(\frac{d_s}{D} \right)^{7/6} \left(\frac{\tau'_0}{\tau_c} - 1 \right) f \left(\frac{u_*}{\omega} \right)$$

where C_m = sediment concentration in weight per unit flow discharge

d_s = sediment mean size

u_* = shear velocity

τ'_0 = shear stress due to grain resistance

τ_c = critical shear stress

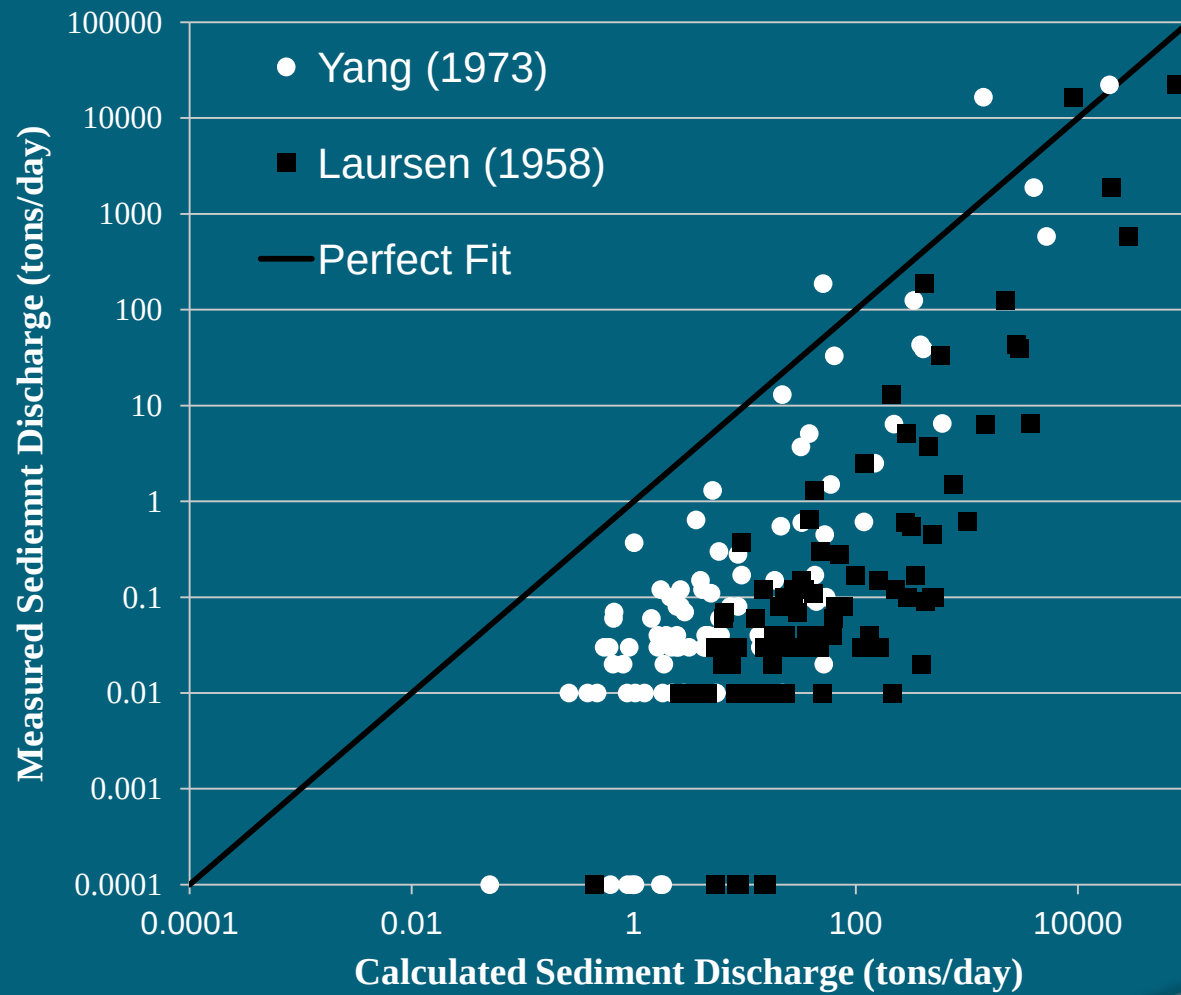
D = flow depth

γ = specific weight

ω = fall velocity

Flow Properties

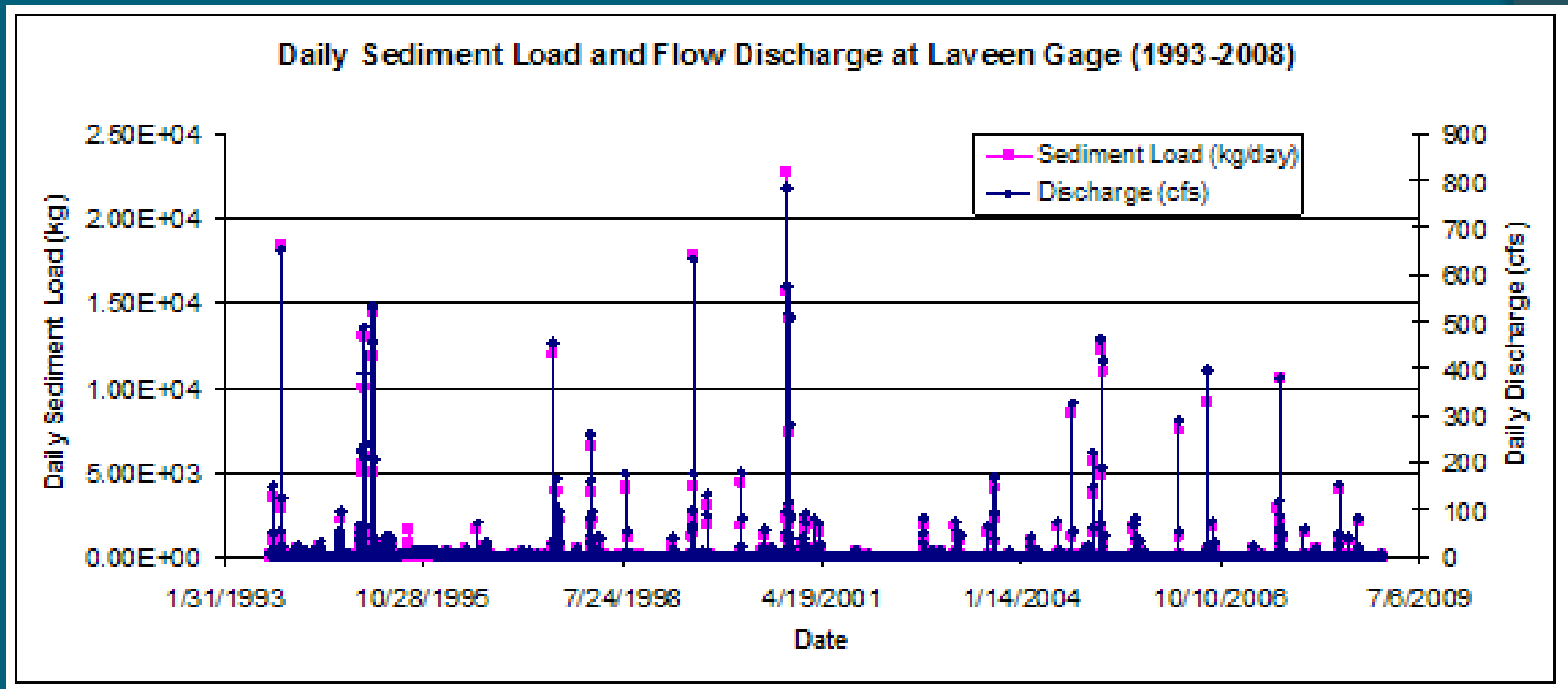
- ◉ Flow depth is assumed to be the measured gage height. Bed slope varies as sedimentation and erosion occurred in the main channel.
- ◉ JE Fuller (2004) showed the bed slope at the Laveen reach varied from 0.5% to 0.9%. Due to the lack of sufficient bed survey, the calculation of sediment load used an averaged bed slope of 0.7%.
- ◉ Fuller (2004) stated that bed material at the lower Santa Cruz varies from 0.4mm to 1.2mm from visual observations. The study assumed the mean sediment size is 0.8mm, which represents sediment size for the lower reach.



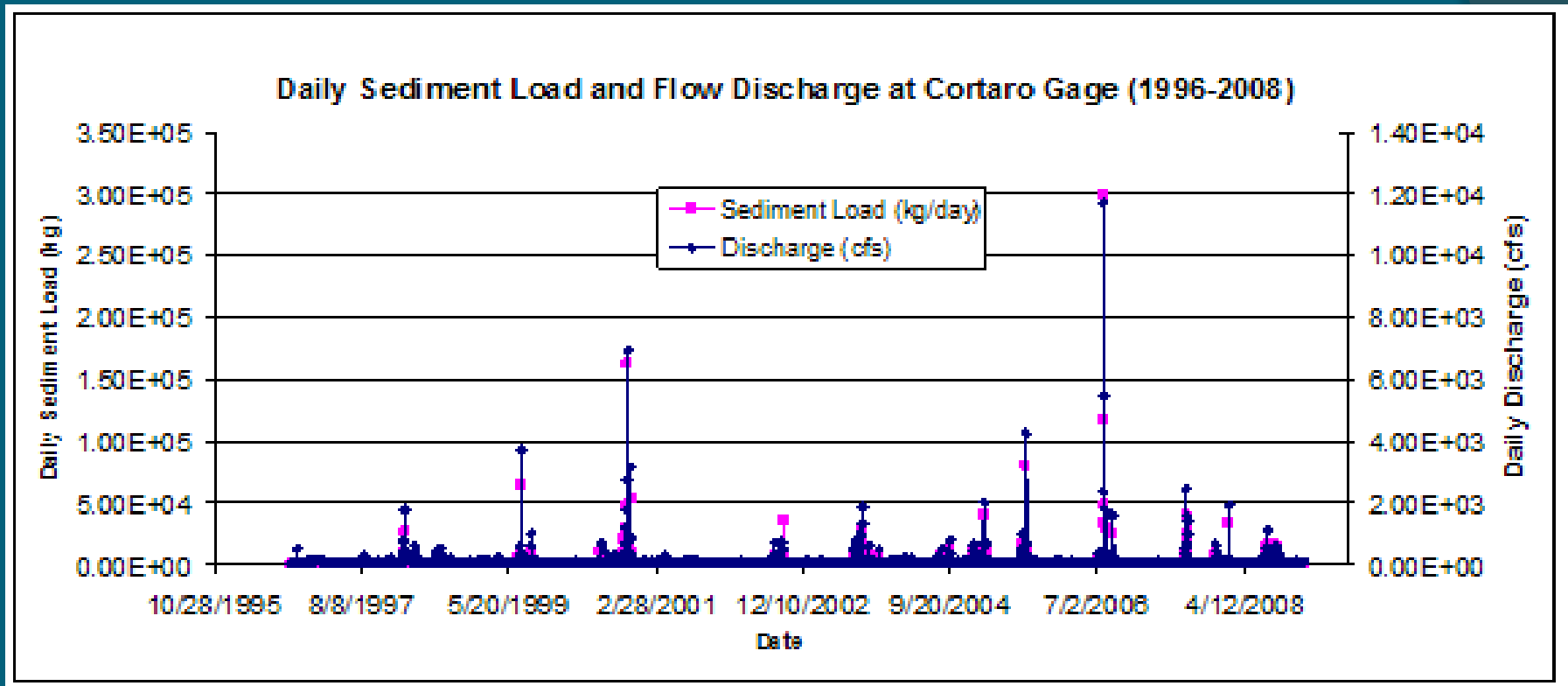
Yang's Eq. vs Laursen' Eq.

- Both equations under-predict the observed suspended sediment load, but Yang (1973)'s equation gives closer matches to the measurements, especially when the daily sediment load is greater than 10 tons/day.
- The averaged relative errors for Yang (1973) and Laursen (1958)'s equations are 20.5% and 281%, respectively. This result attributes to the very large transport rates predicted by the Laursen (1958)'s equation at discharges greater than $28 \text{ m}^3 \text{ s}^{-1}$ (1000 cfs).
- Similar results were observed when applying Laursen (1958)'s equation to the Rillito River in Tucson, AZ (Duan et al., 2008).
- Therefore, this study chose the equation of Yang (1973) to estimate sediment load.

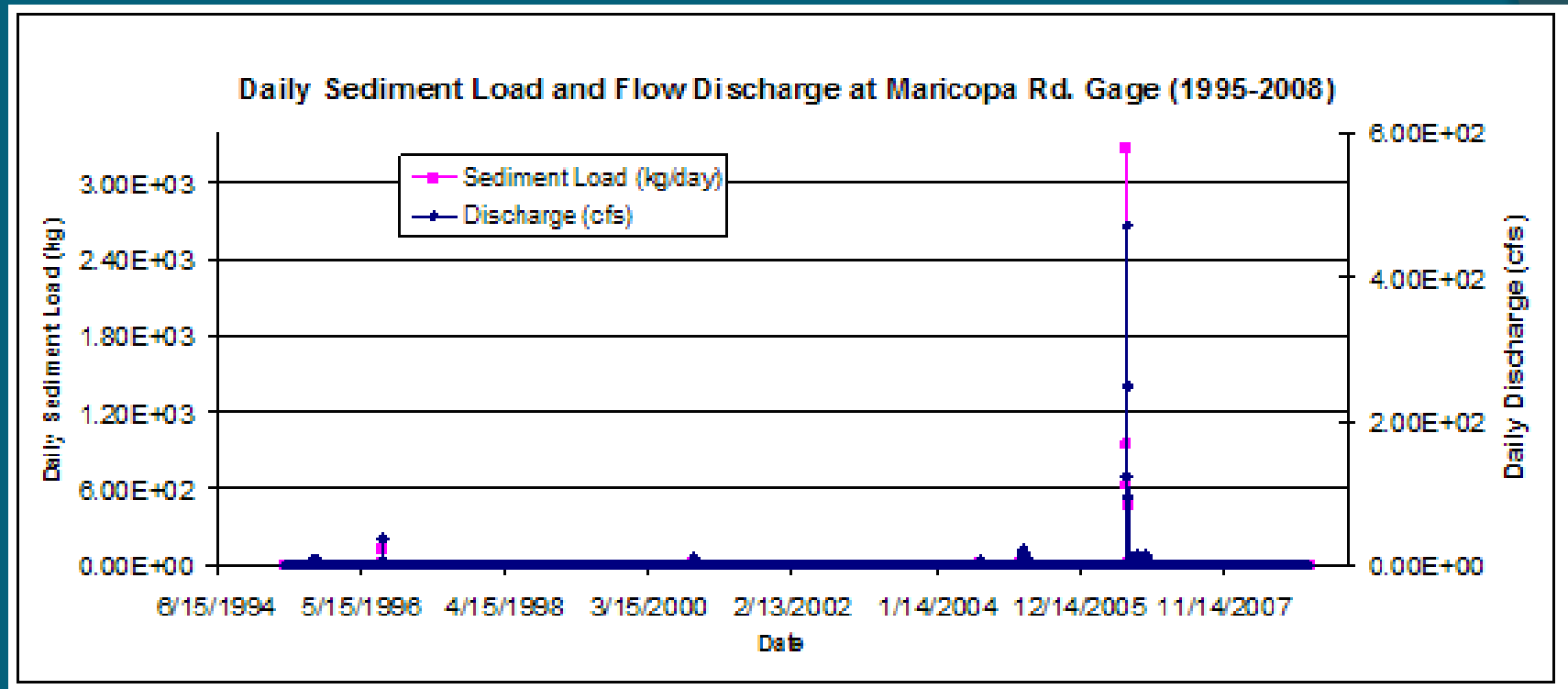
Daily Flow and Sediment Load at Laveen Gage



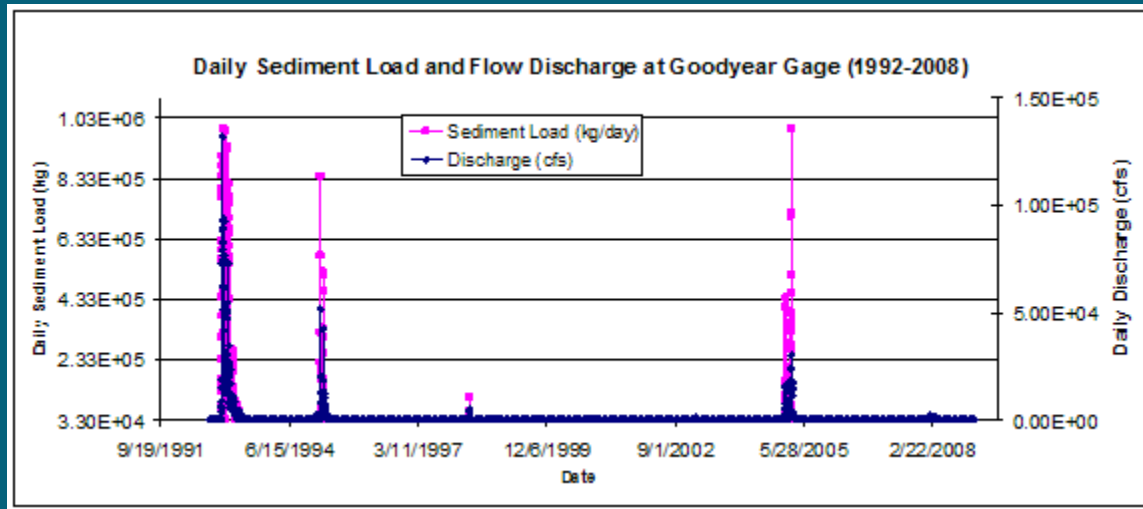
Daily Flow and Sediment Load at Cortaro Gage



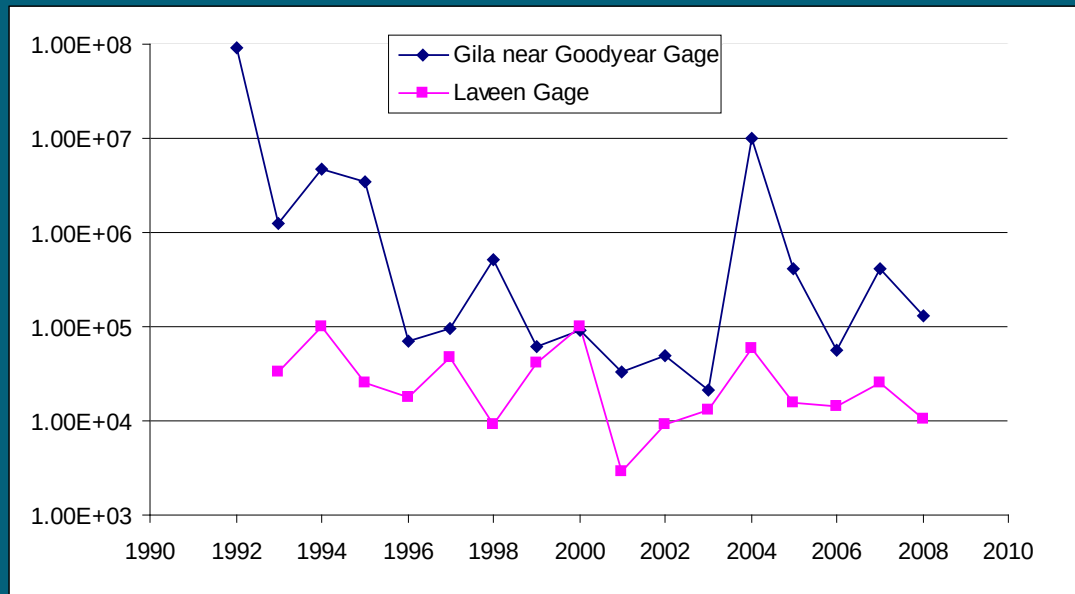
Daily Flow and Sediment Load at Maricopa Road



Daily Flow and Sediment Load at Goodyear Gage



Annual Sediment Load at Laveen and Goodyear Gage



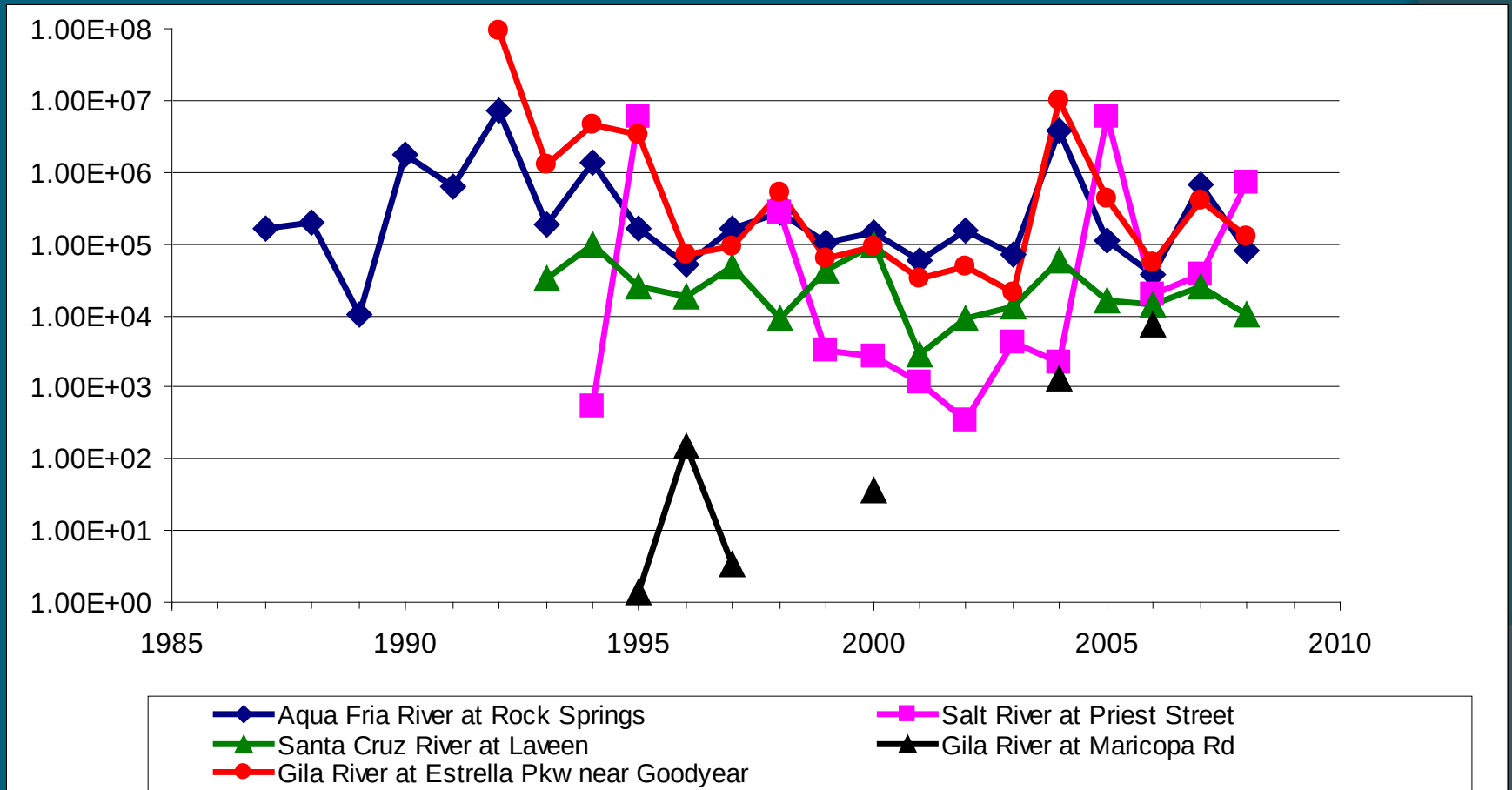
Ratio of Sediment Load at Laveen and Estrella Gage

Year	Ratio (Q_Laveen/Q_Estrella)
1993	0.03
1994	0.02
1995	0.01
1996	0.25
1997	0.50
1998	0.02
1999	0.67
2000	1.08
2001	0.09
2002	0.19
2003	0.62
2004	0.01
2005	0.04
2006	0.26
2007	0.06
2008	0.08

Sediment Load Ratios

- The ratio of annual sediment load at the Laveen Gage to that at the Estrella Parkway Gage ranges from 0.01 in 1995 and 2004 to 1.08 in 2000.
- Since the storms in the Santa Cruz and the Gila River basins are controlled by different storm patterns , the Santa Cruz River can be a primary contributor of sediment load in the reach of Gila River near Estrella Parkway when both the Agua Fria and the Salt Rivers had low flows.
- Although the sediment load in the Santa Cruz River usually is a small portion of that passing through the Estrella Parkway Gage, it can become a significant portion under some special climate conditions, such as the cases of 1997, 1999, 2000 and 2003 shown below.
- If averaging the ratios over the observed 16 years, the annual sediment load at the Laveen Gage is about 23% of that at the Estrella Parkway Gage on the Gila River.

Annual Sediment Load at Confluence



Annual Sediment Load

- The annual sediment load at these gages showed the Gila River at the Estrella Pkw transported the largest sediment load (in red line).
- The second largest one is the Agua Fria River in a navy blue line.
- The third is the Santa Cruz River at the Laveen in green, and followed by the Salt River at the Priest Ave.
- The upstream of Gila River at the Maricopa Rd has the smallest sediment load in which only 1995, 1996, 1997, 2000, 2004, and 2006 had substantial sediment load but the rest having nearly negligible load.

Sediment Load at Rivers near Confluence

- One can find that the Santa Cruz River delivered more sediment load to the confluence than the Salt River from 1999-2004. This phenomenon attributes to the dams and perhaps gravel mining on the Salt River that trapped most of sediment load in the reservoirs.
- The maximum sediment load did not occur in the same year because these rivers belong to different drainage basins and have different climates. Table 2 listed the maximum sediment load at each gage and the date when it happened.

Table 2. Daily Maximum Sediment Load at Each Gage

Gage Name	Date	Maximum Daily Load (tons)
Gila at Maricopa Rd	8/1/2006	3.27
Santa Cruz at Laveen	10/27/2000	22.67
Salt River at Priest	3/7/1995	932.92
Agua Fria at Rock Spring	1/8/1993	2203.05
Gila at Estrella Pkw	1/9/1993	5845.76

Conclusions

- The results showed that the sediment load at the Estrella Pkw come from the upstream of Gila River, the Santa Cruz River, the Salt River and the Agua Fria River.
- Annual sediment load from the Santa Cruz River at the Laveen Gage is about 23% of the sediment load passing through the Estrella Pkw. In 2000, the annual sediment load at the Laveen Gage is slightly greater than the sediment load at the Estrella Pkw when sediment load at both the Salt River and the Agua River were low.
- Sediment load transported to the confluence is greater than the sediment out of it since 1995. More and more sediment is depositing at the confluence because of excessive load from the Santa Cruz, the Salt and the Agua Fria River.

Conclusions

- This study showed that the annual sediment load in the Santa Cruz River can be as high as that in the Gila River at Estrella Pkw. However, the Santa Cruz River usually has less sediment load than the Gila because it's an intermittent river.
- In average, the Santa Cruz River contributed about 12.7% of the total annual sediment load in the Gila River. This contribution can be as high as 41% (e.g. in 2000).
- The intermittent nature of both the Santa Cruz and the Salt River together with the different storm patterns in these two river basins made the flow and sediment load from the Santa Cruz River a major contributor to the Gila River near the Estrella Parkway in recent years.