Table D8. Annual Emissions (2010) - Average Mined per Year 1998-2008

Barge	Mining Events	Activity	Hours	Emission Rates (lb/hr)					Annual Emissions (tons per year)				
				NOx	PM	ROG	CO	CO2	NOx	PM	ROG	CO	CO2
Hanson (TS&G 230)	398	Cruising	2	22.4	0.9	2.2	6.7	1,771.5	8.9	0.4	0.9	2.7	705.1
		Mining	5.5	37.5	1.3	3.3	10.3	2,423.0	41.1	1.4	3.6	11.2	2,652.0
		Unloading	4	17.7	0.5	1.4	4.6	794.3	14.1	0.4	1.1	3.7	632.2
Hanson (DS-10)	398	Cruising	2	16.7	0.7	1.7	5.3	1,273.3	6.6	0.3	0.7	2.1	506.8
		Mining	5.5	25.4	1.0	2.5	7.7	1,989.9	27.8	1.1	2.8	8.5	2,178.0
		Unloading	4	18.2	0.7	1.9	6.3	1,392.8	14.5	0.6	1.5	5.0	1,108.7
Suisun Associates (TS&G 230)	38	Cruising	2	22.4	0.9	2.2	6.7	1,771.5	0.9	0.0	0.1	0.3	67.3
		Mining	5.5	37.5	1.3	3.3	10.3	2,423.0	3.9	0.1	0.3	1.1	253.2
		Unloading	4	17.7	0.5	1.4	4.6	794.3	1.3	0.0	0.1	0.4	60.4
Suisun Associates (DS-10)	37	Cruising	2	16.7	0.7	1.7	5.3	1,273.3	0.6	0.0	0.1	0.2	47.1
		Cruising	2	25.4	1.0	2.5	7.7	1,989.9	0.9	0.0	0.1	0.3	73.6
		Cruising	2	18.2	0.7	1.9	6.3	1,392.8	0.7	0.0	0.1	0.2	51.5
Suisun Associates (Jerico Barge)	75	Cruising	2	8.5	0.4	0.9	2.6	717.4	0.6	0.0	0.1	0.2	53.8
		Mining	5.5	1.9	0.1	0.3	0.9	177.2	0.4	0.0	0.1	0.2	36.6
		Unloading	12	0.9	0.0	0.1	0.7	105.1	0.4	0.0	0.1	0.3	47.3
Jerico	32	Cruising	2	8.5	0.4	0.9	2.6	717.4	0.3	0.0	0.0	0.1	23.0
		Mining	5.5	1.9	0.1	0.3	0.9	177.2	0.2	0.0	0.0	0.1	15.6
		Unloading	12	0.9	0.0	0.1	0.7	105.1	0.2	0.0	0.0	0.1	20.2
Total Emisisons (tons per year)									**123.4**	**4.5**	**11.6**	**36.6**	**8,532.2**

10-62 cont.

TRC

Table D9. Emission Factors for Mining Equipment (2011) - Average Mined per Year 1998-2008

Equipment Name	Type	Manufacture Year [a]	Horsepower [a]	Load Factor [b]	Emission Factor (g/bhp-hr) [c,d]					Emission Rate (lb/hr)				
					NOx	PM	ROG	CO	CO2	NOx	PM	ROG	CO	CO2
Hanson American River	Tug (2 engines)	2003	1,710	0.5	6.93	0.29	0.68	1.97	568.3	13.1	0.5	1.3	3.7	1,071.2
Hanson San Joaquin River	Tug (2 engines)	2001	2,600	0.5	6.93	0.29	0.68	1.97	568.3	19.9	0.8	1.9	5.6	1,628.8
Hanson TS & G	Barge - Main Engine	1983	1,000	0.52	4.85	0.36	0.95	3.07	568.3	5.6	0.4	1.1	3.5	651.5
	Barge - Generator (Aux)	1984	265	0.43	4.73	0.32	1.07	4.33	568.3	1.2	0.1	0.3	1.1	142.8
	Barge - Thruster (Aux)	1984	304	0.43	4.73	0.32	1.07	4.33	568.3	1.4	0.1	0.3	1.2	163.8
Hanson DS-10	Barge - Main Engine	2001	1,100	0.52	6.93	0.29	0.68	1.97	568.3	8.7	0.4	0.9	2.5	716.7
	Barge - Monitor Pump (Aux)	2002	440	0.43	6.93	0.26	0.81	2.78	568.3	2.9	0.1	0.3	1.2	237.0
	Barge - Flood Pump (Aux)	2002	440	0.43	6.93	0.26	0.81	2.78	568.3	2.9	0.1	0.3	1.2	237.0
	Barge - Generator (Aux)	1984	375	0.43	4.73	0.32	1.07	4.33	568.3	1.7	0.1	0.4	1.5	202.0
Jerico Tug	Tug (2 engines)	2001	1,060	0.5	6.93	0.29	0.68	1.97	568.3	8.1	0.3	0.8	2.3	664.0
	Tug (generator)	2000	64	0.31	6.93	0.46	1.18	3.59	568.3	0.3	0.0	0.1	0.2	24.9
Jerico Barge	Barge Generator (Aux)	2004	99	0.43	4.62	0.46	1.18	3.59	568.3	0.4	0.0	0.1	0.3	53.3
	Barge Pump (Aux)	2001	230	0.43	6.93	0.26	0.81	2.78	568.3	1.5	0.1	0.2	0.6	123.9
Jerico Loader	Loader	2007	195	0.43	4.83	0.12	0.81	3.73	568.3	0.9	0.0	0.1	0.7	105.1

[a] Provided by Project Applicants.

[b] Based on information provided in Appendix B - Emissions Estimation Methodology for Commercial Harbor Craft Operating in California, from CARB's *Technical Support Document: Initial Statement of Reason for Proposed Rule Making, Proposed Regulation for Commercial Harbor Craft*, September 2007.

[c] Assumes all Hanson engines manufactured in or prior to 1985 would meet USEPA Tier 2 NOx standard of 7.8 grams per kilowatt-hour (5.8 grams per brake-horsepower hour) by 2011 adn that all Jerico engines met the USEPA Tier 2 NOx standard of 7.8 grams per kilowatt-hour (5.8 grams per brake-horsepower hour) by 2010.

[d] CO2 emission factors derived from OFFROAD2007. Represents CO2 emission factors for diesel fueled engines.

10-62 cont.

TRC

Table D10. Emission Rates by Activity (2011)

Average Mined per Year 1998-2008

Equipment - Activity	Emission Rate (lb/hr-equipment)				
	NOx	PM	ROG	CO	CO2
Hanson TS&G 230 - Mining					
San Joaquin Tug	19.9	0.8	1.9	5.6	1,628.8
TS&G - Barge - Main	5.6	0.4	1.1	3.5	651.5
TS&G - Barge - Gen - Aux	1.2	0.1	0.3	1.1	142.8
Total	***26.6***	***1.3***	***3.3***	***10.3***	***2,423.0***
Hanson TS&G 230 - Cruising					
San Joaquin Tug	19.9	0.8	1.9	5.6	1,628.8
TS&G - Barge - Gen - Aux	1.2	0.1	0.3	1.1	142.8
Total	***21.0***	***0.9***	***2.2***	***6.7***	***1,771.5***
Hanson TS&G 230 - Unloading					
TS&G - Barge - Main	5.6	0.4	1.1	3.5	651.5
TS&G - Barge - Gen - Aux	1.2	0.1	0.3	1.1	142.8
Total	***6.7***	***0.5***	***1.4***	***4.6***	***794.3***
Hanson DS-10 - Mining					
American River Tug	13.1	0.5	1.3	3.7	1,071.2
DS-10 - Barge (Main)	8.7	0.4	0.9	2.5	716.7
DS-10 - Barge (Generator)	1.7	0.1	0.4	1.5	202.0
Total	***23.5***	***1.0***	***2.5***	***7.7***	***1,989.9***
Hanson DS-10 - Cruising					
American River Tug	13.1	0.5	1.3	3.7	1,071.2
DS-10 - Barge (Generator)	1.7	0.1	0.4	1.5	202.0
Total	***14.7***	***0.7***	***1.7***	***5.3***	***1,273.3***
Hanson DS-10 - Unloading					
Barge - Main	8.7	0.4	0.9	2.5	716.7
Barge - Monitor Pump - Aux	2.9	0.1	0.3	1.2	237.0
Barge - Flood Pump- Aux	2.9	0.1	0.3	1.2	237.0
Barge - Gen - Aux	1.7	0.1	0.4	1.5	202.0
Total	***16.2***	***0.7***	***1.9***	***6.3***	***1,392.8***
Jerico Barge - Mining					
Jerico Barge - Generator	0.4	0.0	0.1	0.3	53.3
Jerico Barge - Monitor	1.5	0.1	0.2	0.6	123.9
Total	***1.9***	***0.1***	***0.3***	***0.9***	***177.2***
Jerico Barge - Cruising					
Jerico Tug - Main	8.1	0.3	0.8	2.3	664.0
Jerico Barge - Generator	0.4	0.0	0.1	0.3	53.3
Total	***8.5***	***0.4***	***0.9***	***2.6***	***717.4***
Jerico Unloading					
Loader	0.9	0.0	0.1	0.7	105.1
Total	***0.9***	***0.0***	***0.1***	***0.7***	***105.1***

10-62 cont.

TRC

Table D11. Annual Emissions (2011) - Average Mined per Year 1998-2008

Barge	Mining Events	Activity	Hours	Emission Rates (lb/hr)					Annual Emissions (tons per year)				
				NOx	PM	ROG	CO	CO2	NOx	PM	ROG	CO	CO2
Hanson (TS&G 230)	398	Cruising	2	21.0	0.9	2.2	6.7	1,771.5	8.4	0.4	0.9	2.7	705.1
		Mining	5.5	26.6	1.3	3.3	10.3	2,423.0	29.1	1.4	3.6	11.2	2,652.0
		Unloading	4	6.7	0.5	1.4	4.6	794.3	5.4	0.4	1.1	3.7	632.2
Hanson (DS-10)	398	Cruising	2	14.7	0.7	1.7	5.3	1,273.3	5.9	0.3	0.7	2.1	506.8
		Mining	5.5	23.5	1.0	2.5	7.7	1,989.9	25.7	1.1	2.8	8.5	2,178.0
		Unloading	4	16.2	0.7	1.9	6.3	1,392.8	12.9	0.6	1.5	5.0	1,108.7
Suisun Associates (TS&G 230)	38	Cruising	2	21.0	0.9	2.2	6.7	1,771.5	0.8	0.0	0.1	0.3	67.3
		Mining	5.5	26.6	1.3	3.3	10.3	2,423.0	2.8	0.1	0.3	1.1	253.2
		Unloading	4	6.7	0.5	1.4	4.6	794.3	0.5	0.0	0.1	0.4	60.4
Suisun Associates (DS-10)	37	Cruising	2	14.7	0.7	1.7	5.3	1,273.3	0.5	0.0	0.1	0.2	47.1
		Cruising	2	23.5	1.0	2.5	7.7	1,989.9	0.9	0.0	0.1	0.3	73.6
		Cruising	2	16.2	0.7	1.9	6.3	1,392.8	0.6	0.0	0.1	0.2	51.5
Suisun Associates (Jerico Barge)	75	Cruising	2	8.5	0.4	0.9	2.6	717.4	0.6	0.0	0.1	0.2	53.8
		Mining	5.5	1.9	0.1	0.3	0.9	177.2	0.4	0.0	0.1	0.2	36.6
		Unloading	12	0.9	0.0	0.1	0.7	105.1	0.4	0.0	0.1	0.3	47.3
Jerico	32	Cruising	2	8.5	0.4	0.9	2.6	717.4	0.3	0.0	0.0	0.1	23.0
		Mining	5.5	1.9	0.1	0.3	0.9	177.2	0.2	0.0	0.0	0.1	15.6
		Unloading	12	0.9	0.0	0.1	0.7	105.1	0.2	0.0	0.0	0.1	20.2
Total Emisisons (tons per year)									**95.5**	**4.5**	**11.6**	**36.6**	**8,532.2**

10-62 cont.

TRC

Table D12. Emission Factors for Mining Equipment (2018) - Average Mined per Year 1998-2008

Equipment Name	Type	Manufacture Year [a]	Horsepower [a]	Load Factor [b]	Emission Factor (g/bhp-hr) [c,d]					Emission Rate (lb/hr)				
					NOx	PM	ROG	CO	CO2	NOx	PM	ROG	CO	CO2
Hanson American River	Tug (2 engines)	2003	1,710	0.5	5.12	0.29	0.68	1.97	568.3	9.7	0.5	1.3	3.7	1,071.2
Hanson San Joaquin River	Tug (2 engines)	2001	2,600	0.5	5.12	0.29	0.68	1.97	568.3	14.7	0.8	1.9	5.6	1,628.8
	Barge - Main Engine	1983	1,000	0.52	4.85	0.36	0.95	3.07	568.3	5.6	0.4	1.1	3.5	651.5
	Barge - Generator (Aux)	1984	265	0.43	4.73	0.32	1.07	4.33	568.3	1.2	0.1	0.3	1.1	142.8
Hanson TS & G	Barge - Thruster (Aux)	1984	304	0.43	4.73	0.32	1.07	4.33	568.3	1.4	0.1	0.3	1.2	163.8
	Barge - Main Engine	2001	1,100	0.52	5.12	0.29	0.68	1.97	568.3	6.5	0.4	0.9	2.5	716.7
	Barge - Monitor Pump (Aux)	2002	440	0.43	4.99	0.26	0.81	2.78	568.3	2.1	0.1	0.3	1.2	237.0
	Barge - Flood Pump (Aux)	2002	440	0.43	4.99	0.26	0.81	2.78	568.3	2.1	0.1	0.3	1.2	237.0
Hanson DS-10	Barge - Generator (Aux)	1984	375	0.43	4.73	0.32	1.07	4.33	568.3	1.7	0.1	0.4	1.5	202.0
	Tug (2 engines)	2001	1,060	0.5	5.12	0.29	0.68	1.97	568.3	6.0	0.3	0.8	2.3	664.0
Jerico Tug	Tug (generator)	2000	64	0.31	4.62	0.46	1.18	3.59	568.3	0.2	0.0	0.1	0.2	24.9
	Barge Generator (Aux)	2004	99	0.43	4.62	0.46	1.18	3.59	568.3	0.4	0.0	0.1	0.3	53.3
Jerico Barge	Barge Pump (Aux)	2001	230	0.43	4.99	0.26	0.81	2.78	568.3	1.1	0.1	0.2	0.6	123.9
Jerico Loader	Loader	2007	195	0.43	4.83	0.12	0.81	3.73	568.3	0.9	0.0	0.1	0.7	105.1

[a] Provided by Project Applicants.

[b] Based on information provided in Appendix B - Emissions Estimation Methodology for Commercial Harbor Craft Operating in California, from CARB's *Technical Support Document: Initial Statement of Reason for Proposed Rule Making, Proposed Regulation for Commercial Harbor Craft*, September 2007.

[c] Assumes all Hanson engines manufactured in or prior to 2003 would meet USEPA Tier 2 NOx standard of 7.8 grams per kilowatt-hour (5.8 grams per brake-horsepower hour) by 2018.

[d] CO2 emission factors derived from OFFROAD2007. Represents CO2 emission factors for diesel fueled engines.

10-62 cont.

TRC

Table D13. Emission Rates by Activity (2018)
Average Mined per Year 1998-2008

Equipment - Activity	Emission Rate (lb/hr-equipment)				
	NOx	PM	ROG	CO	CO2
Hanson TS&G 230 - Mining					
San Joaquin Tug	14.7	0.8	1.9	5.6	1,628.8
TS&G - Barge - Main	5.6	0.4	1.1	3.5	651.5
TS&G - Barge - Gen - Aux	1.2	0.1	0.3	1.1	142.8
Total	***21.4***	***1.3***	***3.3***	***10.3***	***2,423.0***
Hanson TS&G 230 - Cruising					
San Joaquin Tug	14.7	0.8	1.9	5.6	1,628.8
TS&G - Barge - Gen - Aux	1.2	0.1	0.3	1.1	142.8
Total	***15.9***	***0.9***	***2.2***	***6.7***	***1,771.5***
Hanson TS&G 230 - Unloading					
TS&G - Barge - Main	5.6	0.4	1.1	3.5	651.5
TS&G - Barge - Gen - Aux	1.2	0.1	0.3	1.1	142.8
Total	***6.7***	***0.5***	***1.4***	***4.6***	***794.3***
Hanson DS-10 - Mining					
American River Tug	9.7	0.5	1.3	3.7	1,071.2
DS-10 - Barge (Main)	6.5	0.4	0.9	2.5	716.7
DS-10 - Barge (Generator)	1.7	0.1	0.4	1.5	202.0
Total	***17.8***	***1.0***	***2.5***	***7.7***	***1,989.9***
Hanson DS-10 - Cruising					
American River Tug	9.7	0.5	1.3	3.7	1,071.2
DS-10 - Barge (Generator)	1.7	0.1	0.4	1.5	202.0
Total	***11.3***	***0.7***	***1.7***	***5.3***	***1,273.3***
Hanson DS-10 - Unloading					
Barge - Main	6.5	0.4	0.9	2.5	716.7
Barge - Monitor Pump - Aux	2.1	0.1	0.3	1.2	237.0
Barge - Flood Pump- Aux	2.1	0.1	0.3	1.2	237.0
Barge - Gen - Aux	1.7	0.1	0.4	1.5	202.0
Total	***12.3***	***0.7***	***1.9***	***6.3***	***1,392.8***
Jerico Barge - Mining					
Jerico Barge - Generator	0.4	0.0	0.1	0.3	53.3
Jerico Barge - Monitor	1.1	0.1	0.2	0.6	123.9
Total	***1.5***	***0.1***	***0.3***	***0.9***	***177.2***
Jerico Barge - Cruising					
Jerico Tug - Main	6.0	0.3	0.8	2.3	664.0
Jerico Barge - Generator	0.4	0.0	0.1	0.3	53.3
Total	***6.4***	***0.4***	***0.9***	***2.6***	***717.4***
Jerico Unloading					
Loader	0.9	0.0	0.1	0.7	105.1
Total	***0.9***	***0.0***	***0.1***	***0.7***	***105.1***

10-62 cont.

TRC

Table D14. Annual Emissions (2018) - Average Mined per Year 1998-2008

Barge	Mining Events	Activity	Hours	Emission Rates (lb/hr)					Annual Emissions (tons per year)				
				NOx	PM	ROG	CO	CO2	NOx	PM	ROG	CO	CO2
Hanson (TS&G 230)	398	Cruising	2	15.9	0.9	2.2	6.7	1,771.5	6.3	0.4	0.9	2.7	705.1
		Mining	5.5	21.4	1.3	3.3	10.3	2,423.0	23.4	1.4	3.6	11.2	2,652.0
		Unloading	4	6.7	0.5	1.4	4.6	794.3	5.4	0.4	1.1	3.7	632.2
Hanson (DS-10)	398	Cruising	2	11.3	0.7	1.7	5.3	1,273.3	4.5	0.3	0.7	2.1	506.8
		Mining	5.5	17.8	1.0	2.5	7.7	1,989.9	19.5	1.1	2.8	8.5	2,178.0
		Unloading	4	12.3	0.7	1.9	6.3	1,392.8	9.8	0.6	1.5	5.0	1,108.7
Suisun Associates (TS&G 230)	38	Cruising	2	15.9	0.9	2.2	6.7	1,771.5	0.6	0.0	0.1	0.3	67.3
		Mining	5.5	21.4	1.3	3.3	10.3	2,423.0	2.2	0.1	0.3	1.1	253.2
		Unloading	4	6.7	0.5	1.4	4.6	794.3	0.5	0.0	0.1	0.4	60.4
Suisun Associates (DS-10)	37	Cruising	2	11.3	0.7	1.7	5.3	1,273.3	0.4	0.0	0.1	0.2	47.1
		Cruising	2	17.8	1.0	2.5	7.7	1,989.9	0.7	0.0	0.1	0.3	73.6
		Cruising	2	12.3	0.7	1.9	6.3	1,392.8	0.5	0.0	0.1	0.2	51.5
Suisun Associates (Jerico Barge)	75	Cruising	2	6.4	0.4	0.9	2.6	717.4	0.5	0.0	0.1	0.2	53.8
		Mining	5.5	1.5	0.1	0.3	0.9	177.2	0.3	0.0	0.1	0.2	36.6
		Unloading	12	0.9	0.0	0.1	0.7	105.1	0.4	0.0	0.1	0.3	47.3
Jerico	32	Cruising	2	6.4	0.4	0.9	2.6	717.4	0.2	0.0	0.0	0.1	23.0
		Mining	5.5	1.5	0.1	0.3	0.9	177.2	0.1	0.0	0.0	0.1	15.6
		Unloading	12	0.9	0.0	0.1	0.7	105.1	0.2	0.0	0.0	0.1	20.2
Total Emisisons (tons per year)									**75.5**	**4.5**	**11.6**	**36.6**	**8,532.2**

10-62 cont.

TRC

Additional Materials Received

SEPTEMBER 2010

SAN FRANCISCO ESTUARY & WATERSHED SCIENCE

Sponsored by the Delta Science Program and the UC Davis John Muir Institute of the Environment

Anthropogenic Influence on Recent Bathymetric Change in West–Central San Francisco Bay

Patrick L. Barnard[1] and Rikk G. Kvitek[2]

ABSTRACT

Two multi-beam sonar surveys of west–central San Francisco Bay, California, were conducted in 1997 and 2008. Bathymetric change analysis between the two surveys indicates a loss of 14.1 million m^3 (–3.1 cm yr^{-1}) of sediment during this time period, representing an approximately three-fold acceleration of the rate that was observed from prior depth change analysis from 1947 to 1979 for all of Central Bay, using more spatially coarse National Ocean Service (NOS) soundings. The portions of the overlapping survey areas between 1997 and 2008 designated as aggregate mining lease sites lost sediment at five times the rate of the remainder of west–central San Francisco Bay. Despite covering only 28% of the analysis area, volume change within leasing areas accounted for 9.2 million m^3 of sediment loss, while the rest of the area lost 4.9 million m^3 of sediment. The uncertainty of this recent analysis is more tightly constrained due to more stringent controls on vertical and horizontal position via tightly coupled, inertially aided differential Global Positioning Systems (GPS) solutions for survey vessel trajectory that virtually eliminate inaccuracies from traditional tide modeling and vessel motion artifacts. Further, quantification of systematic depth measurement error can now be calculated through comparison of static surfaces (e.g., bedrock) between surveys using sea-floor habitat maps based on acoustic back-scatter measurements and ground-truthing with grab samples and underwater video. Sediment loss in the entire San Francisco Bay Coastal System during the last half-century, as estimated from a series of bathymetric change studies, is 240 million m^3, and most of this is believed to be coarse sediment (i.e., sand and gravel) from Central Bay and the San Francisco Bar, which is likely to limit the sand supply to adjacent, open-coast beaches. This hypothesis is supported by a calibrated numerical model in a related study that indicates that there is a potential net export of sand-sized sediment across the Golden Gate, suggesting that a reduction in the supply of sand-sized sediment within west–central San Francisco Bay will limit transport to the outer coast.

KEYWORDS

bathymetry, multi-beam sonar, estuary, anthropogenic, dredging, aggregate mining, sediment transport

1 U.S. Geological Survey, Coastal and Marine Geology Program, 400 Natural Bridges Drive, Santa Cruz, CA 95060; corresponding author email: pbarnard@usgs.gov

2 Seafloor Mapping Lab, Division of Science and Environmental Policy, California State University, Monterey Bay, 100 Campus Center, Seaside, CA 93955-8001

INTRODUCTION

Multi-beam sonars use swaths of sound pulses focused perpendicular to the direction of a ship to measure depths of the seafloor. Within the last decade, multi-beam sonar system technology has advanced to enable imaging of the seafloor with increased spatial coverage (sub^{-1} m grid resolution) and angular resolution, allowing a greater number of beams per swath, increased ping frequency (5 Hz in 30 m of water) and speed (3,000 soundings/sec), and the potential of measuring depths with resolution of a few centimeters. Modern systems can collect data at boat speeds of up to 16 km hr^{-1} while still maintaining density of up to 10 soundings per m^2 in 50 m water depth, a four-fold increase in the last decade. By combining sub-meter resolution multi-beam data with the sub-decimeter positioning accuracy of differential GPS surveying, the seafloor position can now be mapped with unprecedented detail and precision. The goal of this paper is to report the results of bathymetric change analysis in west–central San Francisco Bay, California, using the first multi-beam surveys performed with differential GPS covering this region. This information is critical for the sediment-management community who must assess the impact of anthropogenic influences such as aggregate mining and dredging on the regional sediment supply.

STUDY AREA

San Francisco Bay is a large estuary with a number of economically significant harbors in one of the most developed regions of the United States (Figure 1). The San Joaquin and Sacramento rivers had, from the period 1938 to 2005, an annual mean fresh-water discharge rate into the San Francisco Bay of 800 m^3 s^{-1} (DWR 2007). Despite this accounting for 40% of California's drainage area, fresh-water input represents less than 1% of the tidal prism of 2 x 10^9 m^3 served by the Golden Gate tidal inlet, the only point of exchange with the Pacific Ocean. Tidal currents in the inlet throat peak at over 2.5 m s^{-1}, and can exceed 1 m s^{-1} even on the edge of the San Francisco Bar (i.e., ebb tidal delta), which is more than 10 km seaward of the inlet throat (Barnard and others 2007) (Figure 1). Landward of the Golden Gate, west–central San Francisco Bay is the deepest part of the entire estuary, containing the coarsest sediment, and the strongest currents. Bedrock pinnacles and sandy shoals focus currents and produce a wide range of bedform morphologies (Rubin and McCulloch 1980; Barnard and others, in press). Wave energy in the Bay is primarily generated by local winds, and plays only a minor role in sediment transport throughout the deeper portions of the bay. However, the impact of local, wind-generated waves and deep ocean swell can induce significant turbulence and sediment transport in the shallow, inter-tidal areas, where fine sediment dominates the substrate (Talke and Stacey 2003).

PRIOR WORK

Major anthropogenic changes to the San Francisco Bay Coastal System (which incorporates the San Francisco Bay, the mouth of the Sacramento–San Joaquin Delta, and the mouth of the San Francisco Bay, including the adjacent open coast) began during the Gold Rush in the 19th century and have continued to the present. The influx of an estimated 1.15 x 10^9 m^3 of sediment from hydraulic mining during the Gold Rush (Gilbert 1917) in concert with major building development in the coastal wetlands in San Francisco Bay has exerted a strong influence on San Francisco Bay evolution during the last 150 years. Anthropogenic activities in the San Francisco Bay Coastal System have permanently removed at least 200 million m^3 of sediment in the last century from borrow pit mining (54 million m^3), aggregate mining (26 million m^3), and dredging (120 million m^3) (USACE 1996; Friends of the Estuary 1997; Chin and others 1997, 2004; Dallas 2009; Dallas and Barnard 2009). However, this is a minimum estimate because not all records have been compiled. For instance, records are missing from 1976 to 1996 for dredging and borrow pit mining for the San Francisco waterfront, Alameda Air Base, BART tunnel, and Oakland Airport, and other records are incomplete. A majority of the sediment was removed from Central Bay (52%), with lesser amounts removed from the North Bay (28%), San Francisco Bar (18%), and South Bay (2%). Grain sizes were not recorded for most of the documented events,