Post Basin-Complex Baseline Monitoring of the Big Sur River (October, 2008)

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Introduction

The Santa Lucia Range has a rapid uplift rate and an even higher erosion rate (Ducea and Kidder 2003). Ducea and Kidder (2003) suggest that most of the long-term erosion of the Santa Lucia Range is dominated by slope failure processes. Those who maintain the public highways of the central coast can attest to the natural instability of the hillsopes in this region (Willis et al., 2001). On the other hand, anyone who has watched the Big Sur watershed on the scale of decades will recognize that the long-term average erosion rate is not met on an annual basis. Rather, watershed erosion is punctuated by episodic seasons of extreme denudation followed by several years or decades of minor adjustments. The extreme events are triggered by El Nino winters, fire, and earthquakes. When any of those triggers overlap, the effect is amplified. Intense fires of the 2008 summer season in the Big Sur watershed have set the stage for an episode of extreme erosion (Fig. 1). The rainfall distribution and magnitude this winter (water year 2008-09) will dictate how the near-term fire-weakened hill slopes will respond.

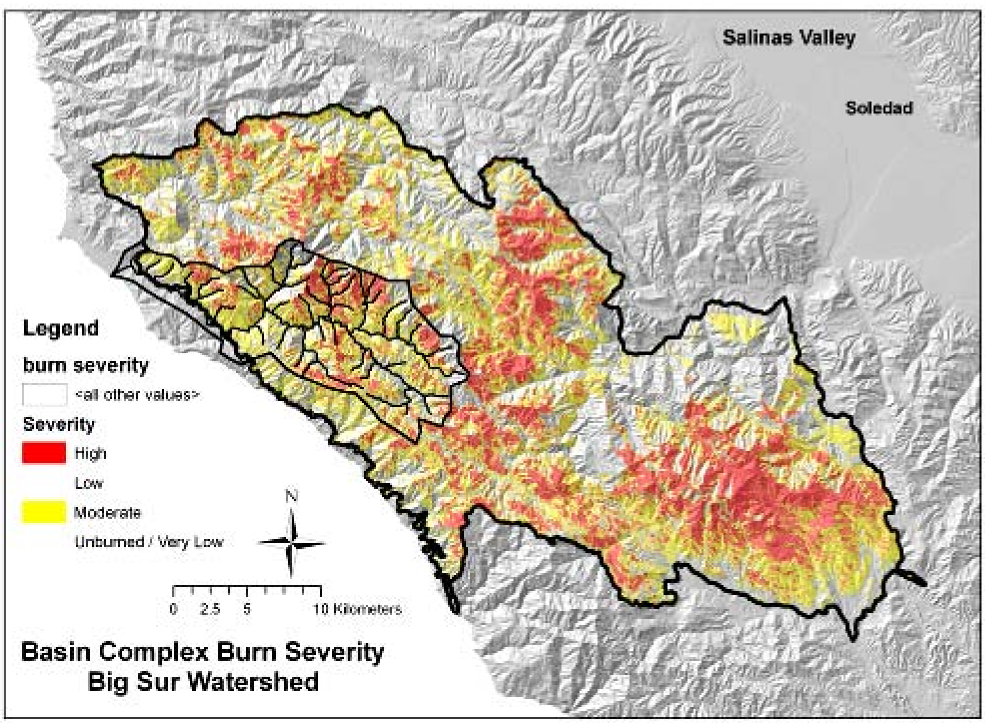


Figure 1: Burn severity of the Basin Complex fire. (GIS data from USDA (2008)).

Fire and post-fire impacts are part of the natural cycle of ecology and geology in Mediterranean climates of the world. The Santa Lucia Range periodically burns when lightening or human activities ignite seasonally dry forest and chaparral (Table1). Following these fires, the normal hill-slope hydrology is strongly modified by the development of hydrophobic soils, removal of duff, and lack of vegetation canopy. The resulting erosion can unleash enormous volumes of soil, rock, and vegetative debris over a short time period (Fig. 2). The short-term impacts of this erosion can include loss of property and life, and impaired river and valley-bottom habitat function. The longer term effects include valley bottom aggradation and improved gravel supply for steelhead spawning (once the muddy substrate is winnowed).

Table 1: Large fires in the Big Sur watershed.

Date	Fire Name	Acres Burned
1894	no name	NA
7/1/1903	no name	50,000
1906	no name	150,000
8/1/1972	Molera Fire	4,300
8/1/1977	Marble Cone Fire	178,000
1985	Rat Creek Fire	50,000
9/8/1999	Kirk Complex Fire	86,000
6/8/2008	Indians Fire	81,378
6/21/2008	Basin-Complex Fire	162,818

(Griffin, 1978; Henson, 1996)

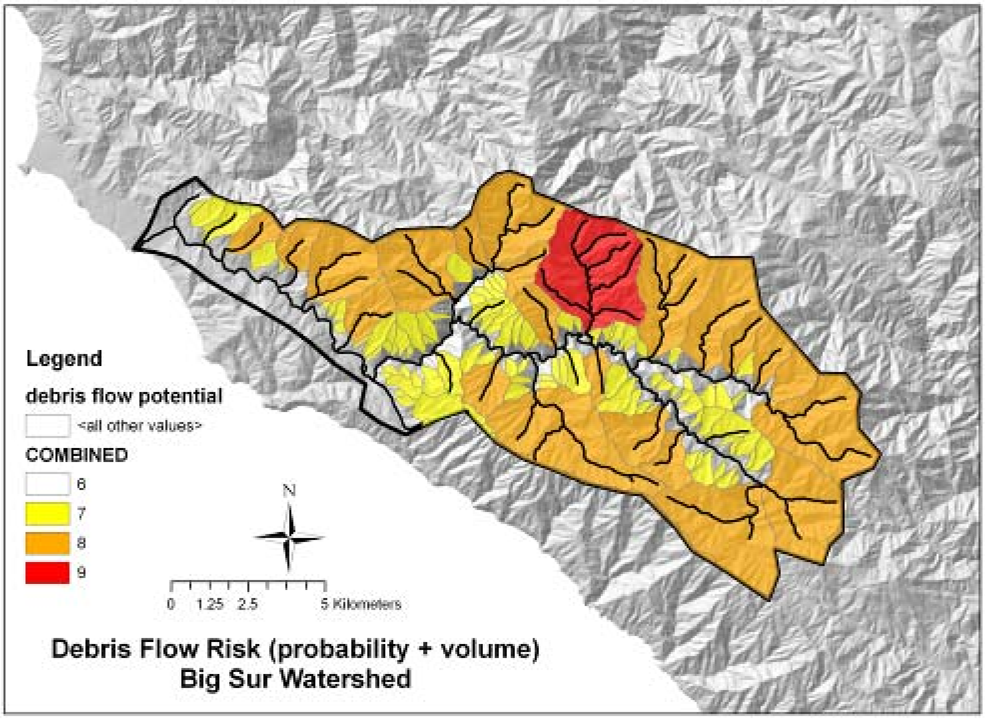


Figure 2: Debris flow risk of the Big Sur watershed See Table 2 for legend details (GIS data from Cannon (2008)).

Table 2: Debris Flow Risk in the Big Sur Watershed (GIS data from Cannon (2008), Risk method from Cannon et al. (in press)).

Combined risk (Fig. 2)	Volume (m^3)	%chance of event	number of sub-basins	area (km2)	% of watershed
6	0-1,000	>80%	1	0	0%
7	1,001-10,000	>80%	101	26	18%
8	10,001 – 100,000	>80%	37	86	57%
9	>100,000	>80%	2	10	7%
			total area at risk	123	81%

In anticipation of strong post fire impacts, we have begun a monitoring campaign with the intent of capturing near-term environmental impacts and longer-term recovery along the lower Big Sur River. This study provides baseline observations at 8 monumented cross sections along the Big Sur River and one tributary. These observations can be used as a comparison to future surveys to measure impact and recovery following the 2008-2009 rain season. The monitoring parameters include cross section survey, cross section particle size assessment, and general site photography. Water quality parameters measured at each site include pH, turbidity, specific conductance, dissolved oxygen (mg/l, and %), nitrogen, and temperature.

More background on the watershed geology, habitat concerns, and burn conditions of the Big Sur watershed can be found in the following reference:

Smith, D.P., Castorani, S., Dillon, H., Dillon, L., Illse, J., Ritz, C., Spear, B., Stern, J., and Frey, J., 2008, Post-Fire Baseline Monitoring of Big Sur River Lagoon: November/December 2008: Final class report for Watershed Science and Policy (ESSP 660), The Watershed Institute, California State University Monterey Bay, Publication No. WI-2008-7, 45 pp.

(A draft of the referenced report is appended at the end of this document).

Methods

Goals and Approach

Our goal is to document environmental conditions existing along the Big Sur River valley between the mouth and the limit of Steelhead migration in Pfeiffer Big Sur State Park. Future studies will use these data as a baseline from which to quantify impacts and recovery from post-fire runoff.

We selected 8 monitoring sites that give a snapshot of conditions along the length of the study reach. The sites were selected to isolate the effects of the major tributaries, Post, Juan Higuera, and Pheneger Creeks (Fig. 3; Table 3). The sites were measured in late September and early October 2008 before any significant rain of the 2008-09 season.

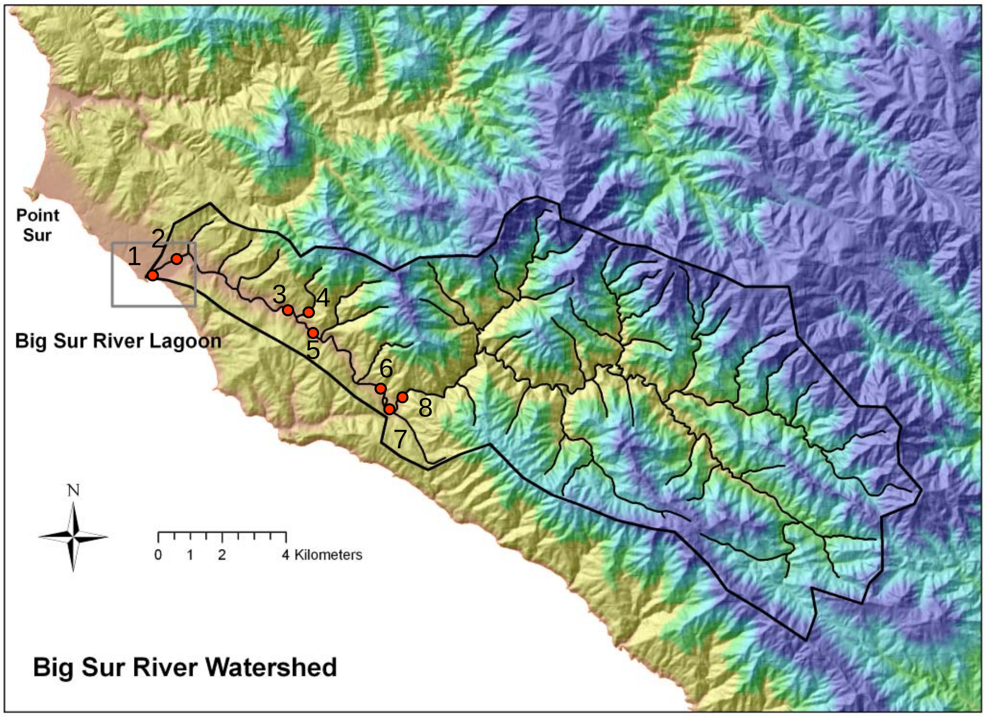


Figure 3: Monitoring sites along the Big Sur River. See Table 3 for description.

Table 3: Monitoring sites shown in Figure 3

Site number	Name	Strategy
1	Andrew Molera mouth	Impacts near mouth
2	Andrew Molera parking lot	Easy access near mouth
3	Below Pheneger	Mainstem impacts from tributary
4	Pheneger	High risk of debris flow
5	Below Juan Higuera	Mainstem impacts from tributary
6	Below leech field	Leech field impacts
7	Below Post	Mainstem impacts from tributary
8	Above gauge	Limit of anadromy

Measured Parameters

We collected a subset of environmental indicators as a baseline for detecting and quantifying change in the Big Sur River basin in 8 sites. These indicators include a monumented cross section, particle count, photo monitoring, pH, turbidity, specific conductance, dissolved oxygen (mg/l, and %), nutrients, and temperature. GPS coordinates were recorded to establish the location of the bench marks that were placed at each site for future reference.

Cross sections were surveyed with rotating laser and tight cross section tape. Surveys closed with less than 1 cm vertical error. Particle counts were 100 evenly-spaced counts that used the Wolman method, directly along the cross section tape. Photo monitoring included substrate and local channel conditions. Water quality parameters were measured in the field except for nitrogen and urea, which were analyzed at the CSUMB water quality laboratory.

Observations

The data for the baseline monitoring is provided below, following the reference section. The particle counts typically show that there was an excess of fine sediment draping the larger framework particles even before run-off impacts occurred. At least two rain events have moved through the watershed since the initial monitoring work was done. The Big Sur River rose to 200 cfs in early November (Fig. 4). When the flow subsided visual and photo monitoring indicated that a new mud veneer was present on the channel bottom and low banks. A photo captured from the new USGS web cam in Pfeiffer Big Sur State Park shows that the rain even of mid December has produced more mud- rich runoff that will deepen the growing mud veneer (Fig. 5). Compare Figure 5 to the water clarity in late September 2008 before the rain (Fig 6).

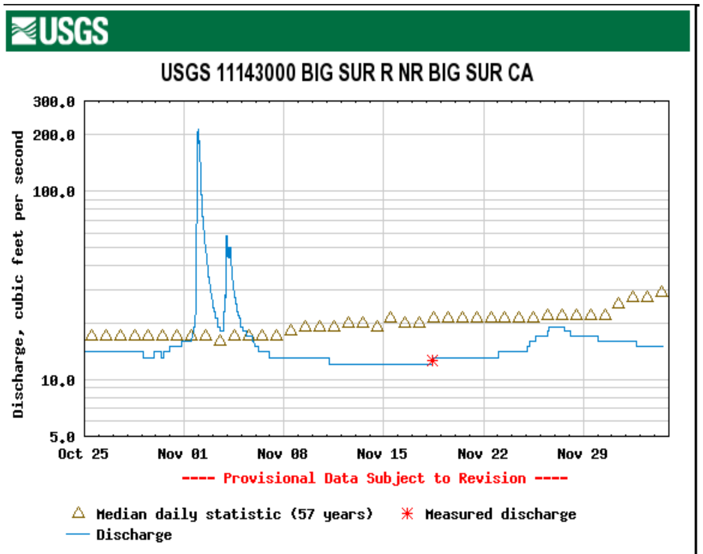


Figure 4: Stream response to early November rains.

Figure 5: Muddy water resulting from the mid December rainfall.

Figure 6: Clear water near USGS gage in late September 2008.

Acknowledgements

- This work was partially funded by the Pelican Network (http://www.pelicannetwork.net), parent organization of the still-forming Stewards of the Big Sur River.
- Jack Ellwanger
- Ken Ekelund
- Land owners who provided access to private property
- CSUMB Water Quality Laboratory

References

Cannon, S.H. (2008) Geologic Hazards Team. Letter to Monterey County Office of Emergency Services, Rob Clyburn.

Cannon, S.H., Gartner, M.G., Rupert, M.G., Michael, J.A., Rea, A.H., Parrett, C. (in press) Predicting the probability and volume of post-wildfire debris flows in the intermountain Western U.S. : Bulletin of the Geological Society of America.

Ducea, M.N., House, M., Kidder, S., 2003, Late Cenozoic denudation and uplift rates in the Santa Lucia Mounains, California. Geology, v. 31, p. 139-142.

Griffin JR. July 1978. After the Marble Cone Fire of 1977: The Marble Cone Fire ten months later. FREMONTIA California Native Plant Society.

Hecht, B. (1981) Sequential changes in bed habitat conditions in the upper Carmel River following the Marble-Cone fire of August 1977, in Warner, R.E. and Hendrix, K.M., eds., California riparian systems: ecology, conservation and productive management. University of California Press, 134-141.

Henson P, Usner DJ. 1996. The Natural History of Big Sur. Published by University of California Press. (5) 232-243.

Rosenberg, L. 2001. Geologic resources and constraints Monterey county California. County of Monterey Environmental Resource Policy Department.

[USDA] United States Department of Agriculture United States Forest Service. Los Padres National Forest. (2008) Executive Summary: Basin Complex Fire/Indians Fire BAER Initial Assessment. Internet Resource: www.fs.fed.us/r5/lospadres/fire/baer/gallery/basin-indian-baer-initial.pdf

Willis, C.J., Manson, M.W., Brown, K.D., Davenport, C.W., and Domrose, C.J., 2001, Landslides in the Highway 1 corridor: Geology and slope stability along the Big Sur coast between Point Lobos and San Carpoforo Creek, Monterey and San Luis Obispo Counties, California: California Department of Conservation Division of Mines and Geology, pp.40.

Data

The data provided here has also been provided in electronic format to Ken Ekelund for distribution to those who will benefit from the original data set. Additional photos are available as well.

Monitoring sites that follow this page

Site number	Name
1	Andrew Molera mouth
2	Andrew Molera parking lot
3	Below Pheneger
4	Pheneger
5	Below Juan Higuera
6	Below leech field
7	Below Post
8	Above gauge

SITE 1

Site Name	Andrew Molera State Park Near Mouth
Date	9/21/2008
Time	13:11
Names	Mary, Cooper, Emily
GPS UTM	10s 0602793 4015910 left bench mark
Description	

Up stream from where the beach access trail reaches the right bank fo the river. There is clearing on the left bank with a small unmaintained trail of of the main trail.

Nutrients / Water Chemistry	**Name: Mary**	**Hydrolab #: 43**
Ph	7.56	**Sample Bottle Name**
Turbity	0	Andrew Molera River Mouth 10/1/08
Specific Conductence ms/cm	332.1	
DO mg/l	8.3	
DO %	83.1	
Temp C	14.72	
Nitrate + Nitrite (mg N/L)	0.011	
Ammonium (mg N/L)	0.003975	
SRP (mg P/L)	0.007772	
Urea (mg N/L)	29.873	

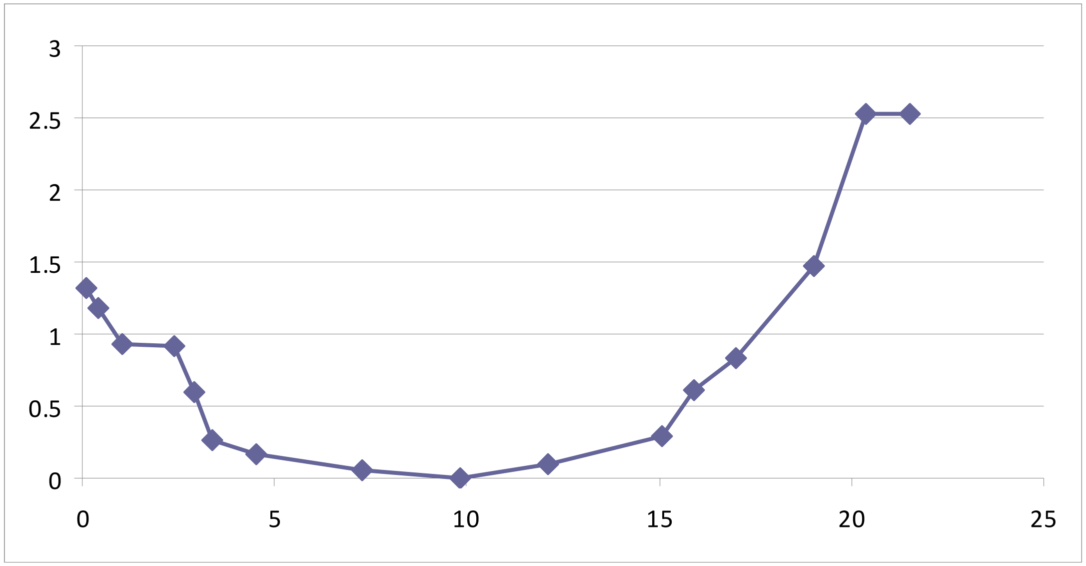
SITE 1 (cont.)

Particle Count		Name: Mary and Cooper			sample every 13cm		
Number	Size cm	Number	Size cm	Number	Size cm	Number	Size cm
1	<.05	26	0.05	51	0.1	76	0.2
2	<.05	27	0.05	52	0.2	77	11.5
3	<.05	28	2.1	53	0.1	78	3.2
4	<.05	29	<.05	54	2.5	79	12.1
5	<.05	30	<.05	55	6.1	80	3.8
6	<.05	31	5.7	56	5.2	81	0.2
7	<.05	32	0.75	57	2	82	0.1
8	<.05	33	4.3	58	15.1	83	0.2
9	<.05	34	1.2	59	0.6	84	8.8
10	<.05	35	2.4	60	0.2	85	8.1
11	<.05	36	6	61	15.1	86	0.3
12	<.05	37	1.4	62	0.5	87	0.2
13	<.05	38	13	63	1.6	88	12
14	<.05	39	5	64	0.05	89	0.2
15	<.05	40	1.9	65	1	90	1.7
16	<.05	41	7	66	4	91	1.5
17	9.2	42	4.9	67	5.4	92	5.4
18	<.05	43	10.5	68	0.05	93	3
19	2.4	44	5.8	69	0.05	94	0.6
20	<.05	45	0.1	70	8.5	95	2
21	1.4	46	8.5	71	0.05	96	7.5
22	<.05	47	0.05	72	0.5	97	5.7
23	<.05	48	0.1	73	0.05	98	0.2
24	<.05	49	7.4	74	4.1	99	3.8
25	4.4	50	0.1	75	0.2	100	10.8

SITE 1 (cont.)

Cross section	**Name: Cooper**		**Type: Laser level**
Shot Number	**Height**	**Location**	**Description**
1	1.44	21.5	fore shot left bench mark
2	1.435	20.35	meters
3	2.493	19	
4	3.137	17	
5	3.35	15.9	left bank
6	3.666	15.05	
7	3.869	12.1	
8	3.964	9.8	thalweg
9	3.912	7.3	
10	3.804	4.5	
11	3.694	3.4	
12	3.366	2.9	right bank
13	3.051	2.4	
14	3.038	1.05	
15	2.78	0.4	right bench mark
16	2.64	0.1	
17	1.441	21.5	back shot left bench mark

SITE 1 (cont.)



Cross section. All values in meters.

SITE 2

Site Name	Andrew Molera State Park Parking Lot
Date	9/21/2008
Time	10:40
Names	Emily, Cooper, Mary
GPS UTM	10s 0603789 4016416 center of cross section
Description	

Up stream from where the main trail from the parking lot crosses the river. The right bench mark is located on a small path from a group of picnic benches in the parking lot.

Nutrients / Water Chemistry	**Name: Emily**	**Hydrolab #: 43**
Ph	7.9	**Sample Bottle Name**
Turbity	0	Andrew Molera 1 Parking Lot 10/1/08
Specific Conductence ms/cm	337.8	
DO mg/l	10.46	
DO %	101.8	
Temp C	14.08	
Nitrate + Nitrite (mg N/L)	0.018	
Ammonium (mg N/L)	0.00504	
SRP (mg P/L)	0.008073	
Urea (mg N/L)	5.2035	

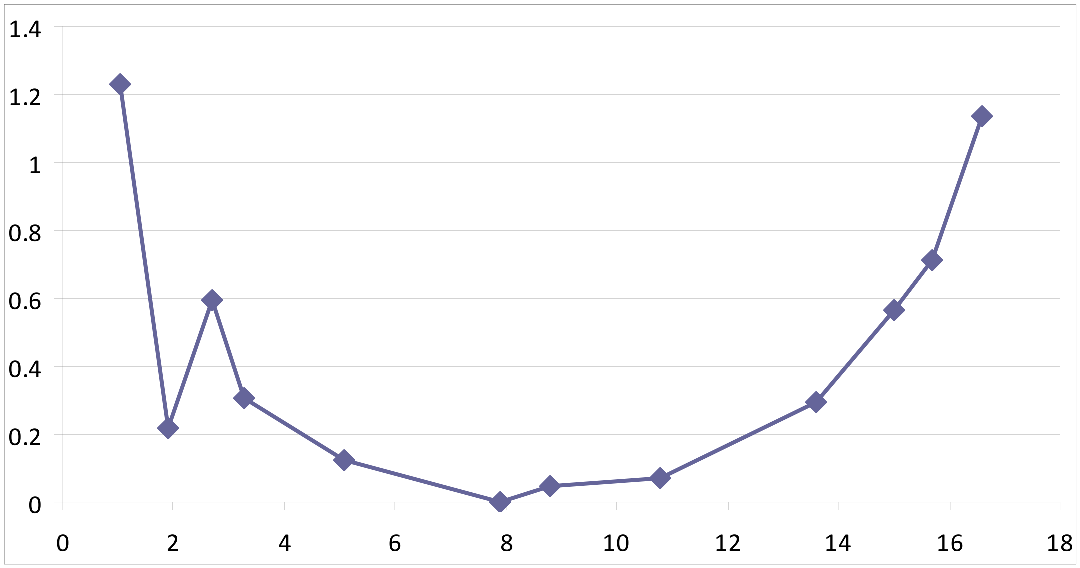
SITE 2 (cont.)

Particle Count		**Name: Emily and Cooper**			**sample every 13cm**		
Number	**Size cm**	**Number**	**Size cm**	**Number**	**Size cm**	**Number**	**Size cm**
1	0.05	26	7.6	51	11.5	76	5.5
2	0.05	27	9	52	2.1	77	0.1
3	0.05	28	0.05	53	12.8	78	0.4
4	0.1	29	0.2	54	4.3	79	3.4
5	0.05	30	6.6	55	1.2	80	3.8
6	0.05	31	6.4	56	2.3	81	0.4
7	0.05	32	5.6	57	6.8	82	1.9
8	0.75	33	0.8	58	0.15	83	0.3
9	0.05	34	0.1	59	0.6	84	7.3
10	0.05	35	2.2	60	2.5	85	3.1
11	0.05	36	0.05	61	2	86	0.1
12	0.75	37	0.7	62	0.9	87	2.8
13	0.05	38	4	63	5	88	5.5
14	0.05	39	6.9	64	1.6	89	1.4
15	1	40	3.5	65	6.5	90	7.8
16	0.1	41	1.1	66	4.1	91	2.3
17	0.1	42	4.8	67	6	92	9.1
18	0.5	43	0.1	68	3.7	93	2.1
19	0.2	44	1.2	69	5.8	94	0.2
20	0.1	45	13.5	70	0.1	95	1.9
21	1.5	46	1.4	71	3	96	1.9
22	0.1	47	11	72	1.7	97	9
23	0.7	48	4.1	73	0.9	98	2.2
24	0.5	49	4.3	74	0.2	99	1.2
25	0.6	50	0.8	75	5.7	100	0.15

SITE2 (cont.)

Cross section		**Name: Cooper**	**Type: Laser level**
Shot Number	**Height**	**Location**	**Description**
1	1.755	1.05	fore shot / right bench mark
2	2.77	1.9	
3	2.39	2.7	right bank
4	2.683	3.3	
5	2.864	5.1	
6	2.986	7.9	thalweg
12	2.941	8.8	
7	2.914	10.8	
8	2.694	13.6	
9	2.422	15	left bank
10	2.273	15.7	
11	1.852	16.6	left bench mark / meters
13	1.752		back shot / right bench mark

SITE 2 (cont.)



Cross section. All values in meters.

SITE 3

Site Name	Below Pheneger Creek
Date	9/27/2008
Time	1:15
Names	Emily, Cooper
GPS UTM	10S 0606888, 4014757 Center of Cross Section
Description	
15 m downstream of private bridge to Lockwood house. In line with pump house. LBM 2.4 m from large tree in a line with the pump house. RBM 2 m from downstream lower tree, 2.5 m from upstream tree.	

Nutrients / Water Chemistry	**Name: Emily**	**Hydrolab #: 43**
Ph	7.99	**Sample Bottle Name**
Turbity	0	Below Phenager Creek 10/1/08
Specific Conductence ms/cm	339.4	
DO mg/l	10	
DO %	101.1	
Temp C	15.97	
Nitrate + Nitrite (mg N/L)	0.0515	
Ammonium (mg N/L)	0.00755	
SRP (mg P/L)	0.01	
Urea (mg N/L)	7.081	

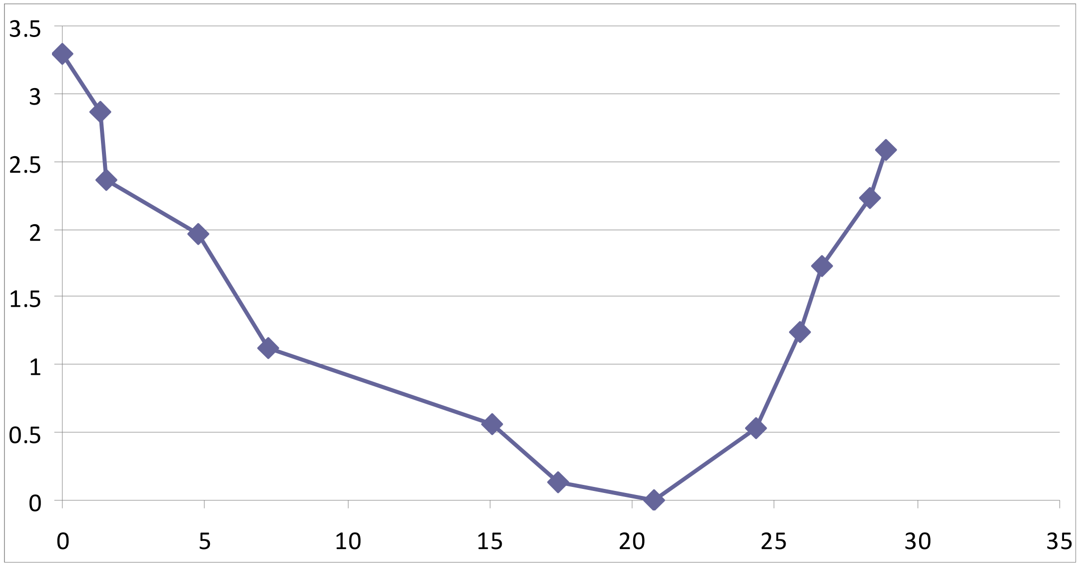
SITE 3 (cont.)

Particle Count		**Name: Cooper**			**sample every 8cm**		
Number	**Size cm**	**Number**	**Size cm**	**Number**	**Size cm**	**Number**	**Size cm**
1	6.5	26	1.3	51	3.5	76	9.6
2	1.1	27	8.8	52	1.5	77	28.5
3	3.7	28	41	53	0.7	78	28.5
4	10.4	29	41	54	15.5	79	28.5
5	5.9	30	41	55	18	80	47
6	19	31	41	56	0.2	81	47
7	14.7	32	41	57	0.1	82	47
8	14.7	33	0.9	58	0.1	83	47
9	9	34	12	59	0.1	84	23
10	11.5	35	2.6	60	12.5	85	23
11	19	36	10	61	10.5	86	23
12	19	37	13.6	62	10.5	87	2
13	10.5	38	11.3	63	0.2	88	10
14	5.5	39	11.7	64	1.5	89	10
15	13.5	40	13.5	65	1	90	25
16	10.7	41	0.3	66	0.1	91	0.3
17	0.2	42	29	67	16	92	18
18	1.7	43	29	68	79	93	0.1
19	11.4	44	11.1	69	79	94	0.05
20	7.4	45	11.1	70	79	95	26
21	7.4	46	22.5	71	79	96	0.05
22	3.5	47	4	72	79	97	roots
23	11.6	48	7.8	73	79	98	roots
24	11.6	49	1.8	74	79	99	roots
25	6.7	50	1.5	75	16.5	100	roots

SITE 3 (cont.)

Cross section		**Name: Emily**		**Type: Laser level**
Shot Number	**Height**	**Location**	**Distance**	
1	2.502	2.4	fore shot / left bench mark	2.193
2	1.395	0		3.3
3	1.825	1.3	top of cut bank	2.87
4	2.326	1.55	bottom of cut bank	2.369
5	2.736	4.75		1.959
6	3.574	7.2		1.121
7	4.136	15.1	left bank	0.559
8	4.555	17.4		0.14
9	4.695	20.75	thalweg	0
10	4.167	24.35	right bank	0.528
11	3.45	25.85		1.245
12	2.961	26.65		1.734
13	2.468	28.35	right bench mark	2.227
14	2.115	28.9		2.58
15	2.502	2.4	back shot / left bench mark	2.193

SITE 3 (cont.)



Cross section. All values in meters.

SITE 4

Site Name	Pheneger Creek
Date	9/28/2008
Time	12:00
Names	Cooper, Emily
GPS UTM	LBM 10S 0607328, 4014553 RBM 10S 0607329, 4014565
Description	

On Don Mcqueen's property across the road from Big Sur Campgrounds. Ask the campground attendent to open the gate. Approximately 100 m up the road, after the redwood structure, turn left into the 1st major turnout. The cross section is directly in front of turnout. The right bench mark is below the group of redwood trees across the creek.

Nutrients / Water Chemistry	**Name: Emily**	**Hydrolab #: 43**
Ph	7.96	**Sample Bottle Name**
Turbity	0	
Specific Conductence ms/cm	394.1	
DO mg/l	10	
DO %	98.1	
Temp C	14.64	Phenager Creek 10/1/08
Nitrate + Nitrite (mg N/L)	0.03	
Ammonium (mg N/L)	0.002486	
SRP (mg P/L)	0.0065885	
Urea (mg N/L)	5.1645	

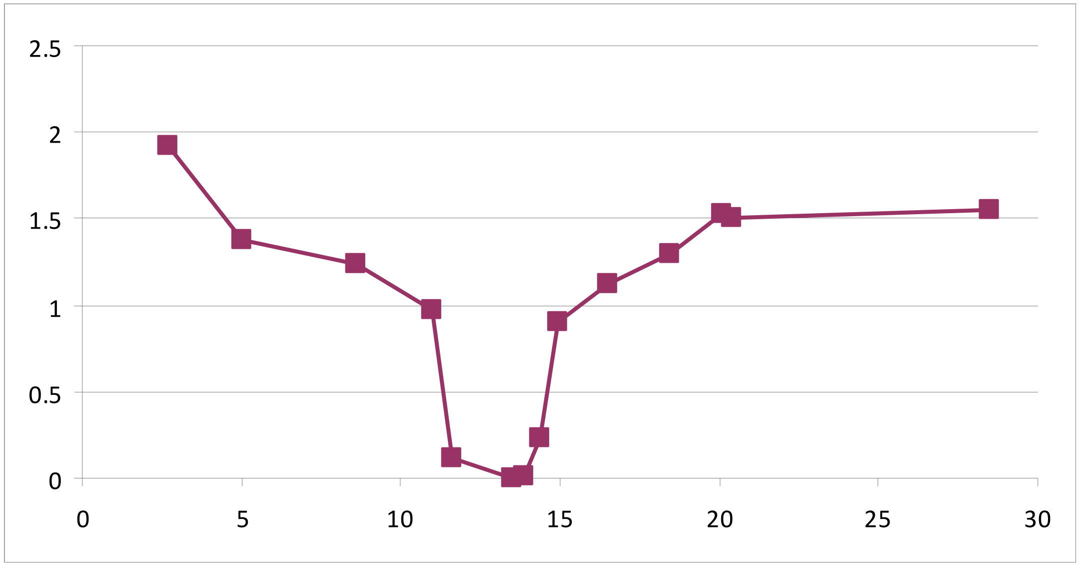
SITE 4 (cont.)

Particle Count		**Name: Emily**			**sample every 2cm**		
Number	**Size cm**	**Number**	**Size cm**	**Number**	**Size cm**	**Number**	**Size cm**
1	3.5	26	<.05	51	7	76	29
2	3.5	27	<.05	52	7	77	29
3	0.7	28	<.05	53	1.1	78	29
4	2.2	29	<.05	54	0.4	79	29
5	13	30	<.05	55	0.4	80	26
6	13	31	<.05	56	0.3	81	26
7	13	32	<.05	57	0.2	82	26
8	13	33	<.05	58	3	83	26
9	13	34	0.1	59	3	84	2
10	13	35	0.5	60	29	85	1.2
11	13	36	5	61	29	86	26
12	13	37	5	62	29	87	0.4
13	13	38	5	63	29	88	0.5
14	1.5	39	0.6	64	29	89	26
15	8.5	40	1	65	29	90	26
16	8.5	41	0.8	66	29	91	0.1
17	8.5	42	1.2	67	29	92	12
18	8.5	43	1.4	68	29	93	12
19	8.5	44	0.9	69	29	94	12
20	0.5	45	0.7	70	29	95	12
21	0.1	46	1	71	29	96	4
22	8	47	1.5	72	29	97	4
23	0.1	48	1.5	73	29	98	0.6
24	<.05	49	1	74	29	99	16
25	<.05	50	7	75	29	100	16

SITE 4 (cont.)

Cross section		**Name: Cooper**	**Type: Laser level**
Shot Number	**Height**	**Location**	**Description**
1	2.367	6.65	fore shot / left benchmark
2	1.757	2.7	
3	2.298	5.05	
4	2.446	8.6	
5	2.711	11	
6	3.563	11.6	left bank
7	3.681	13.5	thalweg
9	3.667	13.9	right bank
8	3.451	14.4	
10	2.78	14.95	
11	2.556	16.5	
12	2.381	18.45	
13	2.15	20.1	
14	2.178	20.4	right bench mark
15	2.132	28.5	
16	2.366	6.65	back shot / left bench mark

SITE 4 (cont.)



Cross section. All values in meters.

SITE 5

Site Name	Below Higuera
Date	9/27/2008
Time	10:30
Names	Emily, Cooper
GPS UTM	10S 0607409, 4014152 Center of Cross Section
Description	

South end of Big Sur Campground behind campsite #108. Left bench mark 0.9 m towards river from tree with 2 main stems. Right bench mark 2 m away from river from tree with 4 main trunks.

Nutrients / Water Chemistry	**Name: Emily**	**Hydrolab #: 43**
Ph	7.98	**Sample Bottle Name**
Turbity	0	Below Higuera 10/1/08
Specific Conductence ms/cm	335.3	
DO mg/l	10.15	
DO %	101.1	
Temp C	15.35	
Nitrate + Nitrite (mg N/L)	0.0675	
Ammonium (mg N/L)	-0.00055	
SRP (mg P/L)	0.011	
Urea (mg N/L)	2.9455	

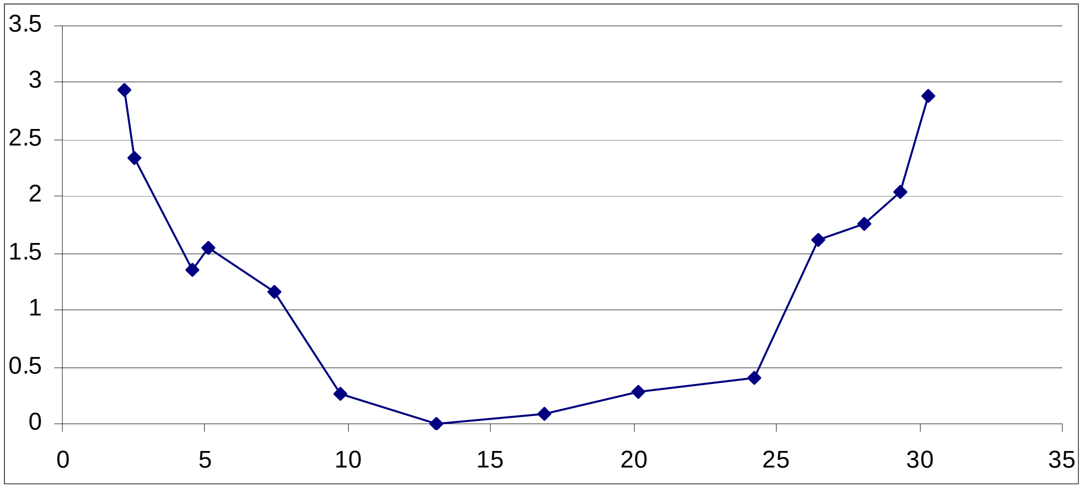
SITE 5 (cont.)

Particle Count		**Name: Emily**			**1-60 sampled every 18cm/61-100 every 25cm**		
Number	**Size cm**	**Number**	**Size cm**	**Number**	**Size cm**	**Number**	**Size cm**
1	0.1	26	4.7	51	0.2	76	8
2	4.5	27	15	52	4.8	77	10.5
3	1.2	28	15.8	53	6.5	78	3
4	11.3	29	14.5	54	0.3	79	6.7
5	13.6	30	7.1	55	1.4	80	7.8
6	31	31	6.4	56	13.5	81	15
7	1.6	32	10.4	57	7	82	0.2
8	3.8	33	4.5	58	4.5	83	0.1
9	9.3	34	1.8	59	10	84	13
10	10.4	35	2.2	60	1.6	85	8.5
11	33	36	8	61	1.2	86	10.2
12	46	37	12	62	0.1	87	3.6
13	0.4	38	15.5	63	0.2	88	2.9
14	15.5	39	10.5	64	0.05	89	2.2
15	58	40	10.8	65	10.7	90	3.3
16	58	41	10	66	1.6	91	46
17	2.5	42	18.5	67	9.4	92	46
18	2.2	43	0.2	68	17.4	93	46
19	4.1	44	6	69	29	94	16.5
20	18	45	12	70	29	95	22
21	3.5	46	18.5	71	7.7	96	4
22	18.5	47	28	72	14	97	19.4
23	2.4	48	6	73	16	98	11.8
24	19	49	13	74	17	99	2.7
25	20.8	50	17.5	75	15.5	100	23.5

SITE 5 (cont.)

Cross section		**Name: Cooper**	**Type: Laser level**
Shot Number	**Height**	**Location**	**Distance**
1	2.555	5.1	fore shot / left bench mark
2	1.156	2.2	
3	1.766	2.5	
4	2.74	4.55	
5	2.551	5.1	
6	2.941	7.45	
7	3.831	9.75	left bank
8	4.1	13.1	thalweg
9	4.018	16.85	
10	3.818	20.15	right bank
11	3.691	24.2	
12	2.482	26.45	
13	2.338	28.1	right bench mark
14	2.053	29.3	
15	1.212	30.3	
16	2.55	5.1	back shot / left bench mark

SITE 5 (cont.)



Cross section. All values in meters.

SITE 6

Site Name	Below Leech Field
Date	9/28/2008
Time	16:00
Names	Emily, Cooper
GPS UTM	LBM 10S 0608764, 4013298 RBM 10S 0608811, 4013319
Description	
Down a small trail off of a turn out on the west side of Hwy 1. Just before the sign to Pfieffer Burns State Park. Cross section is on a small bend in the river.	

Nutrients / Water Chemistry	**Name: Emily**	**Hydrolab #: 43**
Ph	7.91	**Sample Bottle Name**
Turbity	0	Below Leech Field 10/1/08
Specific Conductence ms/cm	320.3	
DO mg/l	10.14	
DO %	102	
Temp C	15.73	
Nitrate + Nitrite (mg N/L)	0.01087	
Ammonium (mg N/L)	0.003771	
SRP (mg P/L)	0.008528	
Urea (mg N/L)	1.225	

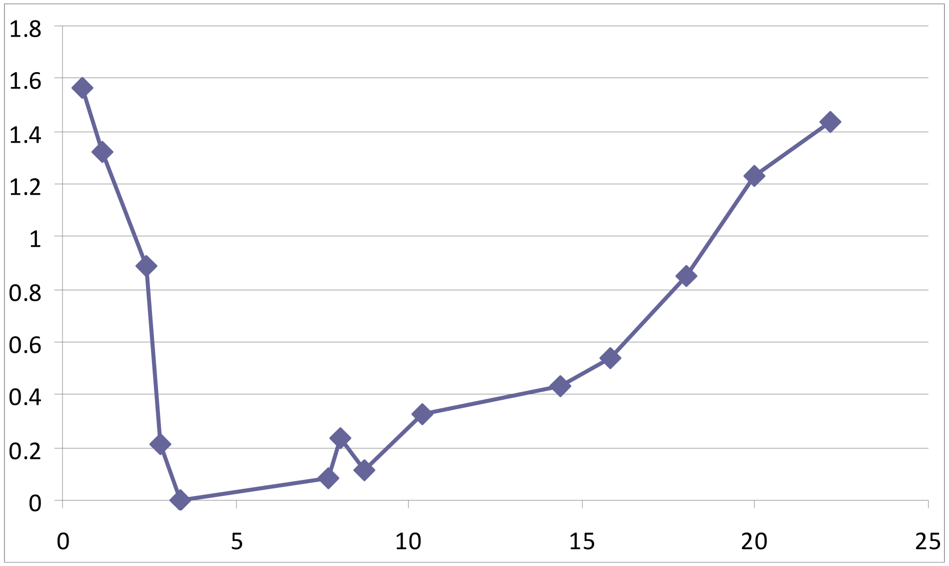
SITE 6 (cont.)

Particle Count		**Name: Emily**			**sample every 8cm**		
Number	**Size cm**	**Number**	**Size cm**	**Number**	**Size cm**	**Number**	**Size cm**
1	6.5	26	0.1	51	19	76	4.8
2	0.7	27	5.5	52	19	77	9
3	0.5	28	9.4	53	10	78	2.8
4	3.7	29	0.9	54	10	79	3.5
5	2.2	30	9.8	55	0.7	80	8.3
6	17.5	31	0.1	56	7.4	81	11.4
7	17.5	32	22	57	13	82	2.5
8	17.5	33	22	58	11.7	83	4.5
9	17.5	34	19	59	11.7	84	7.5
10	10.5	35	19	60	22	85	9
11	10.5	36	19	61	22	86	1.2
12	1	37	2.5	62	22	87	0.6
13	10	38	12.5	63	0.3	88	4.3
14	0.5	39	12.5	64	13	89	8
15	6.3	40	6	65	18	90	0.7
16	0.8	41	10.5	66	8.5	91	6.5
17	0.7	42	2.5	67	10.5	92	<0.05
18	0.5	43	16.5	68	11	93	7.5
19	4.5	44	24	69	13	94	<0.05
20	10.6	45	24	70	13	95	0.05
21	13	46	7.5	71	10	96	0.1
22	13	47	0.2	72	10.7	97	<0.05
23	0.7	48	0.4	73	4	98	<0.05
24	23	49	8.5	74	9	99	0.1
25	23	50	19	75	1	100	roots

SITE 6 (cont.)

Cross section	Name: Cooper		Type: Laser level
Shot Number	**Height**	**Location**	**Distance**
1	2.01	21.35	fore shot / left bench mark
2	1.864	22.15	At base of redwood
3	2.067	19.95	
4	2.45	18	
5	2.756	15.8	
6	2.861	14.35	
7	2.973	10.4	left bank
8	3.181	8.7	
9	3.06	8.05	
10	3.21	7.7	
11	3.297	3.4	thalweg
12	3.084	2.85	right bank
13	2.406	2.4	
14	1.975	1.15	right bench mark
15	1.729	0.6	
16	2.01	21.35	Back shot / left bench mark

SITE 6 (cont.)



Cross section. All values in meters.

SITE 7

Site Name	Below Post Creek
Date	9/28/2008
Time	14:30
Names	Emily, Cooper
GPS UTM	RBM 10S 0610117, 4011538 LBM 10S 0610119, 4011518
Description	

Pfeifer Burns Park 20 m down from Post Crk confluence with Big Sur River.

Nutrients / Water Chemistry	**Name: Cooper**	**Hydrolab #: 43**
Ph	8.36	**Sample Bottle Name**
Turbity	0	Below Post Creek 10/1/08
Specific Conductence ms/cm	312.8	
DO mg/l	10.43	
DO %	106.7	
Temp C	16.52	
Nitrate + Nitrite (mg N/L)	0.009449	
Ammonium (mg N/L)	0.009509	
SRP (mg P/L)	0.012	
Urea (mg N/L)	8.021	

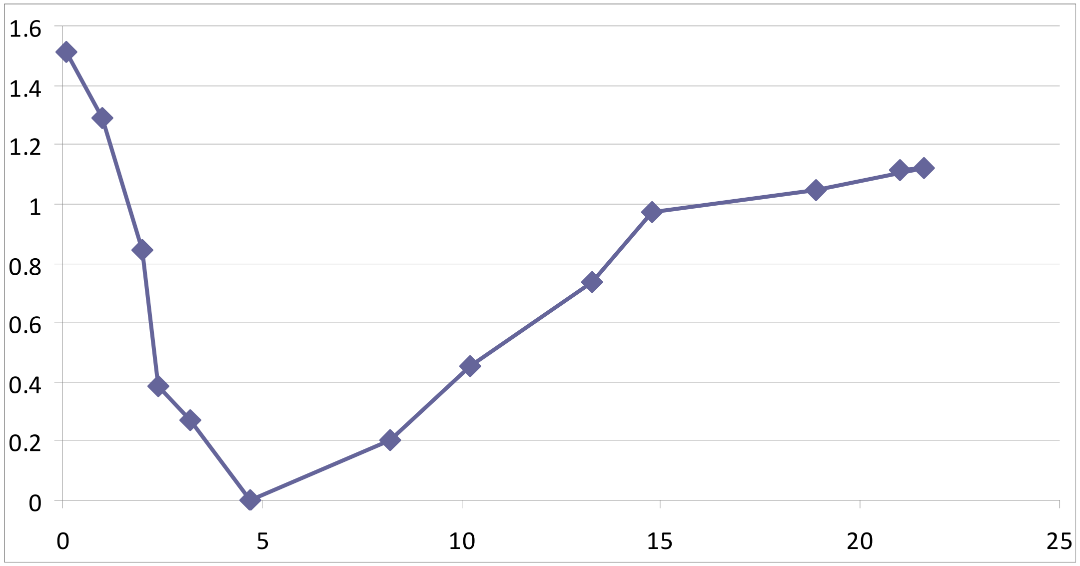
SITE 7 (cont.)

Particle Count		**Name: Cooper**			**sample every 8cm**		
Number	**Size cm**	**Number**	**Size cm**	**Number**	**Size cm**	**Number**	**Size cm**
1	5.4	26	52	51	39	76	3.5
2	8	27	52	52	39	77	20.5
3	16.6	28	52	53	39	78	6.1
4	16.6	29	52	54	39	79	2.4
5	8	30	45.5	55	28	80	0.1
6	9.8	31	45.5	56	28	81	8
7	9.8	32	45.5	57	28	82	8.2
8	1.4	33	45.5	58	16	83	0.05
9	5.3	34	6.5	59	16	84	0.1
10	4.8	35	9	60	2.2	85	12
11	8.5	36	8.8	61	9	86	12
12	0.1	37	23	62	0.9	87	root
13	12.5	38	23	63	7	88	0.05
14	12.5	39	23	64	7	89	0.05
15	2.5	40	17	65	21.5	90	root
16	4.8	41	17	66	3.6	91	0.6
17	9.8	42	24	67	3.6	92	17
18	23	43	24	68	9.5	93	3.8
19	23	44	24	69	8.5	94	45.5
20	23	45	8	70	8.5	95	6.4
21	4.4	46	8	71	16	96	24
22	11.5	47	12	72	16	97	52
23	3.5	48	39	73	21	98	5.3
24	52	49	39	74	21	99	5.2
25	52	50	39	75	7	100	6.1

SITE 7 (cont.)

Cross section		**Name: Emily**		**Type: Laser level**
Shot Number	**Height**	**Location**	**Distance**	
1	2.17	21	fore shot / right bench mark	1.113
2	2.162	21.6		1.121
3	2.238	18.9	right bank	1.045
4	2.312	14.8		0.971
5	2.549	13.3		0.734
6	2.831	10.2	right bank	0.452
7	3.08	8.2		0.203
8	3.283	4.7	thalweg	0
9	3.014	3.2		0.269
10	2.897	2.4	left bank	0.386
11	2.441	2		0.842
12	1.991	1		1.292
13	1.773	0.1	left bench mark / meters	1.51
14	2.169	21	back shot / right bench mark	1.114

SITE 7 (cont.)



Cross section. All values in meters.

SITE 8

Site Name	Upstream from Gauge
Date	9/21/2008
Time	14:50
Names	Mary, Cooper, Emily
GPS UTM	10s 0610267 4012058 center of cross section
Description	
20 yards down stream of trail closure	

Nutrients / Water Chemistry	**Name: Emily**	**Hydrolab #: 43**
Ph	8.15	**Sample Bottle Name**
Turbity	0	Above Gauge 10/1/08
Specific Conductence ms/cm	302	
DO mg/l	10.28	
DO %	102.8	
Temp C	15.42	
Nitrate + Nitrite (mg N/L)	0.0135	
Ammonium (mg N/L)	0.008672	
SRP (mg P/L)	0.011	
Urea (mg N/L)	-0.6705	

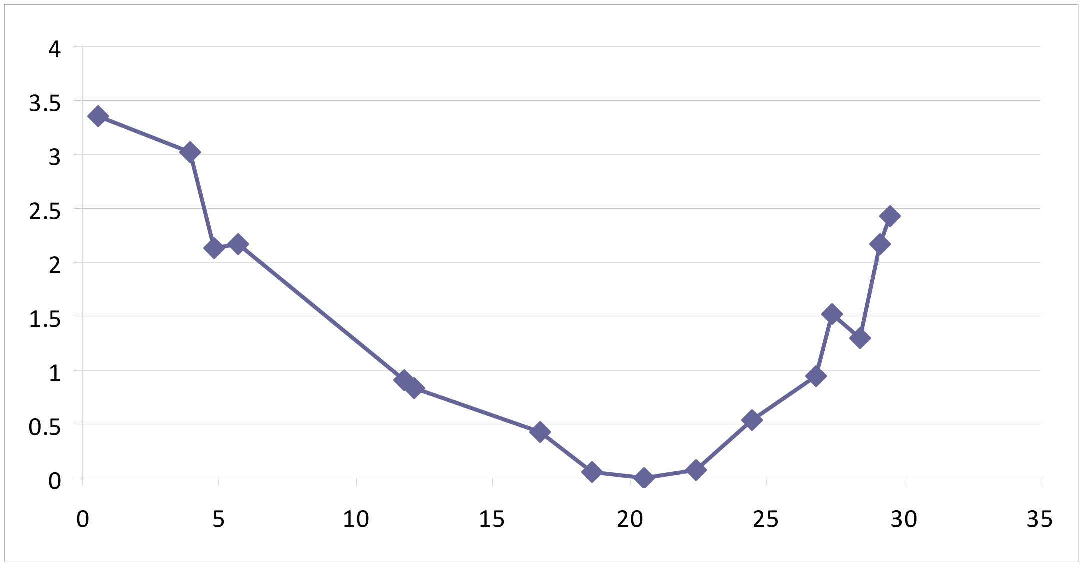
SITE 8 (cont.)

Particle Count		Name: Mary and Cooper			sample every 8cm		
Number	**Size cm**	**Number**	**Size cm**	**Number**	**Size cm**	**Number**	**Size cm**
1	2.7	26	9.5	51	23	76	23.5
2	3.9	27	20.5	52	15	77	23.5
3	1.2	28	38	53	26	78	17.5
4	0.2	29	38	54	26	79	20.5
5	11.5	30	38	55	1.1	80	20.5
6	11.5	31	38	56	2.2	81	9.1
7	0.3	32	9	57	21	82	28
8	35	33	44	58	1.5	83	1.1
9	0.2	34	44	59	12	84	26.5
10	0.2	35	44	60	38	85	1.9
11	0.2	36	44	61	38	86	2.8
12	0.5	37	44	62	38	87	36
13	0.2	38	44	63	38	88	36
14	0.8	39	44	64	38	89	25
15	11	40	1.3	65	12	90	55
16	11	41	4.6	66	12	91	55
17	0.2	42	35	67	10.5	92	55
18	8	43	35	68	10.5	93	5.1
19	65	44	1.5	69	10	94	5.5
20	65	45	65	70	12.2	95	29.5
21	65	46	65	71	16.2	96	29.5
22	65	47	65	72	16.2	97	1.2
23	65	48	65	73	1.5	98	10
24	65	49	3.1	74	6	99	23.5
25	65	50	15	75	3	100	23.5

SITE 8 (cont.)

Cross section		**Name: Cooper**	**Type: Laser level**
Shot Number	**Height**	**Location**	**Description**
1	1.425	0.6	fore shot / left benchmark
2	1.763	3.95	meters
3	2.65	4.85	
4	2.601	5.7	
5	3.863	11.8	
6	3.94	12.1	
7	4.342	16.7	left bank
8	4.721	18.6	
9	4.776	20.5	thalweg
10	4.71	22.45	
11	4.236	24.45	right bank
12	3.83	26.85	
13	3.262	27.4	
14	3.48	28.45	
15	2.616	29.15	right bench mark
16	2.349	29.5	
17	1.426	0.6	back shot / left bench mark

SITE 8 (cont.)



Cross section. All values in meters.

Central Coast Watershed Studies

CCoWS

Post-Fire Baseline Monitoring of Big Sur River Lagoon: November/December 2008

Publication No. WI-2008-7

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Executive Summary

The Basin Complex Fire of 2008 burned over 90% of the Big Sur watershed. Preexisting geologic conditions make the region especially prone to erosion and slope failure, particularly following wildfire. The combination of topography, geology and anticipated rains make about 80% of the watershed prone to debris flows. Excess sediment and large woody debris will probably impact the entire lower Big Sur basin, including the lagoon at the mouth of the river. Impacts can best be understood in the context of baseline monitoring that captures the extant environmental characteristics before the impacts occur. This study provides a set of observations that can be used to measure impact and recovery following the 2008-2009 rainy season. The monitoring parameters include topographic survey, sediment character, channel margin position, and photography. The study covers the mouth and head of the lagoon.

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Table of Contents

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1 Introduction

1.1 Background

The Big Sur Watershed in the Santa Lucia Range of central California was impacted by wildfire during summer 2008. Based upon previous wildfire events in the region, and early rain events in the 2008-09 water year, the Big Sur tributaries and main stem will be impacted by excess runoff and excess sediment yield. Public infrastructure, private property, businesses, and natural resources are now at risk as the winter rainy season approaches. This report provides an account of baseline environmental conditions for the Big Sur Lagoon at the mouth of the Big Sur River (Fig. 1).

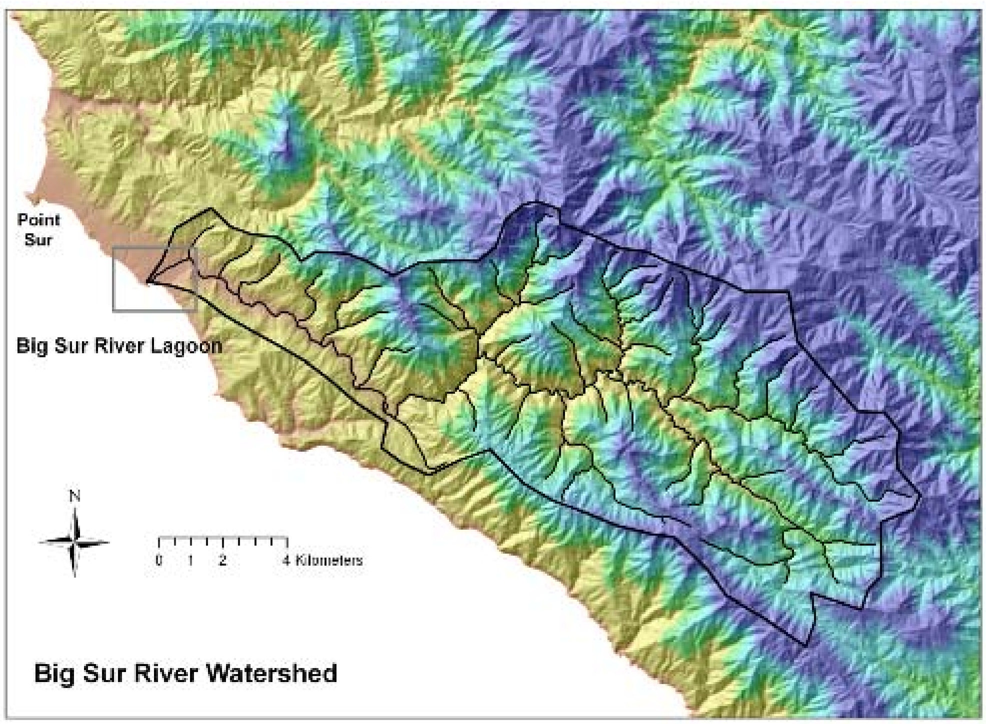

Figure 1: General study area.

Declining environmental conditions from post-wildfire slope failures in California are jeopardizing habitat for steelhead trout (*Oncorhynchus mykiss*). California steelhead, listed as threatened under the federal Endangered Species Act, are sensitive to environmental changes. Historically, rivers in California have supported large numbers of steelhead. Current population estimates are significantly reduced from their historic highs. Factors attributed to the population decline include the destruction of freshwater habitat. Researchers and experts in California agree that water quality problems and freshwater diversions are exacerbating steelhead habitat concerns (Hecht, 1981; Bond, 2006). The 2008 statewide wildfires are further threatening steelhead habitat from excessive soil yields and debris flows. This report will document baseline conditions in the Big Sur River Lagoon in California, a known steelhead habitat located below an intensively burned watershed.

The Big Sur River Lagoon is a 17-acre riverine estuary positioned at the mouth of the Big Sur River. The lagoon, located 26 miles south of Carmel-by-the-Sea, receives input from the Big Sur River and the surrounding 150 km^2 watershed. Tidal mixing and wave action from the ocean also contribute to the lagoon. The Big Sur River and lagoon are recognized steelhead stream habitats. In 2005, the National Oceanic and Atmospheric Administration (NOAA) identified this body of water as critical habitat for steelhead trout (70 FR 52488). Estuaries on the California Central Coast are important for steelhead (Bond, 2006) and other aquatic taxa. Estuaries provide a point-of-entry for winter spawning events, a transitional zone for smolts to acclimate to the marine environment and habitat for juveniles. Water quality in the lagoon can greatly influence juvenile success. Generally, steelhead prefer low temperatures, low salinity and high dissolved oxygen (Smith, 1990; Bond, 2006).

Wildfires can cause soils to be hydrophobic. Hydrophobic soils have the potential to cause exaggerated runoff and intensify soil erosion. In 2008, the Big Sur River headwaters experienced a wildfire burn to 92% of the watershed. The United States Geological Society (USGS) reported the Basin Complex Fire of July 2008 produced moderate to high soil burn throughout the catchments. Potential influence from wildfires can include changes in water chemistry from additions of ash, accelerated sediment yield, debris flows, landslides and loss of vegetation. A report from the Burned Area Emergency Rehabilitation (BAER) team stated the Big Sur River was at serious risk during any significant winter storms for the next three years from fire related issues (USDA, 2008).

Debris flow prediction can rapidly assess areas of concern in post-fire regions. Cannon et al. (in press) analyzed landscape features in a Western mountain setting using a Geographic Information System (GIS) platform to model debris-flow potential. The model successfully predicted debris flows based on estimated rainfall, severity of the burn and site variables such as slope and elevation in a specific catchment. The Big Sur River drains the western portion of the Santa Lucia Range. Federal and State reports forecast catastrophic slope failure and debris flow events in the surrounding range (Cannon, 2008; USDA, 2008). These events could deliver excessive sediment yields and large woody debris yields to the lagoon and beach area. A model of the watershed region will identify areas of concern above the lagoon and assess the potential of debris flow into the lagoon.

1.2 Steelhead and Other Species of Concern

The Big Sur River lagoon provides seasonal and year-round habitat for many fishes and invertebrates several of which are federally endangered and threatened species. In 2005 the Big Sur River was identified as critical habitat (70 FR 52488 – 52627) for steelhead trout (*Oncorhynchus mykiss*), which is listed as threatened under the federal Endangered Species Act.

Steelhead utilize the river mouth and lagoon in various parts of their life cycle. Unlike the Carmel and Salinas Lagoons that remain closed to the ocean for several months of the year, the Big Sur Lagoon mouth is perennially open in average water years because of the robust perennial flow from the generally undeveloped watershed. During the winter and spring, the sandbar which provides a barrier between the freshwater river and the ocean is fully breached. This process is critical in the temporal cycle of the lagoon and allows access for adult steelhead to migrate from the ocean to freshwater for spawning as well as access for juvenile steelhead to enter the ocean (Bond 2006). After the winter rains, the sandbar gradually builds and river mouth narrows. High tides and high surf during low flow times create a seasonal mildly saline lagoon. Throughout the summer and fall the lagoon becomes a rearing habitat for steelhead and provides a brackish environment where steelhead undergo smolting. Smolting is the transitional phase in which steelhead acclimate to salt water from freshwater conditions. Juvenile steelhead usually rear 1 to 2 years in the freshwater river before smolting and entering the ocean (Bond 2006).

Other species of concern observed near the Big Sur lagoon include California red-legged frog (*Rana draytonii*) and western pond turtle (*Actinemys marmorata*).

1.3 Summer 2008 Fires in the Big Sur Watershed

The combined Basin Complex and Indians Fires burned approximately 240,000 acres in several watersheds of the northern Santa Lucia Range (USDA 2008). Using GIS layers from Rosenberg (2001), USDA (2008) and Cannon (2008) we describe the watershed geology, and estimate the extent and severity of the burn in the Big Sur Watershed.

The Big Sur watershed is a WNW-facing, structurally-controlled drainage network that drains 151 km^2 of steep mountainous topography (Table 1; Fig. 1).

Table 1: Geometry of Big Sur Watershed

drainage area	151 km^2
shape	elongate
drainage	Dendritic with local fault control
aspect	wnw
hydraulic length	27 km
relief	4500 m
relief ratio	0.17
max elevation	4800

The watershed is underlain by 85% metamorphic rock, 19% igneous rock, and 15% sedimentary rock and recent deposits (Fig. 2). Five percent of the watershed is covered by existing historic landslides (Fig. 3), and there are slopes with high potential for landslides throughout the watershed (Fig. 4). The region has steep hill slopes and the bedrock is both deeply weathered and pervasively fractured and faulted, resulting in ubiquitous high erosion potential (Fig. 5).

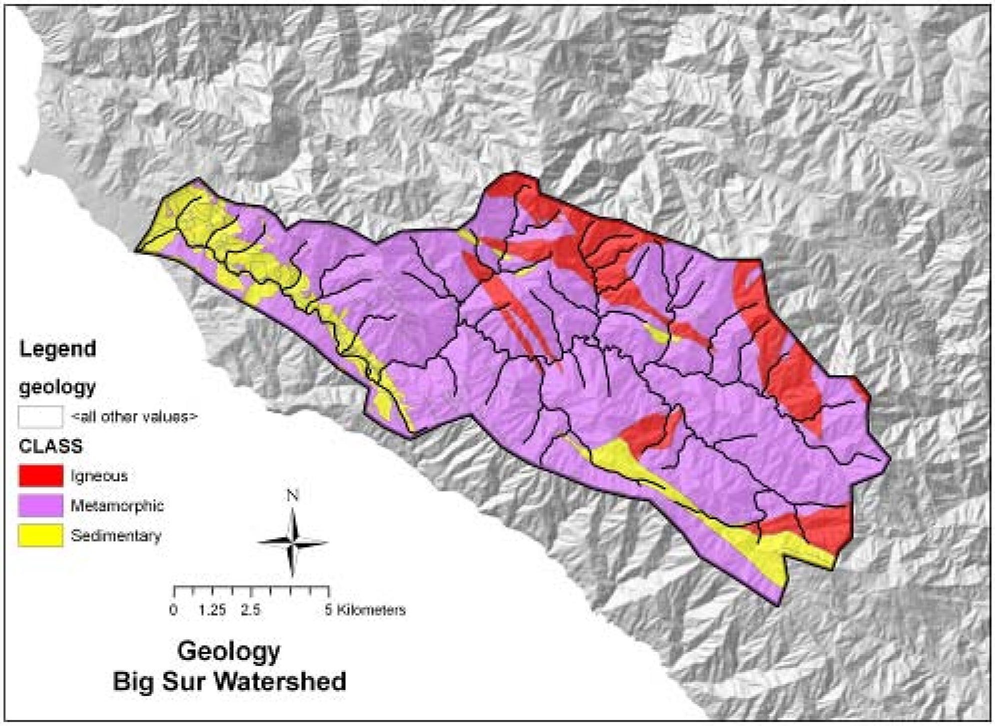

Figure 2: Basic Geology of the Big Sur Watershed (GIS data from Rosenberg (2001)).

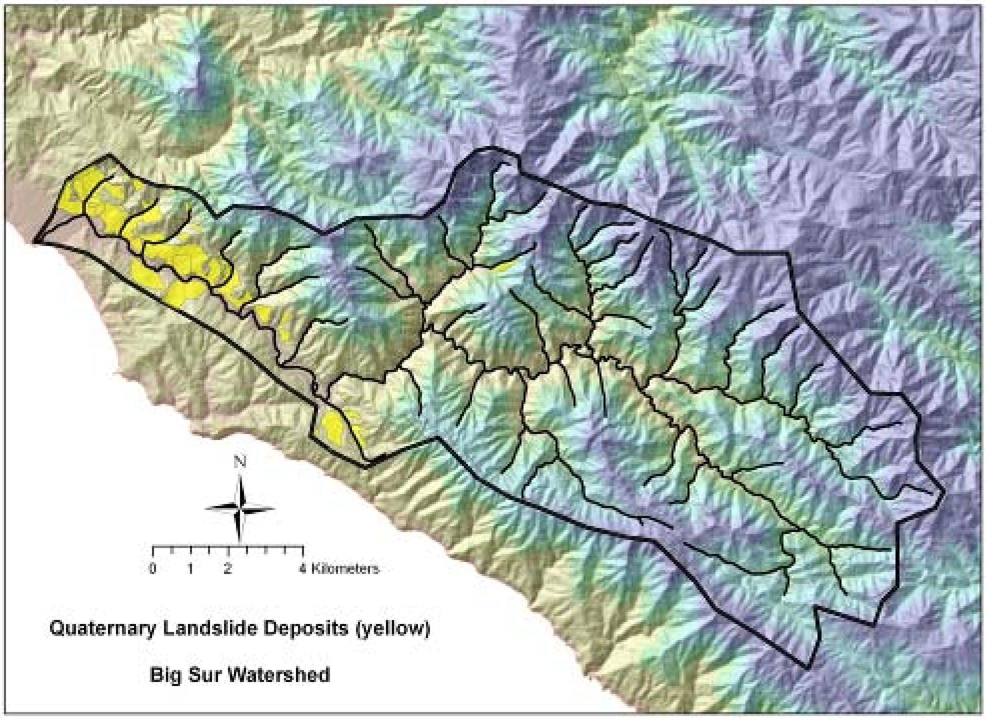

Figure 3: Historic landslide deposits in the Big Sur Watershed (GIS data from Rosenberg (2001)).

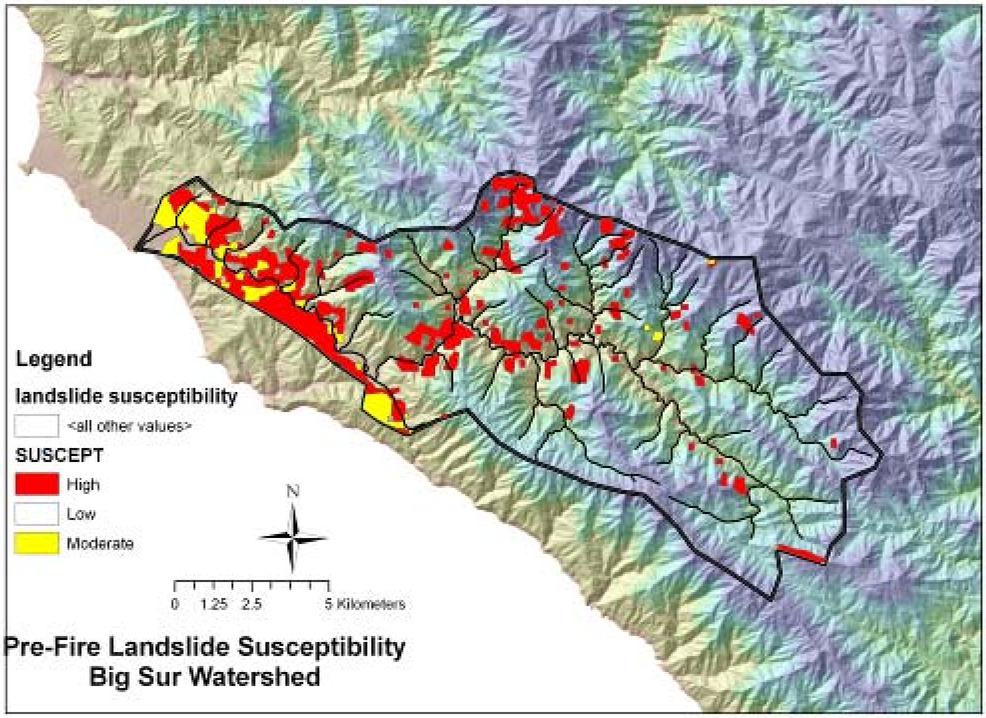

Figure 4: Landslide susceptibility in the Big Sur Watershed (GIS data from Rosenberg (2001))

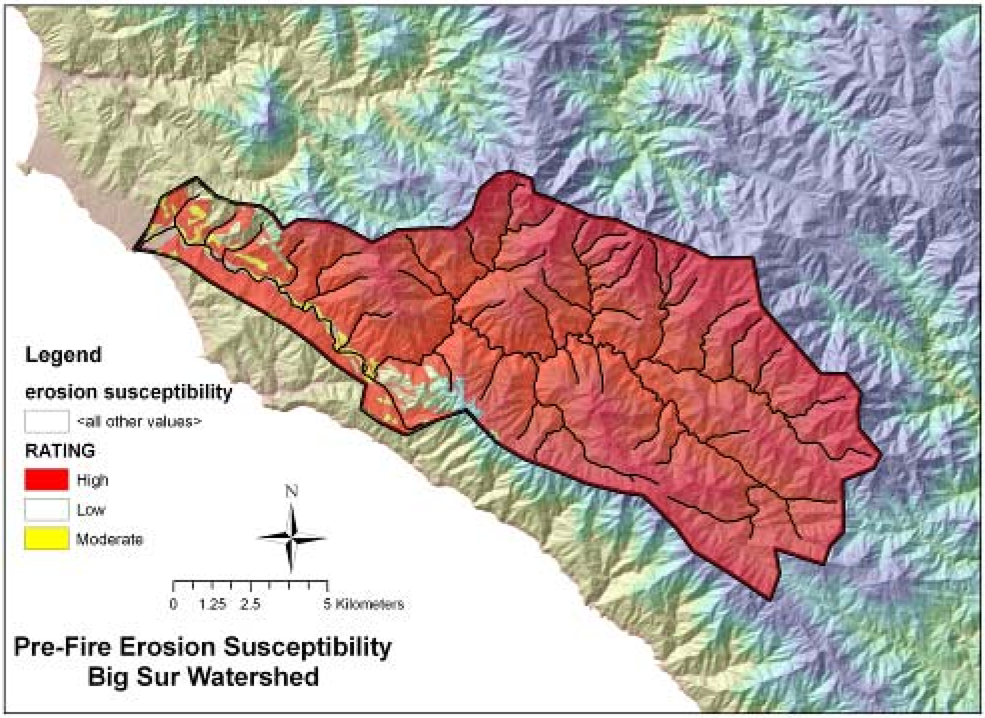

Figure 5: Erosion Potential (GIS data from Rosenberg (2001))

Figure 6 and Table 2 show the burn severity distribution in the Basin Complex Fire. Cannon et al., (in press) have found that the moderate-to-high burn severity areas generate the majority of debris flows during post-fire rains events; 65% of the Big Sur watershed falls in that category.

Table 2: Burn Severity in the Big Sur Watershed (GIS data from USDA (2008))

Severity	Area (km^2)	Percent of watershed
Unburned / Very Low	22	16%
Low	26	19%
Moderate	65	46%
High	27	19%
total burned	139	92%
total mod+high	91	65%

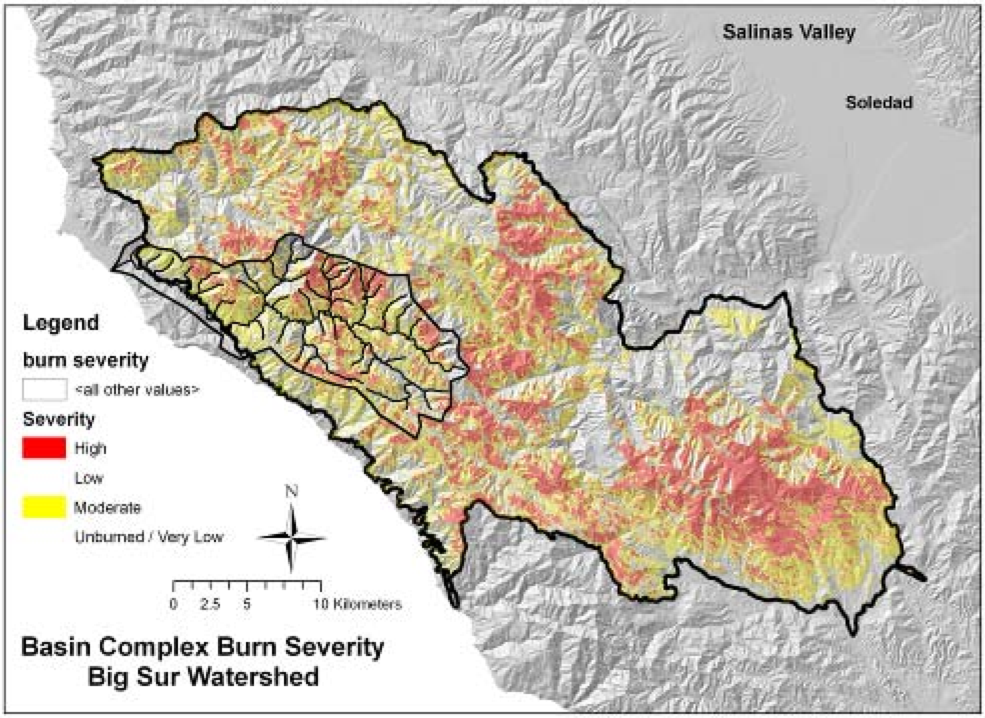

Figure 6: Burn severity of the Basin Complex fire. See Table 2 for more details. (GIS data from USDA (2008)).

Slope failure and debris-flow generation are the primary risk in the first few years following a fire in the Big Sur basin. Debris flow risk has been modeled in other parts of the country with reasonable success (Cannon et al. in press). The Cannon et al. (in press) model was used on over 850 sub-watersheds of the Basin Complex fire (Cannon 2008). Cannon (personal communication, 2008) supplied model data in GIS format so that we could estimate risks within sub-regions of the Bain Complex Fire perimeter. Analysis of 141 sub-watersheds composing the Big Sur watershed indicates that approximately 80% of the Big Sur watershed is at high risk of developing debris flows through increased erosion or slope failures (Fig. 7 and Table 3). The model figures might underestimate the true risk owing to the naturally weak substrate of the northern Santa Lucia Range (Figs. 5 and 6). Lions Creek draining Ventana Cone has the highest risk of a very high volume debris flow (red watershed in Fig. 7)

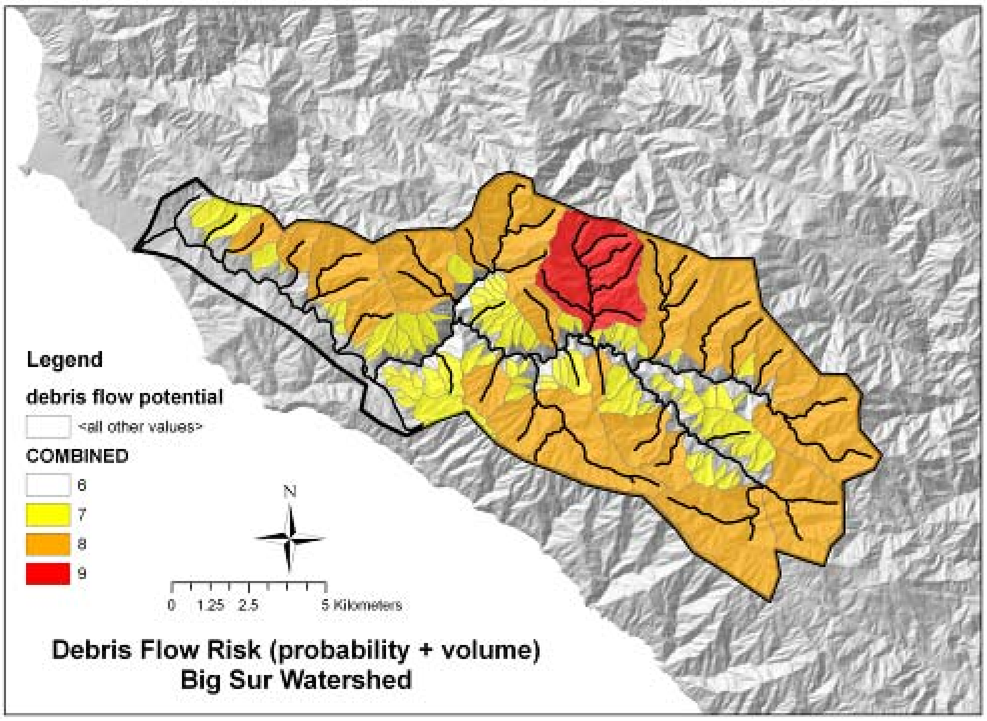

Figure 7: Debris flow risk of the Big Sur watershed See Table 3 for legend details (GIS data from Cannon (2008)).

Table 3: Debris Flow Risk in the Big Sur Watershed (GIS data from Cannon (2008); Risk method from Cannon et al. (in press)).

Combined Risk (Fig. 7)	Volume (m^3)	%chance of event	number of sub-basins	area (km2)	% of watershed
6	0-1,000	>80%	1	0	0%
7	1,001-10,000	>80%	101	26	18%
8	10,001 – 100,000	>80%	37	86	57%
9	>100,000	>80%	2	10	7%
			total area at risk	123	81%

In summary, the combination of steep topography, pre-existing weak substrate and broad distribution of moderate to severe burns in the watershed strongly indicate that short term negative consequences are in store for the Big Sur River and lagoon. Exacerbating the high risk is the 30-year time lag since the previous large burn in the watershed. The long time frame since the previous fire has allowed the growth of a thick regolith layer that can now be mobilized by slope failure and erosion.

1.4 Study Objectives

Steelhead habitat in the lagoon is susceptible to degradation. Burnt regions in multiple catchments in the surrounding watershed will generate runoff that will change the topography and bathymetry thus affecting steelhead habitat. The objectives of this report are to document baseline conditions for the immediate and long-term post-fire changes in physical habitat of the mouth of the Big Sur River and lagoon. Baseline monitoring can detect changes in environmental features that serve to act as an indicator for possible threats to the lagoon. These data and report will be provided to State Parks to be used for management of the area. The chief data products are total station surveys to show local channel morphology, GPS survey showing the present channel margins in relation to past channel positions, channel-bottom sediment characteristics, and an archive of digital photography from various perspectives.

We focused our attention on two parts of the lagoon. On November 13 and December 4 we worked at the mouth of the lagoon (Fig. 2). On November 20, we worked at the head of the lagoon, the most upstream reach of river that is typically influenced by tides (Fig. 8).

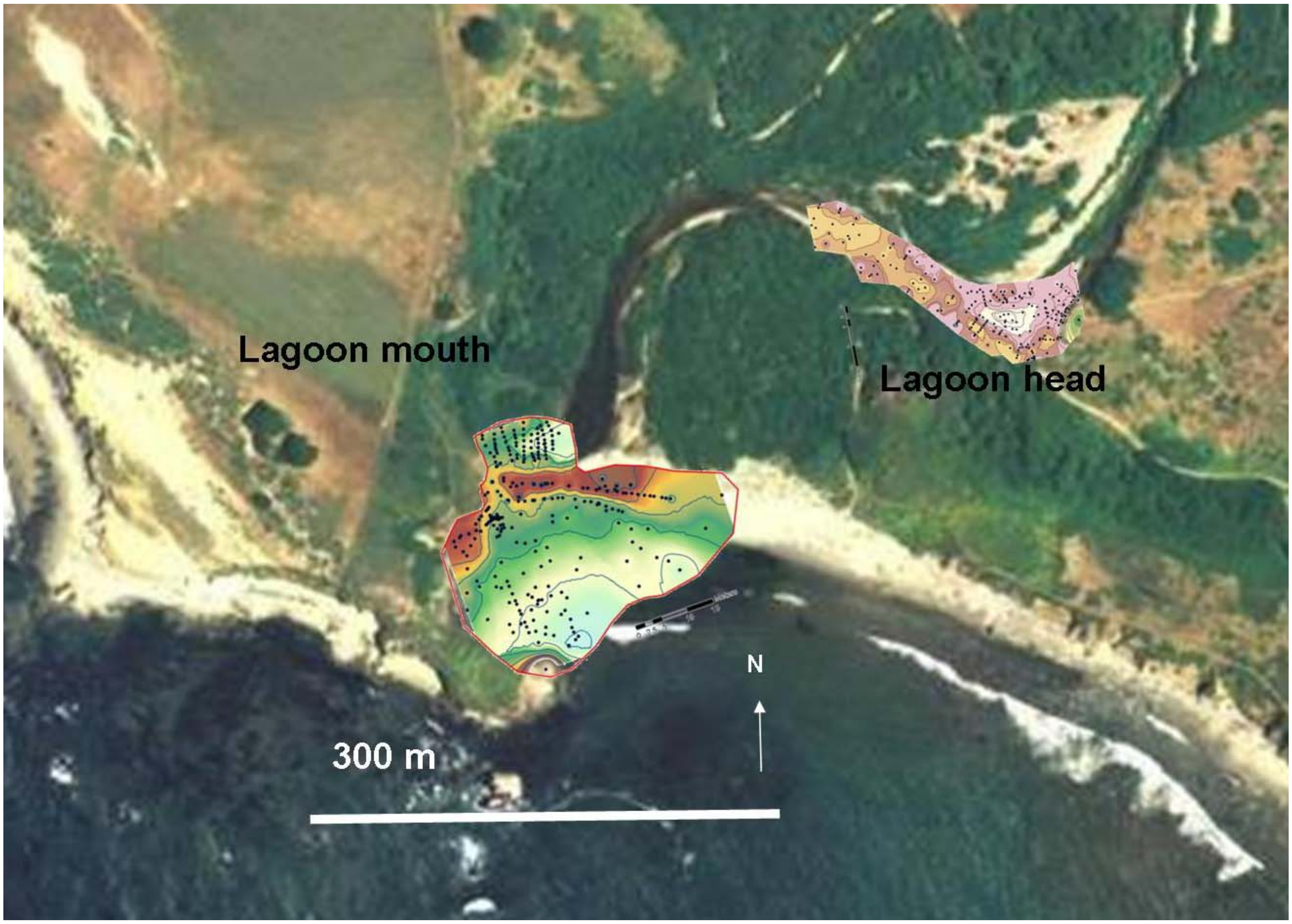

Figure 8: Survey data covering study sites at mouth and head of the Big Sur Lagoon.

2 Methods

2.1 Goals and Approach

The goal of this work is to document environmental conditions existing at the Big Sur lagoon so that anticipated post-fire effects can be better documented. Our intent was to document conditions in the entire lagoon, but time constraints limited our work to the mouth and head. The head was selected because it will be the first to see aggradation as excess sediment enters the lagoon system. There is a break in slope of the water surface where stream flow interfaces with tidally influenced backwater.

2.2 GPS

We collected GPS point data along the edge of the water at the Big Sur River lagoon using a Trimble 2005 series handheld GPS unit. GPS points were collected during the afternoon hours (1200-1530 hours) between November 13 and December 4, 2008.

On November 13, 2008, GPS points were collected along the edge of the water at the Big Sur River mouth (Fig. 2). GPS points collected along the edge of water on November 20, 2008 were taken at the lagoon head (Fig. 2). On December 4, 2008, GPS points were collected between the November 13 and November 20 surveys to connect the two surveys.

For each GPS point location, a substrate type was associated with the point. The substrate categories included: sand (s), mud (m), gravel (g), cobble (c), and rock (r). While this substrate information tells us what substrate was present at the time of the data collection, its application is limited due to the incomplete representation of the substrate across the lagoon using this approach. Those data are not presented in this report.

We imported our GPS points into ArcMap 9.2 in State Plane NAD 1983 projection in order to create a Big Sur River lagoon watercourse boundary file. We then projected this layer file onto aerial photos of the Big Sur River lagoon from 1994, 2003, and 2007. This allowed us to compare movement of the river channel over time.

2.3 Bathymetry and Topography

Three-dimensional topographic data were collected using Topcon 211 and Topcon 3002 total stations. The 3002 instrument is capable of collecting XYZ data with or without a prism reflector, which increased survey efficiency during our first date during low tide. All other surveys used a prism pole with both instruments. Using a 2.5 meter prism pole allowed "blind" areas to be correctly surveyed and provide access to areas submerged by water (bathymetry). Points were collected on random transects across the river channel at major breaks in slope. Beach profile data were collected at various locations that seemed to indicate a break in slope across the planar surface.

The total stations were referenced to semi-permanent benchmarks at both the lagoon mouth and lagoon head. We assigned an NEZ location of 0, 0, 100 (m) to each benchmark and selected distant objects to set false north at each site. Original survey data are available from the first author. Total station precision was checked by shooting identical points with each total station. Closing errors were typically 0.02 m root mean square.

Data were downloaded from the total station to personal computer for post processing. We decided to keep the data in its project reference framework, rather than shifting and rotating the data cloud into the state plane projection used with the GPS data due to time limitations. Given the reproducibility of the reference framework, future surveys using identical setup inputs and benchmarked locations can provide precise time series datasets for comparison.

The survey of the lagoon head on 11/20/2008 was combined with survey data collected on 11/11/2008 by students in the undergraduate Geomorphic Systems class at CSU-Monterey Bay.

Filtered text files were imported into ArcGIS 9.2 where a raster was created using the Inverse Weighted Distance (IDW) tool in spatial analyst. Spatial Analyst extension was used to subtract the elevation differences between the repeated surveys at the lagoon mouth from 11/13/2008 and 12/4/2008.

2.4 Sediment Analysis

Multiple pebble count transects were performed at both the lagoon head (Fig 9) and mouth (Fig. 10). Sediment transect counts were performed in the river bed and adjacent bars and banks. Randomly chosen individual particles were measured at their intermediate axis with a metric ruler. Fine particles <2mm were counted, but sand and mud particle sizes were estimated based on field observations and not measured. Percent fines, arithmetic mean and standard deviation were calculated for each transect, lagoon head, mouth, and all locations to help determine baseline lagoon conditions. Pebble counts were tallied into particle size classes. Percent pebble counts were graphed into histograms.

Figure 9: Sediment transects at the Big Sur lagoon head location. TH2 is located on a riffle, and TH4 goes across a cobble bar.

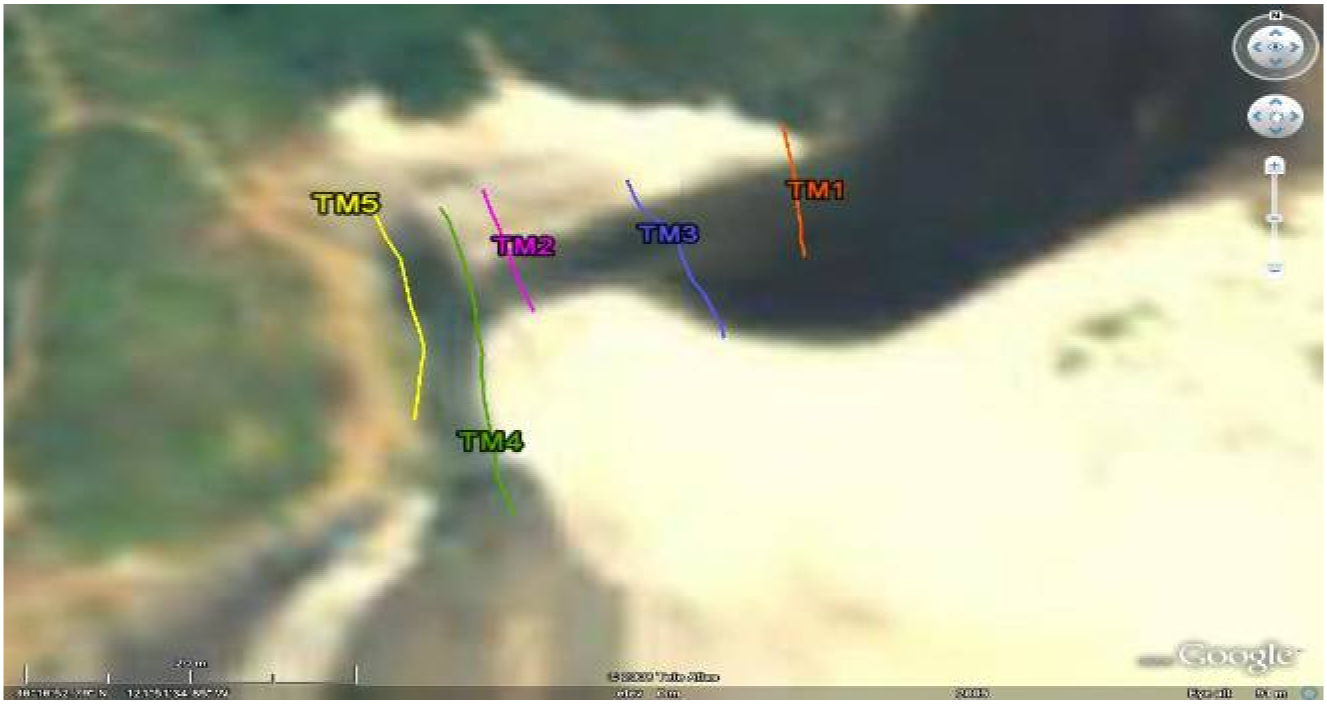

Figure 10: Sediment transects at the Big Sur lagoon mouth.

We conducted a Kruskal-Wallis test for nonparametric data on the unclassified pebble measurements to examine the variability between transects at both the head and mouth of lagoon. Adjacent transects were tested for differences using a Wilcoxon rank sum test. In order to make recommendations for follow-up monitoring, we conducted post hoc power analyses. Statistical analyses were conducted using R Statistical Package (R Development Core Team 2008).

2.5 Photo-monitoring

Many documentary oblique photographs were shot. These include both single scenes at various scales and multiple-photo panoramas of broader regions. These photos were neither benchmarked nor scaled to quantify change; they will be useful to demonstrate gross qualitative changes in environmental characteristics at the lagoon mouth and head.

2.6 Other data available for this study

All original data sets to be used for post-fire runoff comparisons are archived with Dr. Douglas Smith in the Division of Science and Environmental Policy at CSU-Monterey Bay.

3 Results

3.1 Bathymetry and Topography

Post-processed field data were imported into GIS where a raster was created using the Inverse Weighted Distance (IDW) tool in spatial analyst. The resulting maps illustrate surveyed locations and interpolated points. Figure 11 shows topography of the lagoon mouth on 11/13/08.

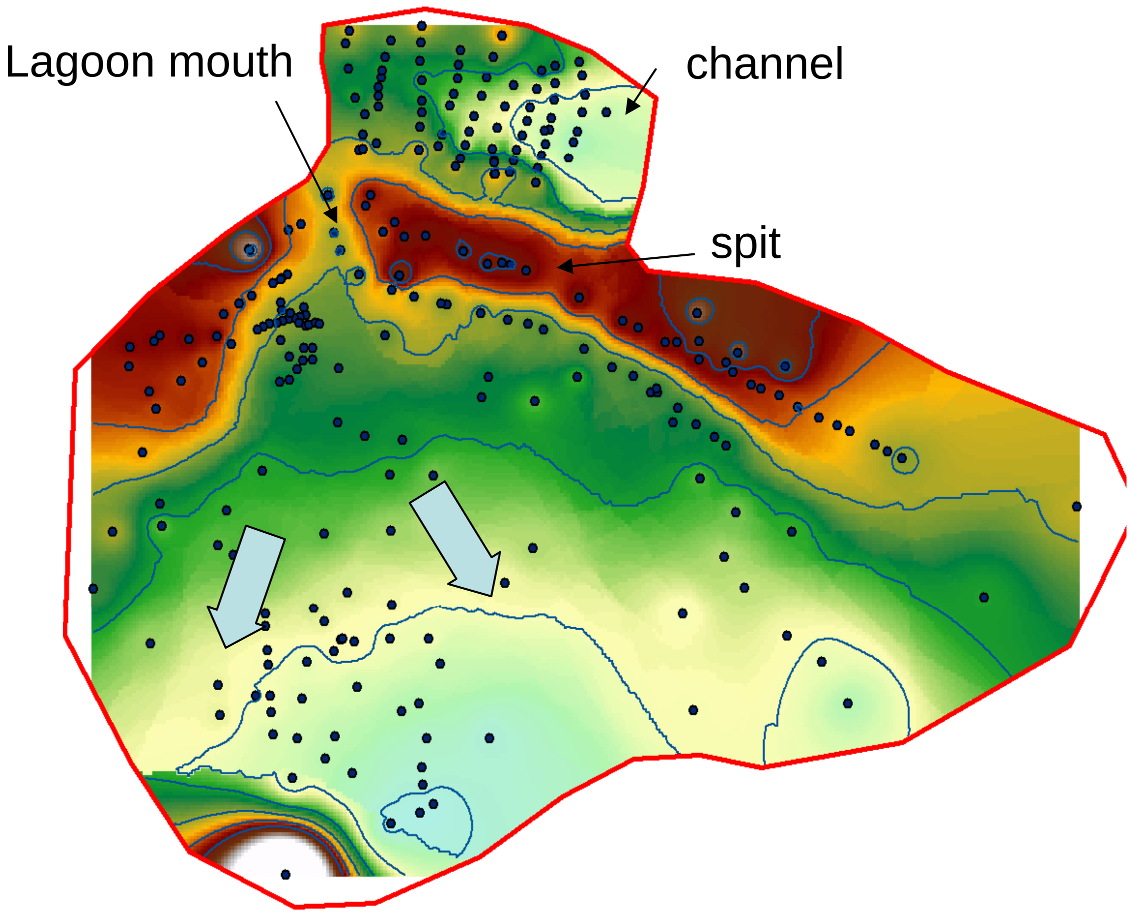

Figure 11: Total station data interpolated into a raster image of the lagoon mouth using Inverse Distance Weighted averaging. Colors correspond to elevation zones where light green and light blue correspond to lowest elevations and red areas represent higher elevations. Red boundary is a user-created line to clip the raster to fit the data points. Points are in a local arbitrary reference frame. Red and white areas have greatest elevations and light green and light blue have the lowest elevations. Rocky cliff extends upward in upper left and bottom of the image. A horizontal sand spit runs parallel to the shore and constricts the lagoon mouth

Higher areas (red) are located across the mouth in the form of a partial lagoon barrier or river mouth spit, along with the bluff backed beach and cliff where total stations were setup. The deepest areas (light green to light blue) appear at the base of the bluff nearest the ocean, where highest wave energy occurs, and the upper part of the lagoon system behind the gravel bar. A plug of sediment provides hydrologic control over freshwater outflow into the ocean. At the lagoon head, a riffle just before the big bend marks the approximate endpoint of saltwater influence (Fig. 12).

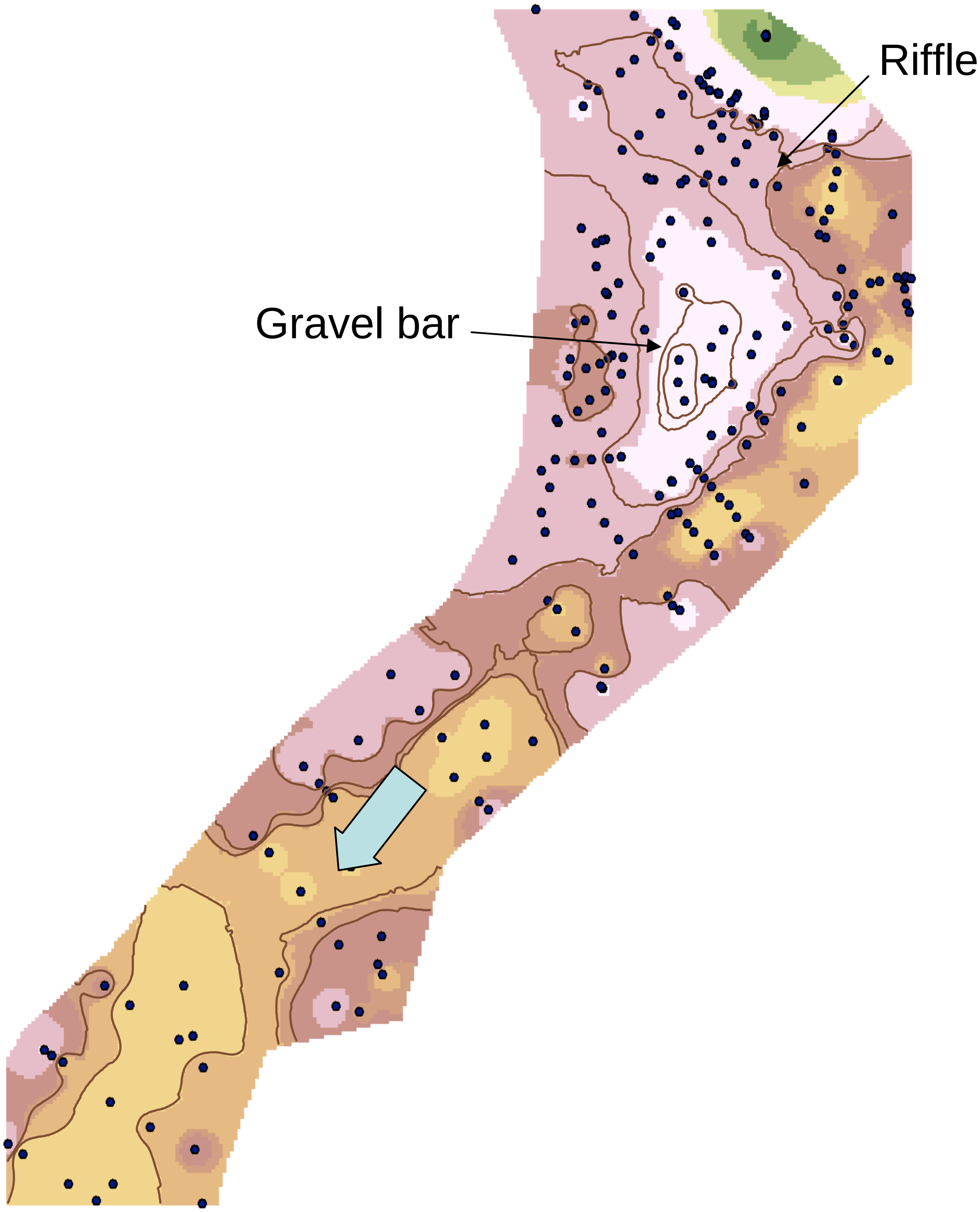

Figure 12: Lagoon head survey at a sharp right bend in the river channel. Colors correspond to elevation zones. Lght tan correspond to low elevations while purple and white areas represent higher elevations. Water elevation during survey approximately located along purple/sandy color interface. Arrow indicates flow direction. A gravel point bar was present at the white colored area, with water flowing outside in the tan areas.

A resurvey of the lagoon mouth on 12/04/08 maps natural variability within the system Given good point density and overlapping transects between repeated surveys (Fig. 13), comparison of elevation values could quantify variability at the lagoon mouth. Raster subtraction of the survey dates 11/13/08 from 12/04/08 (Fig. 14) yielded approximate change over 3 week period that included several days of large surf

This is a highly dynamic system with observed changes over a 3 week period without fire impact.

Figure 13: December 4, 2008 total station data point cloud and interpolated raster plotted on top of November 11, 2008 clipped raster. Both rasters were clipped using appropriate user-created mask. White corresponds to the higher elevations and dark green corresponds to the lower elevations. Color ramp used for each survey dataset is identical, providing the ability to qualitatively examine variability within the system.

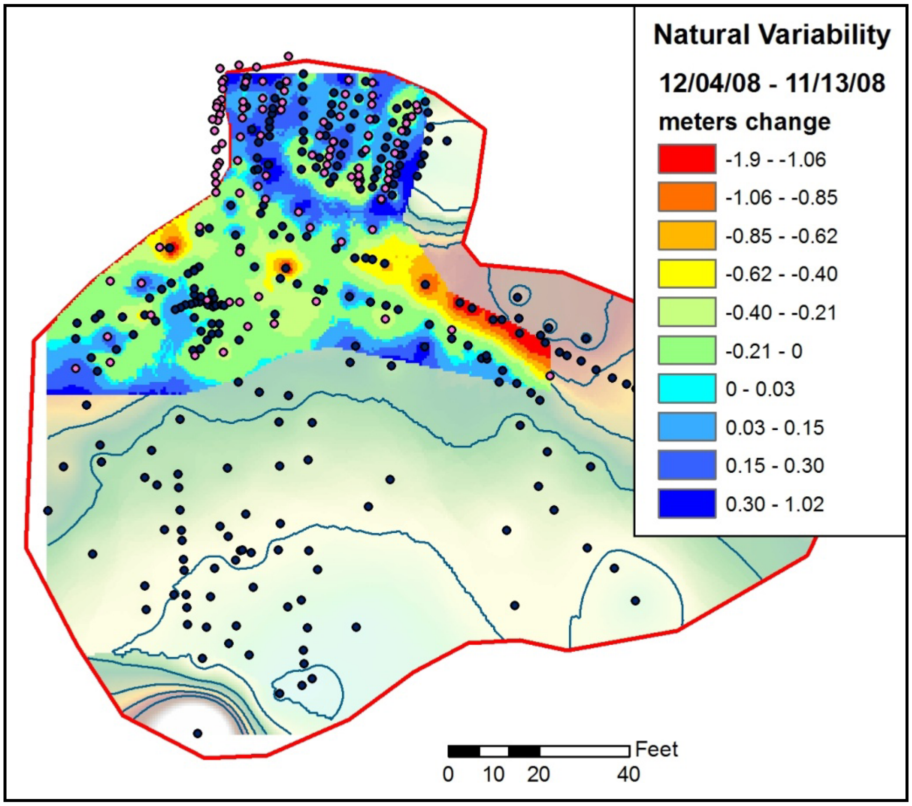

Figure 14: Raster subtraction of November 11th and December 12th clipped datasets plotted over muted November 11th interpolated raster. Point cloud from both surveys are shown. Changes in areas with low point density are less defendable than those with greater point density. Depth changes are in meters and warmer colors indicate erosion while cooler colors indicate accretion.

3.2 GPS

The result of the GPS points collected and the GIS mapping is a delineation of the current lagoon edge at the Big Sur River lagoon. This layer file can be used as a baseline for the location of the lagoon edge. The series of maps (Figs. 15, 16 and 17) illustrates the movement of the Big Sur River channel between 1994 and 2007. This series of maps shows that the position of the channel has rapidly changed, even in the absence of high sediment loads imposed by fire impacts. Figure 17, the Big Sur River lagoon layer file projected onto a 2007 Google image, provides a reasonably accurate representation of the current location of the Big Sur River lagoon, as the projection error is estimated at only half a meter based upon our local comparison with optical survey data. The layer file, created from GPS point data taken in November and December 2008, can be used as a baseline for comparison with future post-fire impact surveys.

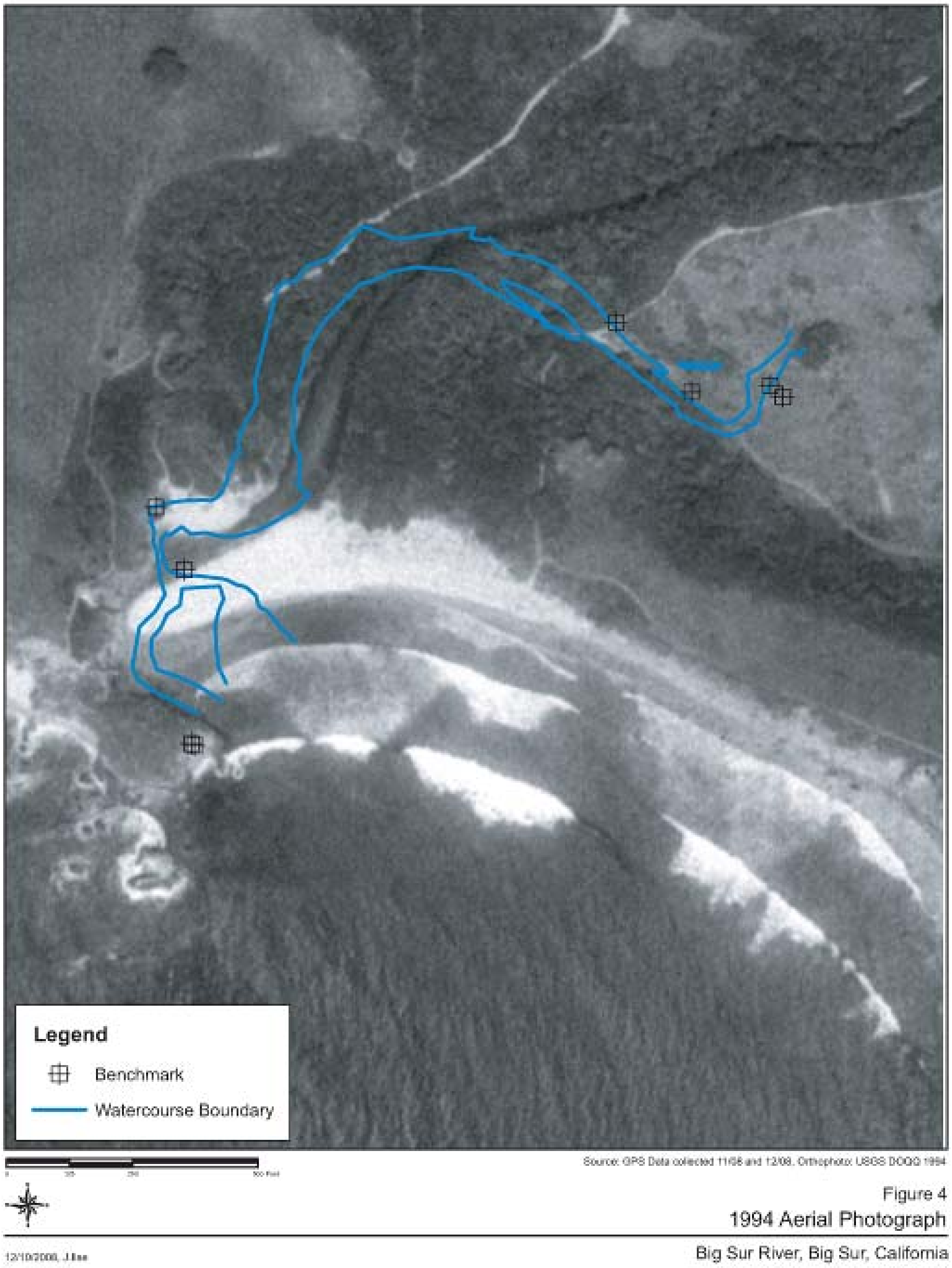

Figure 15: GPS position of channel margins plotted on 1994 aerial photograph.

Figure 16: GPS position of channel margins plotted on 2003 aerial photograph.

Figure 17: GPS position of channel margins plotted on 2007 aerial photograph.

3.3 Channel Sediment Characteristics

Arithmetic mean and standard deviation results are given in Table 1 for each transect and overall average. Figures 18 and 19 show histograms of percent pebble counts for each particle class size on each transect. The mean is approximately shown as a black circle hovering above the appropriate size class, with a black triangle representing the mean calculated with the fine particles removed (<2mm). With the exception of TH3, all histograms show a bi-modal distribution of particle sizes with a strong fines spike <2mm. The fines are present as a thin veneer on framework grains and as interstitial fill. The Big Sur transects range from poorly sorted to extremely poorly sorted when the fines are included.

Table 1: Percent fines, arithmetic mean and standard deviation for sediment transect particle measurements (mm). Green column includes all measurements, and the orange column does not include fine particles in the calculations (<2mm). "TM#" transects are from the Big Sur lagoon mouth analyzed on Dec. 04, 2008, and the "TH#" transects are from the Big Sur lagoon head analyzed on Nov. 20, 2008. Averages for the lagoon head and mouth locations as well as all transects are located at the bottom.

Transect	% Fines	With Fines		Without Fines	
	(<2mm)	Mean (mm)	Std. Dev. (mm)	Mean (mm)	Std. Dev. (mm)
TM1	31	24.0	19.6	34.8	12.9
TM2	38	25.5	26.6	41.3	22.2
TM3	60	12.0	17.3	29.5	15.3
TM4	66	23.3	40.4	67.3	42.5
TM5	43	29.2	33.5	51.0	29.1
TH1	50	28.7	45.7	57.4	50.6
TH2	36	52.3	64.3	81.3	63.9
TH3	0	79.8	51.8	79.8	51.8
TH4	37	35.7	44.3	56.9	43.9
TH5	67	9.6	15.7	28.8	13.3
TH6	12	51.3	34.7	58.3	30.8
TH7	52	35.5	43.4	73.9	31.9
TH8	32	45.5	41.6	66.9	32.9
TH9	8	58.9	28.9	64.1	23.8
TH10	32	45.2	50.8	66.4	48.7
TH11	12	64.1	50.9	72.8	47.9
TH12	4	218.2	159.5	227.3	156.1
Average M	**48**	**22.8**	**27.5**	**44.8**	**42.2**
Average H	**29**	**60.4**	**52.6**	**77.8**	**49.6**
Average M & H	**38**	**41.6**	**40.1**	**61.3**	**45.9**

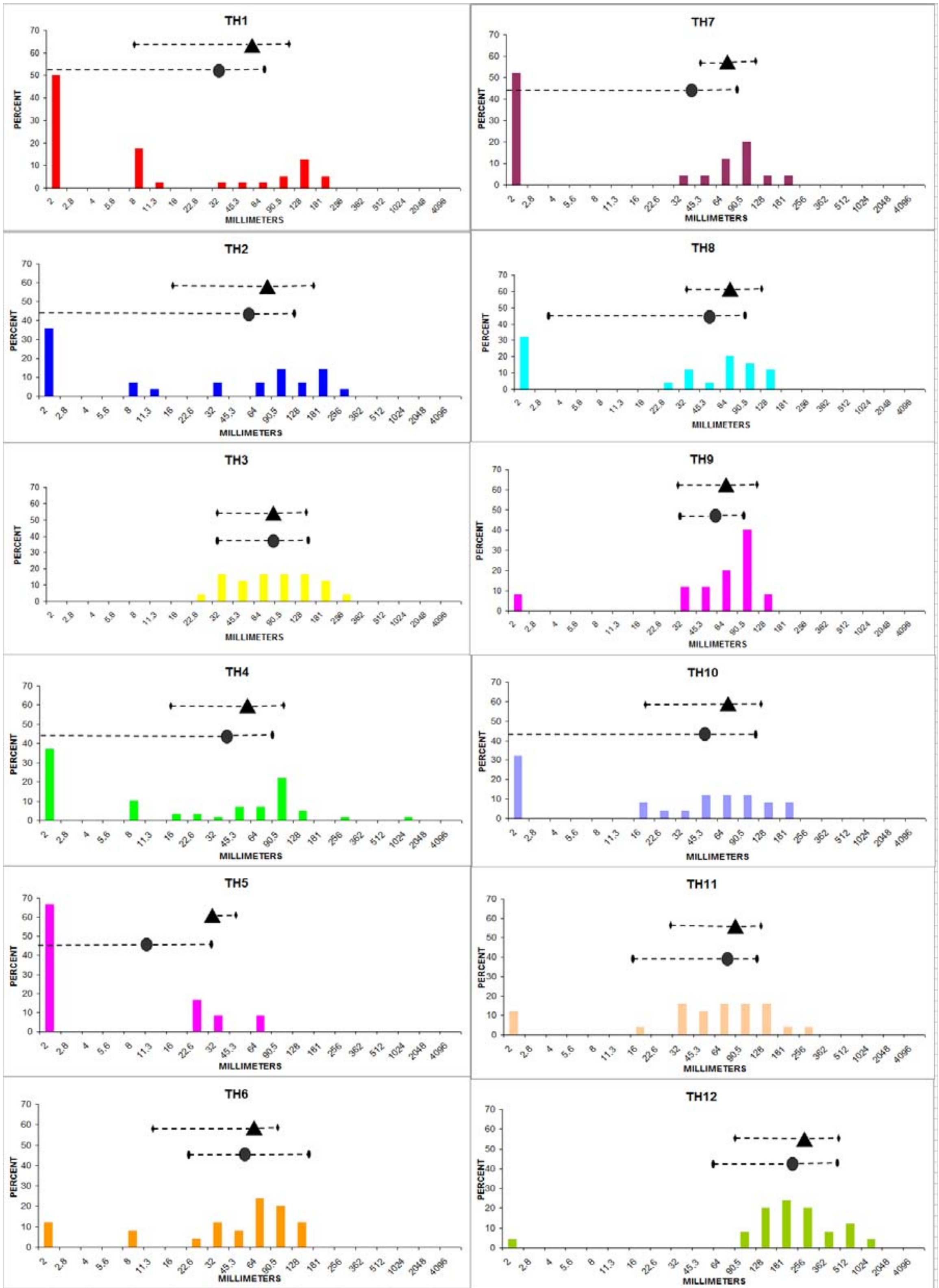

Figure 18: Histograms for lagoon head transects showing mean with (circle) and without (triangle) fines. Dashed lines represent standard deviation.

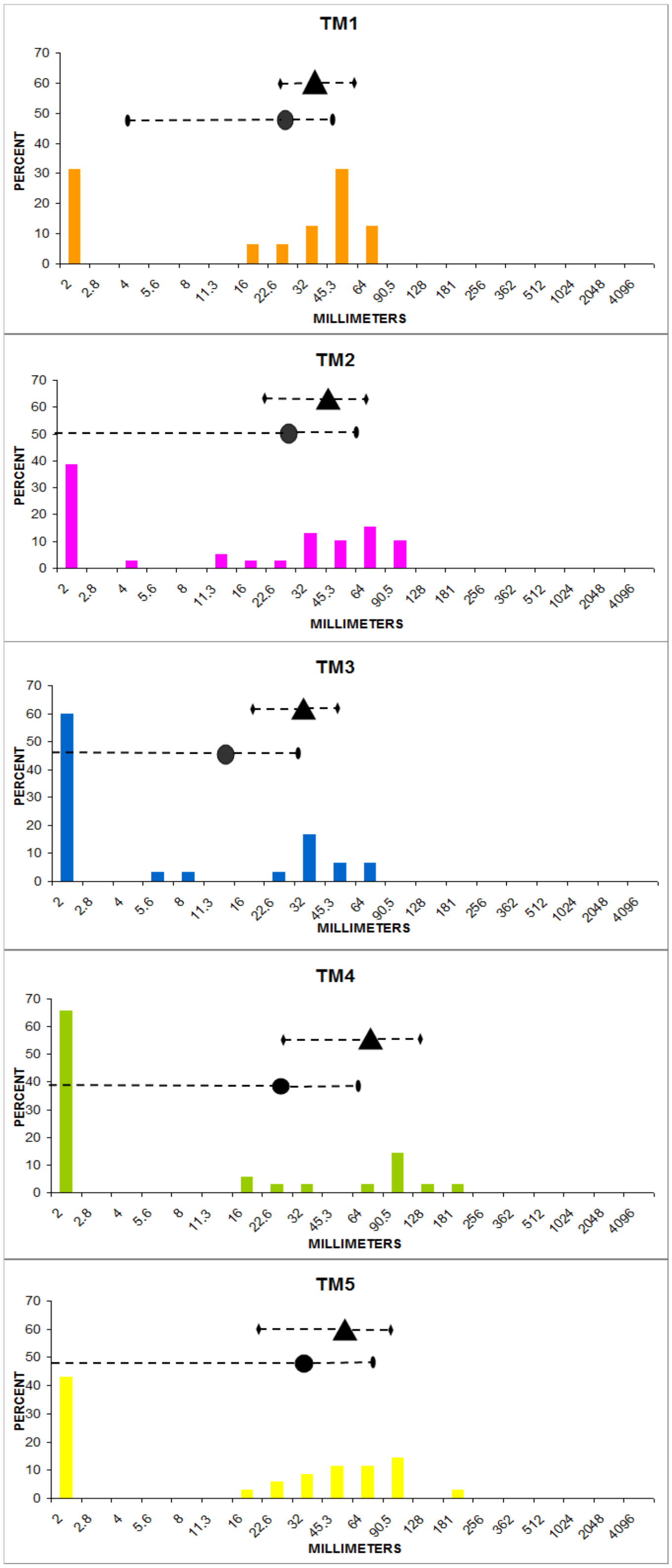

Figure 19: Histograms for lagoon mouth transects showing mean with (circle) and without (triangle) fines. Dashed lines represent standard deviation.

A Kruskal-Wallis test conducted on the 12 pebble count transects at the lagoon head showed significant variability between transects ($\alpha=0.05$, $p=4.491e-14$; Fig. 20). The Wilcoxon rank sum test for differences between adjacent transects showed differences between five of the adjacent transects ($\alpha=0.05$, Fig. 20). The five pebble count transects placed at the mouth of the lagoon showed no variability between transects ($\alpha=0.05$, $p=0.1063$) following the Kruskal-Wallis test (Fig. 21).

We conducted post hoc power analyses to determine optimal sampling for future efforts. At the lagoon head, we recommend six well-placed transects to adequately capture the variability of the area surveyed (Fig. 22). Pebble counts within each of these transects should be increased to 105 in order to detect a smallest meaningful difference (SMD) of 30 mm ($\alpha=0.05$). Increasing the pebble count to lower the SMD below 30 mm would significantly increase sampling effort. At the mouth of the lagoon, pebble counts could be conducted using either three transects of 105 counts each or five transects of 65 counts each to assess the area sampled during the baseline survey ($\alpha=0.05$). These recommended pebble counts would capture an SMD of 12 mm and 15 mm respectively ($\alpha=0.05$).

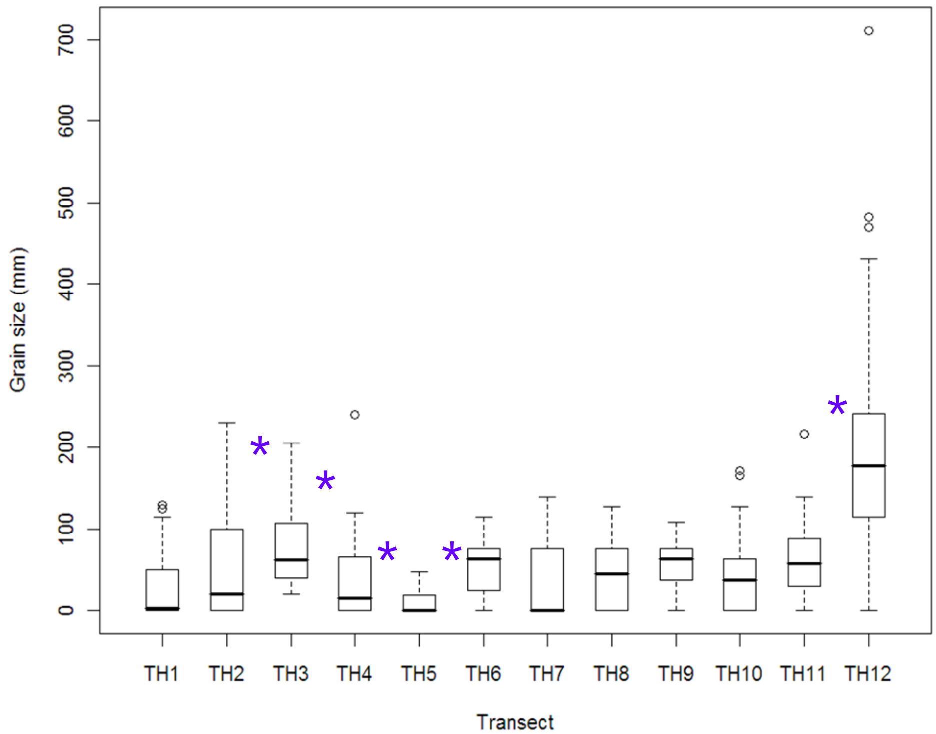

Figure 20. Boxplot of 12 pebble count transects at the head of Big Sur River Lagoon. Asterisk (*) indicates a significant difference (α=0.05) between adjacent transects.

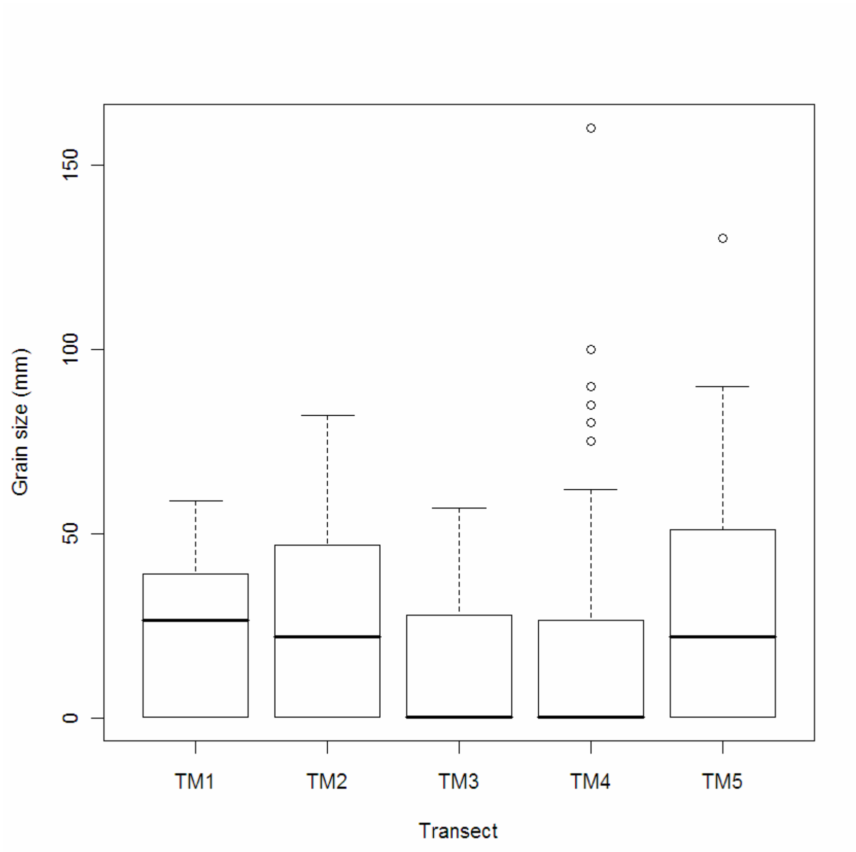

Figure 21. Boxplot of 5 pebble count transects at the mouth of Big Sur River Lagoon. No significant differences between transects were found (α=0.05, p=0.1063).

Figure 22. Pebble count transects at the Big Sur River lagoon head in 2008. Red circles indicate the six recommended transect locations for future surveys.

3.4 Photo-monitoring

A subset of photos is provided here. Figure 23 shows an overview of the lagoon mouth. Figure 24 shows the natural variability in the lagoon mouth following a period of high waves. Changes can be seen in the amount of organic debris in the spit and the shape of the spit following the high waves in late November (Fig. 24). Figure 25 shows a close-up view of the mouth on December 4.

Figure 26 and 27 are views downstream from the right bend at the lagoon head. Figure 28 is the upstream from the lagoon head, immediately above the riffle defining the limit of tidal influence. An initial increase in mud is documented in the substrate along the gravel bar at the Lagoon head (Fig. 29). This mud veneer was not present during a site visit on November 16. Between November 16 and November 20, there was the first significant rain of the water year in the Big Sur watershed. The runoff produced a peak flow of 200 cfs, and apparently brought the first fine-grained sediment yield as well.

Figure 23: Mouth of Big Sur River Lagoon during low tide. (November 2008)

Figure 24: Lower reach, mouth of Big Sur River Lagoon. Time series comparison from November 20th 2008 (left) and December 4th 2008 (right), note kelp deposit.

Figure 25: Lower reach, point-of-entry of Big Sur River Lagoon mouth and ocean. (December 2008)

Figure 26: Lagoon head. View downstream from gravel point bar (November 2008).

Figure 27: Lagoon head. View downstream across gravel point bar (November 2008).

Figure 28: View upstream of Big Sur River Lagoon. Upstream edge of gravel point bar visible in bottom of photo. Note mud veneer on gravel and along bank (November 2008).

Figure 29: Lagoon head. Various levels of substrate embeddedness at the upstream edge of the gravel bar (November 2008).

Figure 30: Lagoon head. Riffle delimiting the upper boundary of tidal influence in the river. Raw, freshly eroded bank is at apex of sharp right bend (November 2008).

4 Discussion

Baseline data were collected for the upper and lower terminations of the Big Sur Lagoon. Natural variability is great at the lagoon mouth as storms rearrange the river mouth spit geometry, and the lagoon head, where bank erosion is lengthening the river channel.

In keeping with historic post-fire effects, we anticipate an increase in bed load, suspended load, and large woody debris in the system during the 2008-2009 winter. This change has the potential for adverse short-term environmental effects in the lagoon. Channel bottom variability might become reduced as deeper areas are infilled by sediment. Fine sediment will likely cover the framework of coarse gravel.

Recent historic aerial photos analyzed in this study indicate that the mouth of the Big Sur River is typically located adjacent to the rocky cliff at the northern end of the spit. This observation suggests that the mouth position is in decadal-scale steady-state equilibrium, with an "average position" that does not vary through decades.

In contrast, the position of the lagoon head, especially the sharp right bend, is not in decadal-scale steady-state equilibrium with current watershed (or local) conditions. It has monotonically shifted south, gradually increasing the river length and decreasing its average slope. The abrupt change from dense riparian forest to un-forested terrace (Fig. 31) provides the context for a positive feedback between bank erosion and greater shear stress. As the outer bank erodes into the weak terrace materials, the stout riparian bank vegetation downstream from the bend resists any change. The result of this uneven erosion is a gradually decreasing radius of curvature in the bend (Fig. 31). The tighter bend, resulting from this erosion, increases the stream attack angle on the bank and the attendant shear stress on the weak bank (Fig 30). The bend currently has a radius of curvature that is approximately one half the value typically found in unmodified streams of the same size.

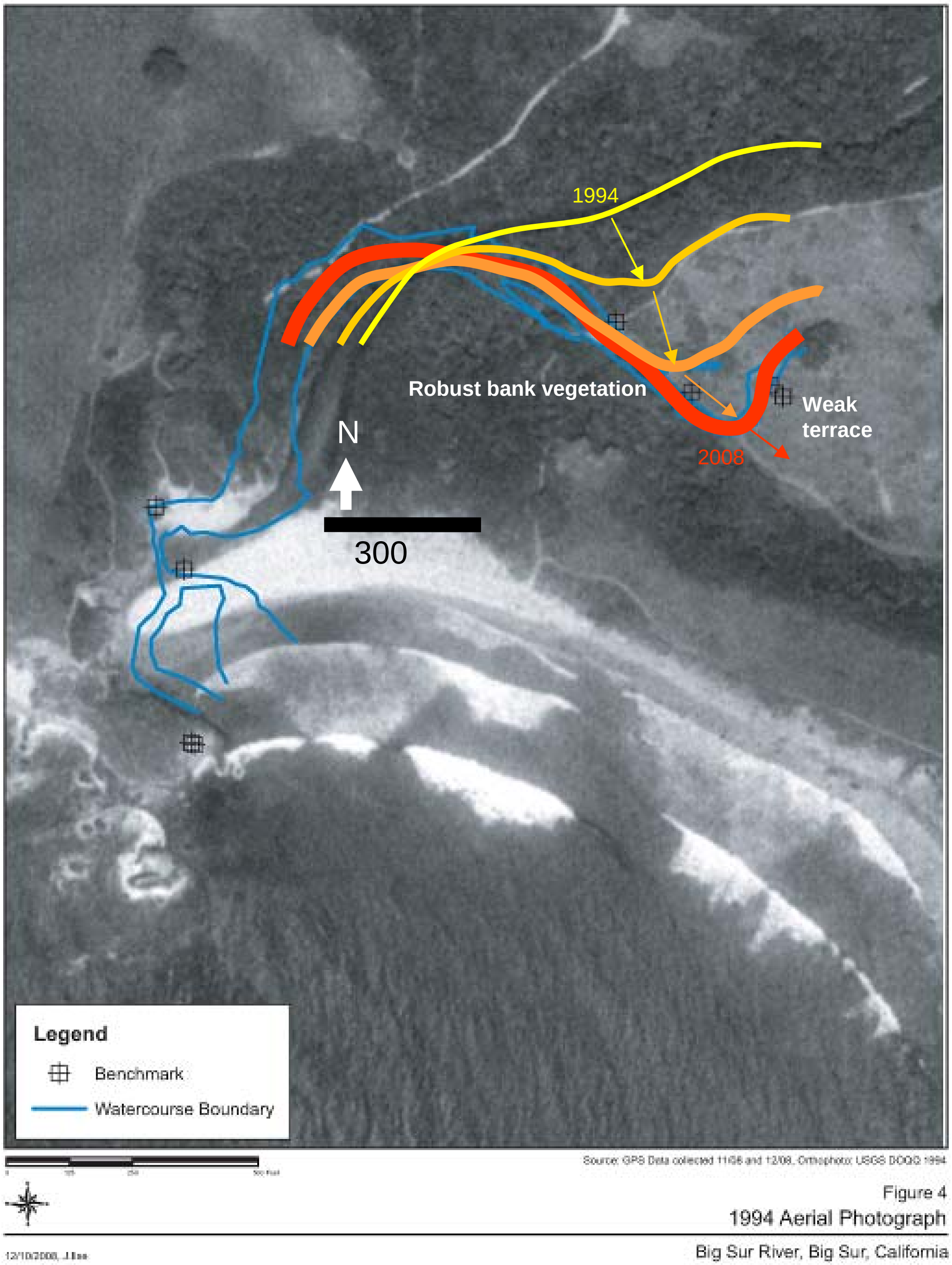

Figure 31: Approximate recent positions of the lagoon channel based upon remnant topography of aerial photographs and recent GPS (Figs 15,, 16, and 17).

Based on our analysis of historical aerial photographs, and personal observations through time, we predict continued rapid erosion along the outer bank of the bend above the lagoon head. There are few mature trees with complex root systems or young stream-bank willows along the apex of the bend for stabilization (Figs. 30 and 32). The presence of a high longitudinal water-surface slope, tall bank height, steep bank angle, weak floodplain deposits, and lack of root density on the outer bank of a bend with diminutive radius of curvature (Fig. 31) allow us to predict continued rapid erosion at this point in the river.

Figure 32: Detail of weak floodplain deposits underlying eroding terrace (November 2008).

We also expect increased erosion on the outer bank from increased shear stress ($\tau = \gamma RS$) during large storm events in the post-fire rainy season. Shear stress (τ) is defined as stress which is applied parallel or tangential to a face of a material; in this case the hydraulic stress applied to the riverbank. The components of shear stress are the specific density of water (γ), which is equal to 9800 kg/m^3; the hydraulic radius (R) of the channel, and the slope (S) of the water surface. Large storm events will likely transport large amounts of sediment downstream. Sediment deposition on the inner bend of the channel will cause the hydraulic radius (R) of the channel to sporadically increase which will cause an increase in shear stress (τ) on the outer bank of the curve.

Large storm events also transport large woody material. We predict that if large wood makes its way to the lagoon it is likely to pile up and cause a log jam at the upstream bend location due to the extreme curvature in the bend. Shear stress can be extreme where the backed up water finds pathways around the debris.

4.1 Future studies and data needs

We recommend performing a repeat study following the 2008-09 storm season to capture the immediate impacts of the Basin Complex Fire, and studies in subsequent years to mark the gradual recovery to pre-fire conditions captured in this report. Future studies should include the entire lagoon.

5 References

Bond, M.H. (2006) Importance of Estuarine Rearing to Central California Steelhead (*Oncorhynchus mykiss*) Growth and Marine Survival. University of California at Santa Cruz. Available at: http://www.cemar.org/pdf/Bond%20Thesis%20Lagoon%20Rearing.pdf

Cannon, S.H. (2008) Geologic Hazards Team. Letter to Monterey County Office of Emergency Services, Rob Clyburn.

Cannon, S.H., Gartner, M.G., Rupert, M.G., Michael, J.A., Rea, A.H., Parrett, C. (in press) Predicting the probability and volume of post-wildfire debris flows in the intermountain Western U.S. : Bulletin of the Geological Society of America.

Federal Register 50 CFR Part 226, 52488-52536. National Oceanic and Atmospheric Administration. Endangered and Threatened Species; Designation of Critical Habitat for Seven Evolutionarily Significant Units of Pacific Salmon and Steelhead in California; Final Rule.

Hecht, B. (1981) Sequential changes in bed habitat conditions in the upper Carmel River following the Marble-Cone fire of August 1977, in Warner, R.E. and Hendrix, K.M., eds., California riparian systems: ecology, conservation and productive management. University of California Press, 134-141.

R Development Core Team. 2008. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

Smith, J.J. (1990). The effects of sandbar formation and inflows on aquatic habitat and fish utilization in Pescadero, San Gregorio, Waddell and Pomponio estuary/lagoon systems, 1985-1989, Report prepared under interagency agreement 84-04-324, between trustees for California State University the California Department of Parks and Recreation. 38 pp. + appendix

Rosenberg, L. 2001. Geologic resources and constraints Monterey county California. County of Monterey Environmental Resource Policy Department.

[USDA] United States Department of Agriculture United States Forest Service. Los Padres National Forest. (2008) Executive Summary: Basin Complex Fire/Indians Fire BAER Initial Assessment. Internet Resource: www.fs.fed.us/r5/lospadres/fire/baer/gallery/basin-indian-baer-initial.pdf