Analysis of Eel River Cross Sections
at Gravel Mining Sites, 1997-2007

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Introduction

Gravel extraction, or mining, from Humboldt County rivers has been used to supply aggregate to various users for decades. Because of concerns surrounding potential impacts to river infrastructure (bridges, municipal water facilities, etc.) and river-dependent animals and plants, it is important to monitor the river corridor to detect potential impacts.

In July, 1997, the Humboldt County Board of Supervisors adopted the *Interim Monitoring Program and Adaptive Management Practices for Gravel Removal from the Lower Eel and Van Duzen Rivers (IMP)*, which required monitoring, formally established the County of Humboldt Extraction Review Team (CHERT) and extended the team's scope to include the Eel River system. Monitoring requirements for gravel operators include annual river cross section surveys to track changes in river channels near mining operations. These cross sections are used to evaluate river conditions annually as part of the process by which each year's proposed mining operations are reviewed and often revised to reduce or eliminate impacts.

Eel River cross section data have accumulated since about 1997 and have been used in the annual mining review process. ; no longer-term analysis of them has taken place until now. As part of the pending renewal of federal and state permits, a longer-term analysis of cross sections was deemed necessary to support impact evaluation and protection/mitigation strategies. This report provides analysis of river physical trends that will be considered along with other information in the permit renewal process.

Geomorphic issues of concern differ between the Mad and Eel rivers. When the gravel mining review process began on the Mad River in 1992, there were serious concerns about the relationship between gravel mining and channel bed lowering (aka, bed degradation) that was adversely affecting fish habitat, threatening bridge stability and impacting performance of municipal water supply facilities. To our knowledge, the only location in the Eel River system which had a similar issue was in the lower Van Duzen River, where three bridges cross the river just upstream of the delta at the confluence with the Eel River. Several years ago, the US Highway 101 bridge was retrofit to make it less vulnerable to pier scour. The status of the third bridge, supporting railroad tracks owned by North Coast Railroad Authority, is unknown.

Although flood history and gravel recruitment (gravel transported during floods) characteristics differ between the Mad and Eel river systems, the main difference between these systems with respect to gravel mining centers on the relative volumes of mining and recruitment. Historical mining volumes on the Mad River were high relative to recruitment, leading to the river infrastructure and fish habitat problems that triggered controversy and heightened regulatory controls in the early 1990s. Since then, Mad River mining volumes have been reduced to levels that are consistent with the current estimate of mean annual recruitment (MAR) and the problems perceived in the 1990s seem to have subsided.

At present there is no estimate of MAR for the Eel River system, but it is almost certainly substantially greater than present mining levels. While certain methods of mining and locally excessive volumes can affect instream habitat in the short term, the river does not appear to suffer from long term or broad scale channel bed degradation from gravel mining. Furthermore, the CHERT adaptive management program authorized by the IMP specifically addresses preventing local over-extraction and avoids/minimizes mining methods that cause aquatic and riparian habitat damage.

Although there is a perception that Eel River gravel mining is generally not causing excessive channel bed degradation, the cross section analysis here provides a tool for examining the issue. But unlike the Mad River, Eel River gravel extraction sites are clustered in several river reaches that are far apart from one another. This precludes a system-wide analytical approach, limiting the analysis to a more localized scope that cannot link geomorphic processes occurring, for example, in the South Fork Eel River with those in the lower Eel River.

Eel River Gravel Mining

Table 1 describes the gravel mining sites in the Eel River, which are primarily concentrated in four river reaches, with three isolated sites far removed from others. Because the isolated sites are far removed from other extractions and only intermittently extracted, the likelihood of cumulative geomorphic impacts is small. Consequently, this analysis is limited to just the four primary river reaches described below.

Table 1. Description of gravel mining reaches in the Humboldt County portion of the Eel River watershed.

Approximate Length (miles)	Mining Reaches in the Eel River
8	**Lower Eel River:** The Lower Eel River Reach extends approximately eight miles downstream from the mouth of the Van Duzen River to just downstream of Fernbridge. This reach is within the Coastal Zone, thus Coastal Development Permits are required for gravel extraction.
5	**Lower Van Duzen River:** The Lower Van Duzen River Reach extends upstream approximately five miles from the mouth of the Van Duzen River. Only the lower portion of one site lies within the Coastal Zone (Leland Rock).
26	**Middle Reach of Eel River:** The Middle Reach of the Eel River extends upstream from Scotia (River mile 20) for approximately 26 miles to River Mile 46. These sites are extracted intermittently by Humboldt Redwoods Co..
17	**South Fork Eel River:** The South Fork Reach extends from Garberville (River mile 33) upstream to Cooks Valley near the Mendocino County line (River mile 50). There is a considerable distance (about 20 river miles) between the Randall and Wallan & Johnson sites near Garberville and Cooks Valley at the Humboldt/Mendocino county line.
	Isolated Sites: Three extraction sites are geographically isolated from the rest. These are the *Satterlee Bar* on the main stem of the Eel river at Fort Seward, the *PL Bar* on the Van Duzen River, and the *Charles Bar* on Larabee Creek.

Eleven gravel mining operators extract gravel from 23 sites within the four reaches, as shown in Table 2. Many of the sites listed in Table 2 are not mined every year. In the Lower Eel, Singley, Worswick, Drake and Hansen Bars are extracted intermittently. In the Middle Reach Eel River, Humboldt Redwoods Co. (formerly Pacific Lumber Co.) has special permit constraints that limit the frequency of extraction from specific bars. Mined volumes vary widely from year-to-year, and volumes actually extracted are typically much less than the volumes approved by regulatory agencies (Table 3). An average of 665,000 cubic yards (cy) of gravel were approved for extraction annually since 1997, of which about 442,000 cy, or about two-thirds of that approved, were actually extracted. No Middle Reach Eel River bars were mined from 2004 through 2006. Annual extraction volumes on a site-by-site basis can be found in the annual CHERT post-extraction reports at: http://co.humboldt.ca.us/planning/smara/default.asp?inc=slm

Table 2. Gravel mining operators and sites in the Eel River (listed by reach in upstream order; excludes isolated sites).

Operator	Site
Lower Eel River	
Eureka Ready Mix	Singley Bar
Humboldt County	Worswick Bar
Mallard Pond	Drake Bar
Mercer Fraser	Sandy Prairie Plant B
Mercer Fraser	Sandy Prairie Plant A
Hansen Trucking	Hansen Bar (currently unpermitted)
Eureka Ready Mix	Hauck Bar
Van Duzen River	
Rock and Gadbury	Leland Rock Bar
Jack & Mary Noble	Van Duzen River Ranch Bars
Tom Bess	Bess East & West Bars
Middle Reach Eel River	
Humboldt Redwoods Company	Lower Scotia Bar
Humboldt Redwoods Company	Scotia Dam Bar
Humboldt Redwoods Company	Lower & Upper Truck Shop Bars
Humboldt Redwoods Company	Dinner Creek Bar
Humboldt Redwoods Company	Three Mile Bar
Humboldt Redwoods Company	Elinor Bar
Humboldt Redwoods Company	Holmes/Larabee Bar
Humboldt Redwoods Company	South Fork Bar
Humboldt Redwoods Company	Bowlby Bar
Humboldt Redwoods Company	Vroman Bar
Humboldt Redwoods Company	Maynard Bar
South Fork Eel	
Wallan &Johnson	Wallan Bar
Randal Sand & Gravel	Home Bar
Randal Sand & Gravel	Twooby Park Bar
Randal Sand & Gravel	County Bar
Mercer Fraser	Cooks Valley Bar (Humboldt County)
Mercer Fraser	Cooks Valley Bar (Mendocino County)

Table 3. Approved and extracted gravel mining volumes in the Eel River since 1997 (excludes isolated sites).

Lower Eel River			
Year	Approved Volume (cubic yards)	Extracted Volume (cubic yards)	Percent
1997	561,700	326,500	58%
1998	399,100	273,000	68%
1999	471,400	290,500	62%
2000	291,300	208,600	72%
2001	389,900	119,300	31%
2002	387,300	220,000	57%
2003	318,300	163,900	51%
2004	188,840	120,305	64%
2005	199,370	166,280	83%
2006	235,495	208,240	88%
2007	243,097	177,334	73%
Totals	**3,685,802**	**2,273,959**	**62%**
Years	**11**	**11**	**---**
Averages	**335,073**	**206,724**	**62%**

Middle Eel River			
Year	Approved Volume (cubic yards)	Extracted Volume (cubic yards)	Percent
1997	147,300	84,900	58%
1998	157,900	99,400	63%
1999	134,900	124,900	93%
2000	160,100	131,000	82%
2001	116,100	64,000	55%
2002	132,767	121,608	92%
2003	74,030	54,060	73%
2004	0	0	n/a
2005	0	0	n/a
2006	0	0	n/a
2007	89,990	64,424	72%
Totals	**1,013,087**	**744,292**	**73%**
Years	**11**	**11**	**---**
Averages	**92,099**	**67,663**	**73%**

South Fork Eel River			
Year	Approved Volume (cubic yards)	Extracted Volume (cubic yards)	Percent
1997	67,700	74,700	110%
1998	75,400	70,100	93%
1999	85,400	75,900	89%
2000	75,700	53,700	71%
2001	66,000	43,100	65%
2002	58,163	48,122	83%
2003	87,060	54,660	63%
2004	80,730	50,745	63%
2005	82,770	36,480	44%
2006	92,000	35,075	38%
2007	90,737	73,956	82%
Totals	**861,660**	**616,538**	**72%**
Years	**11**	**11**	**---**
Averages	**78,333**	**56,049**	**72%**

Van Duzen River			
Year	Approved Volume (cubic yards)	Extracted Volume (cubic yards)	Percent
1997	120,000	81,600	68%
1998	119,100	103,700	87%
1999	159,900	108,800	68%
2000	194,800	121,300	62%
2001	161,700	85,600	53%
2002	202,500	167,400	83%
2003	175,100	123,000	70%
2004	179,045	92,610	52%
2005	159,090	123,170	77%
2006	134,910	104,750	78%
2007	152,773	113,184	74%
Totals	**1,758,918**	**1,225,114**	**70%**
Years	**11**	**11**	**---**
Averages	**159,902**	**111,374**	**70%**

Analysis Methods

Channel Cross Section Data

Channel cross section surveys yield topographic information across a slice of a river channel perpendicular (or nearly so) to the longitudinal centerline of the high flow channel. By comparing one year's survey with another, changes over the intervening time span can be quantified. We were provided cross section survey data in spreadsheet format by the Eel River operators or their consultants. It was first necessary to review the cross section (XS) data to: 1) ensure elevations were based on a consistent vertical datum (we presently use the North American Vertical Datum of 1988, or NAVD88, in all surveys); 2) adjust horizontal positioning as needed so the left and/or right endpoints align; and 3) add data from earlier or later surveys to either or, in some cases, both ends to create a full channel data set for analysis.

Making these adjustments to the data is a time intensive process and results were needed in early 2009. To expedite the analysis, it was agreed by all concerned that using a sampling of the full set of XS (from one to five from each site) and analyzing XS surveys from the beginning, middle and end of the monitoring period would suffice. Using this strategy, we reviewed air photos from recent mining submittals and selected XS from each site that provided reasonable river reach coverage. The years of 1997, 2002, and 2007 were targeted to evaluate temporal changes. Table 4 shows the selected XS and years used in this analysis. In cases where a particular survey year's data were not available or useable, the closest year with useable data was substituted, as shown in Table 4. The "XS#" in Table 4 denotes the codes for identifying cross sections in graphs throughout this report.

Table 4. Eel River cross sections used in this analysis.

Cross sections Analyzed			Survey Years Analyzed [1]		
Operator	Site	XS#	First	Second	Third
Lower Eel River					
Eureka Ready Mix	Singley Bar	SIN 12	1997	2003	2007
Eureka Ready Mix	Singley Bar	SIN 6	1997	2003	2007
Eureka Ready Mix	Singley Bar	SIN 1	1997	2003	2007
Humboldt County	Worswick Bar	WOR 5	1998	2002	2007
Humboldt County	Worswick Bar	WOR 1	1997	2002	2007
Mallard Pond	Drake Bar	DRA 9	1997	2002	2007
Mallard Pond	Drake Bar	DRA 3	1997	2002	2007
Mercer Fraser Co.	Sandy Prairie	SAN 11R	1998	2002	2007
Mercer Fraser Co.	Sandy Prairie	SAN 7	1998	2002	2007
Mercer Fraser Co.	Sandy Prairie	SAN 1	1999	2002	2007
Hansen Trucking	Hansen Bar	HAN 13	1997	2001	2007
Hansen Trucking	Hansen Bar	HAN 0	1997	2002	2007
Eureka Ready Mix	Hauck Bar	HAU 25	1997	2002	2007
Eureka Ready Mix	Hauck Bar	HAU 13	1997	2002	2007
Eureka Ready Mix	Hauck Bar	HAU -3	1997	2002	2007
Van Duzen River					
Leland Rock	Lower Rock Bar	ROC 27	1997	2002	2007
Leland Rock	Lower Rock Bar	ROC 23	1997	2002	2007
Leland Rock	Upper Rock Bar	ROC 17	1997	2002	2007
Leland Rock	Upper Rock Bar	ROC 10	1997	2002	2007
Leland Rock	Upper Rock Bar	ROC 4	1997	2002	2007
Van Duzen River Ranch	Noble Bar	NOB 10	1997	2002	2007
Van Duzen River Ranch	Noble Bar	NOB 7	1997	2002	2007
Van Duzen River Ranch	Noble Bar	NOB 2	1997	2003	2007
Tom Bess	Bess West Bar	BES 14	1997	2002	2007
Tom Bess	Bess West Bar	BES 2	1997	2002	2007
Tom Bess	Bess East Bar	BES 8	1998	2002	2007
Tom Bess	Bess East Bar	BES 4	1998	2002	2007

[1] red font denotes substituted year

Table 4. Eel River cross sections used in this analysis (continued).

Cross sections Analyzed			Survey Years Analyzed [1]		
Operator	Site	XS#	First	Second	Third
Middle Reach Eel River					
Humboldt Redwoods Co.	Lower Scotia Bar	SCO 0	1997	2002	2007
Humboldt Redwoods Co.	Lower Scotia Bar	SCO 2	1997	2002	2007
Humboldt Redwoods Co.	Scotia Dam Bar	SCO 3	1997	2002	2007
Humboldt Redwoods Co.	Scotia Dam Bar	SCO 5	1997	2002	2007
Humboldt Redwoods Co.	Truck Shop Bar	TRU 6	1997	2002	2007
Humboldt Redwoods Co.	Truck Shop Bar	TRU 10	1997	2002	2007
Humboldt Redwoods Co.	Dinner Creek Bar	DIN 13	1997	2002	2007
Humboldt Redwoods Co.	Three Mile Bar	THR 15	1997	2002	2007
Humboldt Redwoods Co.	Three Mile Bar	THR 18	1997	2002	2007
Humboldt Redwoods Co.	Elinor Bar	ELI 8	1997	2002	2007
Humboldt Redwoods Co.	Elinor Bar	ELI 2	1997	2002	2007
Humboldt Redwoods Co.	Holmes/Larabee Bar	HOL 2	1997	2002	2007
Humboldt Redwoods Co.	South Fork Bar	SOU 3	1997	2002	2007
Humboldt Redwoods Co.	Bowlby Bar	BOW 6	1997	2002	2007
Humboldt Redwoods Co.	Bowlby Bar	BOW 1	1997	2002	2007
Humboldt Redwoods Co.	Vroman Bar	VRO 6	1997	2002	2007
Humboldt Redwoods Co.	Vroman Bar	VRO 1	1997	2002	2007
Humboldt Redwoods Co.	Maynard Bar	MAY 2	1997	2002	2007
South Fork Eel River					
Wallan and Johnson	Wallan Bar	WAL 5	1997	2002	2007
Wallan and Johnson	Wallan Bar	WAL 2	1997	2002	2007
Randall Sand and Gravel	Randall Site	RAN 10	1999	2002	2007
Randall Sand and Gravel	Randall Site	RAN 8	1999	2002	2007
Randall Sand and Gravel	Randall Site	RAN 3	1999	2002	2007
Randall Sand and Gravel	Randall Site	RAN 1	1999	2002	2007
Mercer Fraser Co.	Cooks Valley	CVA 12	1998	2002	2007
Mercer Fraser Co.	Cooks Valley	CVA 11	1998	2002	2007
Mercer Fraser Co.	Cooks Valley	CVA 8	1998	2002	2007
Mercer Fraser Co.	Cooks Valley	CVA 3	1998	2002	2007

[1] red font denotes substituted year

Data Extraction Procedure

Data extraction from each cross-section involved six steps:

1) **Estimation of ground-surface elevations at 1-foot intervals:** Ground-surface elevations were estimated at 1-foot intervals across the width of the cross-section by linear interpolation of elevations between adjacent survey points using the Excel macro Lintrp 1.4 (Lehre, 1995).
2) **Selection of reference elevation:** For each cross-section, a *reference elevation* was selected by overlaying the XS for all years on the same graph and choosing an elevation below which lay all significant yearly flow or man-caused changes in bed, bars, and banks. The reference elevation controls which data points are used in computation of mean elevation and cross-sectional area (see Fig. 1 below).
3) **XS computation width limits:** For each year the width of the cross-section *at the reference elevation* (Fig. 1) is determined by inspection of the interpolated elevation values. The ends of the reference line are chosen at those distances whose elevations most closely correspond to the reference elevation. Only XS data within these horizontal limits was used in computations.
4) **Computation of mean elevation of XS:** Mean elevation of the cross-section in each year is computed as the *average* of all the interpolated points included between the right and left ends of the reference elevation line.
5) **Computation of XS area:** The cross-sectional area lying between the reference elevation and the ground surface (see Fig. 1) is computed from the interpolated data by subtracting the ground elevation at each point from the reference elevation and adding all these up (each point represents one-foot of XS width). This XS area has no significance other than for comparing repetitive surveys at a cross section.

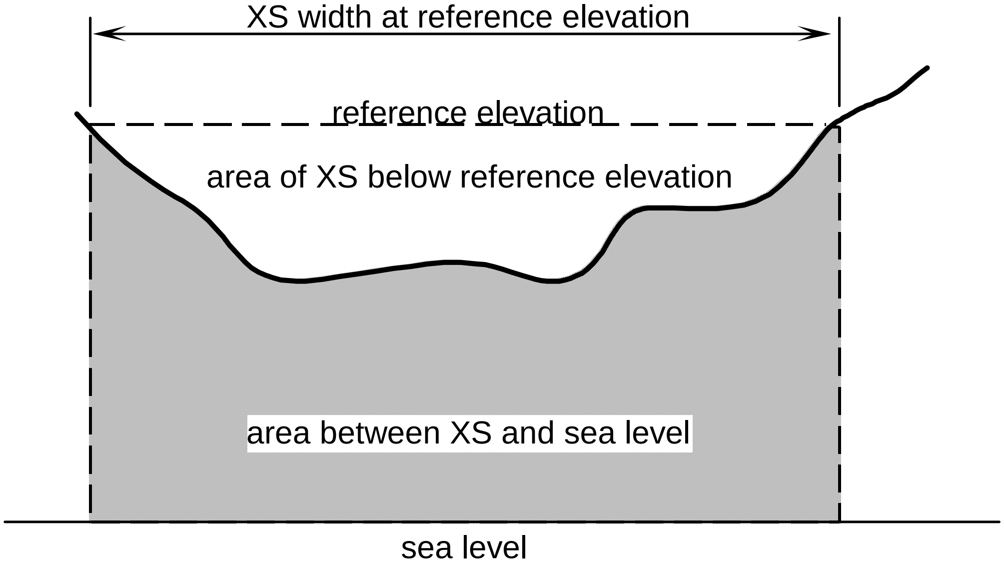


Figure 1. Definition sketch for determination of XS area and mean elevation.

6) **Determination of thalweg elevation:** Thalweg elevation is taken as the minimum elevation in the channel portion of the cross-section. Off-channel excavations (terrace trenches or wetland pits) are excluded since they are not part of the channel, even though they may contain the minimum elevation in the XS.

The resulting data were tabulated by year for each cross-section and are available electronically in the Excel spreadsheet *Eel R XSS Data Summary*.

Mean Bed Elevation, Thalweg Elevation, and Channel Scour and Fill

Mean bed elevation: The *mean bed elevation* of a cross-section is the arithmetic average of all the interpolated elevation points lying between the ends of the reference elevation line (see Fig. 3). This includes all parts of the cross section which have undergone significant elevation changes, due either to stream processes or to gravel extraction. Thus it encompasses not only the low-water and active-channel areas, but also those parts of the floodplain and lower terraces that have experienced erosion, deposition, or extraction.

Thalweg elevation: The *thalweg* is the line of maximum depth of the river. The *thalweg elevation* is thus the lowest channel-related elevation (as opposed to an off-channel or excavation-related elevation) in the cross-section.

Channel scour and fill: Scour represents a loss of gravel from a river bar or channel and will appear on XS as a lowering of elevation at a particular point. Fill represents a gain of gravel. Both scour and fill can occur between any two surveys of a XS. The change in XS area between two surveys being compared is a mathematical summation of scour and fill.

Results

Results from Eel River cross section analyses are summarized for all reaches in Table 5 and in a series of bar graphs for specific to each river reach that show changes between the survey years selected and the net change over the entire period. We also included a line graph with net changes in thalweg and mean bed elevations from 1997 to 2007 (or the closest years to those that were suitable for analysis) for each reach to provide a clearer means to evaluate longitudinal trends.

Reach-averaged trends

Table 5 has reach-averaged thalweg, mean bed, and scour/fill results for the 1997-2007 period. Lower Eel River thalweg elevations decreased while mean bed elevations increased, possibly indicating improved low flow channel confinement. Net scour/fill was positive, consistent with mean bed elevation increase. On the other three reaches, both thalweg and mean bed elevations decreased and net scour/fill was negative, indicating that the three upstream reaches are likely in a degradational phase.

Table 5. Reach-averaged thalweg and mean channel bed elevation changes and net scour/fill for the Eel River, 1997-2007.

River Reach	Thalweg Elev. Change (feet)	Med Bed Elev. Change (feet)	Net Scour/Fill (sq. ft.)
Lower Eel River	-0.44	0.71	418
Middle Reach Eel	-1.23	-0.80	-520
South Fork Eel	-1.33	-0.84	-303
Van Duzen River	-0.07	-0.27	-1386

Lower Eel River

Figures 2 and 3 show incremental and net changes in thalweg and mean bed elevations, respectively. Thalweg elevations generally decreased between 1997 and 2007 in the upstream portion from Hauck Bar to Sandy Prairie, with little net change at the Hansen site in between. Over the same period, mean bed elevations experienced a modest increase, suggesting bar growth coincident with channel deepening, a process that indicates improved fish habitat conditions. In the downstream portion, thalweg elevations increased at most XS along with increases in mean bed elevations, suggesting this sub-reach experienced bed aggradation affecting the full channel width over the decade beginning in 1997. We note that the left (south) bank immediately upstream of Fernbridge has experienced heavy erosion, approaching hundreds of feet laterally, since the 1990s.

Figure 4, depicting channel scour and fill, shows mixed results along the lower Eel River, with alternating scour and fill through the eight mile reach. Little net scour or fill occurred at the upstream end (Hauck Bar), with the highest fill at the Hansen Bar, the highest scour at Sandy Prairie, with small change at the Drake and upper Worswick Bars, and net fill on either side of Fernbridge (lower Worswick and lower Singley Bars). Although there were too few XS used to allow reliable computation of reach-wide gravel volume changes, reach-averaged mean bed elevations rose by about 0.7 feet. Reach-averaged thalweg elevations decreased by about 0.4 feet over the same period (Table 5).

Figure 2. Lower Eel River Thalweg Elevation Change, 1997-2007

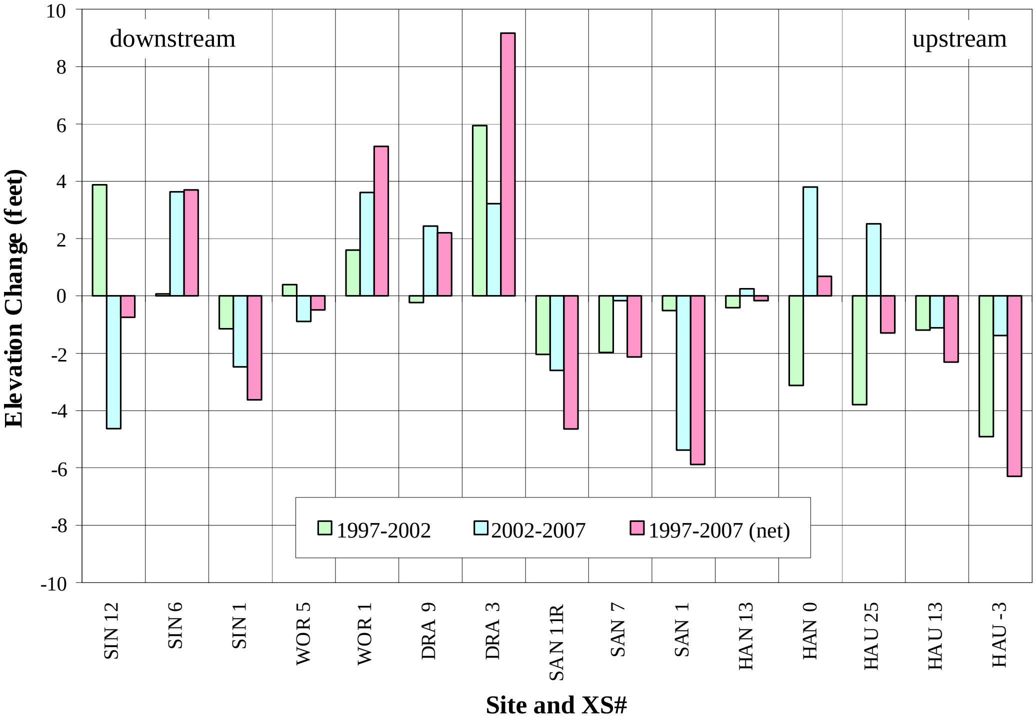


Figure 3. Lower Eel River Mean Bed Elevation Change, 1997-2007

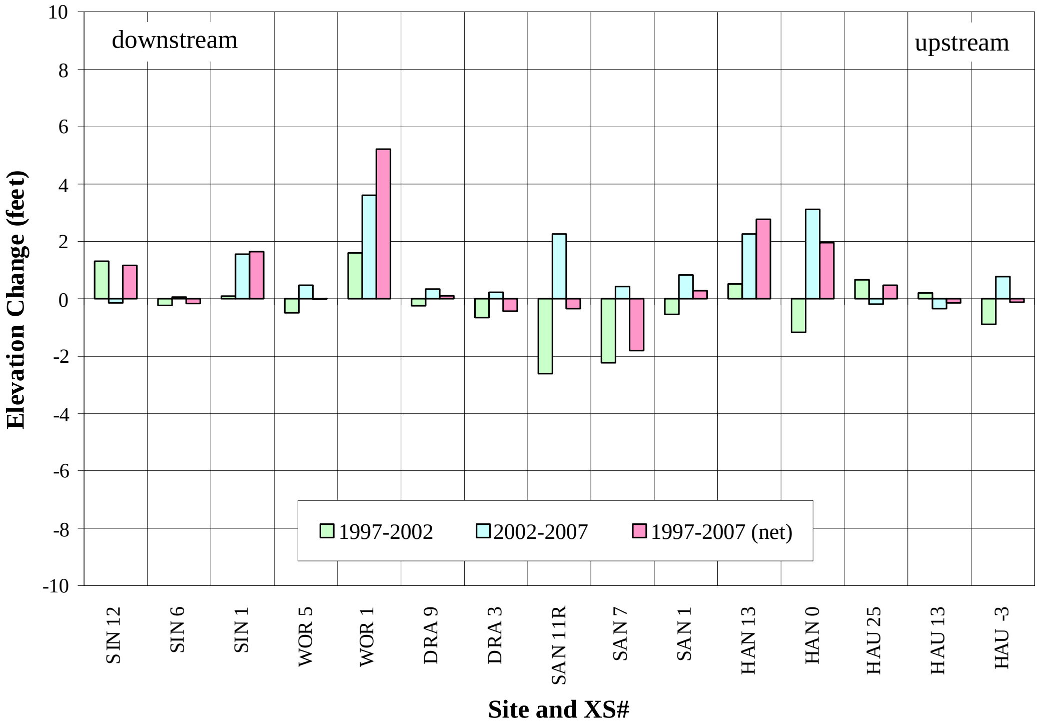


Figure 4. Lower Eel River Channel Bed Scour and Fill, 1997-2007

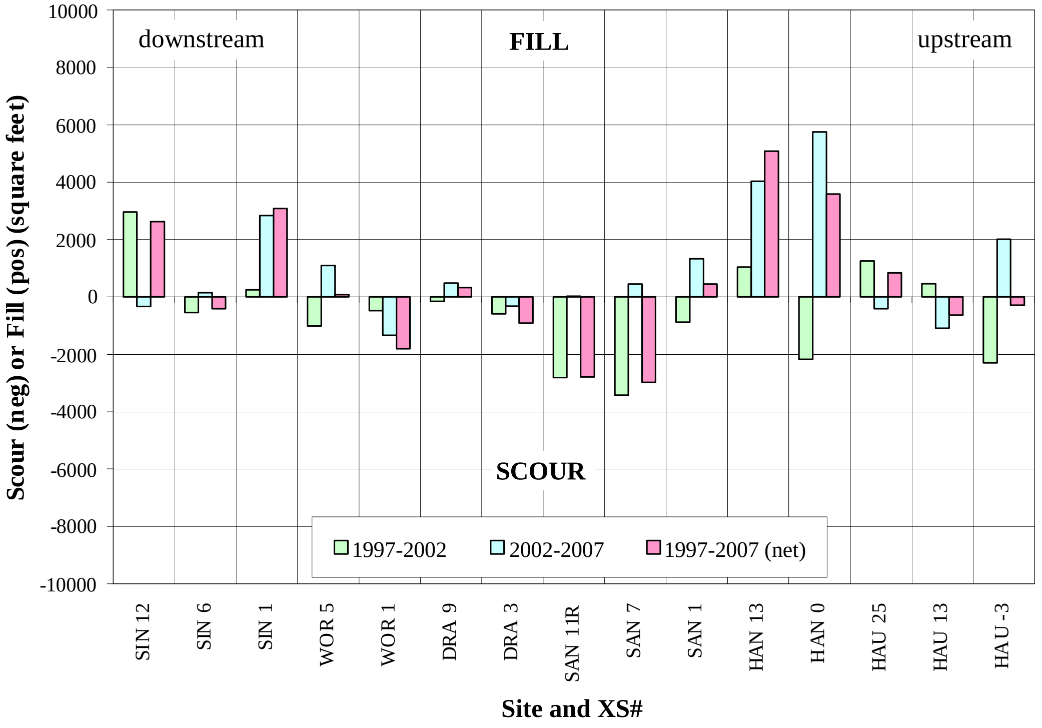


Figure 5. Lower Eel River Thalweg and Mean Bed Elevation Net Change, 1997-2007

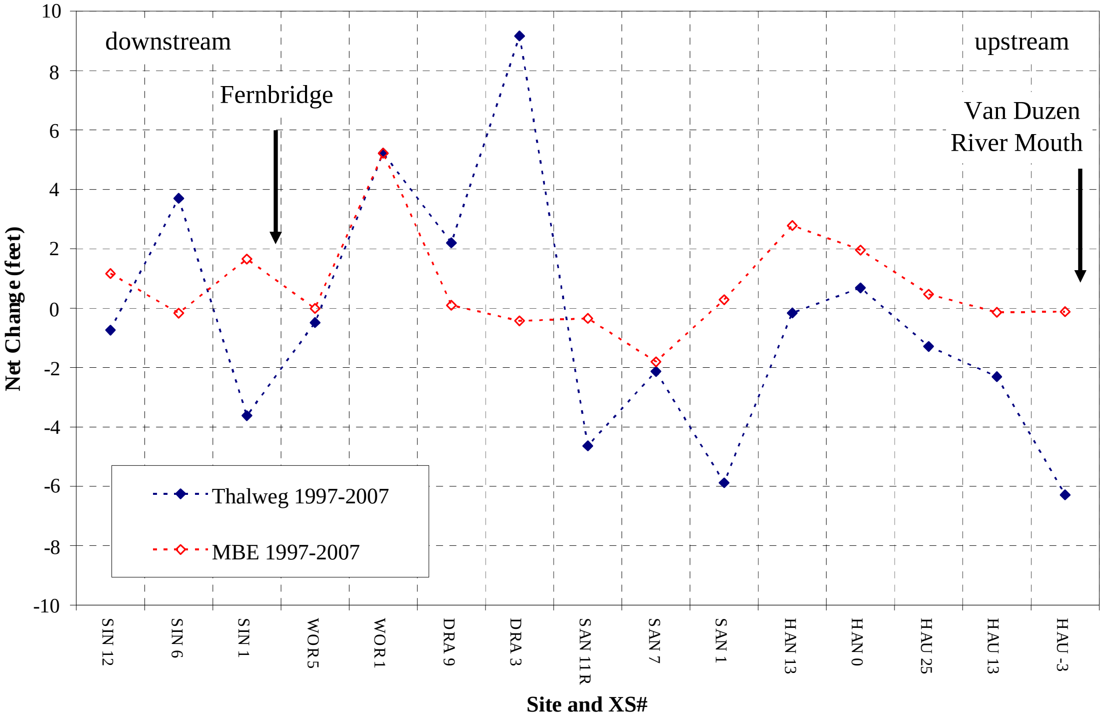


Figure 5 plots thalweg and mean bed elevation changes from 1997 to 2007 as longitudinal lines. Although these are the same data as plotted separately in Figures 2 and 3, associations can be more clearly seen when plotted together. Changes in either of these variables can be due to gravel volume gains or losses, or simply due to movement of channel features such as bars and pools. For example, XS DRA3 (Fig. 5) showed a dramatic increase in thalweg elevation as the pool formerly along the right bank migrated upstream (B. Brown, pers. comm.. 2008).

Van Duzen River

As with the Lower Eel, the Van Duzen mining reach exhibited mixed results (Figs. 6-9). Thalweg elevations increased and decreased over time at many XS, but the net changes for 1997-2007 were generally increases in thalweg elevations at the upstream sites (Bess and Noble), and decreases at the downstream site (Leland Rock), both above and below the Highway 101 and railroad bridges. Mean bed elevations mostly mirrored thalweg elevations, with decreases at the downstream (Leland Rock) site ranging from about 1 to four feet and increases up to four feet at the middle site (Noble). Reach-averaged results (Table 5) showed minimal thalweg elevation change, reflecting the substantial longitudinal differences that averaging cancelled out.

Channel scour and fill were relatively small at the upstream sites, with XS NOB2 a notable exception. Channel avulsion (sudden realignment) monitored by this cross section produced a large amount of scour between 1997 and 2003, followed by large fill from 2003 to 2007 as the old channel and adjacent terrain filled in. Thalweg and mean bed elevations varied together in the Van Duzen, as illustrated in Figure 9, with the exception of XS ROC4, where the thalweg increased in elevation while the mean bed elevation decreased, suggesting a flattening of the channel cross section and possibly a reduction in low flow channel confinement.

Figure 6. Van Duzen River Thalweg Elevation Change, 1997-2007

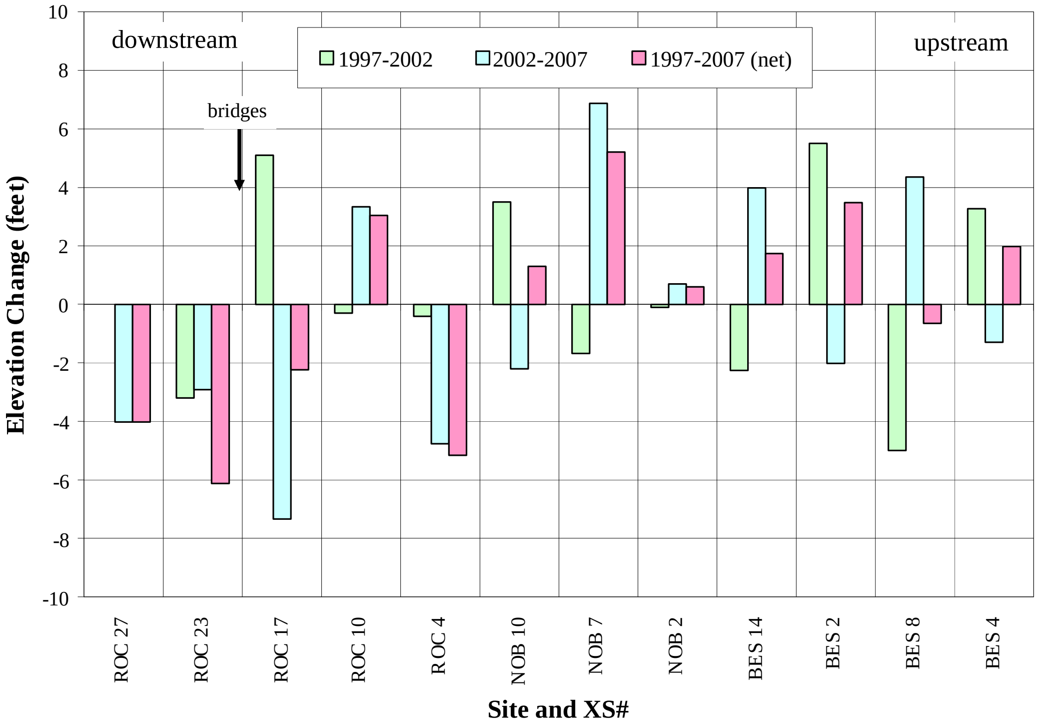


Figure 7. Van Duzen River Mean Bed Elevation Change, 1997-2007

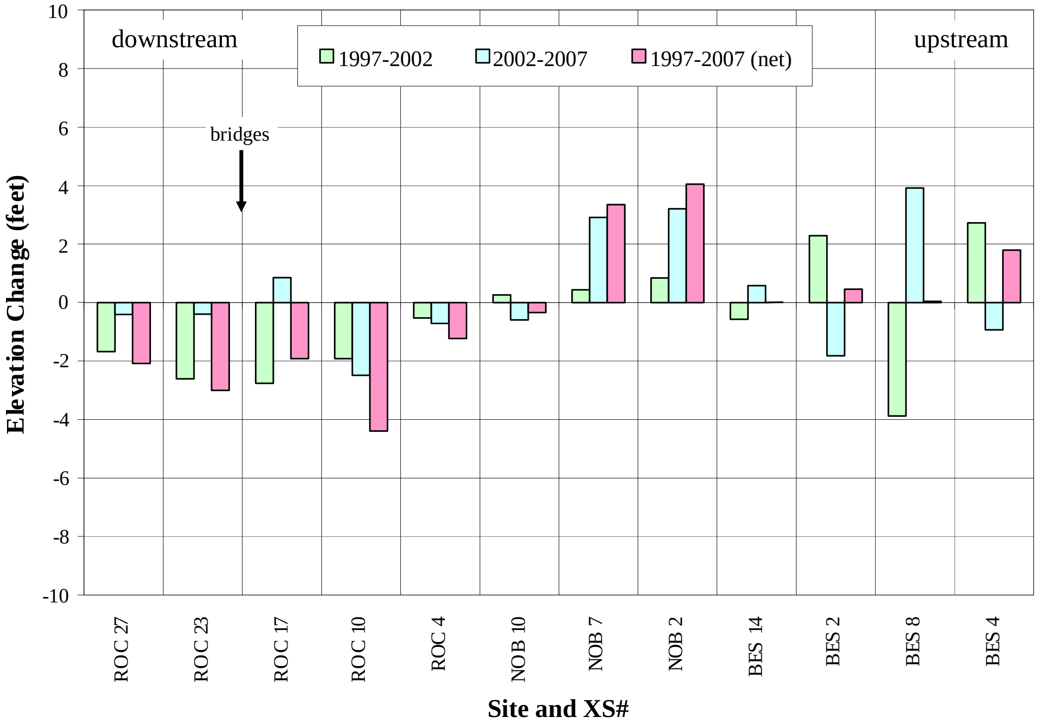


Figure 8. Van Duzen River Channel Bed Scour and Fill, 1997-2007

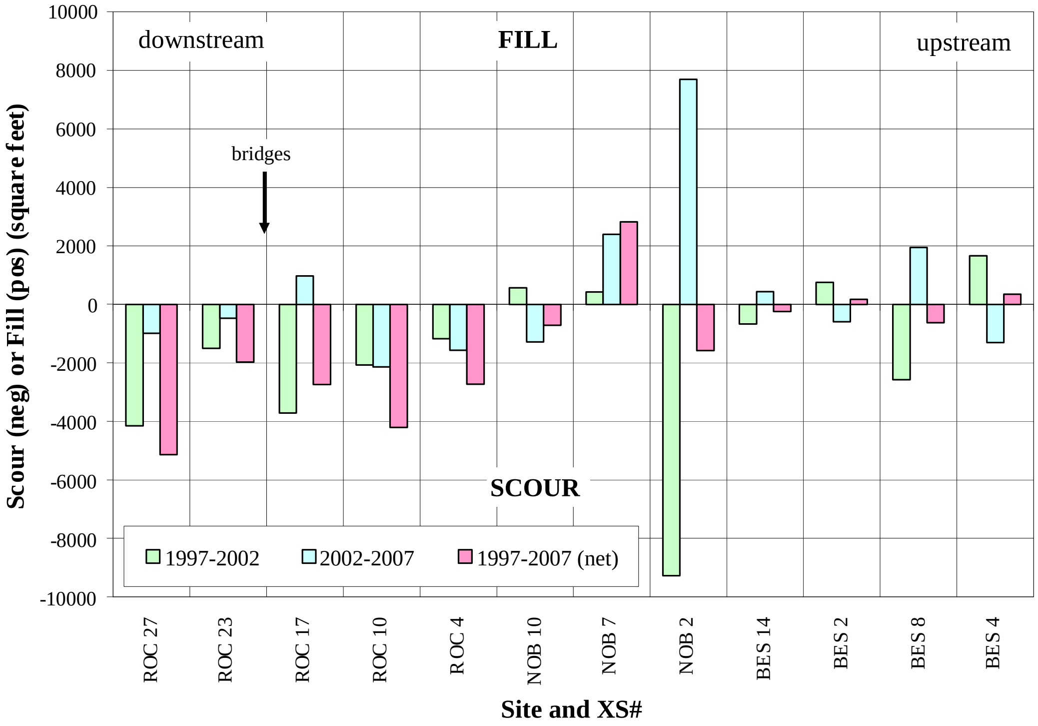
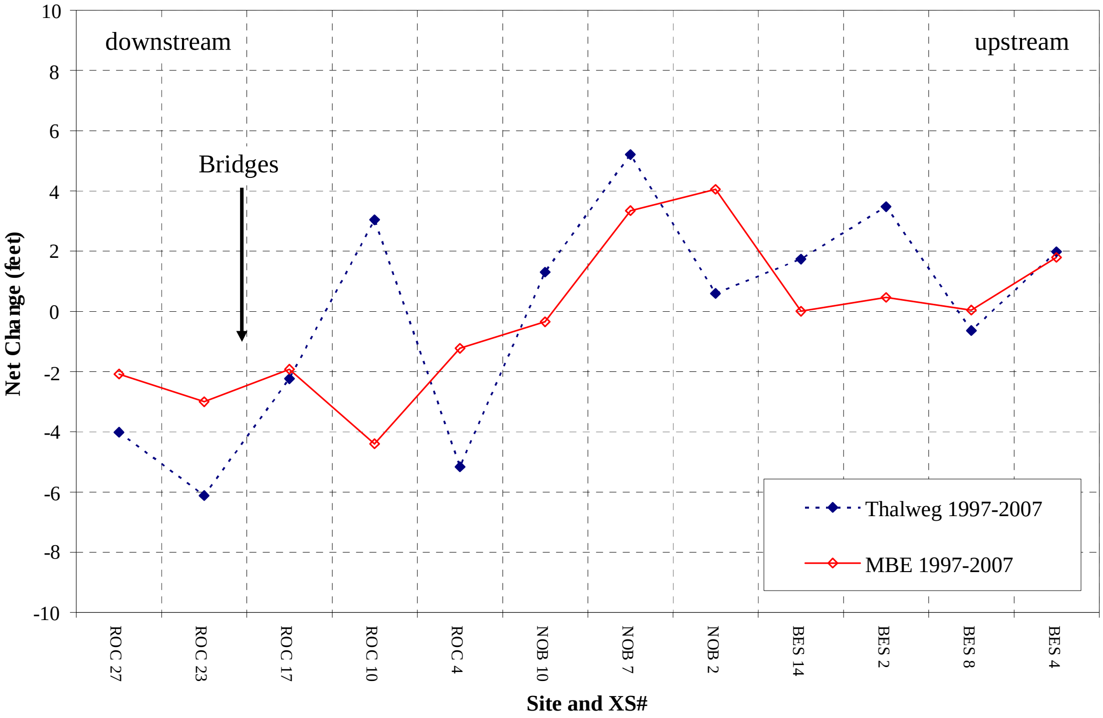


Figure 9. Van Duzen River Thalweg and Mean Bed Elevation Net Change, 1997-2007



Middle Reach Eel River

Channel changes were more subdued and consistent among sites in the Middle Reach Eel than in the Lower Eel. Figures 10-12 show results of thalweg and mean bed elevations and scour/fill with the same vertical scaling as those for the Lower Eel. Consistent with Table 5, the Middle Eel River XS almost exclusively exhibited decreases in thalweg and mean bed elevations. A few XS showed minor increases over the 1997-2002 period, but net decreases for 1997-2007. Increases in mean bed elevation were limited to South Fork and Holmes/Larabee Bars. Figure 13 corroborates this and shows that at most XS, thalweg elevations decreased in concert with mean bed elevations.

Figure 10. Middle Eel River Thalweg Elevation Change, 1997-2007

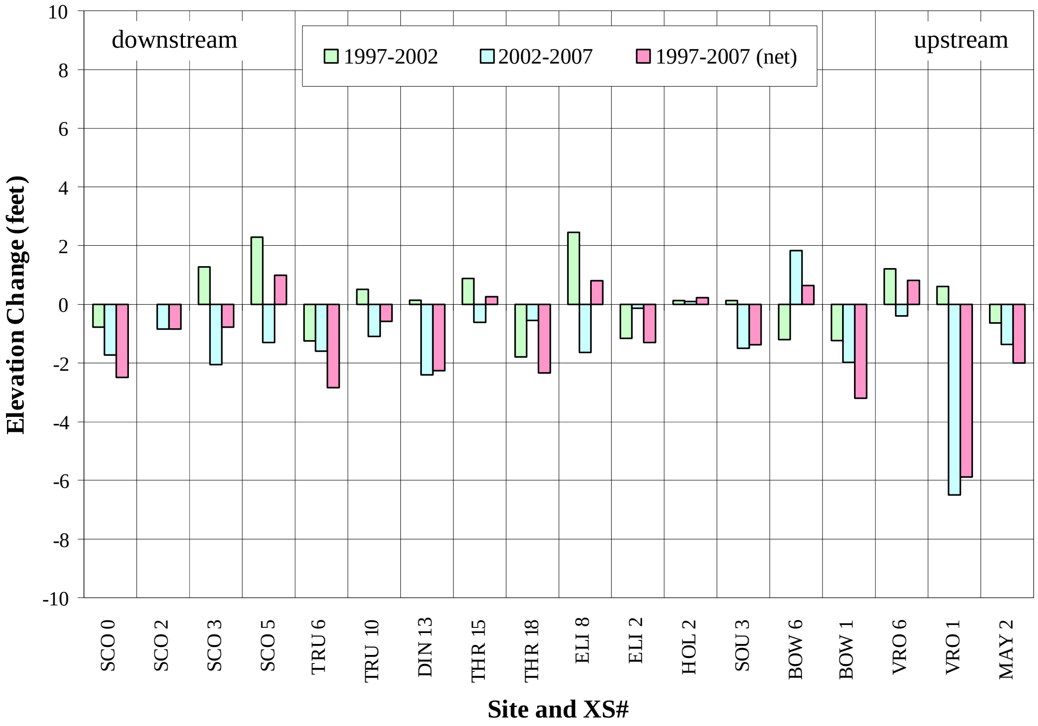


Figure 11. Middle Eel River Mean Bed Elevation Change, 1997-2007

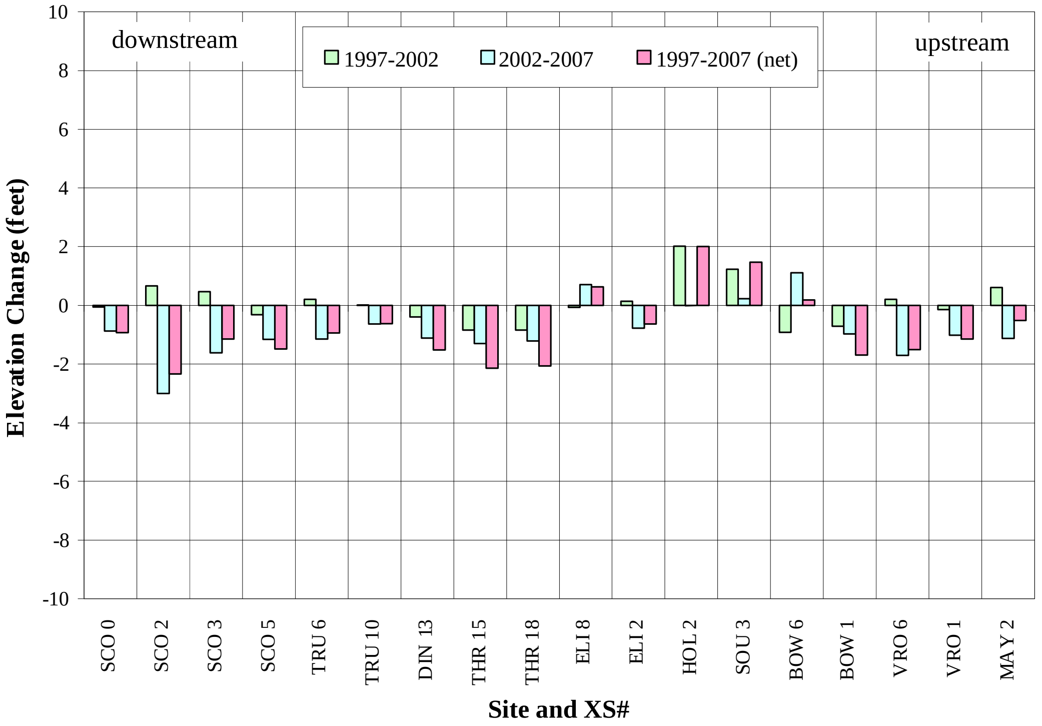


Figure 12. Middle Eel River Channel Bed Scour and Fill, 1997-2007

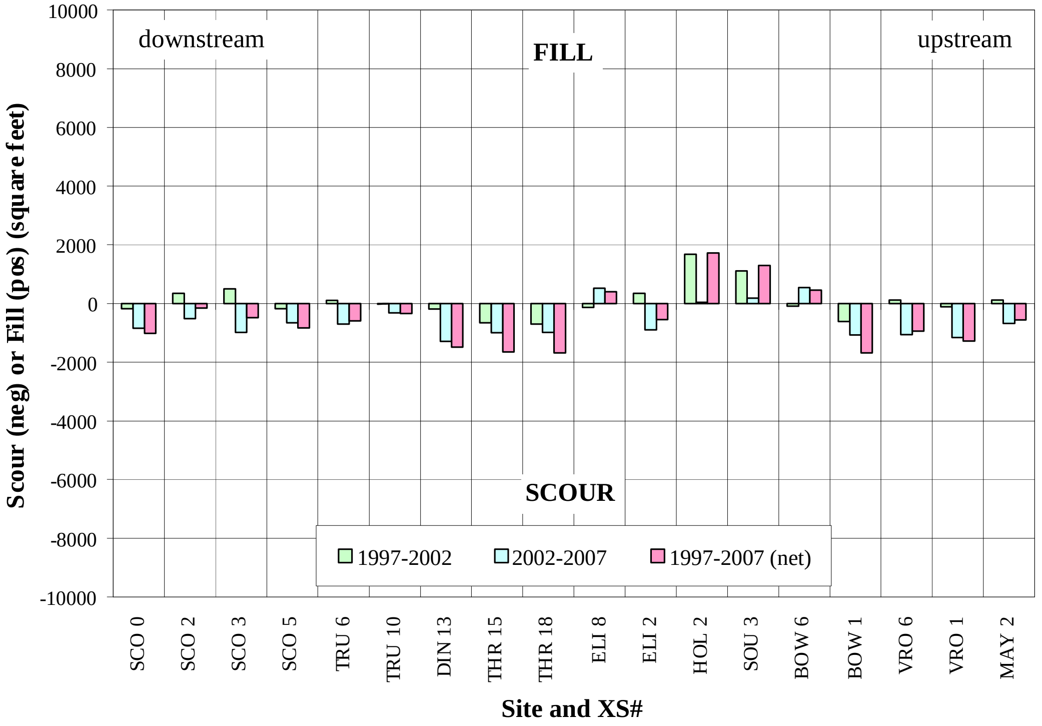
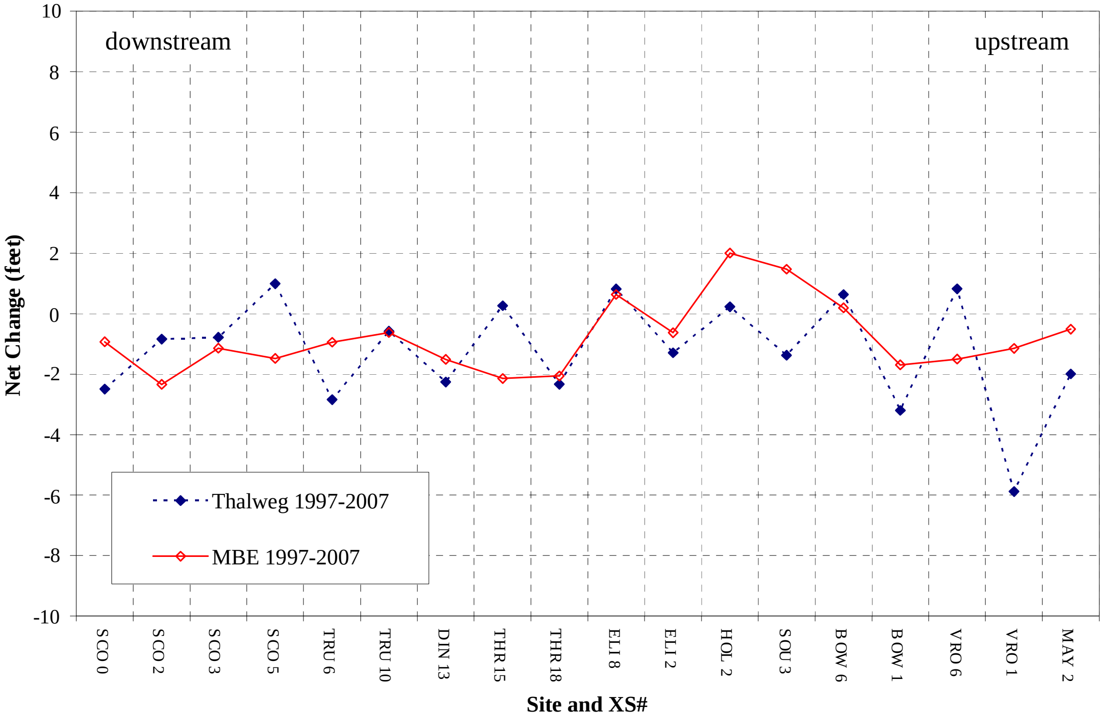


Figure 13. Middle Eel River Thalweg and Mean Bed Elevation Net Change, 1997-2007



South Fork Eel River

Results for the South Fork Eel River were quite similar to those for the Middle Eel. Channel changes were relatively subdued and consistent among sites in the South Fork Eel than in the Lower Eel. Figures 14-16 show results of thalweg and mean bed elevations and scour/fill with the same vertical scaling as those for the Lower Eel. Consistent with Table 5, the South Fork Eel River XS almost exclusively exhibited decreases in thalweg and mean bed elevations. A few XS showed minor increases over the 1997-2002 period, but net decreases were most common during the 1997-2007 period as a whole. Increases in mean bed elevation were limited to the Wallan & Johnson and Randall sites, and were very small. Decreases in thalweg and mean bed elevations ranged to almost four feet at Cooks Valley (CVA, Figures 14-17). Figure 17 corroborates this and shows that at most XS, thalweg elevations decreased in concert with mean bed elevations.

Figure 14. South Fork Eel River Thalweg Elevation Change, 1997-2007

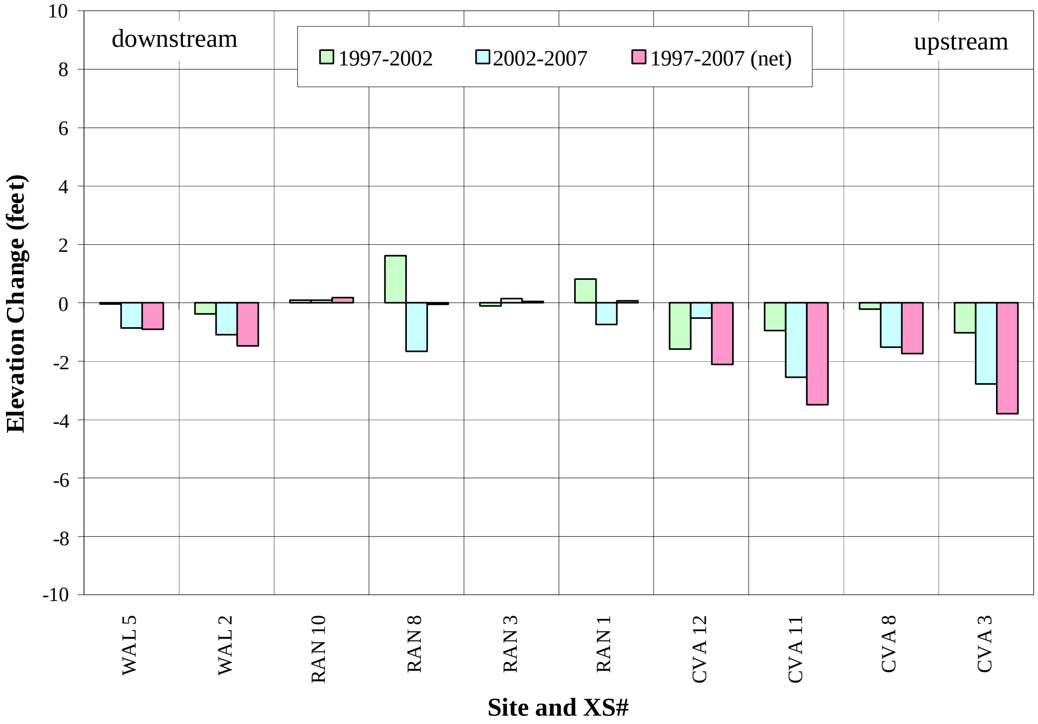


Figure 15. South Fork Eel River Mean Bed Elevation Change, 1997-2007

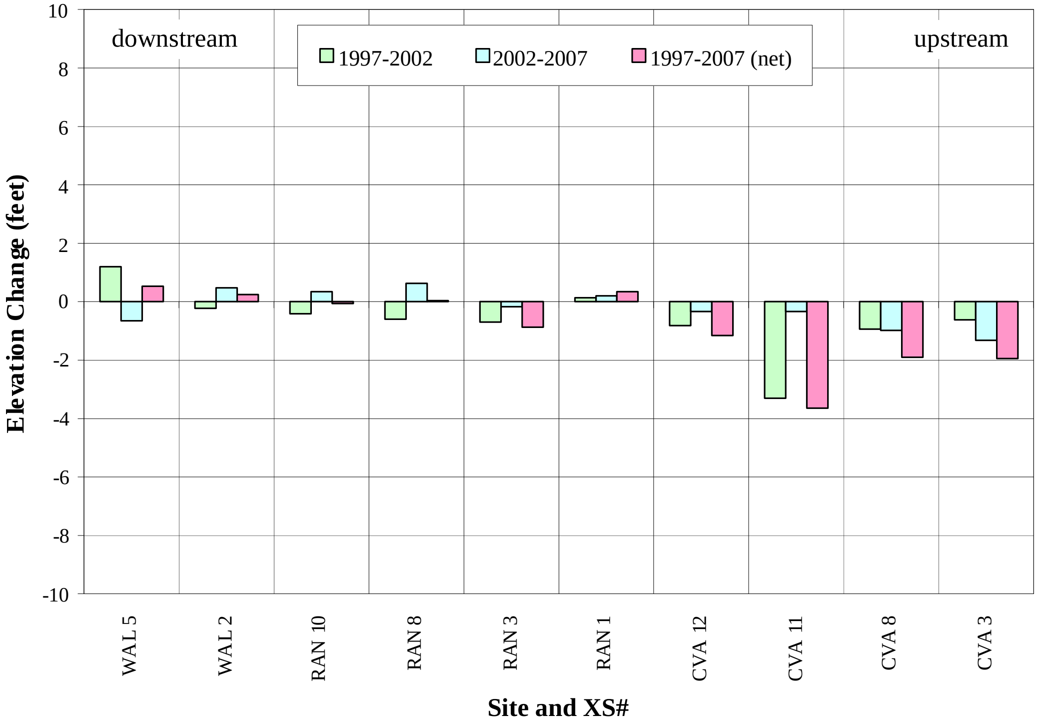


Figure 16. South Fork Eel River Channel Bed Scour and Fill, 1997-2007

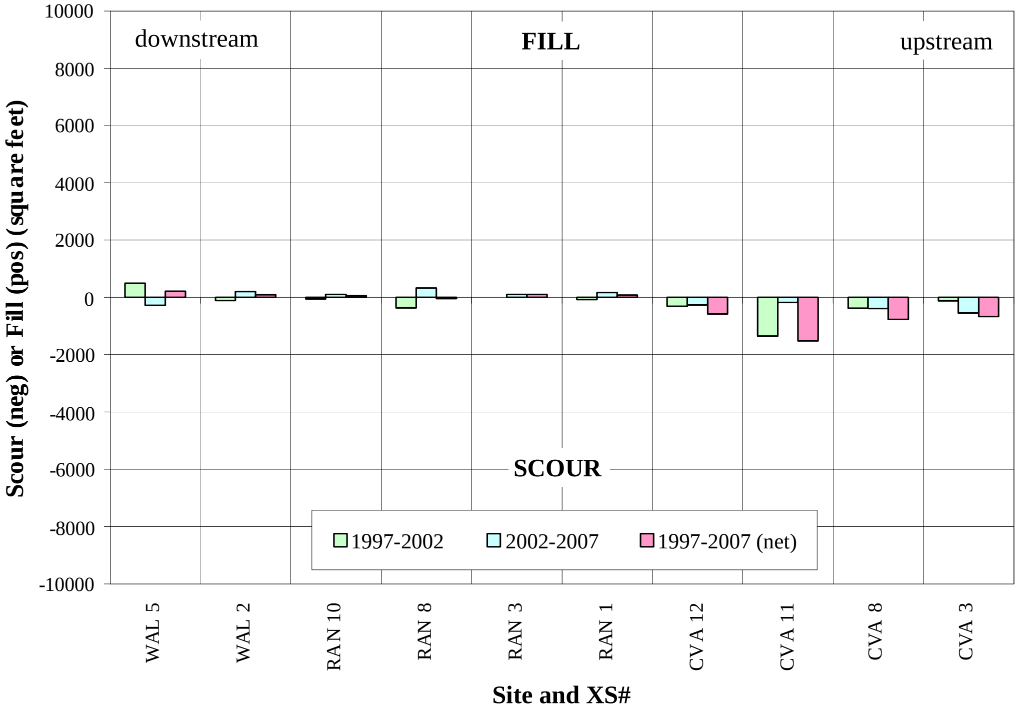
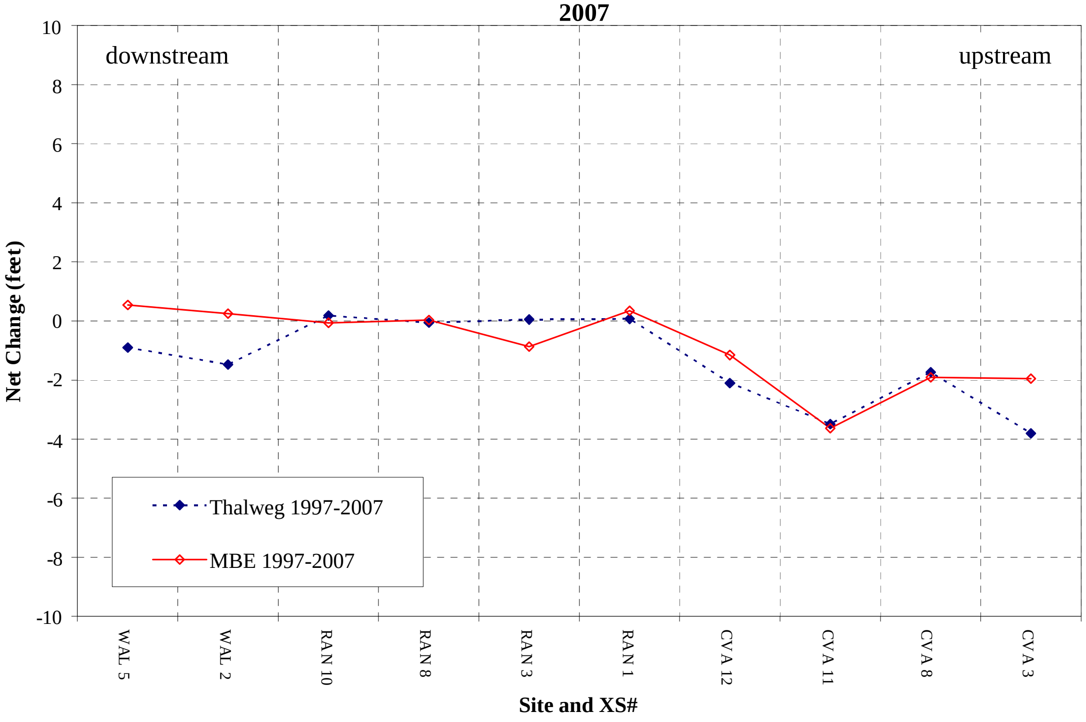


Figure 17. South Fork Eel River Thalweg and Mean Bed Elevation Net Change, 1997-2007



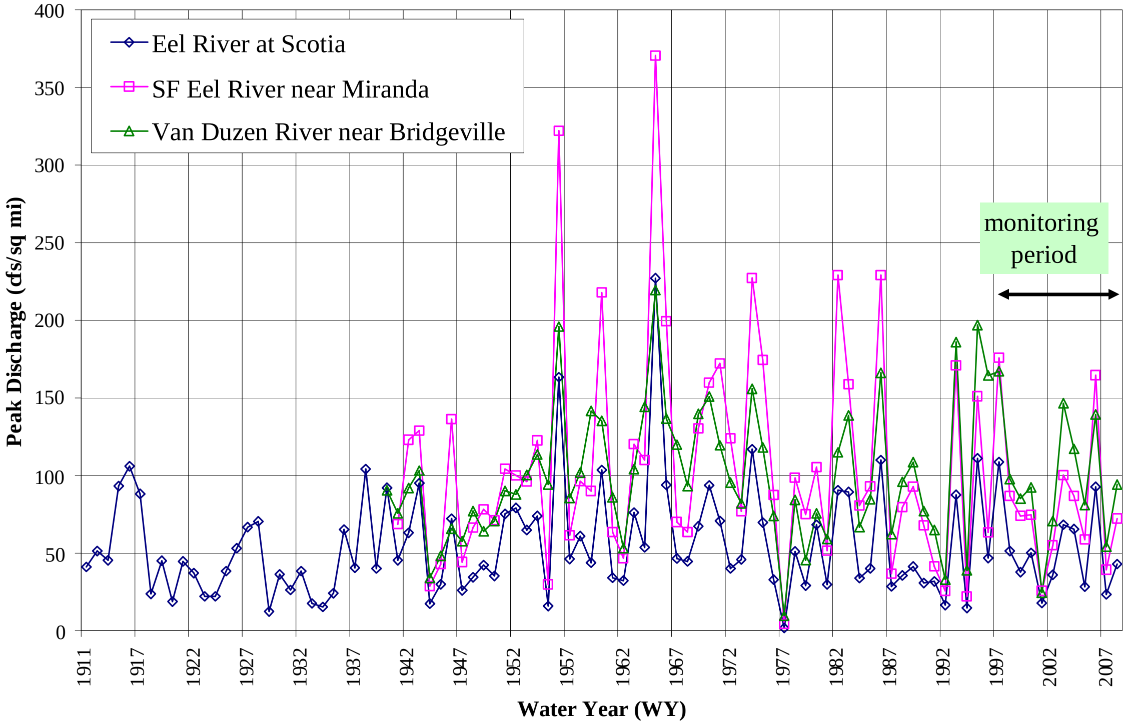
Flood History

Floods are the drivers of channel change, so the history of floods, especially large ones, provides an important context for evaluating changes in river channels. Three USGS stream gaging stations are used as reference sites for river discharge in the Eel River:

Eel River at Scotia (USGS Sta. No. 11477000, drainage area = 3,313 sq. mi.)
South Fork Eel River near Miranda (USGS Sta. No. 11476500, drainage area = 537 sq. mi.)
Van Duzen River near Bridgeville (USGS Sta. No. 11476500, drainage area = 222 sq. mi.)

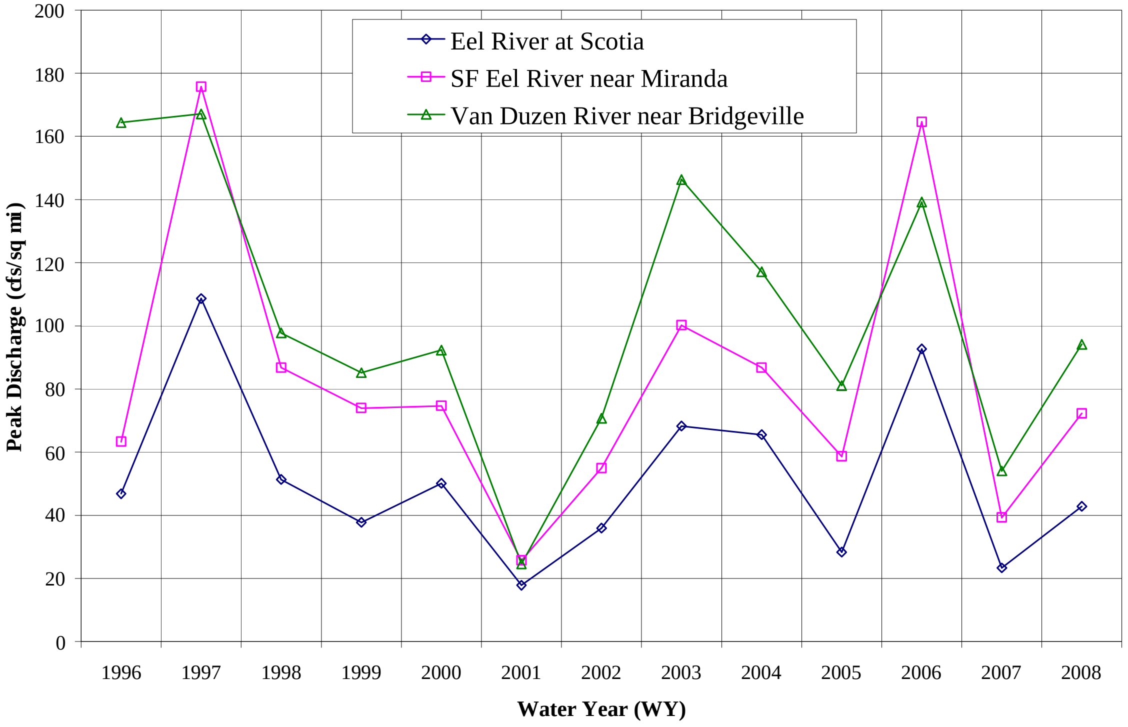
Figure 18 shows the annual maximum instantaneous peak discharges over the period of record (1911-2008), while Figure 19 shows just the peak discharges for the XS monitoring period. Data are expressed on a unit drainage area basis (cfs/sq. mi.) for comparison. By far, the largest floods of record occurred in water years (WY, October-September) 1956 (Dec., 1955) and 1965 (Dec., 1964). Other large floods occurred in WY 1960, 1974, 1982, and 1986. During the monitoring period (1997-2007), several large floods occurred, but all were substantially smaller than these six earlier floods.

Figure 18. Annual maximum peak discharges, Eel River Basin, 1911-2008.



As shown in Figure 19, during the 1997-2007 XS monitoring period, the largest floods occurred WY 1997 (Jan., 1997) and 2006 (Dec., 2005) in the South Fork and Lower Eel rivers. In the Van Duzen, the 2003 (Dec., 2002) flood was slightly larger that that in WY2006. Although smaller than record historical floods, these events were quite capable of transporting large volumes of gravel.

Figure 19. Annual maximum peak discharges, Eel River Basin, 1996-2008.



Discussion

The Eel River channel network spans a very large geographical area from the Pacific Ocean south to the Willits area in Mendocino County. Gravel mining sites participating in Humboldt's adaptive management program span a fair portion of that, all the way to from Fernbridge to the Humboldt-Mendocino County line. Unlike the Mad River, where mining sites and monitoring are concentrated in an eight-mile reach, mining sites in the Eel are clustered in four areas, with those in closest proximity to one another located in the Lower Eel and Van Duzen rivers. Consequently, a sediment budget-derived estimate of mean annual recruitment (MAR) for the Eel River would be based on relatively scant existing information on channel bed sediment supply, storage and changes, and so would have large uncertainty. Should derivation of a reliable estimate of MAR become a high priority, as it would if permits for new, large mining operations are sought, then filling of data gaps would be a necessary first step.

As demonstrated for the Redwood Creek watershed by Madej and Ozaki (1996), transport of channel bed sediment slows as it works its way downstream over the decades following large erosion and sediment delivery events such as the 1964 flood. In a basin the size of the Eel River (3,313 sq. mi. at Scotia), export of coarse sediment would be expected to take much longer than in the much smaller Redwood Creek watershed (287 sq. mi. at Orick). Thus historical floods and massive sedimentation in the 1950s through 1970s in the Eel River system certainly influence contemporary channel form and process.

This cross section analysis showed generally that channel changes were greatest on the Lower Eel and Van Duzen rivers, but that there was no consistent trend among sites in these reaches. Both exhibited areas of elevation increase and decrease. More consistent results came from XS analysis of the other two reaches, Middle Reach and South Fork Eel River, where elevations decreased and scour occurred. Individual sites in these two reaches showed little change or net gravel storage loss.

Comparing observed channel changes with mining rates is the obvious and most simplistic approach to exploring causal relationships, and one would expect channel degradation to exist, or be greatest, where mining volumes were highest. However, the opposite seems to be the case: channel bed elevation decreases and scour were highest where mining volumes were lowest (Middle Reach and South Fork Eel, see Tables 3 and 5). Where gravel mining volumes have been the greatest, mixed results were documented: both gravel accumulation (e.g., increases in mean bed elevation) and loss occurred in the lower Eel and Van Duzen rivers. Within these two reaches, the Leland Rock site stands out as an area of reduced bed elevations and net gravel loss. Whether this was from excessive mining volumes, recovery from aggradation caused by historical floods and sediment delivery to channels, effects from channel constriction imposed by the abutments of the three bridges, or processes unique to the deltaic setting cannot be determined with this analysis.

In a study which was completed about the time XS data first became available for the Eel River, Klein (1998) assembled and reviewed available XS data for the Van Duzen River. His general conclusions stated:

> *"Although the data presented herein is of limited use in making reliable inferences about channel responses in the main stem Van Duzen River, recent changes suggest that mean bed elevations increased in response to the 1965 flood, became even higher following floods in the 1970's, and have been generally lowering in recent years."*

This suggests that the Van Duzen is indeed exporting gravel as channel recovery proceeds. Whether bed lowering at the Leland Rock site is due in part or exclusively to channel and watershed recovery processes is unknown.

As a general conclusion, and based on this abbreviated analysis, we did not discern any large scale, persistent effects of Eel River gravel mining on channel thalweg elevations, mean bed elevations, or scour. It is possible that using only a sampling of XS and survey years caused us to miss something significant, but we doubt it. Gravel mining effects in the Eel River are probably limited to short term, localized effects which the adaptive management program and federal and state oversight attempt to avoid or minimize. Refinement of project-scale minimization measures will continue to be a fundamental component of the adaptive management process, as will instream habitat improvement projects associated with gravel extraction operations.

Literature Cited

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Lehre, A.K. 1995. Lintrp 1.4, an Excel macro for linear interpolation. Humboldt State University, Geology Department website: http://www.humboldt.edu/~geology/courses/geology550/550_macros_templates_index.html

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