COUNTY OF HUMBOLDT EXTRACTION REVIEW TEAM (CHERT)
HISTORICAL ANALYSES OF THE MAD RIVER: 2004 -2007 UPDATE

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for the

Humboldt County Board of Supervisors

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Introduction

This report is an update and an addendum to the County of Humboldt Extraction Review Team report *Historical Analyses of the Mad River: 1993-2003* (Lehre and others, 2005, hereinafter referred to as the *Report*.). That document contains our methodology, rationale, discussion, and conclusions, and the reader is expected to refer to it. The present report updates it with cross-section data collected in water years 2004 through 2007 and revises and re-analyzes earlier cross-section data inconsistent with current surveys. These newer and revised data reaffirm the pattern of erosion, deposition, and cross-sectional change described in detail in our previous report.

Accompanying this report are four supplementary electronic files in zip format:

1) an Excel spreadsheet (*Mad_R_Sediment_1962-2007.zip)* showing bedload and suspended-sediment recruitment calculations;
2) an Excel spreadsheet (*Mad_R_Bank_Erosion_1993-2007.zip*) containing bank erosion measurements and calculations;
3) an Excel spreadsheet (*Mad_R_XSS_Data_Summary_2007.zip*) summarizing the yearly cross- section data and calculations; and
4) a series of Excel spreadsheets (*Mad_R_XSS_1993-2007.zip*) containing all the cross-section data used in the analysis, together with the elevations interpolated at 1-foot distances and the derived yearly elevations, widths, and XS areas. These spreadsheets document clearly all adjustments made by CHERT

All tables referenced in this report are grouped together following the end of the text. Appendices containing graphs used in the analysis follow the tables.

Data Quality and Revision

Analysis of stored sediment volume and cross sectional changes relied on 933 individual cross-section surveys provided by Mad River gravel operators and the HBMWD at 74 locations on the Mad River over the 1993-2007 period. Only 35, or about one half, of the monitoring sites span the entire 15-year period, and of these only 28 have complete yearly records (Table 1). In the *Report*, we identified the following problems with cross-sectional data supplied to us:

1) loss of one or both endpoints due to bank erosion (in some XSS this happened repeatedly), requiring adjustment of XS distances to make the XSS of different years comparable, and introducing uncertainty in XS alignment;

2) incomplete survey between endpoints (e.g., survey of only the near-channel or extracted area, and not of the entire width) requiring part of the XS to be estimated using data from surveys in adjacent years;

3) inconsistent geodetic datum between surveys and sites -- all surveys had to be adjusted to the NAVD88 datum;

4) inconsistent detail between yearly surveys (e.g., in one year the entire width is surveyed in great detail, and in a subsequent year only one-half or one-third as many points are taken) introducing additional error in comparing years;

5) omission of survey of thalweg or deeper parts of the channel in Spring (presumably because of water depth) -- we inserted thalweg data from the Fall survey if available;

6) missing years at XSS;

7) abandonment of a XS or XS realignment (e.g., due to shifting of the channel) without at least one year of overlap with its replacement; and

8) errors in survey distances or elevations discovered when comparing surveys of adjacent years. (These were adjusted by eye to make the aberrant XS consistent with the XSS of the previous and succeeding years.)

CHERT anticipated that the 2004 -2007 survey data could be seamlessly integrated with the adjusted 1993 - 2003 data. Instead, CHERT discovered datum and endpoint inconsistencies, especially in the upstream sites, that required us to re-examine *all* the earlier surveys, including our previous adjustments. For this re-examination, we assumed that data in the 2004-2007 surveys, having been collected with the aid of GPS and total station, are correct. Doug Jager and Randy Klein painstakingly examined all the pre-2004 surveys and, based on the 2004-2007 elevations and positions of known points (such as endpoints or hubs) re-adjusted elevations and distances, and patched in missing pieces so that each set of cross-sections is internally consistent, covers a common width, and honors the NAVD88 datum. (All the pre-2004 cross-sections at Guynup, Emmerson, Blue Lake, Johnson, and Essex bars required such adjustment; additionally the 2004-2007 cross-sections at Blue Lake and Emmerson bars required distance adjustments.) Andre Lehre further adjusted some cross-sections (mainly Johnson Bar) in the course of preparing this update. All cross-section analyses and sediment transport estimates were done by Andre Lehre. Randy Klein contributed the section on bank erosion.

Cross-Section Analysis

Quantities measured: The quantities derived from each cross-section for each year are mean elevation, thalweg elevation, confinement (mean elevation - thalweg elevation), width at reference elevation, and XS area below reference elevation. Yearly changes in channel volume below the reference elevation are computed between pairs of consecutive cross-sections. Details of these computations are contained in the *Report*, and these measurements, yearly changes, and site averages are contained in the electronic file *Mad_R_XSS_Data_Summary_2007.zip*.

Differences from the 2005 Report: Besides interpolation of the 2004-2007 cross-sections at all sites, re-interpolation of all re-adjusted cross-sections was necessary. The reader comparing this analysis with the 2005 *Report* will thus discover differences in the pre-2004 measurements at the Guynup, Emmerson, Blue Lake, Johnson, and Essex sites. These differences are generally not large, but are most pronounced in the volume change calculations.

Three new cross-sections were installed since 2004: Guynup XS 0.1 at the upstream end of the site below the Hatchery bar; Emmerson XS 0+00 at the upstream dripline of the Blue Lake Bridge; and Johnson XS J-5 at the downstream end of Johnson Bar. These cross-sections are included in the elevation, confinement, width, and XS area computations, but have been omitted from the sitewise volume change calculations because they distort comparison with years prior to their installation.

Reference elevations were changed at 23 cross-sections because either elevation adjustments (upstream sites) or bed aggradation (downstream sites) required it. These are identified in Table 1.

Results: The results of the analysis are presented graphically in the figure appendices accompanying this report. Appendix A contains mean elevation, thalweg elevation, confinement, channel width (at reference elevation), and XS area (below reference elevation) for each site plotted against distance upstream for 1993, 1997, 2003, and 2007. These allow quick assessment of spatial and temporal variation in these quantities. In Appendix B sitewise mean changes of each quantity, as well as total volume change, are plotted by site for the periods 1993-1997, 1997-2003, and 2003-2007. These show when and where the channel is filling or enlarging. Appendices C and D contain revised linear regressions relating site mean changes to volume extracted from the sites. Our findings are summarized below.

Cross-section changes: The revised and updated cross-section analysis (Table 2) reaffirms our observations in the 2005 *Report*. Profound differences exist in the responses of the mostly unconfined reach upstream of the A&MRR bridge and the confined or semi-confined downstream. Between 1993 and 1997, the upstream reach underwent an episode of overall mild aggradation, with modest increases in mean and thalweg elevation being balanced by increases in cross-section width and area due to bank erosion. From 1997 to 2003, however, the upstream reach experienced moderate decreases in mean and thalweg elevation together with large increases in cross-section width and area from bank erosion, thus leading to persistent channel enlargement and loss of material from storage. Since 2003 the channel has continued to enlarge, but the rate of enlargement appears to have declined. Confinement has increased slightly due to thalweg lowering. Longitudinal slope increased by about 0.0003 from 1993 to 2003, but by 2007 had decreased again by about that amount (Table 3).

In contrast, the downstream reach has undergone mainly aggradation since 1993. Mean and thalweg elevations have steadily increased, and, with width staying essentially constant, cross-section area has decreased as the bed has raised. Net channel volume decreased substantially, reflecting bar growth. Confinement decreased modestly where thalweg elevations rose more rapidly than mean bar elevation. The bulk of these changes occurred prior to 2003; since 2003 downstream areas have continued to fill, but at a reduced rate. Longitudinal slope has decreased by about 0.0006 - 0.0009 since 1993.

Changes in channel volume: Channel volume, as used here, is the volume between an imaginary surface defined by the reference elevations, and the actual ground surface beneath. It is calculated by the double-end area method. Our methodology and possible sources of error are discussed in detail in the *Report,* and the reader should refer to it.

Table 4 and Figure 1 summarize the cross-section volume changes by bar for the periods 1993-1997, 1997-2003, and 2003-2007.

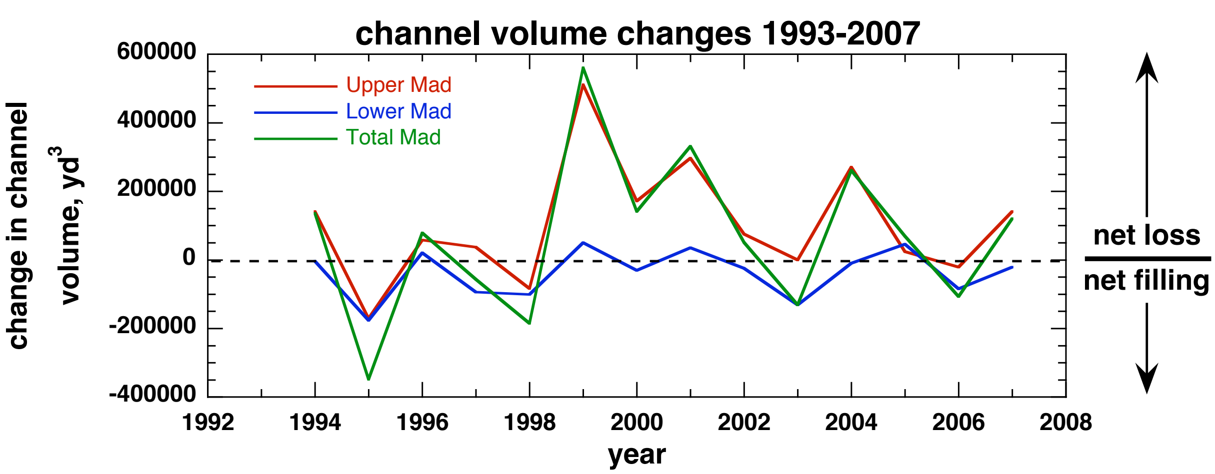


Figure 1. Changes in channel volume with time for Mad River. The year indicated on the axis is that of the end of the computation period, e.g., the value plotted at "1994" is the volume change for the 1993-94 period. Negative values indicate channel aggradation (filling).

For the upstream reach, between 1993 and 1997 the three upstream bars experienced moderate net channel enlargement, while the two downstream bars underwent slightly greater net filling, leaving the reach overall slightly aggraded. It is evident from Figure 1 that the aggradation took place chiefly in 1993-94. From 1997 to 2003, the upstream sites, with the exception of Johnson Bar, experienced massive channel enlargement due mainly to channel widening and bank erosion. Our estimate of 970,000 cu.yd. net loss in 1997-2003 compares well with Fehlman's (2004, p. 7) statement that net loss was "more than 800,000 cubic yards." Figure 1 makes it clear that most of the enlargement occurred in 1998–2000, and that the rate of enlargement declined until 2003, when it again increased. Overall, from 1993-2007, the upstream reach lost around 1,450,000 cu. yd., or 103,000 cu. yd./year.

With the exception of Essex Bar in 1993-1997, all downstream sites have experienced persistent net aggradation (filling) since 1993. From 1993-2007, the downstream reach gained about 530,000 cu. yd., or 37,000 cu. yd./year.

In summary, the large unconfined upstream sites have been major losers of stored sediment, largely through bank erosion rather than downcutting, while the confined or semi-confined downstream sites have undergone significant aggradation. The two do not balance however: upstream erosion is about three times the rate of downstream deposition, and from 1993-2007 the Mad experienced a net loss of about 920,000 cu yd. of bed and bank material, or 66,000 cu. yd./year.

Relation of channel changes to volumes extracted: In the *Report* we used linear regression to relate sitewise average changes in mean elevation, thalweg elevation, confinement, width, XS area, and channel volume to volume of gravel extracted at each site. The revised 1997-2003 regressions, using our re-adjusted data, are given in Appendix C. They differ only slightly from the earlier regressions. We performed the same regressions using the 2004-2007 data. Table 5 summarizes our findings for the 1993-1997, 1997-2003, and 2003-2007 periods. In general, only the upstream sites showed meaningful relations.

In the *Report* we suggest that the 1997-2003 regressions might be useful in predicting channel response to future extraction at the upstream sites, and furthermore used them to estimate the amount of annual extraction that might result in no channel changes. We tested this hypothesis using the 2004 - 2007 data, and it failed. The 1997-2003 and 2004-2007 regressions are shown in Appendix D. With the exception of channel width, the 2004-2007 regression lines are clearly different from the 1997-2003 ones. They do, however, show the same trends.

Bank Erosion

Active channel area: Active channel widths and surface areas were computed in the Mad River PEIR technical appendix (Lehre, 1993) for the period 1952-1992, and in Lehre and others (2005) for 1993-2004. Though the methods differed between the earlier period (1954-92) and the later period (1994-2003), the results are roughly comparable. We did not compute later (2005-2007) active channel areas in this report because they were already determined in Trush (2008) using aerial photography. Trush's "open channelbed" and "active channelbed" categories correspond to active channel area used in Lehre (2005).

Bank erosion calculation: Bank erosion was determined for 1998 through 2007 using a combination of measurements from cross sections and air photos. Because of the small scale and distortion associated with the air photos, they were only used to determine the lengths of bank erosion polygons. Widths and heights of bank erosion were determined from the cross sections, with cross sectional area of bank erosion calculated as the product of width and height. For width, the average of top width and bottom width was used. In some cases, the cross section was oblique to the long axis of the feature. For these cases, the cross sectional area determined from the cross section was reduced by multiplying the area by the cosine of the angle off perpendicular to the long axis (Fig. 2).

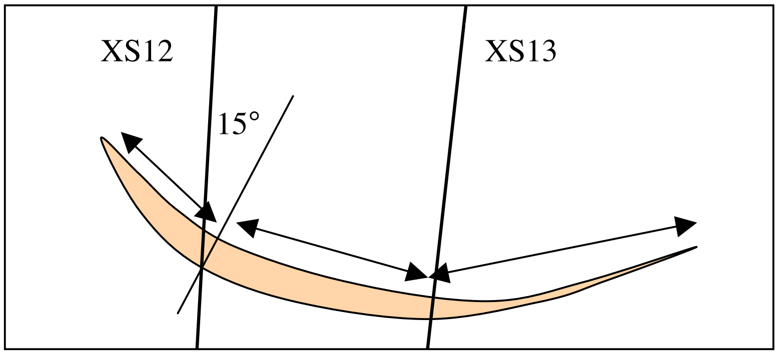


Figure 2 Definition sketch for adjusting XS area for bank erosion estimates at non-perpendicular XS: adjusted area of XS12 with bank erosion = (XS12 area of bank erosion) x (cosine of angle). XS 13 area OK without adjustment.

Where two cross sections intersected a particular bank erosion feature, the eroded areas (adjusted if necessary) were averaged and this was multiplied by the intervening horizontal distance to get a volume of bank loss between the cross sections (double-end-area formula). The volume of bank erosion extending upstream and/or downstream of a cross section was calculated as the erosion area at the cross section divided by 2 and multiplied by the length between the cross section and the ending distance as determined from the air photo. This same formula was also used where only one cross section intersected a bank erosion feature for calculating the volumes upstream and downstream of the cross section.

Bank erosion volumes were calculated individually for each feature, and are reported here as sums for each mining site by each year. Where a bank erosion feature overlapped on two adjacent sites, it was included with the site having the greatest proportion of the volume. Bank erosion volumes determined for this study are shown in Table 6.

As mentioned earlier, we also calculated bank erosion volumes for the 1993-97 period in our 1997 post-extraction report (Klein and others, 1998). These, along with the annual totals from Table 6, are shown in Table 7 for the study reach as a whole.

Figure 3 shows these data in graphical form. As expected, and as with active channel area, bank erosion appears strongly dependent on floods. An exception is seen following the relatively large flood in 1996, when bank erosion was relatively small compared to other large floods in 1995, 1997, and 2003. We cannot explain this phenomenon, other than to suggest that the previous year (1995) was the first large flood for several years, causing a large volume of bank erosion. Perhaps the 1995 flood had ‘reset’ the channel, removing most of the unstable banks, leaving little remaining for the 1996 flood the very next year. Flood flow duration, which was not examined here, may also explain some of this disparity. For the updated period (2005-2007), flood flows were relatively small except for 2005 (47,500 cfs). Again, annual bank erosion volumes trend roughly with peak flows.

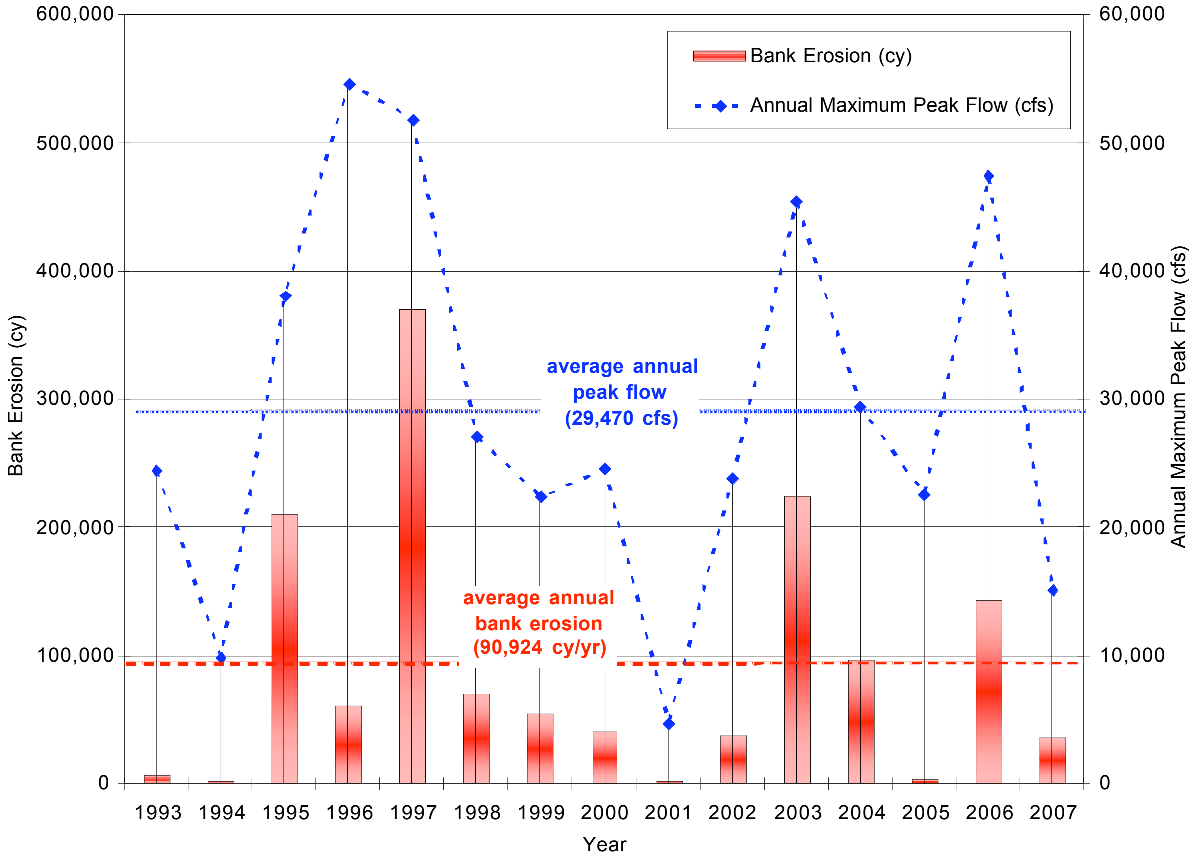


Figure 3 Bank erosion and annual peak flows by year

Sediment Input and Annual Extraction

Bedload: Annual bedload and suspended sediment transport from upstream was estimated from daily discharges at the Arcata gage using Brown's (1973) bedload and suspended-load rating curves. Details of this procedure are given in Lehre (1993). Whether these curves are still valid is unknown; they are, however, all we have available. Suspended sand load at Arcata was estimated as 3% of the total suspended load, based on Brown's (1973) long-term estimate for sand 0.25 - 2mm in diameter. Loads in tons were converted to volumes using a specific weight of 1.55 tons/cu yd, The estimated volumes are shown by year in Figure 4. The daily discharges and actual calculations are available in the supplementary file *Mad_R_Sediment_1962-2007.zip*.

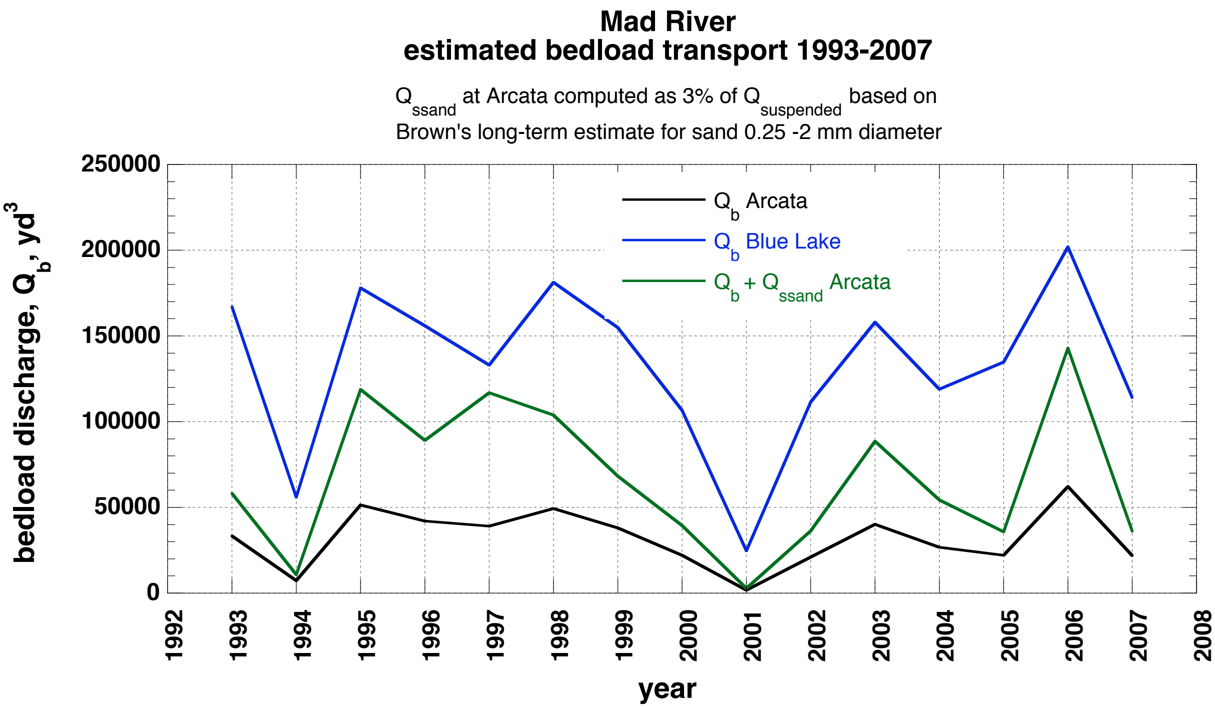


Figure 4 Bedload and suspended sand load by year at Arcata and Blue Lake estimated using Brown's (1973) rating curves

Annual extraction: The actual volume of gravel extracted by year at each site is provided to CHERT by the operators and published in CHERT's post-extraction reports. Figure 5, based on this data, shows total extraction by year for the upper and lower Mad. The data is available in the supplementary file *Mad_R_XSS_Data_Summary_2007.zip*,

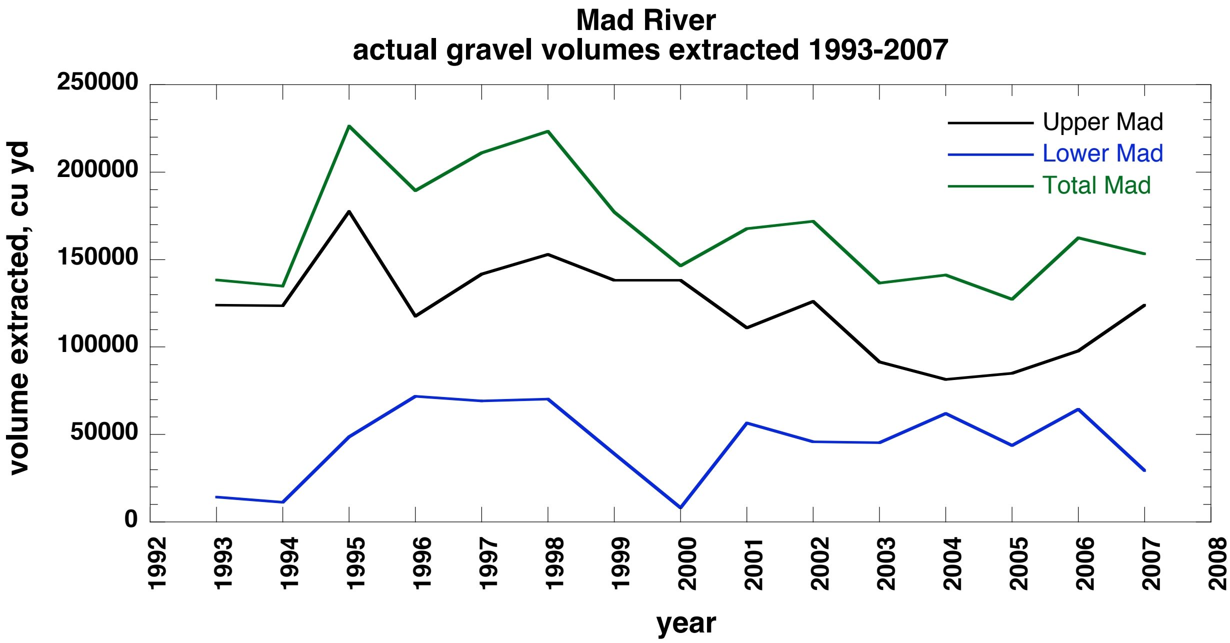


Figure 5 Actual annual gravel extraction by year, upper, lower and total Mad River. The upper Mad includes Guynup, Emmerson, Blue Lake, Christie, and Johnson bars. The lower Mad includes Essex, Johnson-Spini, Miller-Almquist, and O'Neill bars.

Comparison of bed-sediment recruitment, volume extracted, and volume change. In Table 8 we compare total estimated bed sediment input from upstream, actual volume extracted, and total volume change calculated from the cross sections. If all sediment sources and sinks are accounted for in the volume change, a simple volume balance would be:

volume change = volume extracted - (volume input from upstream - volume leaving reach downstream)

Volume eroded from bed and banks within the reach would end up either being extracted, leaving downstream, or, if re-deposited in the reach, counted in the volume change.

For the period 1993-1997, Table 8 indicates a net aggradation (negative volume change) of around 190,000 cu yd. despite more bed material being extracted than was resupplied. This alone suggests that our estimates of sediment input may be in error. But for 1997-2003 and 2004-2007 the volume change is surprisingly similar to the difference between volume extracted and volume input from upstream. This may be fortuitous, an artifact of compensating error in the sediment transport and volume change estimates. Furthermore, it may be erroneous to include all of the sand load in the recruitment estimate. But, taken at face value, it suggests that relatively little sediment is available to be transported downstream below the mining reach, and that extraction continues to outpace replenishment, chiefly at the upstream sites.

Literature Cited

Fehlman, H. 2004. Mad River current characteristics and historical perspective. Prepared for Granite Construction, May 28, 2004. 12 p. with appendices.

Klein, R.D., Lehre, A.K, Jager, D., and Bill Trush. 1998. County of Humboldt Extraction Review Team (CHERT) 1997 Post-extraction Report with Historical Analysis for the Mad River. Unpublished Report to Humboldt County Board of Supervisors. 26 p

Lehre, A.K. 1993. Mad River EIR Technical Supplement Section 3: Estimation of Mad River Grave Recruitment and Analysis of Channel Degradation. Program Environmental Impact Report (PEIR) on Gravel Mining from the Lower Mad River. Humboldt County Planning Department. 28 p.

Lehre, A.K, Trush, W.J., Klein, R.D., and D. Jager. 2005. County of Humboldt Extraction Review Team (CHERT) Historical Analysis of the Mad River: 1993-2005. Unpublished Report to Humboldt County Board of Supervisors. 58 p Note: be sure that you have the version that says "corrected 2009." The original version posted on the Humboldt Co SMARA website has errors in figure numbering.

Trush, W.J. 2008. Lower Mad River woody riparian vegetation trend between WY1994 and WY2007. Appendix A, Draft Supplemental PEIR for Gravel Extraction on the Lower Mad River 18 p.

The Lehre and others 2005 report and digital supplements referred to in this document are available from the Humboldt County SMARA website:

http://co.humboldt.ca.us/planning/smara/default.asp?inc=slm

The Lehre 1993 report is available at:

sftp://www.humboldt.edu//d3/home/univ/geology/public_html/for_download/Lehre_reports/Gravel_report_1993.pdf

Table 1 -- Cross-Sections Used in Analysis

Cross-sections are listed in order from upstream to downstream. Distances upstream provided by R. Brown. Streamline Planning Consultants, except for those marked *, which are estimated from R. Klein's channel CL (centerline) measurements or by scaling from airphotos by Andre Lehre or Doug Jager. Reference elevation is that used in computation of channel mean elevation and cross-sectional area. Reference elevations in teal are different from those in the 2005 report.

XSS upstream of A&MRR Bridge

Site	XS	Distance Upstream, ft	XS Reference Elevation, ft	Period Spanned	Years Missing in Period	No. of Years with XSS
Guynup Bar	0.1	56,401*	97.5	2004 - 2007	none	4
	1	55,373	96.0	1993 - 2007	none	15
	2	54,923	96.0	1993 - 2007	none	15
	3	54,593	94.0	1993 - 2007	none	15
	4	54,213	93.0	1993 - 2007	none	15
	5	53,863	91.0	1993 - 2007	none	15
	6	53,563	90.0	1993 - 2007	none	15
	7	53,138	93.0	1993 - 2007	none	15
	8	52,588	88.5	1993 - 2007	none	15
Emmerson Bar	30+00	52,293	88.0	1994 - 2007	2003	14
	27+00	52,033	87.0	1994 - 2007	none	15
	23+00	51,693	85.0	1994 - 2007	none	15
	18+38	51,308	85.0	1994 - 2007	none	15
	15+00	50,938	85.0	1994 - 2007	none	15
	11+00	50,738	85.0	1994 - 2007	none	15
	6+00	50,263	82.0	1994 - 2007	none	15
	1+00	49,790	78.0	1994 - 2007	none	15
	0+00	49,480*	80.0	2005 - 2007	none	3
Blue Lake Bar	Disk 1	49,110	76.0	1995 - 2007	none	13
	Disk 2	48,835	80.0	1995 - 2007	none	13
	0+00	48,510	80.0	1993 - 2007	none	15
	5+00	48,073	80.0	1993 - 2007	none	15
	10+00	47,623	80.0	1993 - 2007	none	15
	15+00	47,223	80.0	1993 - 2007	none	15
	20+00	46,523	74.0	1993 - 2007	none	15
	25+00	45,893	75.0	1993 - 2007	none	15
	30+00	45,503	74.0	1993 - 2007	none	15
	34+00	45,103	73.0	1993 - 2007	none	15
	38+00	44,603	70.0	1993 - 2007	none	15
	42+00	44,153	70.0	1993 - 2007	none	15
Christie Bar	Section 5 (CH1)	42,997	64.0	1995 - 2007	none	13
	Radial 4	42,647	64.0	1995 - 2003	2002	8
	Radial 3 (CH2)	42,347	64.0	1995 - 2007	none	13
	Radial 2	41,872	63.5	1995 - 2003	2002	8
	CH3	41,400*	62.0	2002 - 2007	none	6
	Radial 1	41,422	63.0	1995 - 1999	none	5
	22+87	40,997	60.0	1993 - 2003	2002	10
	21+64 (CH4)	40,547	59.0	1993 - 2007	none	15
	17+47	40,147	59.0	1993 - 2001	none	9
	CH5	39,734*	58.0	2002 - 2007	none	6
	13+33	39,447	58.0	1993 - 2001	none	9
	9+99	39,147	56.0	1994 - 2001	none	8
	CH6	38,991*	54.0	2002 - 2007	none	6
	6+66	38,797	55.5	1993 - 2001	none	9
	3+33 (CH7)	38,447	55.5	1994 - 2007	none	14
	0+00 (CH8)	38,047	54.0	1993 - 2007	none	15

continued

Table 1 -- Cross-Sections Used in Analysis (continued)

XSS downstream of A&MRR Bridge

Site	XS	Distance Upstream, ft	Reference Elevation, ft	Period Spanned	Years Missing in Period	No. of Years with XSS
Johnson Bar	J-1 (CH-9)	37,597	53.0	1996 - 2007	none	12
	J-2	37,047	53.0	1996 - 2007	none	12
	J-3	36,497	50.0	1996 - 2007	none	12
	J-4	36,167	49.0	1997 - 2007	none	11
	J-5	35,767*	49.0	2005 - 2007	none	3
HBMWD upper	8	30,858	48.5	1992 - 2007	1998, 1999, 2000	13
	7	29,553	44.0	1992 - 2007	1998, 2000	14
	6	28,596	39.0	1992 - 2007	1998, 2000	14
Essex Bar	1	28,304	36.0	1993 - 2007	none	15
	2	27,979	38.0	1993 - 2007	none	15
	3	27,629	40.0	1993 - 2007	none	15
HBMWD lower	5	27,030	40.0	1992 - 2007	1998, 2000	14
	4	25,725	35.5	1994 - 2007	1998, 2000	12
	3	24,681	28.0	1992 - 2007	1998, 2000	14
	2	23,724	31.0	1992 - 2007	1998, 2000	14
	1	22,941	26.0	1992 - 2007	1998, 2000	14
Johnson-Spini Bar	1	21,081	27.0	1990 - 2007	1992	17
	2	20,756	29.0	1991 - 2007	1992	17
	3	20,366	28.0	1990 - 2007	1992	17
	4 †	19,886	28.0	1990 - 2007	1992	17
Miller-Almquist Bar	5	19,506	27.0	1994 - 2007	none	14
	6	19,170	24.0	1994 - 2007	none	14
	7	18,760	20.0	1994 - 2007	none	14
O'Neill Bar	8	17,780	18.0	1995 - 2007	none	13
	9	17,480	18.0	1995 - 2007	none	13
	10	17,180	19.0	1995 - 2007	none	13
	11	16,880	25.0	1995 - 2007	none	13
	12	16,580	19.0	1995 - 2007	none	13

† According to Aldaron Laird, former agent for Miller Farms, this cross-section should be included as part of the Miller-Almquist site. However as it spans the both the downstream end of the Johnson-Spini right bank bar and the upstream end Miller-Almquist left bank bar (formerly referred to as the Johnson-Spini left bank bar) we have chosen to leave it as the data was originally supplied to us.

Table 2 -- Summary of Mad River cross-section changes, 1993-2007

	upstream sites			**downstream sites**		
	1993-1997	**1997-2003**	**2003-2007**	**1993-1997**	**1997-2003**	**2003-2007**
XS mean elevation	increase	decrease	some decrease	mostly increase	increase	small increase
XS thalweg elevation	increase or no change	decrease	decrease or no change	lowering upstream increase downstream	increase	increase
***XS* confinement**	variable	increase or no change	increase or no change	increase	mostly decrease	variable
XS width	increase	increase	modest increase	no change	mostly no change	slight decrease
XS area	modest increase	great increase	modest increase	decrease (filling)	modest decrease (filling)	small decrease (filling)
XS volume	slight decrease	great increase	increase	decrease	decrease	slight decrease
channel slope	small increase	v. small increase	small decrease	modest decrease	v. small decrease	small decrease

Table 3 -- Estimates of longitudinal channel slope

	longitudinal slope			
year	**upstream thalweg**	**upstream mean elevation**	**downstream thalweg**	**downstream mean elevation**
1993	0.00224	0.00237	0.00193	0.00193
1997	0.00248	0.00249	0.00154	0.00172
2003	0.00250	0.00245	0.00155	0.00164
2007	0.00226	0.00231	0.00100	0.00133

Table 4 -- Spatial variation of changes in volume

To reduce round-off errors in summing and averaging, quantities in this table are given to more significant figures than justified; individual values should be rounded to the nearest thousand before citation or use. Negative values indicate net filling.

	total volume change in period for site, cu. yd.		
Site	**1993-1997**	**1997-2003**	**2003-2007**
Guynup Bar	6,120	109,251	166,945
Emmerson Bar	102,988	49,007	76,661
Blue Lake Bar	96,702	366,919	-15,168
Christie Bar	-77,656	523,698	181,266
Johnson Bar	-64,297	-79,092	4,945
HBMWD upper	-46,531	-76,719	-12,468
Essex Bar	1,523	-1,922	-3,394
HBMWD lower	-28,259	-67,150	-27,340
Johnson-Spini Bar	-115,688	-19,261	-5,644
Miller-Almquist Bar	-31,616	-20,339	-13,024
O'Neill Bar	-33,864	-17,697	-9,314
Total upstream	63,857	969,783	414,649
Total downstream	-254,435	-203,088	-71,184
Total Mad	-190,578	766,695	343,465

Table 5 -- Summary of relations between gravel extraction and geomorphic response, Mad River 1993-2007

	upstream sites			downstream sites		
	1993-1997	**1997-2003**	**2003-2007**	**1993-1997**	**1997-2003**	**2003-2007**
XS mean elevation	increase with increasing extraction; weak relation	decrease with increasing extraction; strong relation	greater decrease with increasing extraction; weak relation	increase with increasing extraction; moderate relation	no relation	slight decrease with increasing extraction; weak relation
XS thalweg elevation	no relation	decrease with increasing extraction; weak relation	greater decrease with increasing extraction; moderate relation	increase with increasing extraction; weak relation	no relation	no relation
XS confinement	no relation	no relation	mod. increase with increasing extraction; weak relation	no relation	no relation	no relation
XS width	no relation	increase with increasing extraction; moderate relation	increase with increasing extraction; strong relation	slight increase with increasing extraction; relation suspect	probably no relation	probably no relation
XS area	decrease with increasing extraction; moderate relation	increase with increasing extraction; strong relation	greater increase with increasing extraction; strong relation	decrease with increasing extraction; moderate relation	probably no relation	probably no relation
XS volume	decrease with increasing extraction; moderate relation	increase with increasing extraction; strong relation	greater increase with increasing extraction; strong relation	decrease with increasing extraction; relation suspect	no relation	no relation

Table 6 -- Annual bank erosion volumes by site and year for the lower Mad River, 1998-2007 (cy = cubic yards).

	Site[1]					Ann Total
Period	**MRS**	**EMM**	**BLU**	**CHR**	**JOH**	**(cy)**
1997-98	16,812	19,842	19,729	12,953	1,913	71,249
1998-99	2,046	93	25,597	10,808	16,228	54,772
1999-00	0	1,546	16,059	11,564	11,250	40,419
2000-01	0	74	0	1,788	298	2,160
2001-02	7,856	1,822	8,768	14,849	4,875	38,170
2002-03	47,920	10,584	88,376	49,178	28,322	224,380
2003-04	8,046	14,556	48,169	26,744	0	97,517
2004-05	467	2,256	222	133	0	3,078
2005-06	29,324	35,024	34,269	32,094	13,511	144,222
2006-07	0	0	0	36,888	0	36,888
Site Total	**112,471**	**85,797**	**241,189**	**197,000**	**76,397**	**712,854**

[1]Site codes are as follows: MRS is Mad River Sand and Gravel; EMM is Emmerson Bar; BLU is Blue Lake Bar; CHR is Christie Bar; JOH is Johnson Bar

Table 7 -- Annual bank erosion volumes and peak discharges for the lower Mad River, 1993-2007.

Year	**Bank Erosion (cy)**	**Peak Discharge (cfs)**
1993	7,000	24,500
1994	2,000	9,840
1995	211,000	38,100
1996	61,000	54,700
1997	370,000	51,900
1998	71,249	27,100
1999	54,772	22,400
2000	40,419	24,600
2001	2,160	4,790
2002	38,170	23,900
2003	224,380	45,500
2004	97,517	29,400
2005	3,078	22,600
2006	144,222	47,500
2007	36,888	15,200
Total =	**1,363,854**	**---**
Average =	**90,924**	**29,469**

Table 8 -- Comparison of estimated bed-sediment recruitment, actual extraction, and total volume change for the Mad River.

To reduce round-off errors in summing and averaging, quantities in this table are given to more significant figures than justified; individual values should be rounded to the nearest thousand before citation or use. Negative values indicate net filling.

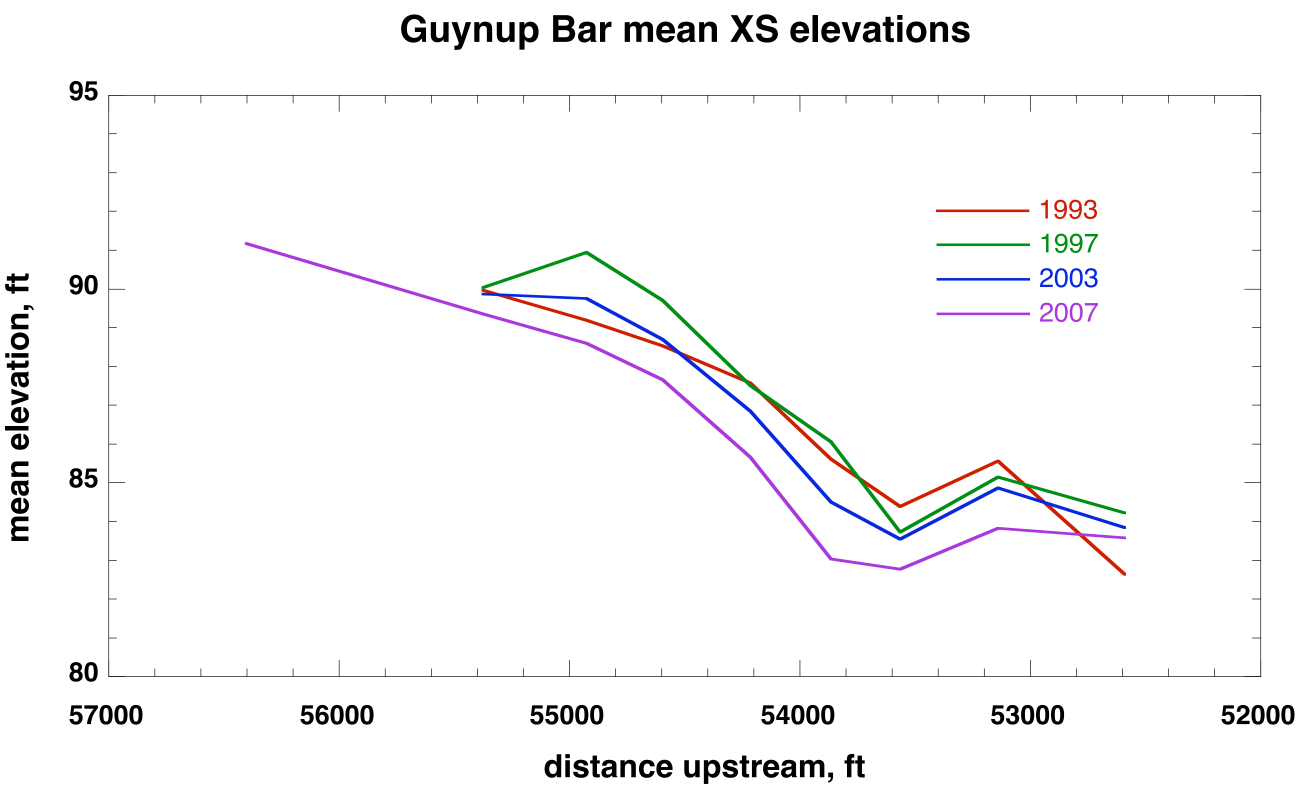
	volume, cu yd			
	1993-1996	**1997-2003**	**2004-2007**	**1997-2007**
bedload	173,244	172,781	133,206	305,987
suspended sand load	220,673	166,548	136,008	302,556
total bed sediment inflow	393,916	339,329	269,214	608,543
actual volume extracted	689,080	1,234,513	584,211	1,818,724
extraction - inflow	295,164	895,184	314,997	1,210,181
volume change from XSS	-190,578	766,696	343,465	1,110,158

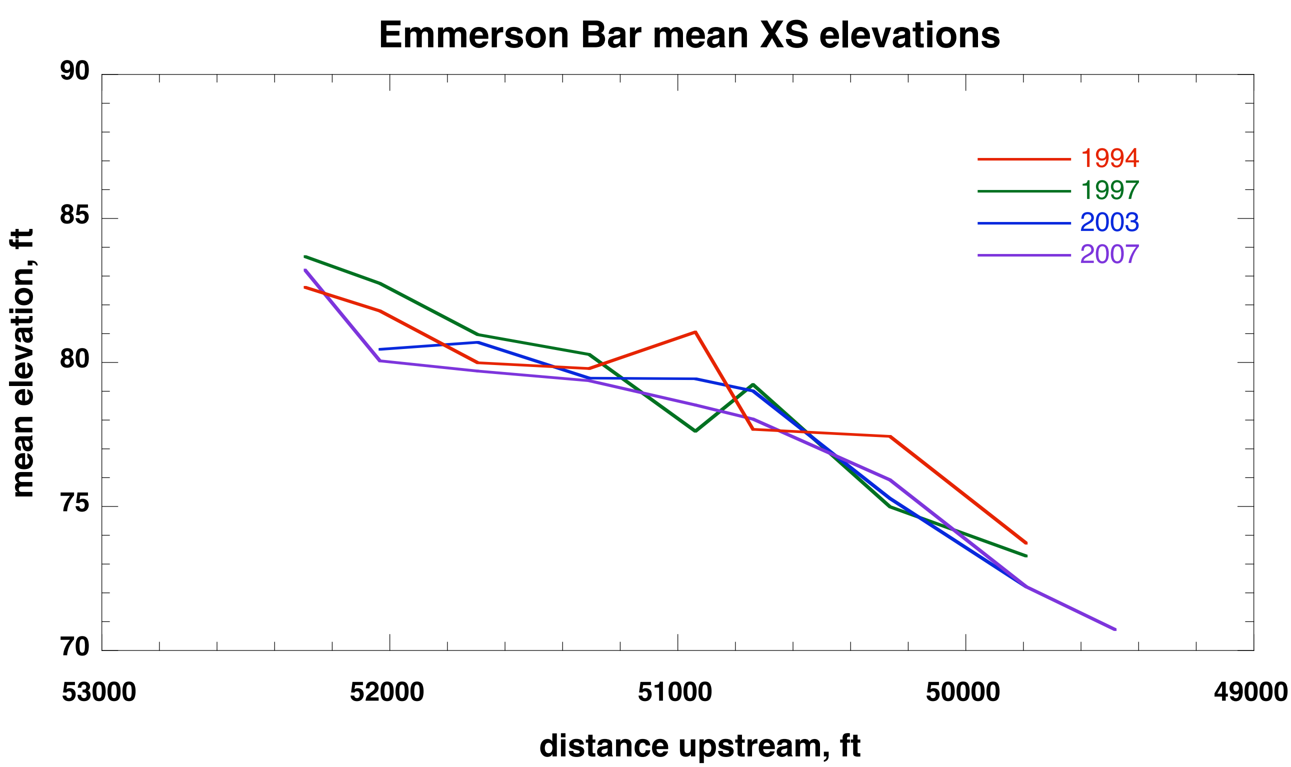
Appendix A

Streamwise variation, by site, in cross-section characteristics for 1993, 1997, 2003, 2007

mean XS elevation
thalweg elevation
confinement
width
XS area

XS Mean Elevation vs Distance Upstream





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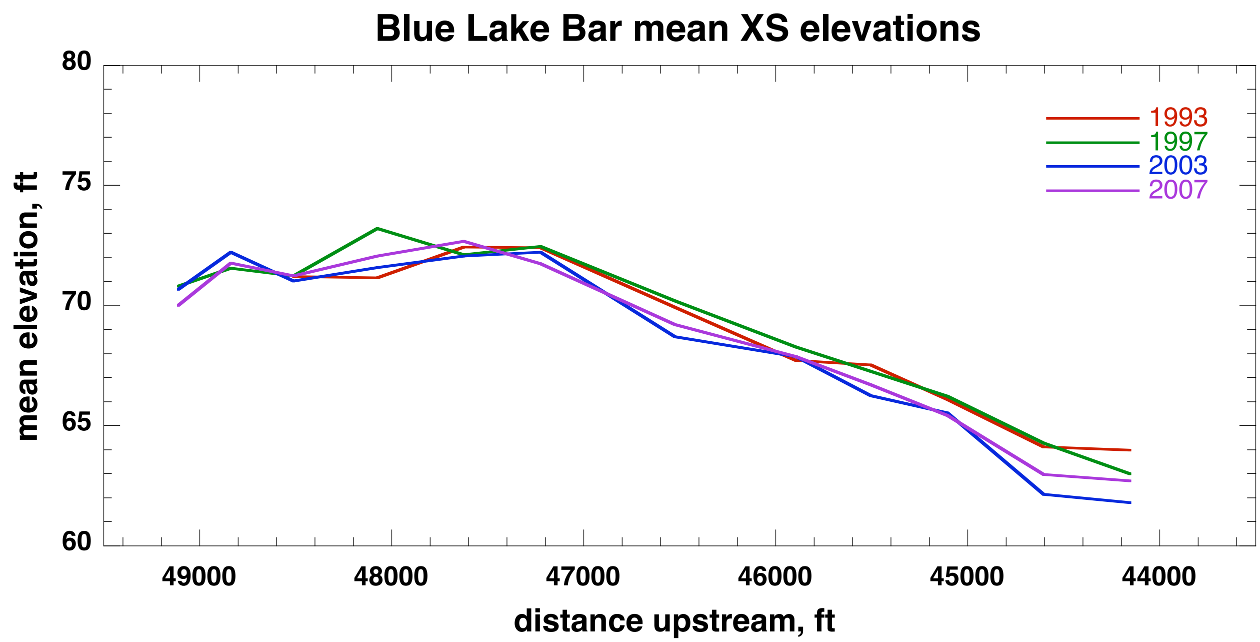

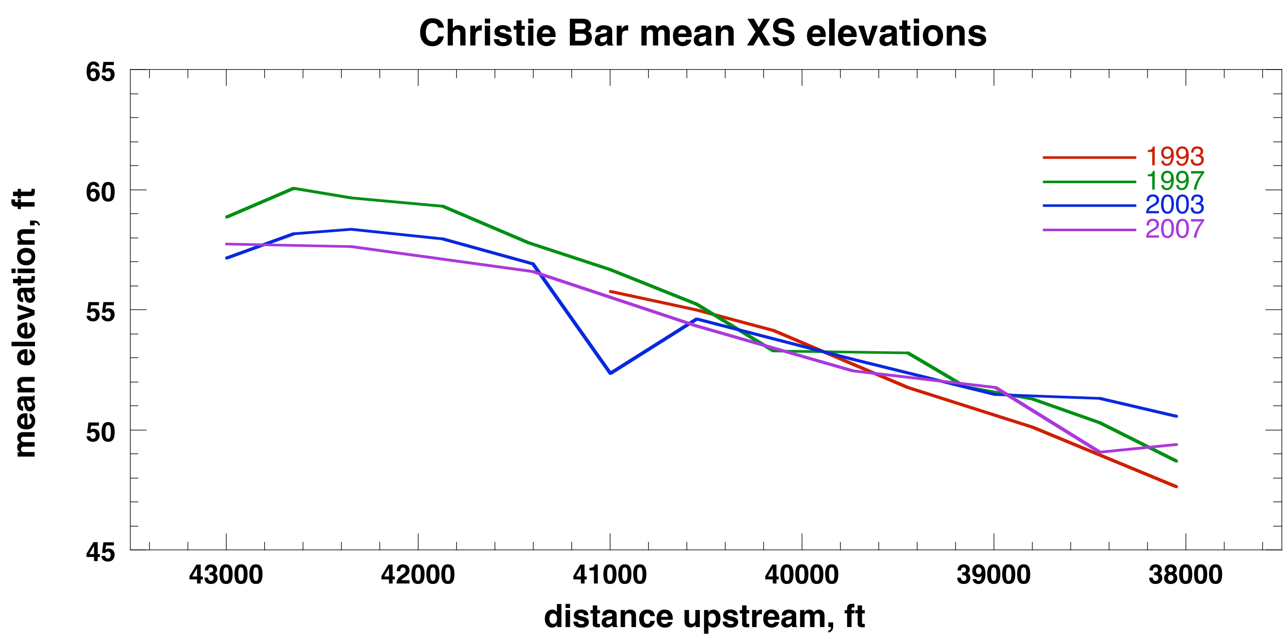

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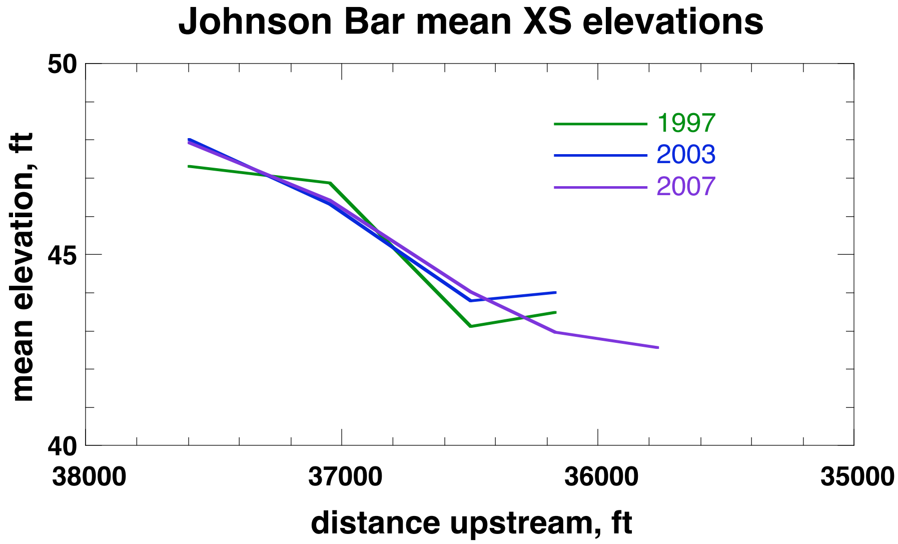

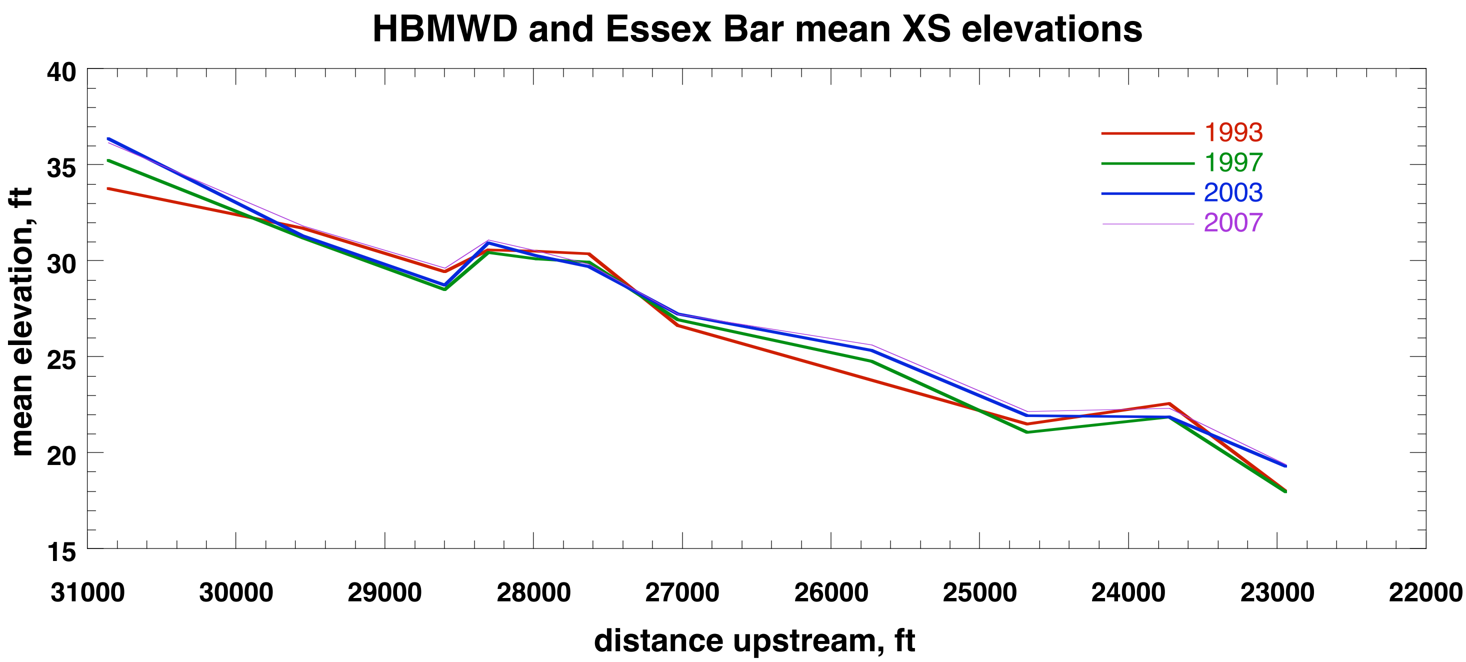

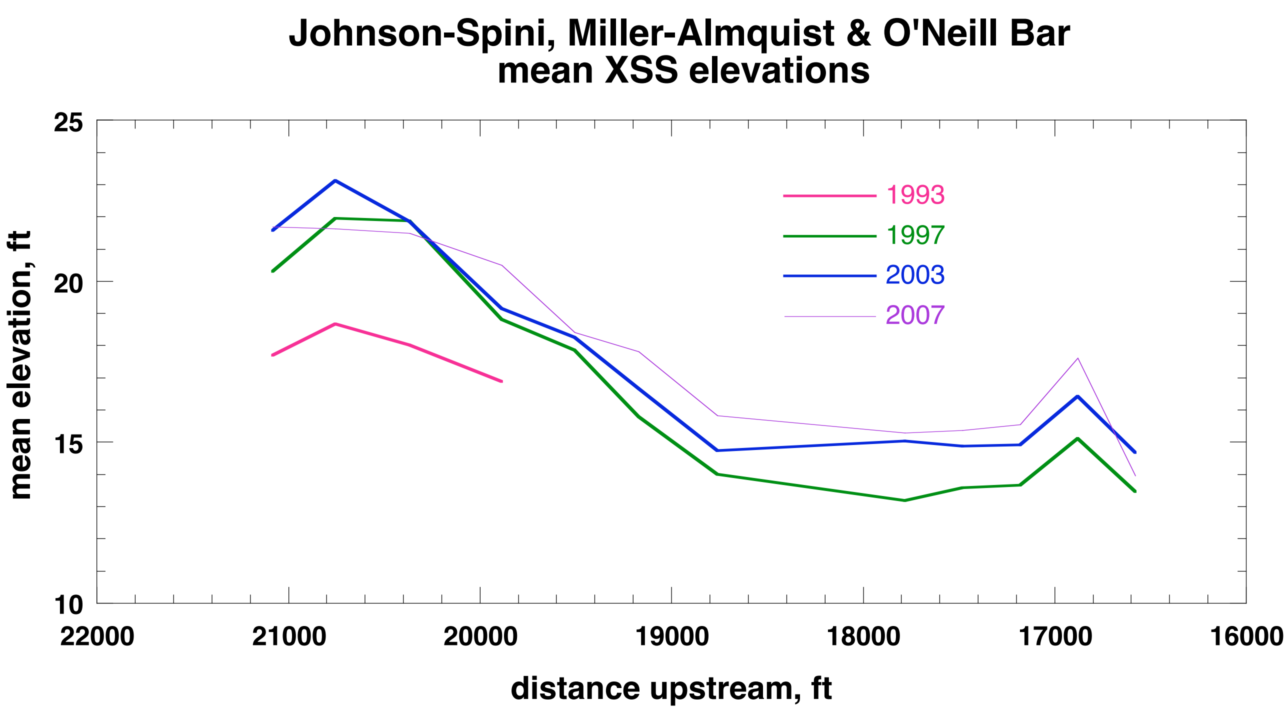

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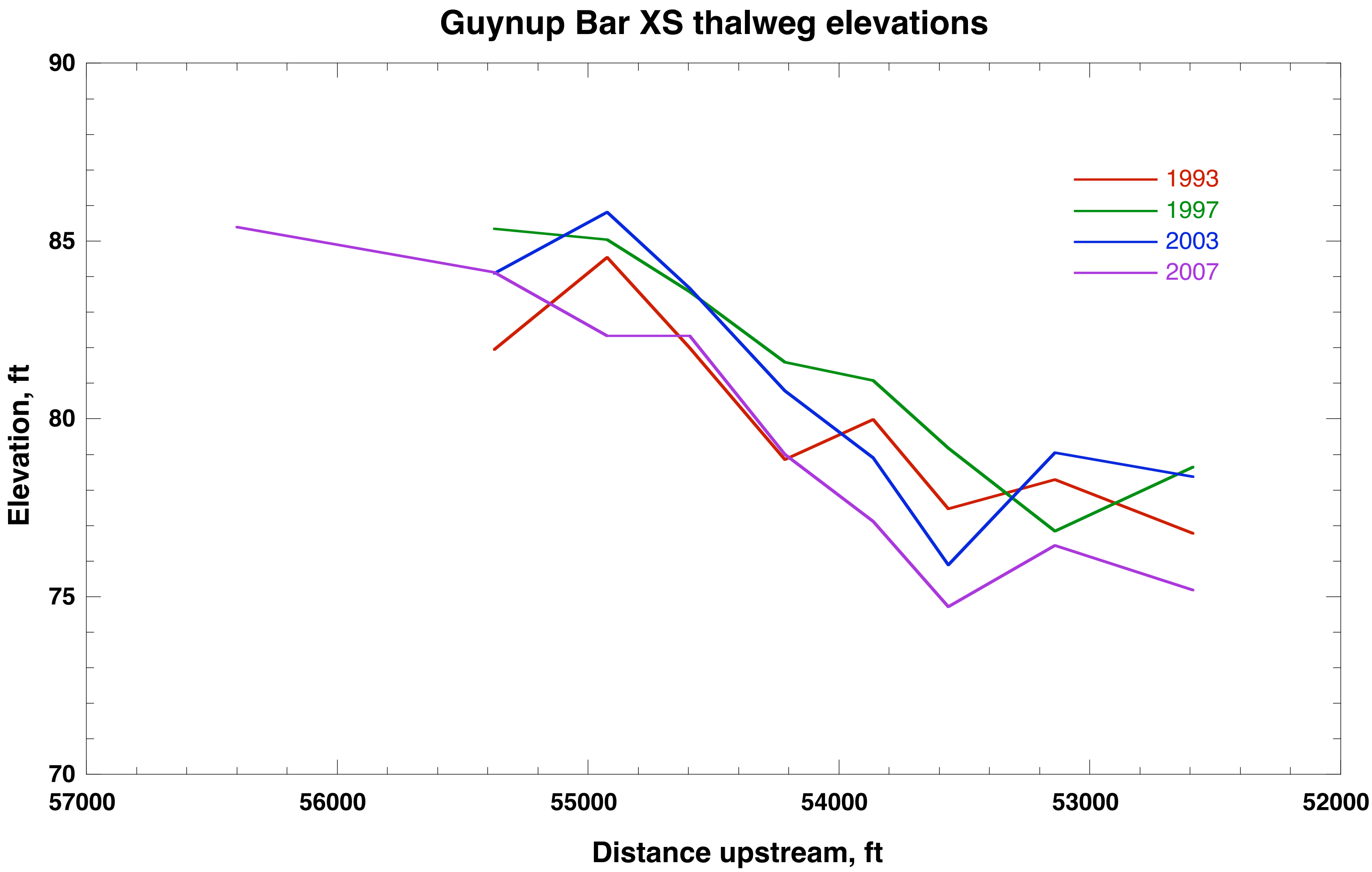
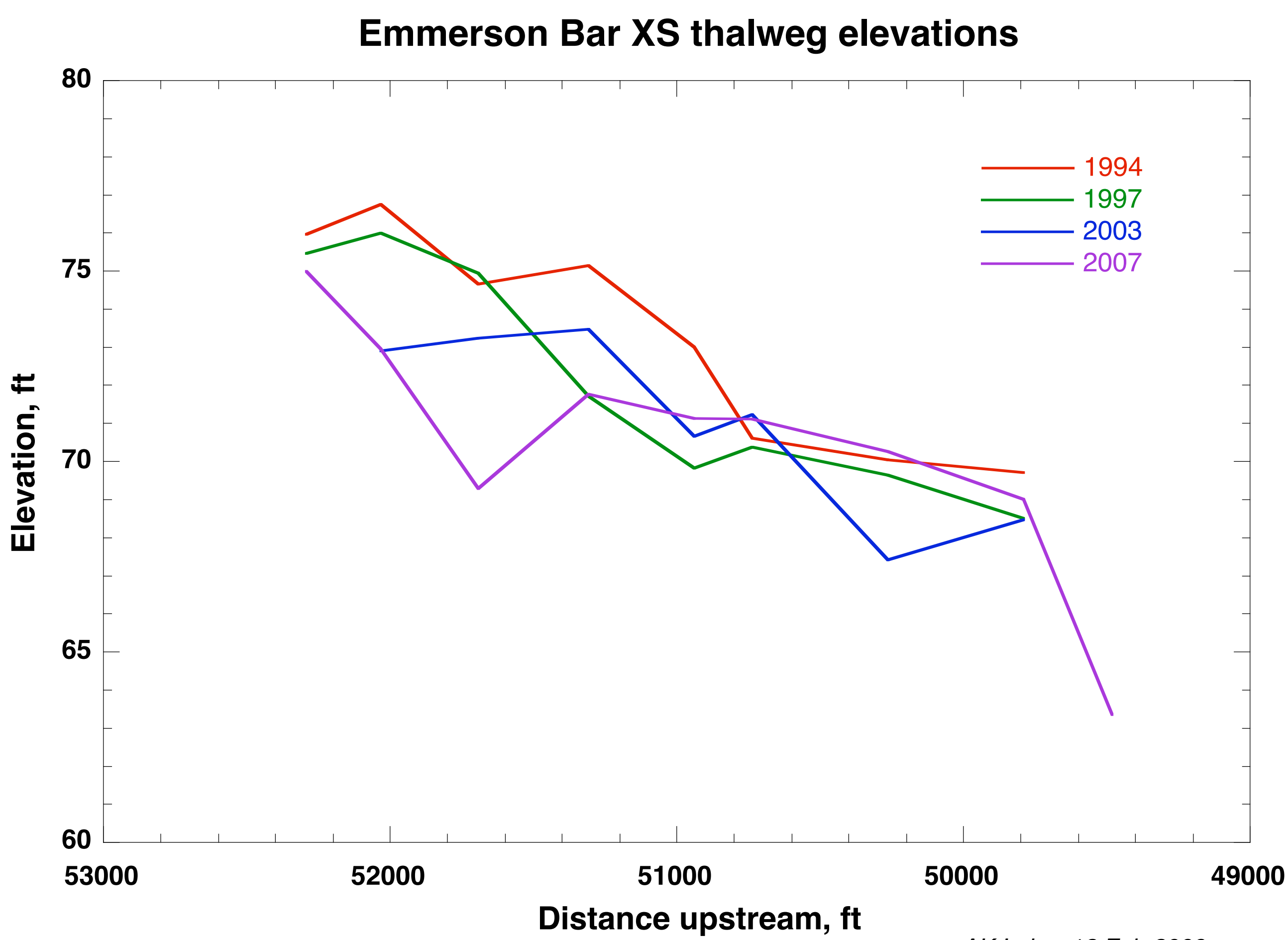
Thalweg Elevation vs Distance Upstream





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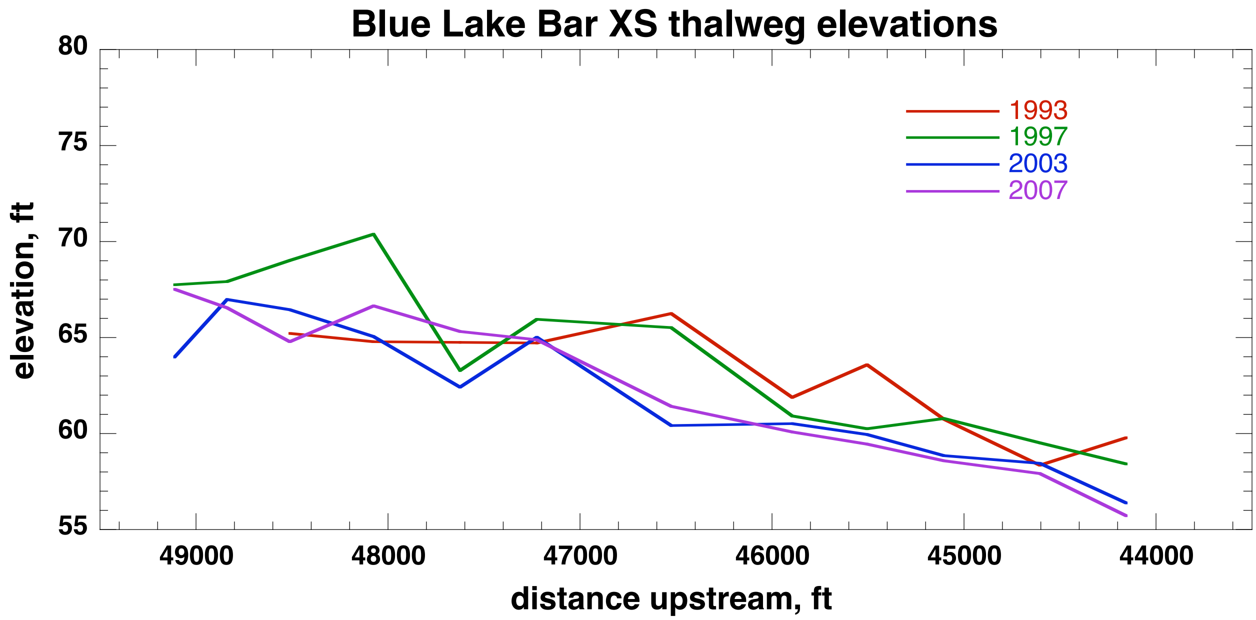

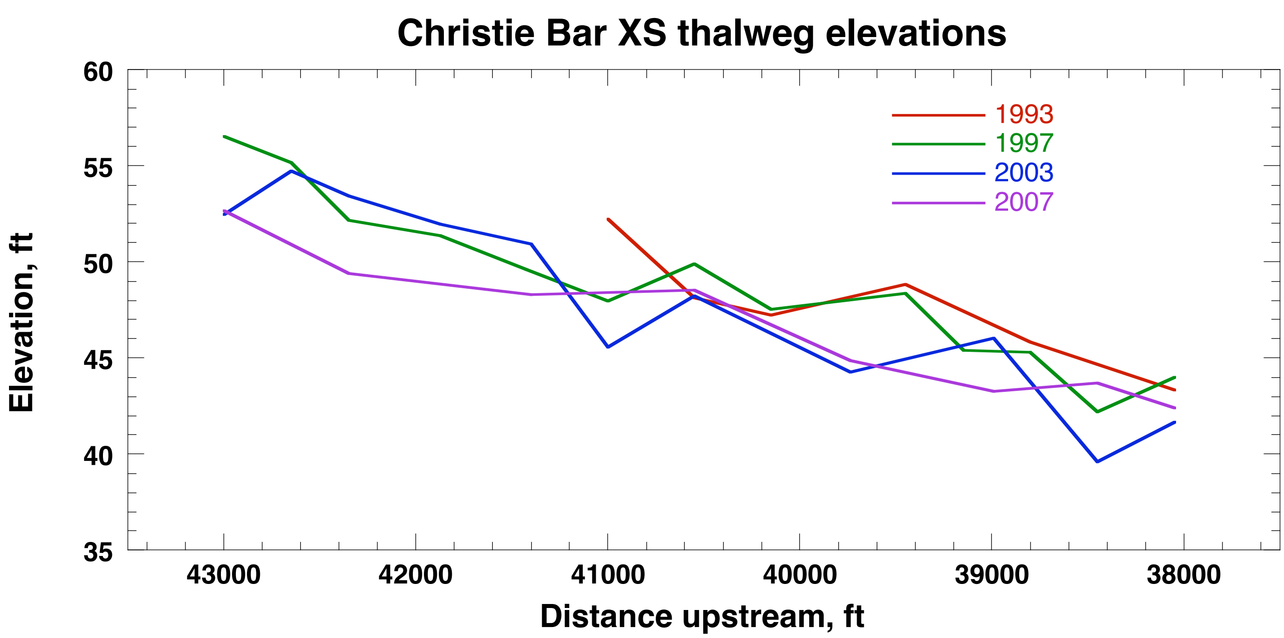

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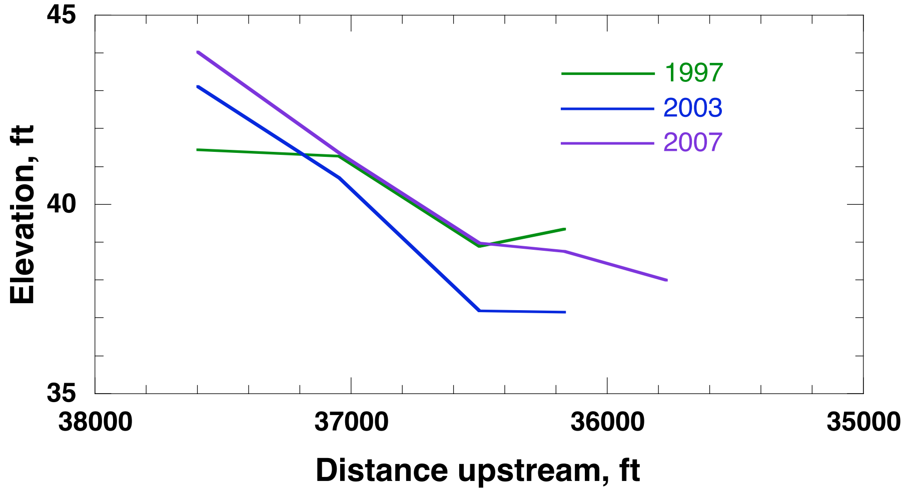
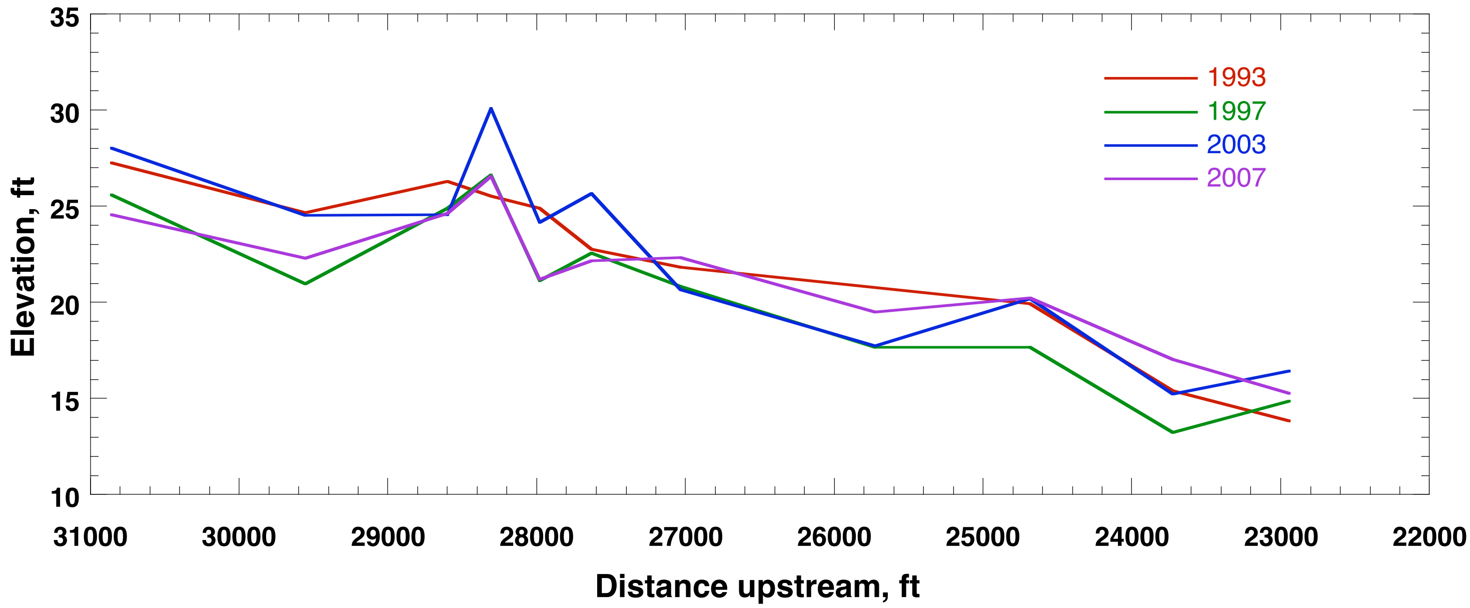
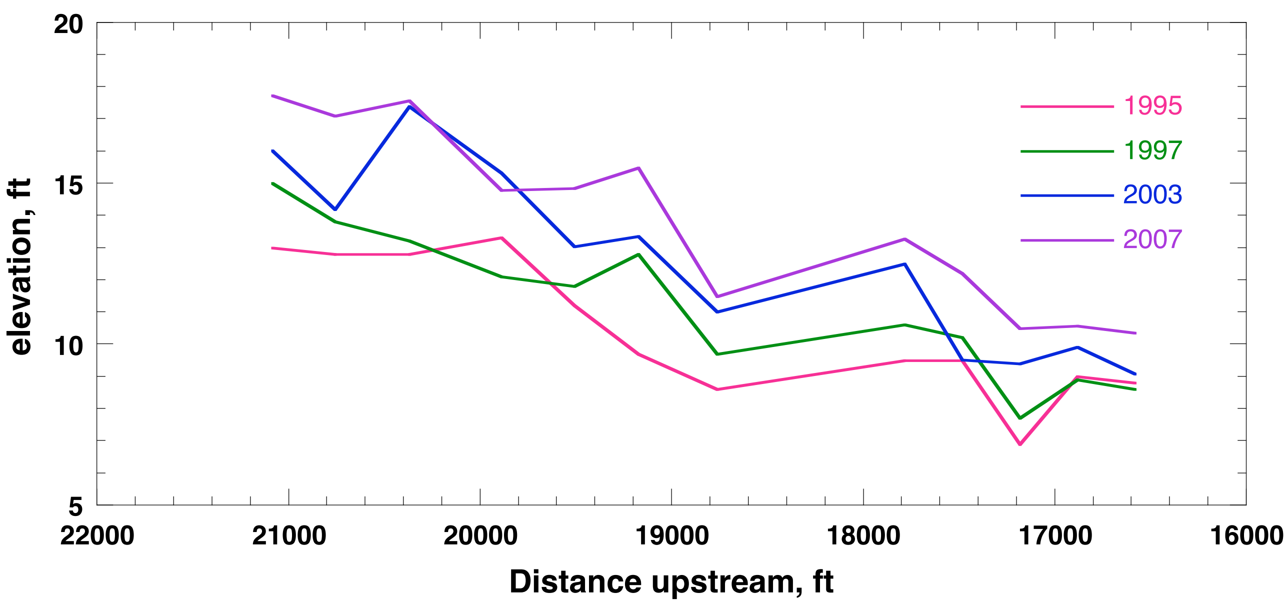
Johnson Bar XS thalweg elevations



HBMWD and Essex Bar XS thalweg elevations



Johnson-Spini, Miller-Almquist & O'Neill Bar XSS thalweg elevations



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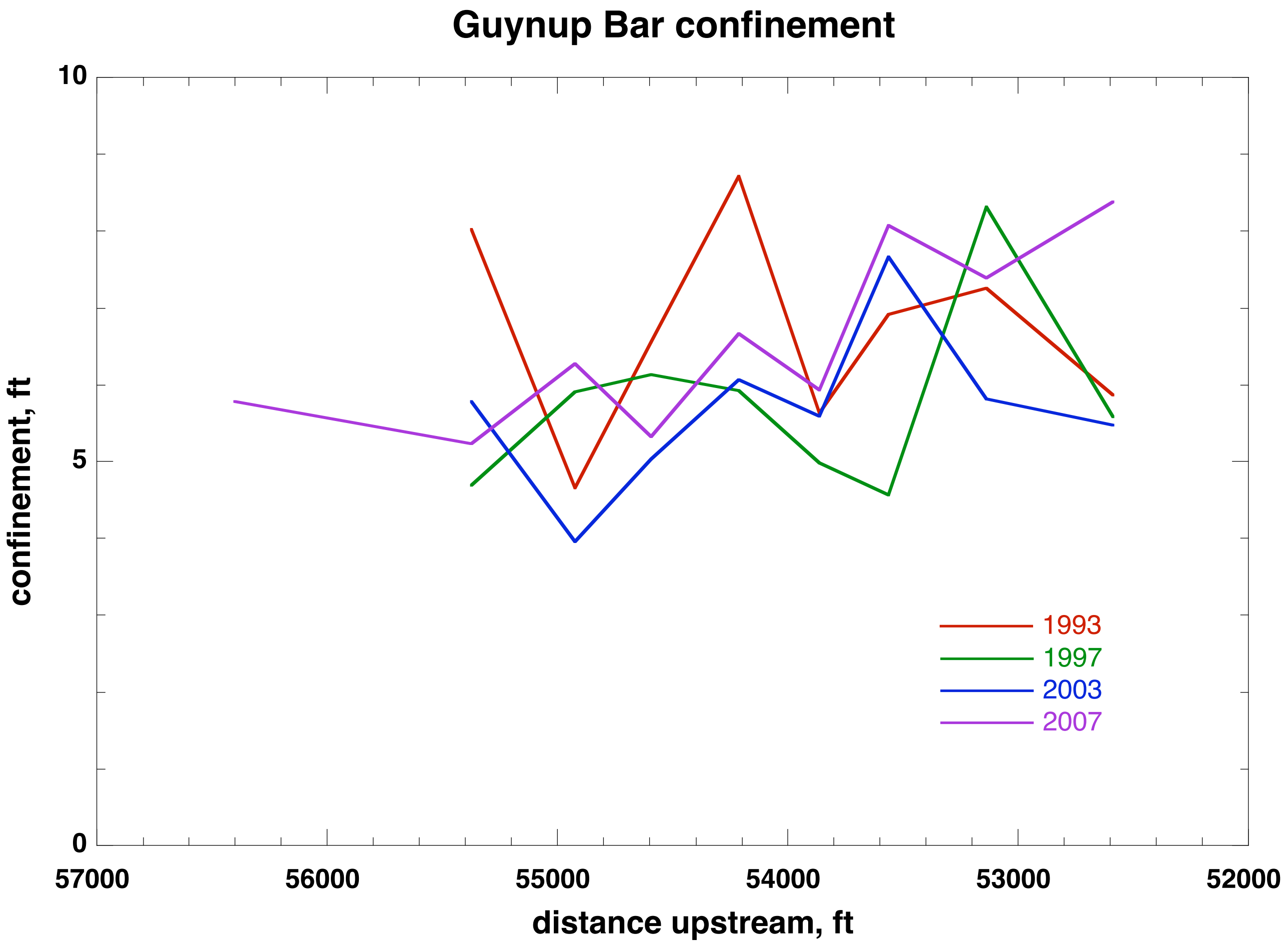
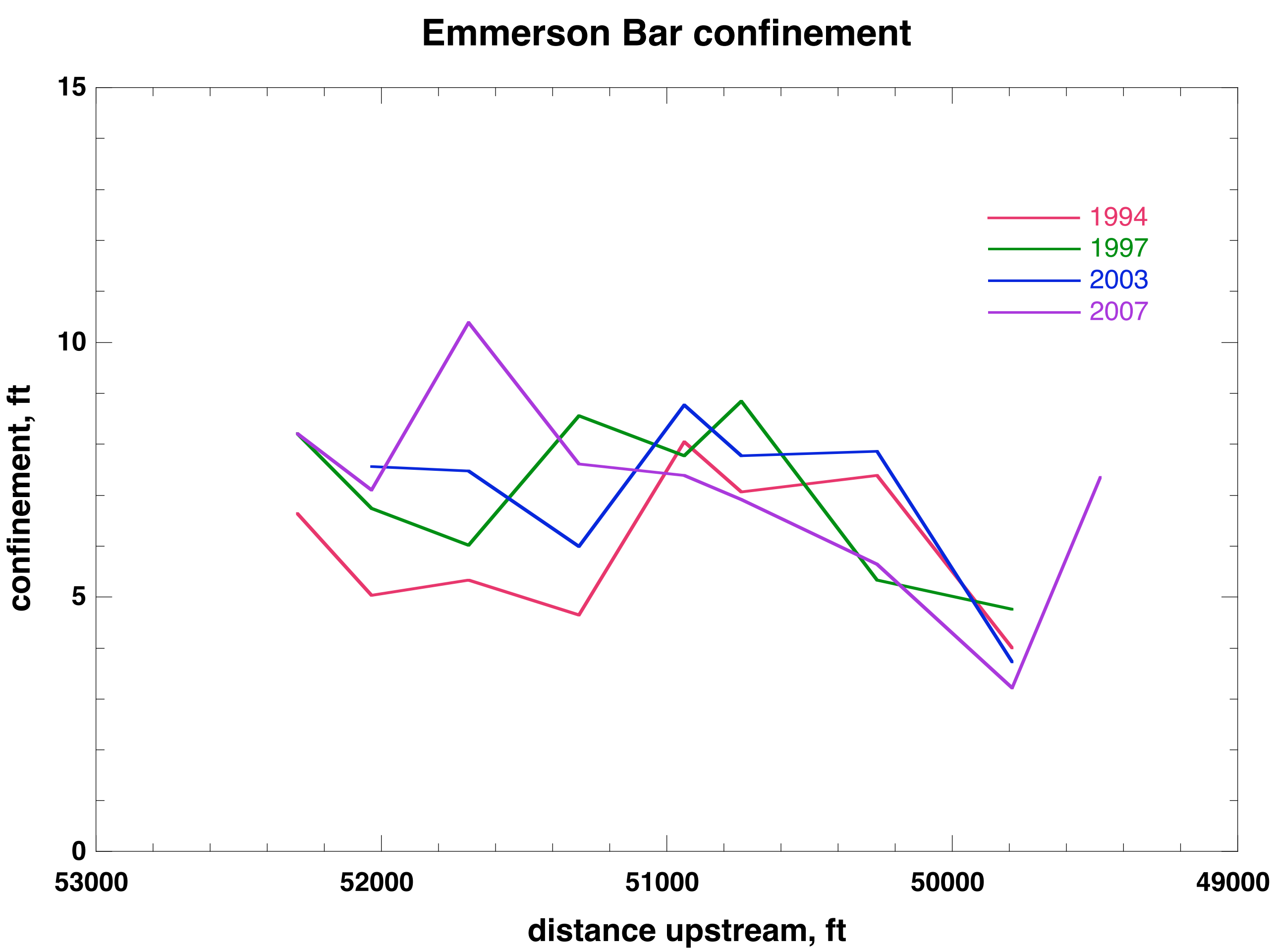
Confinement vs Distance Upstream





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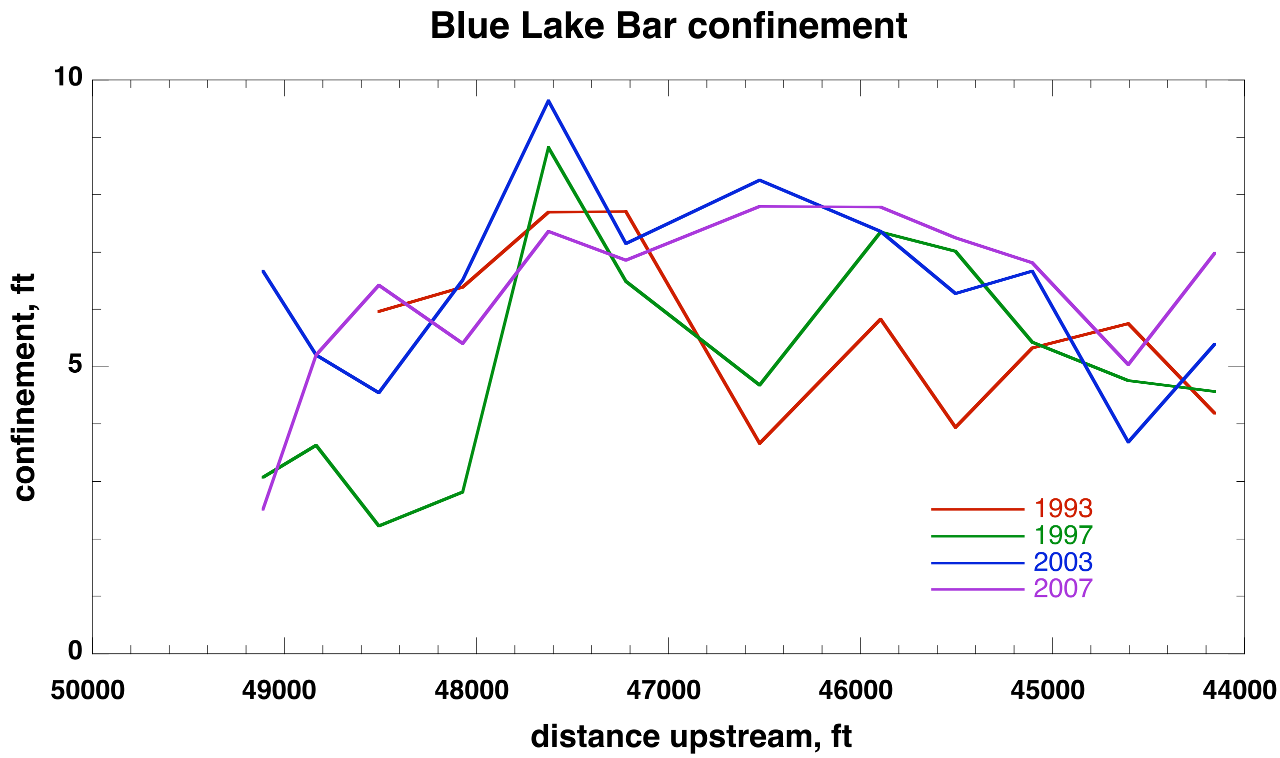

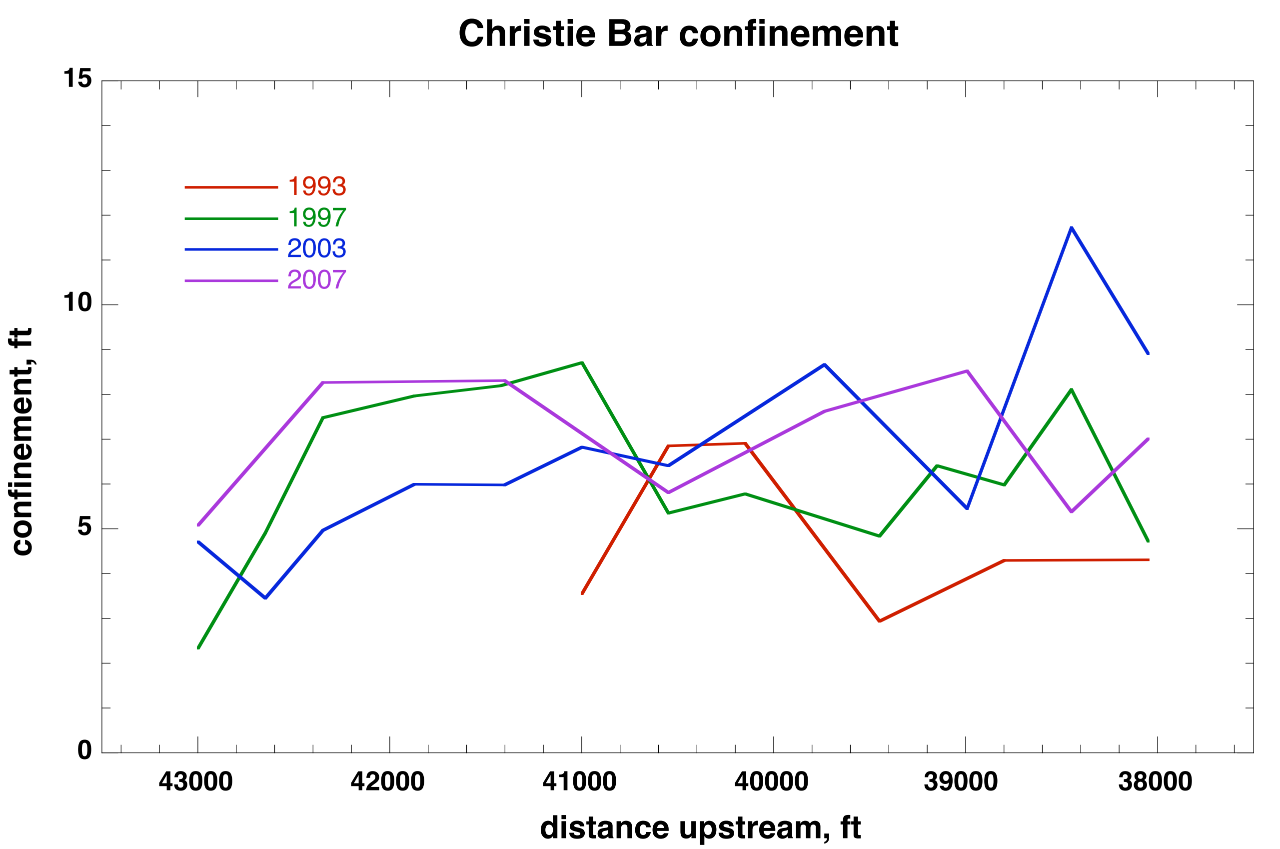

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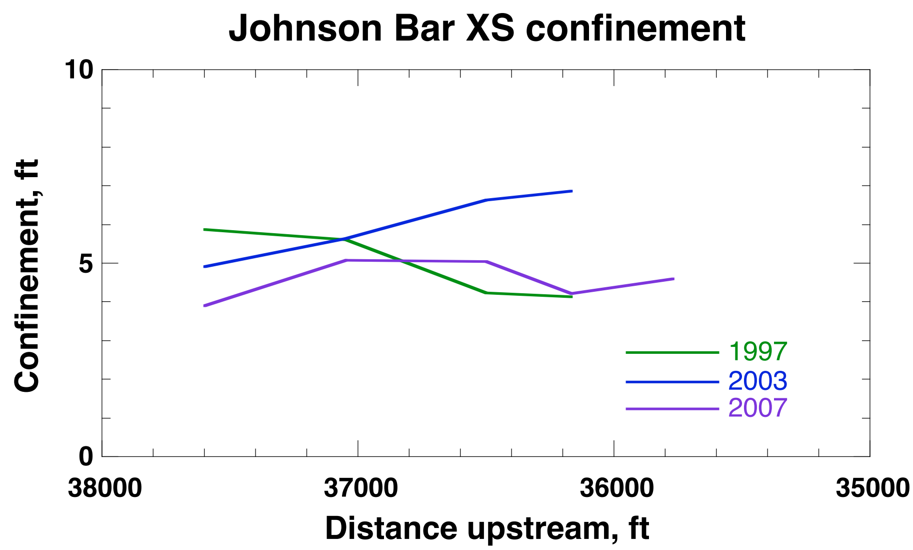

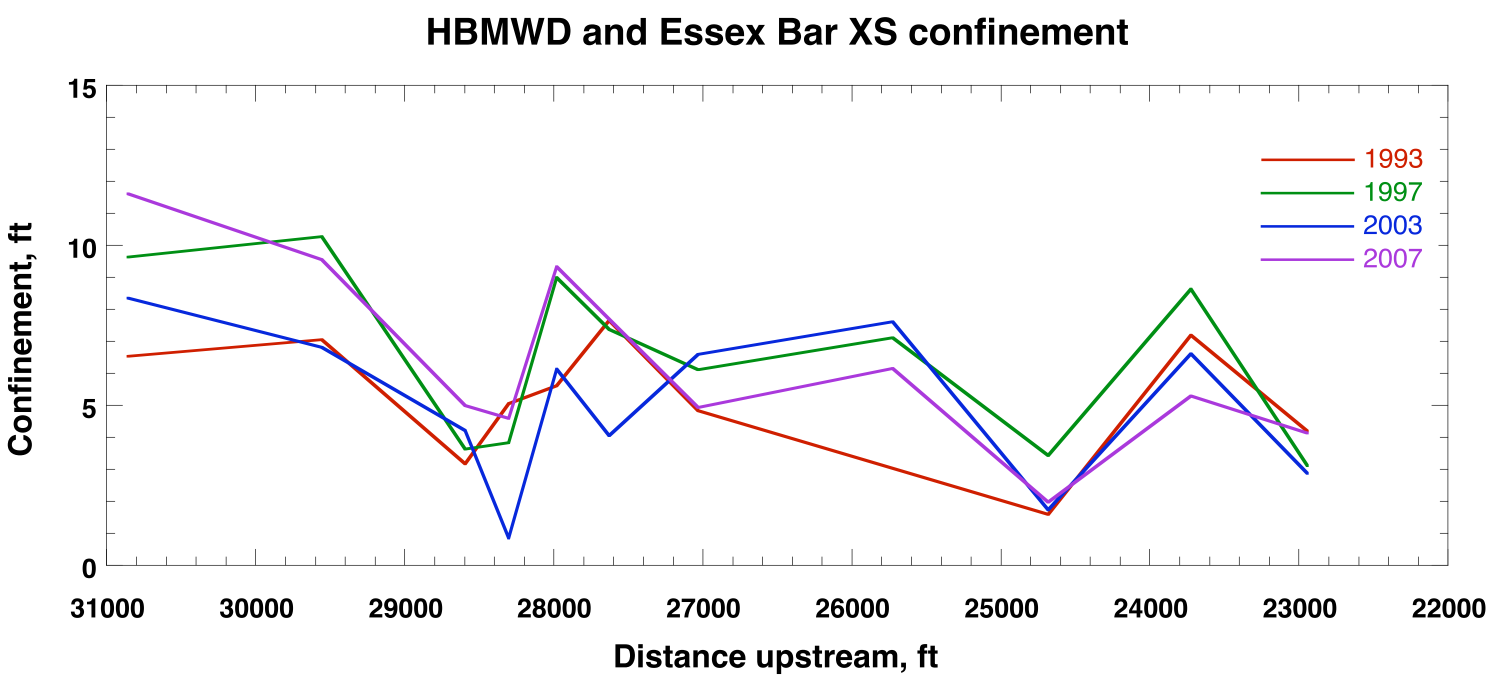

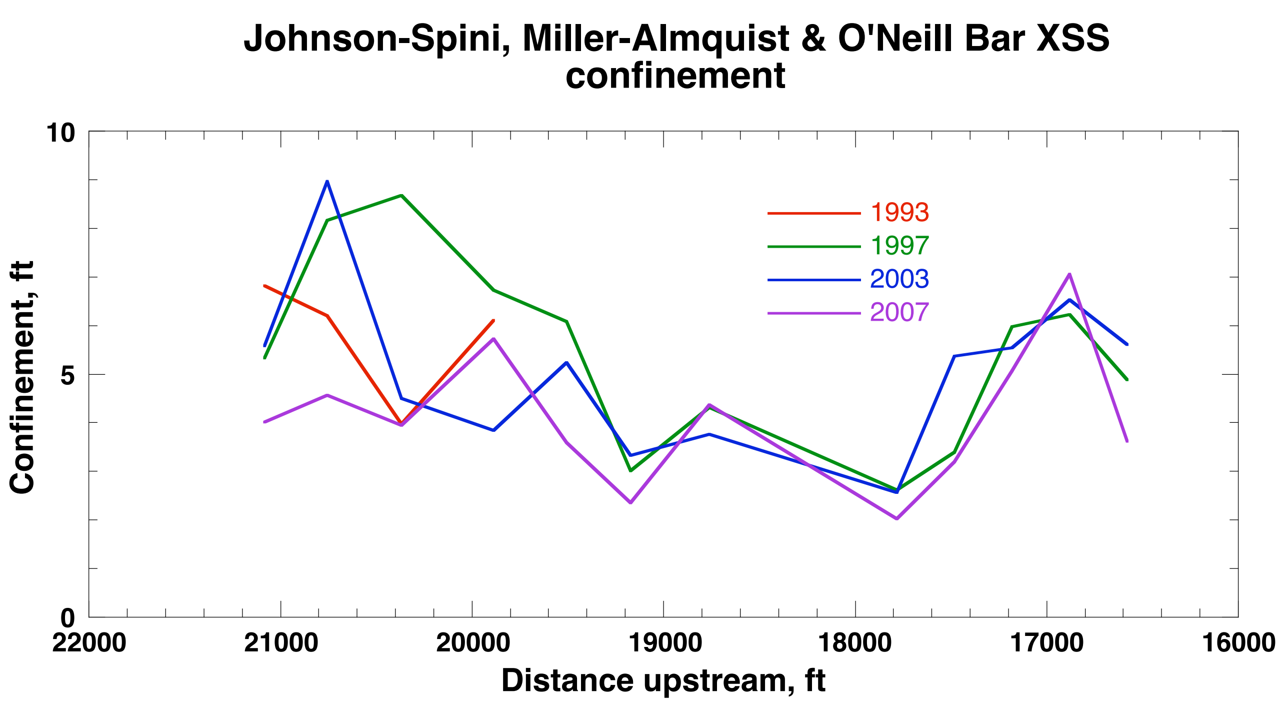

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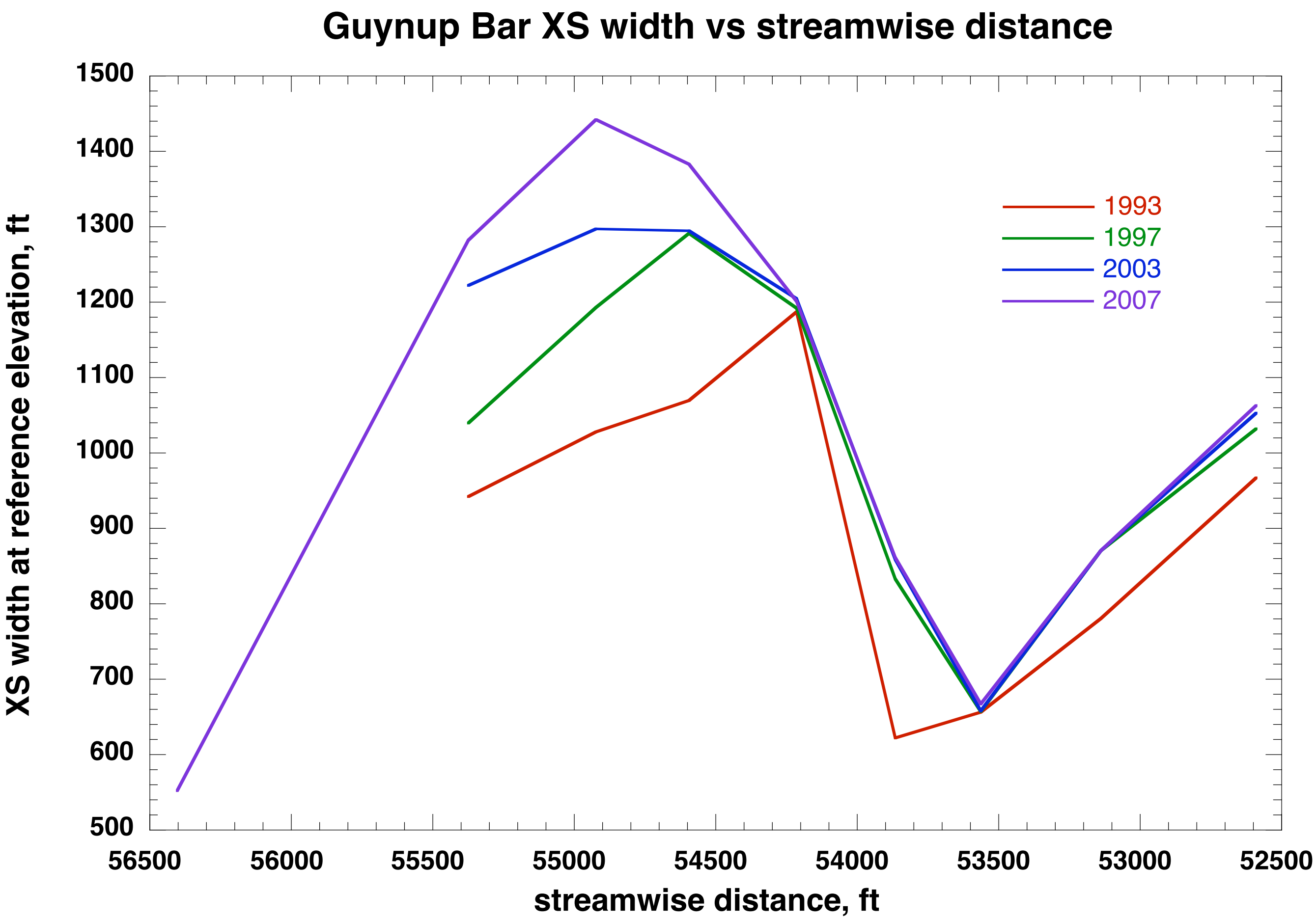
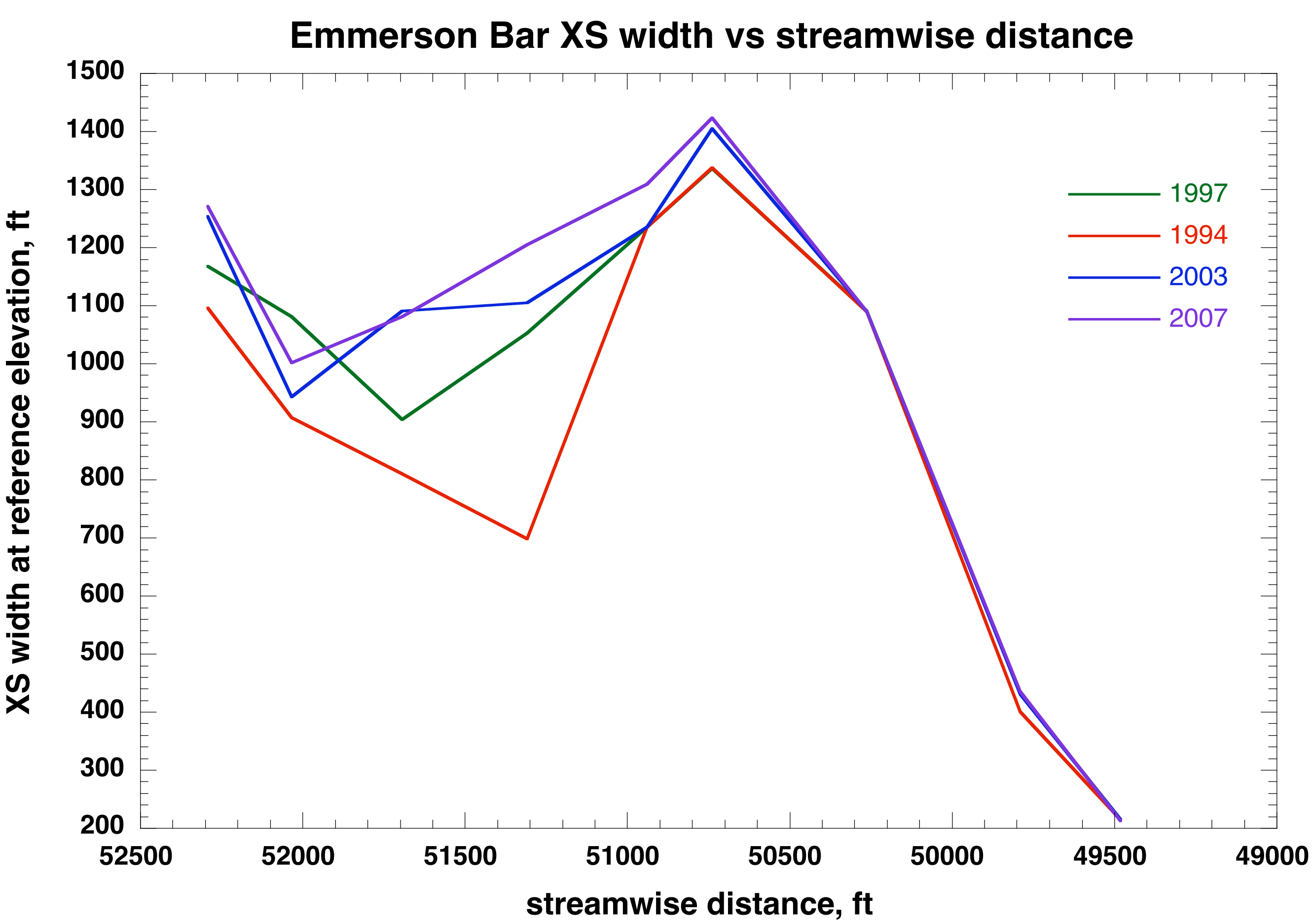
XS Width vs Distance Upstream





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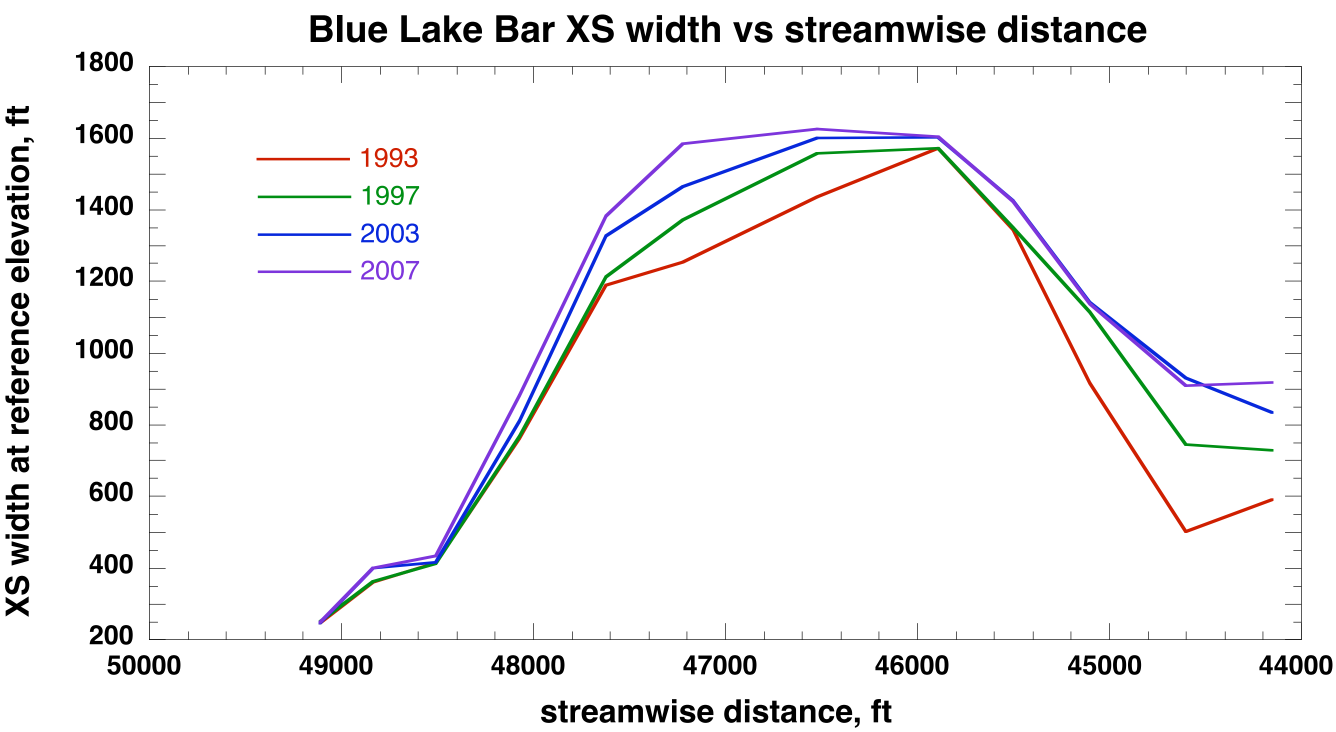

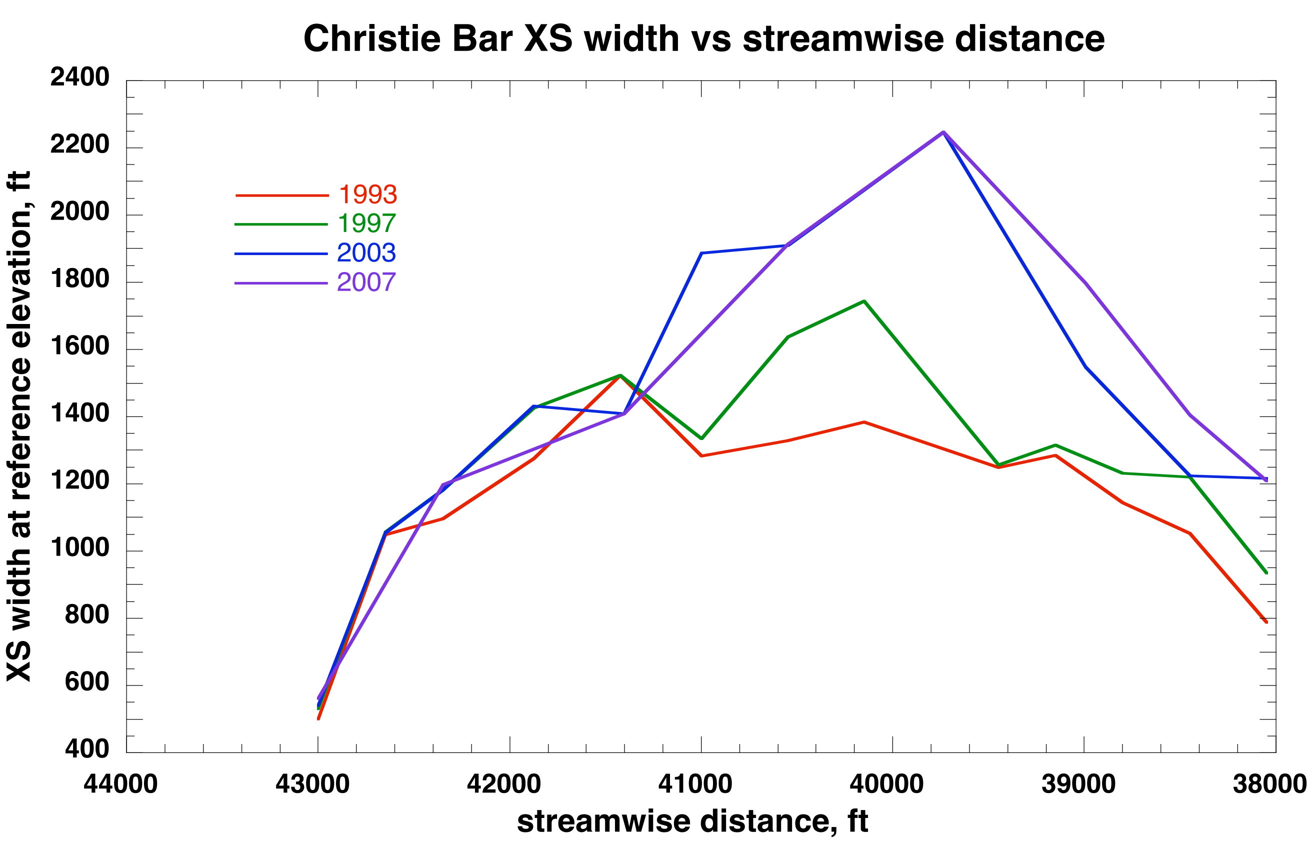

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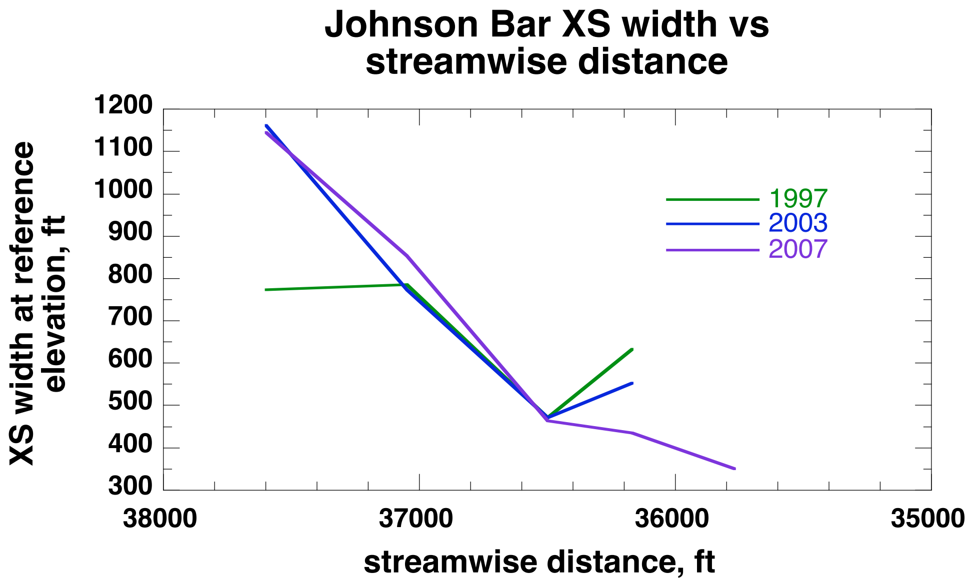

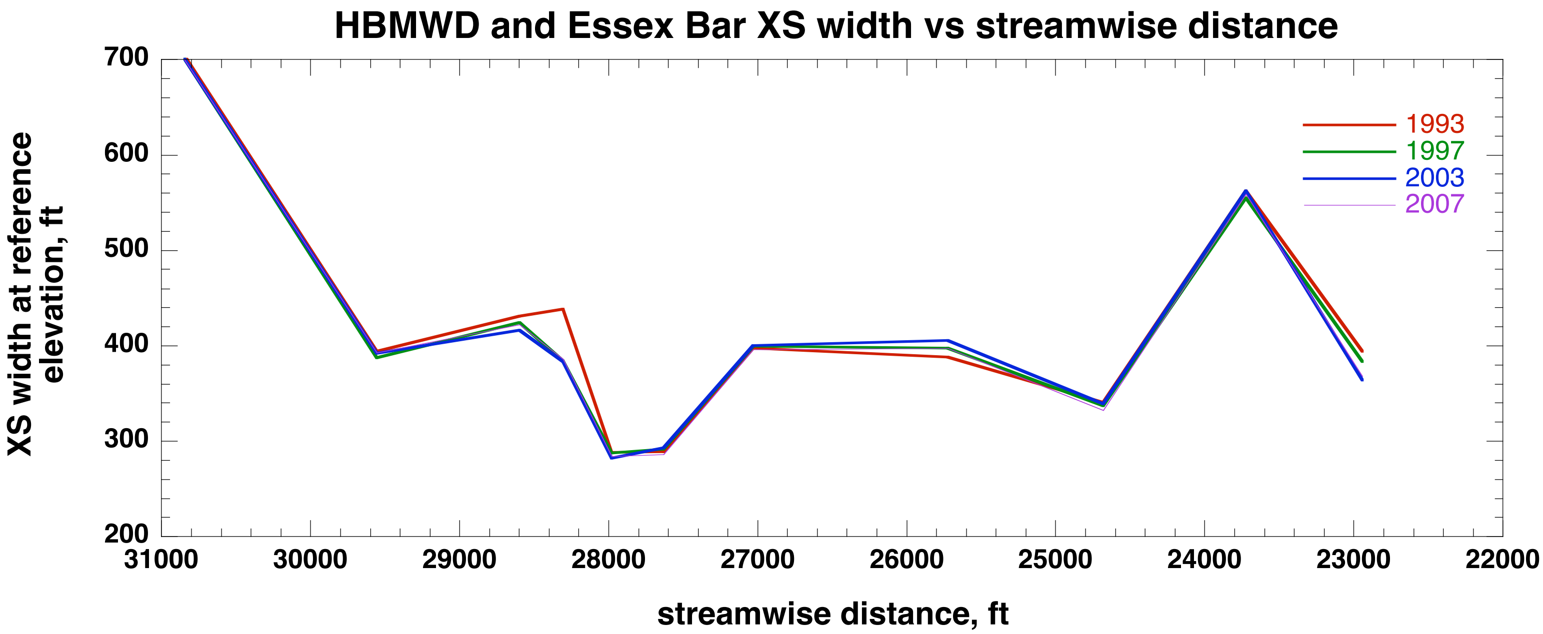

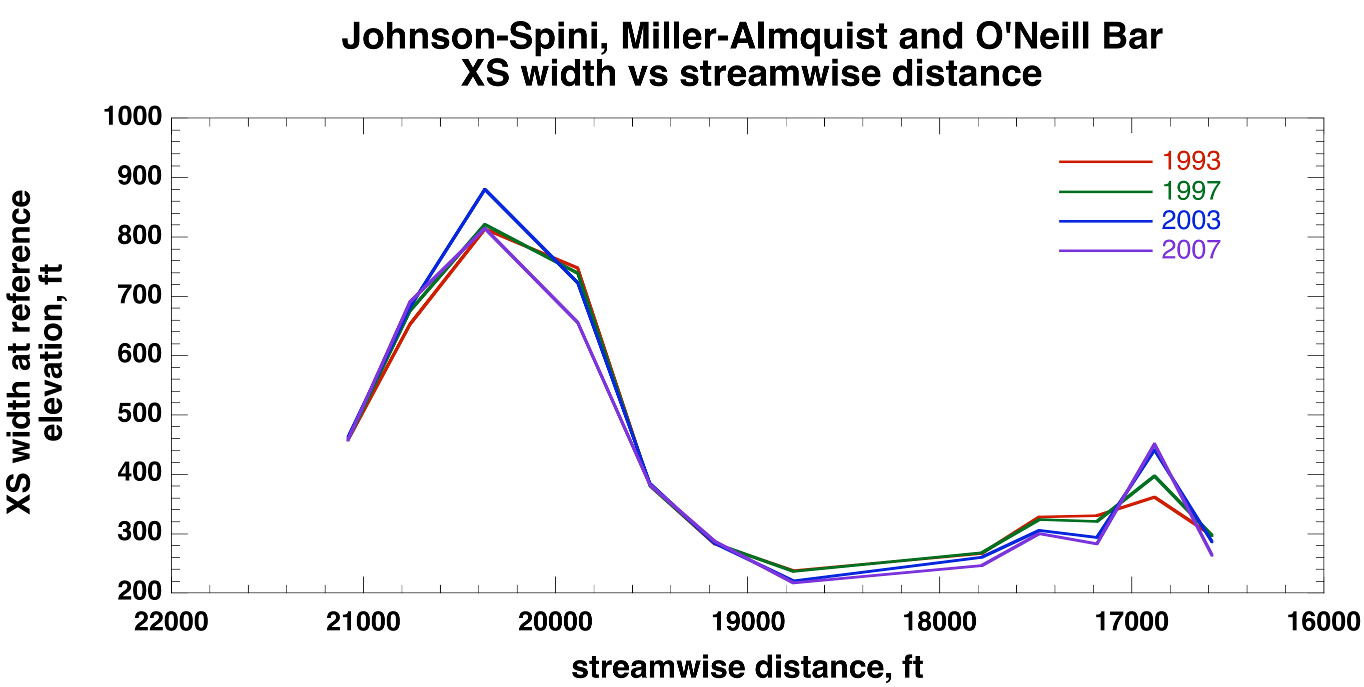

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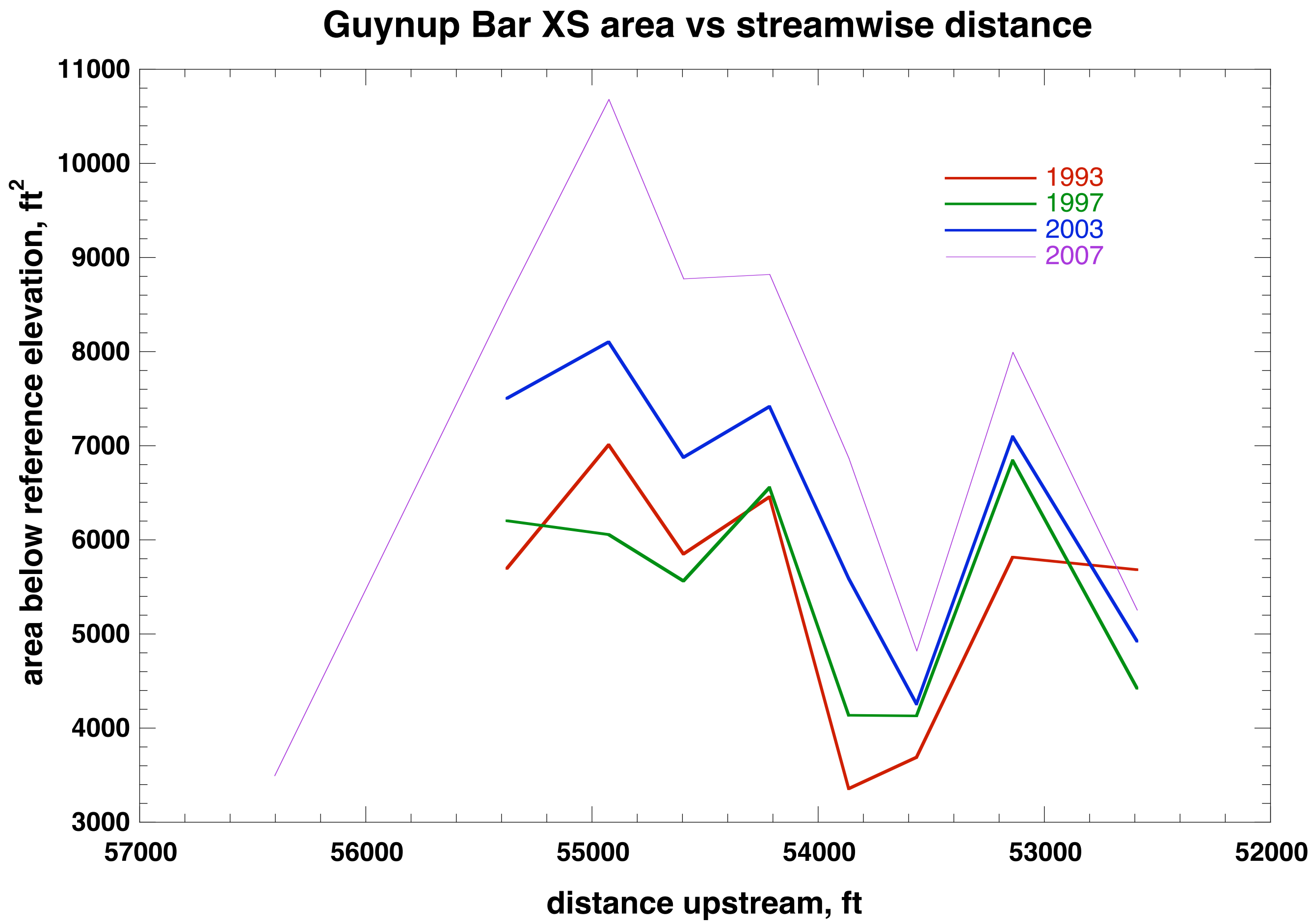
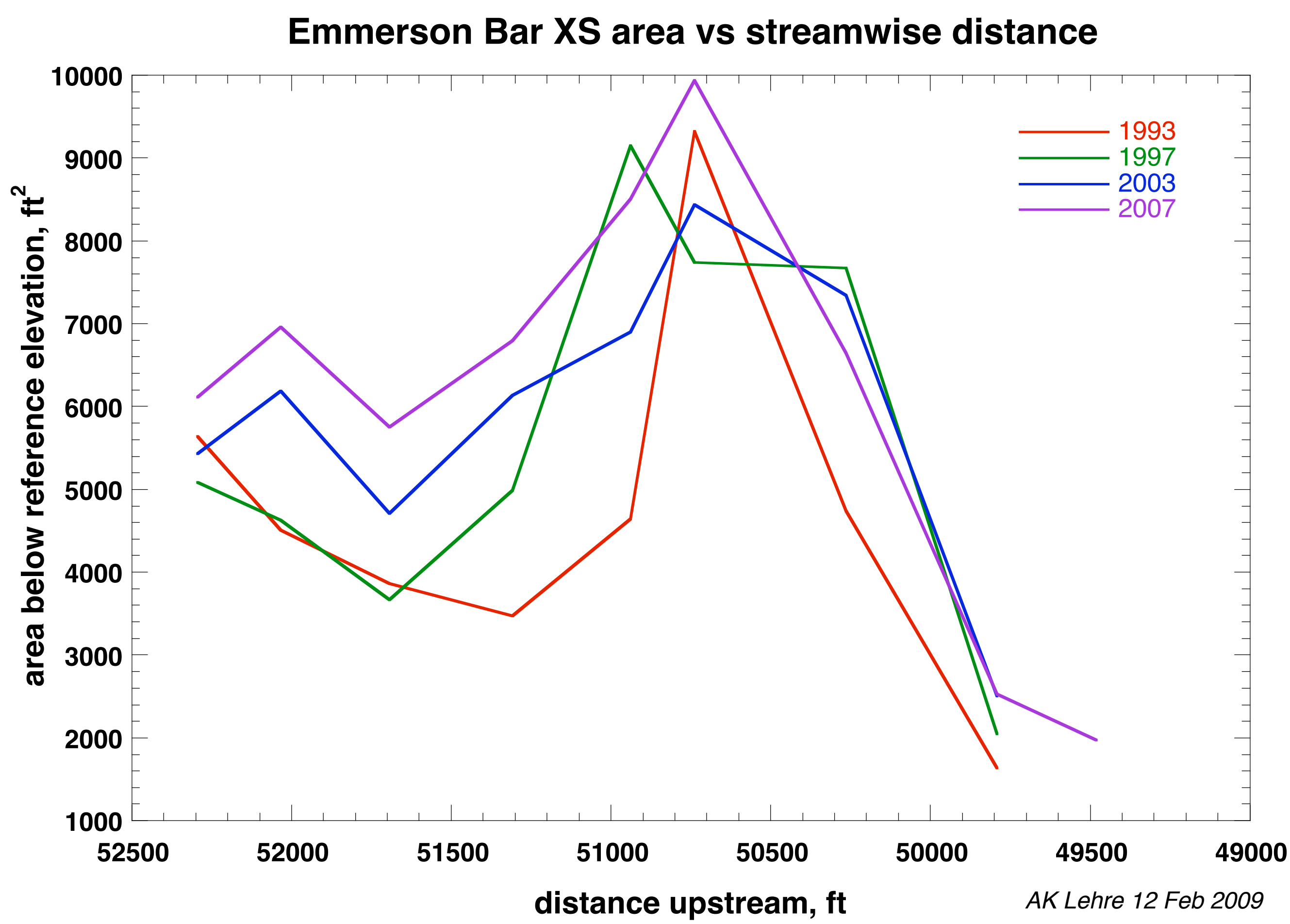
XS Area vs Distance Upstream





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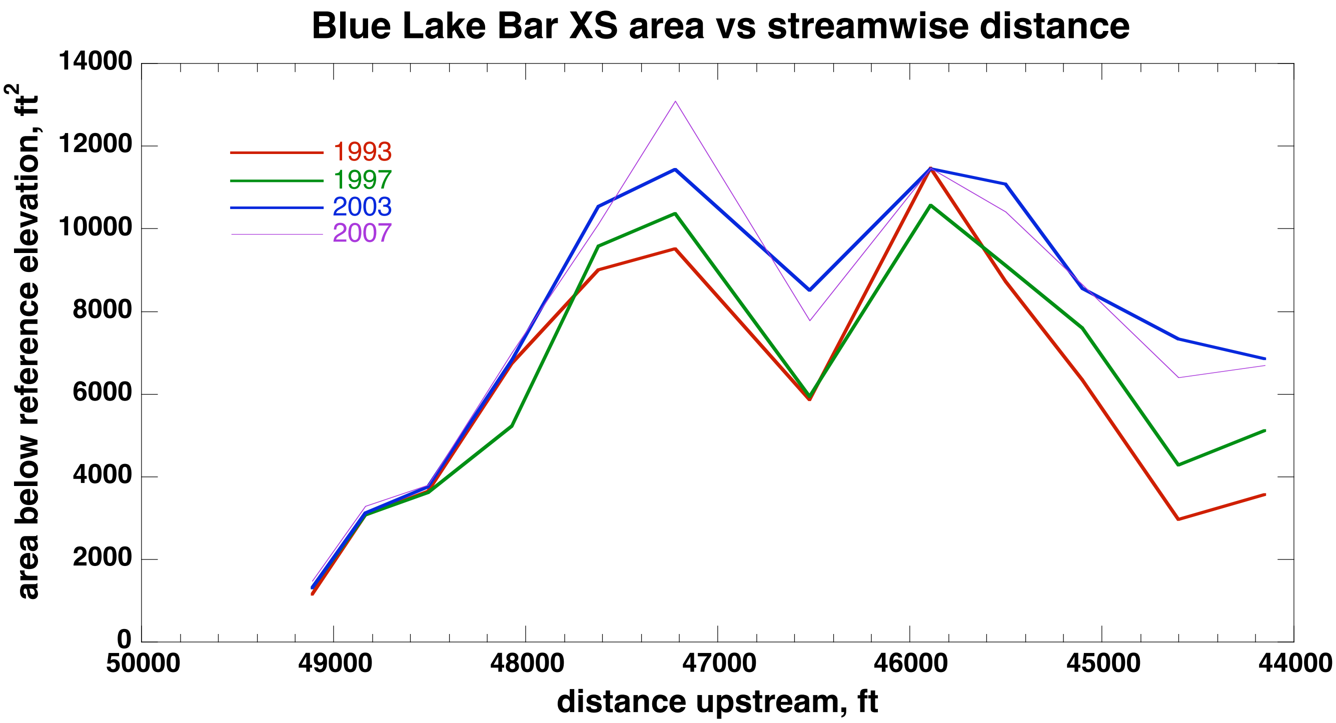

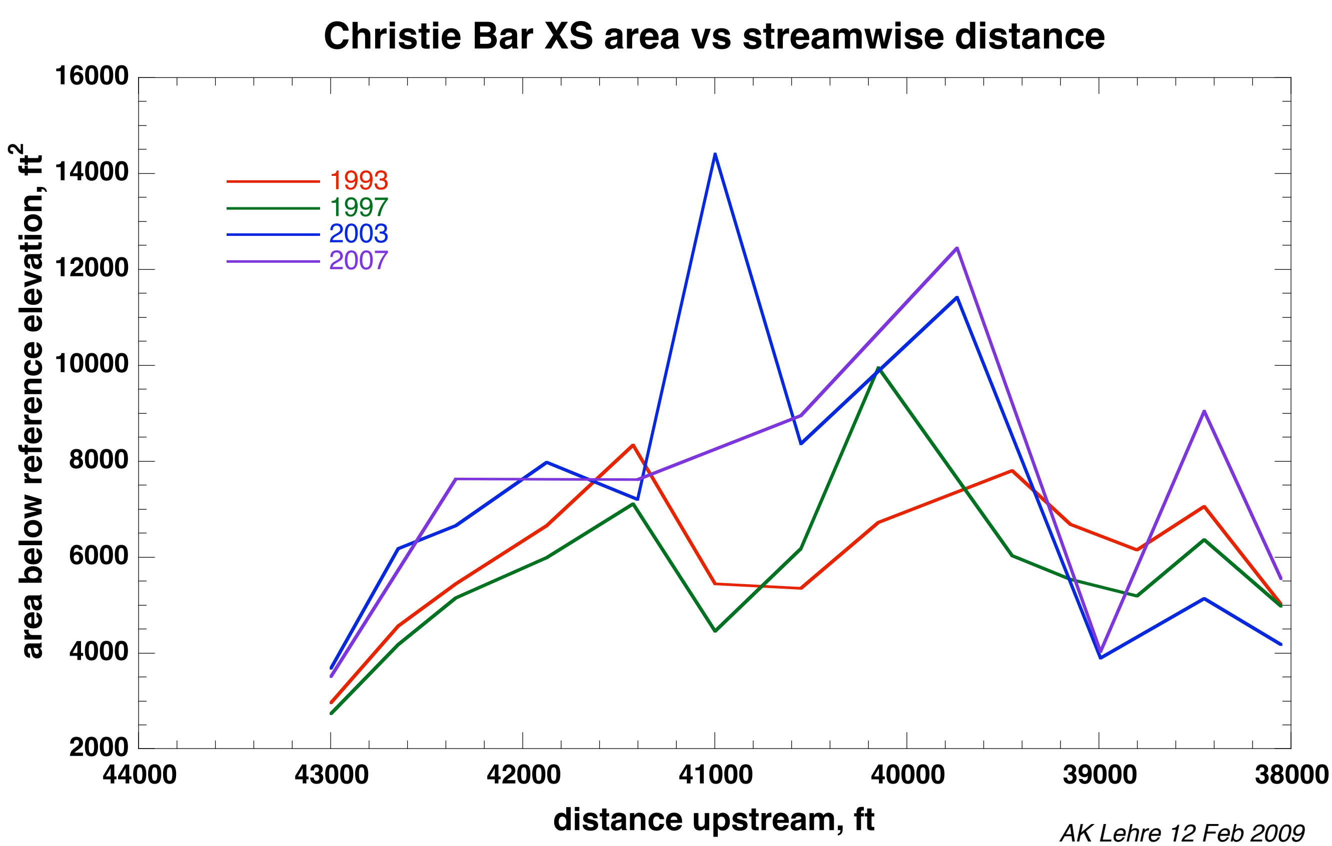

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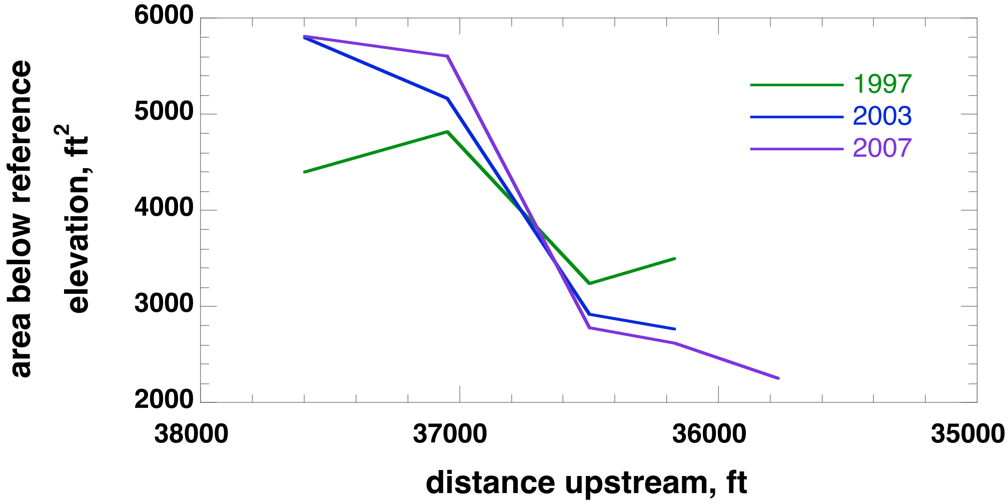
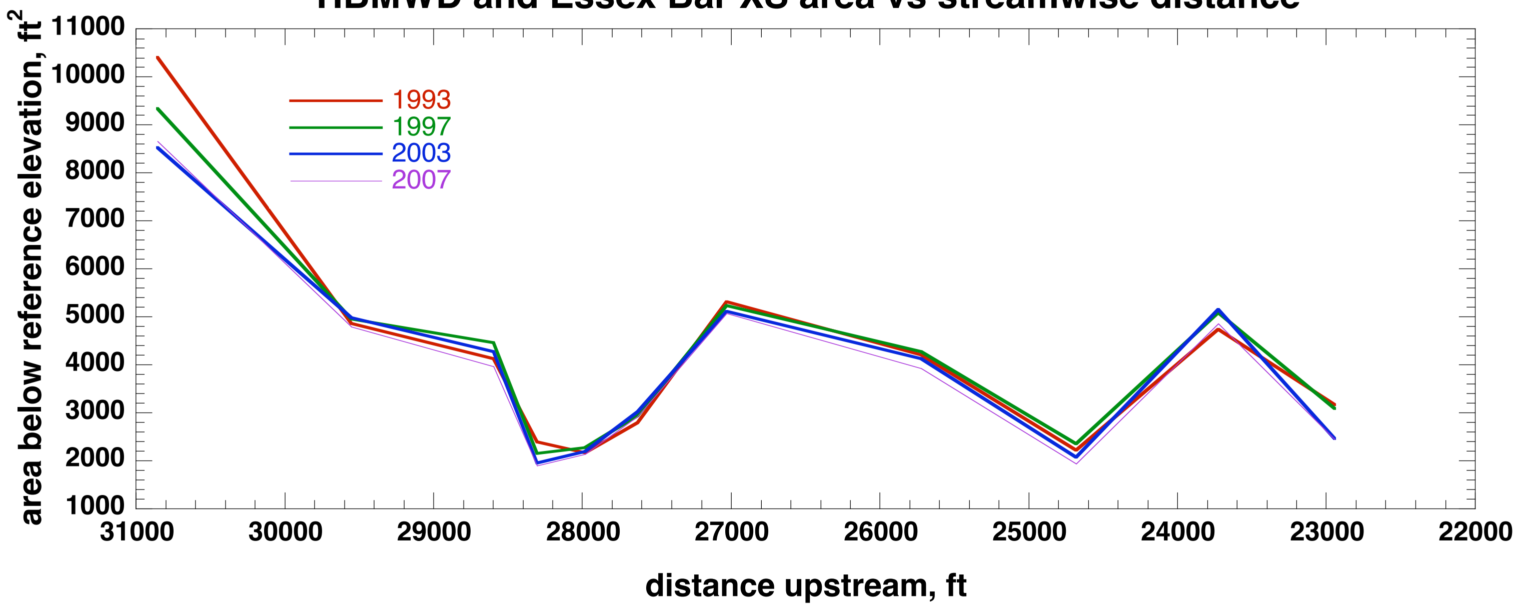
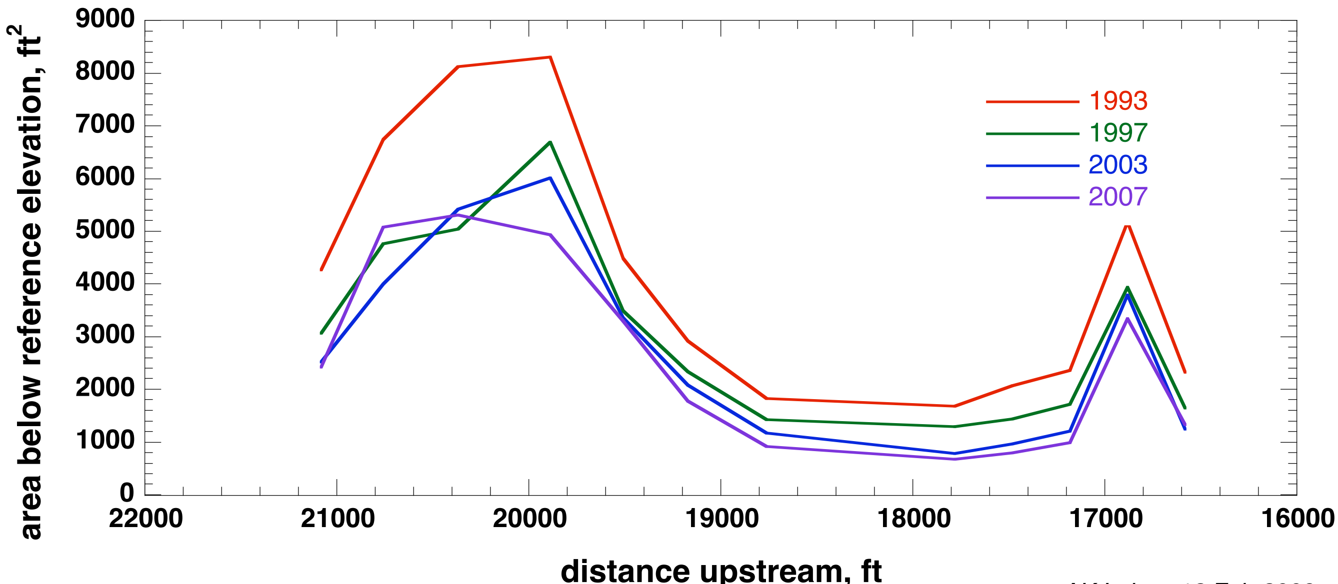
Johnson Bar XS area vs streamwise distance



HBMWD and Essex Bar XS area vs streamwise distance



Johnson-Spini, Miller-Almquist and O'Neill Bars XS area vs streamwise distance



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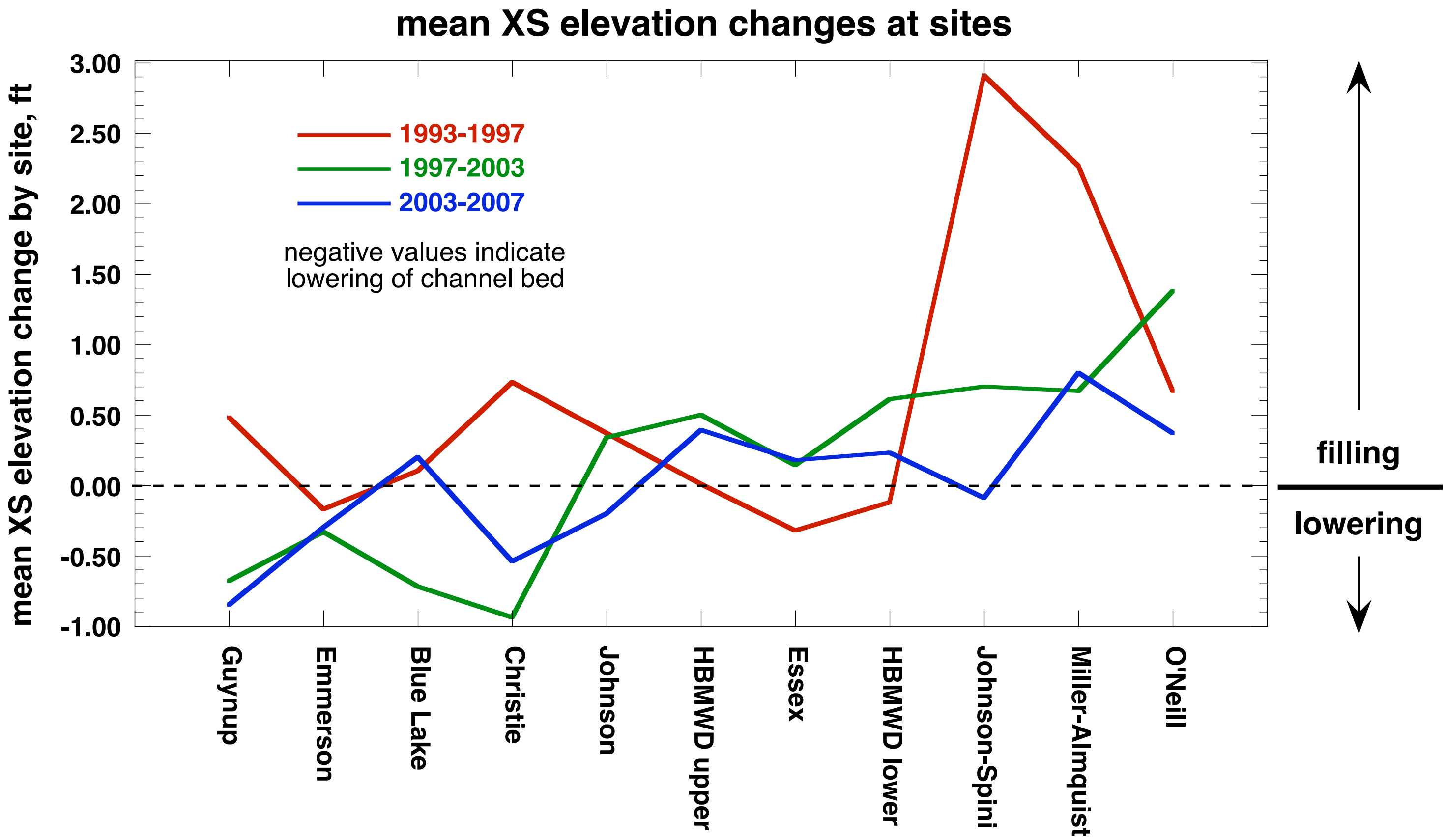
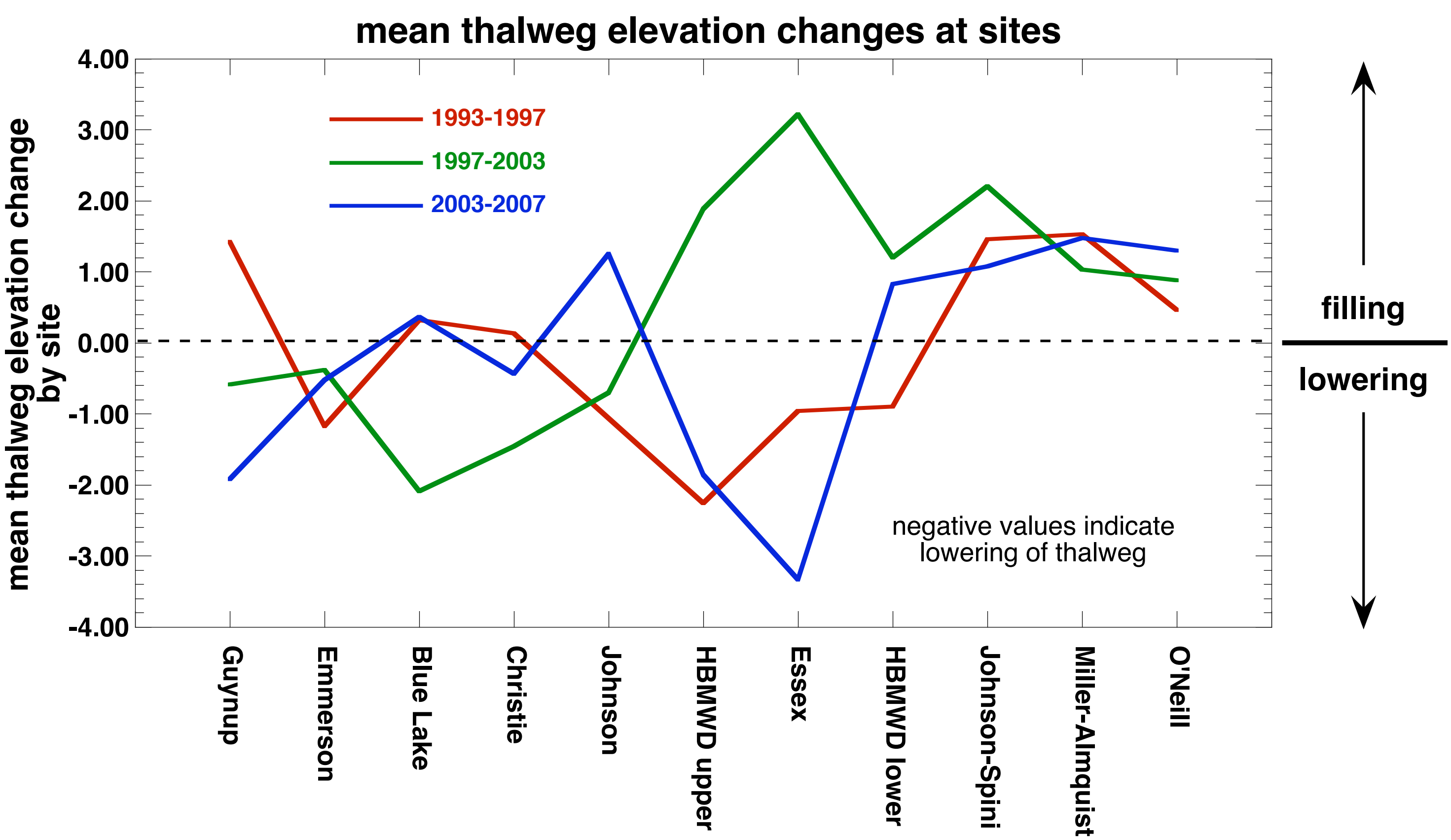
Appendix B

Downstream changes in sitewise mean cross-section properties for
1993-1997, 1997-2003, 2003-2007

mean XS elevation
thalweg elevation
confinement
width
XS area
channel volume





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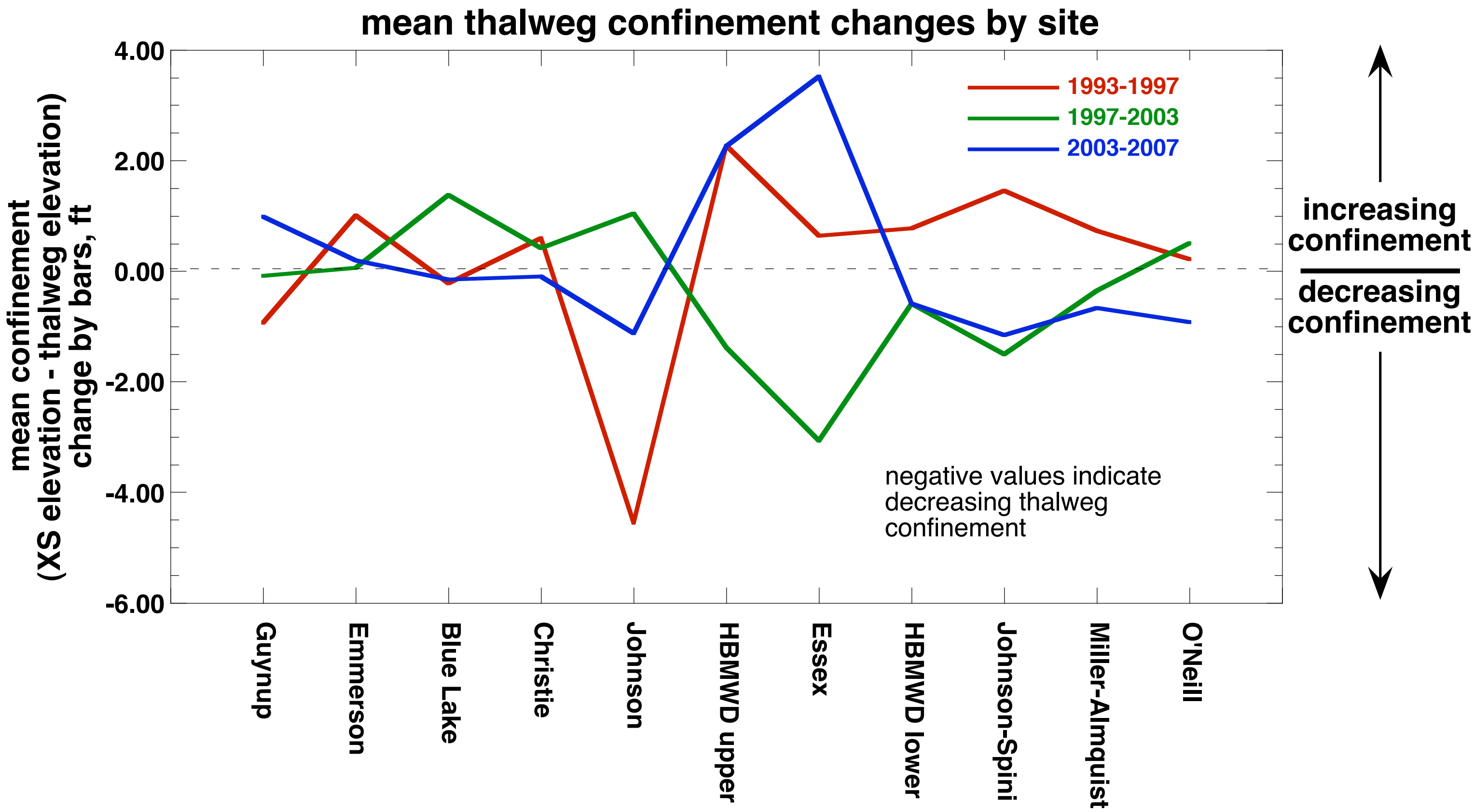
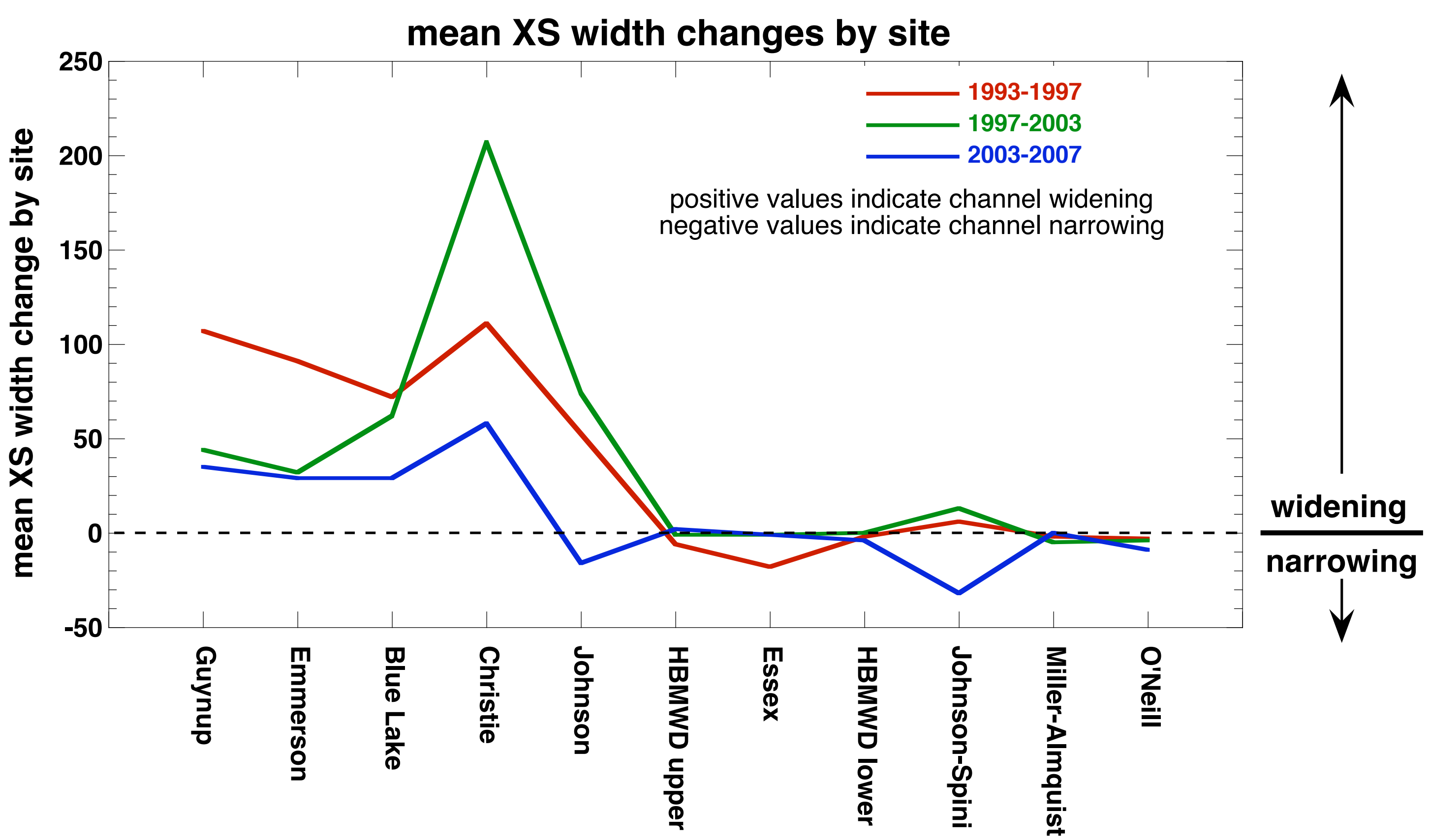
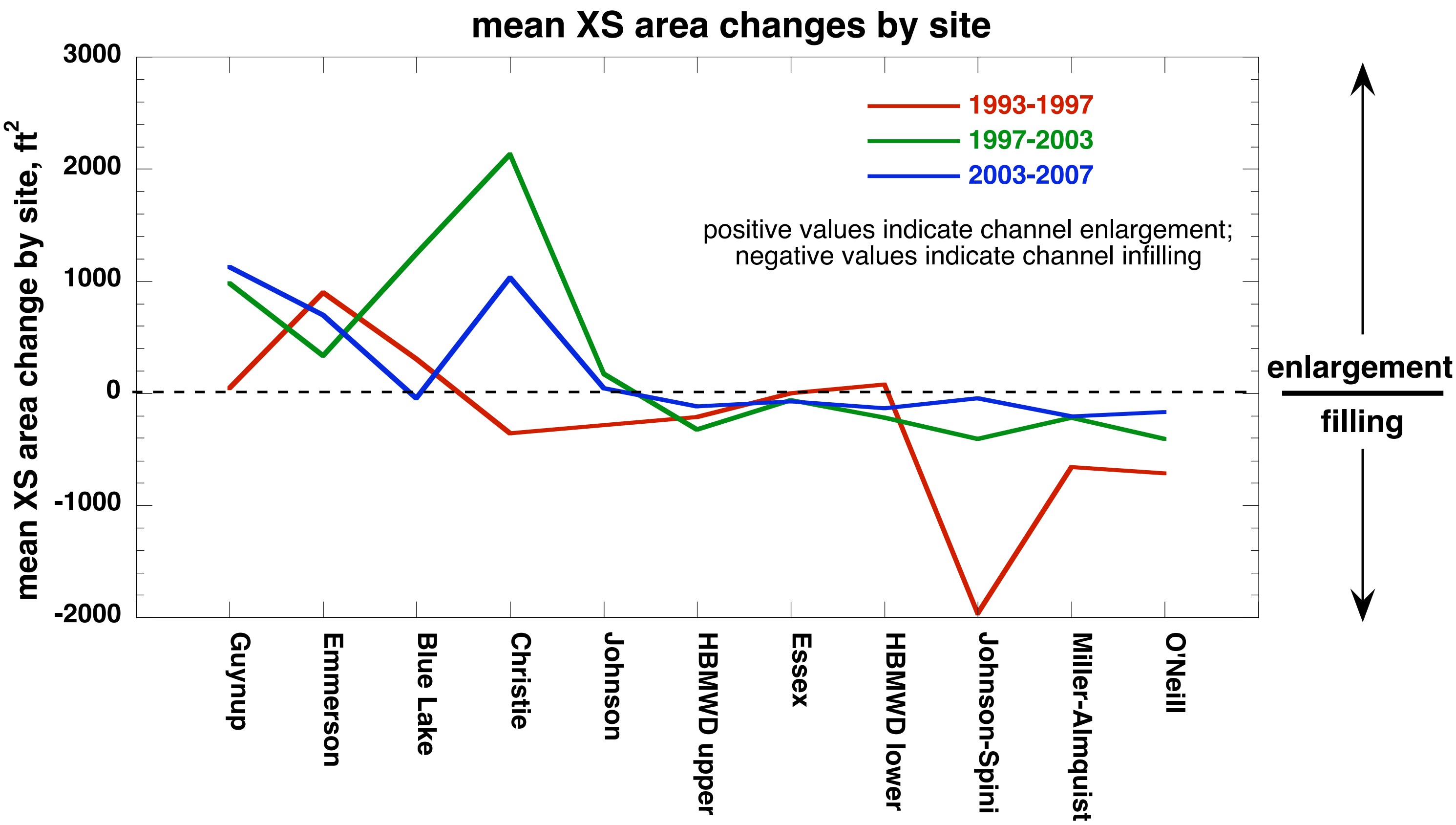
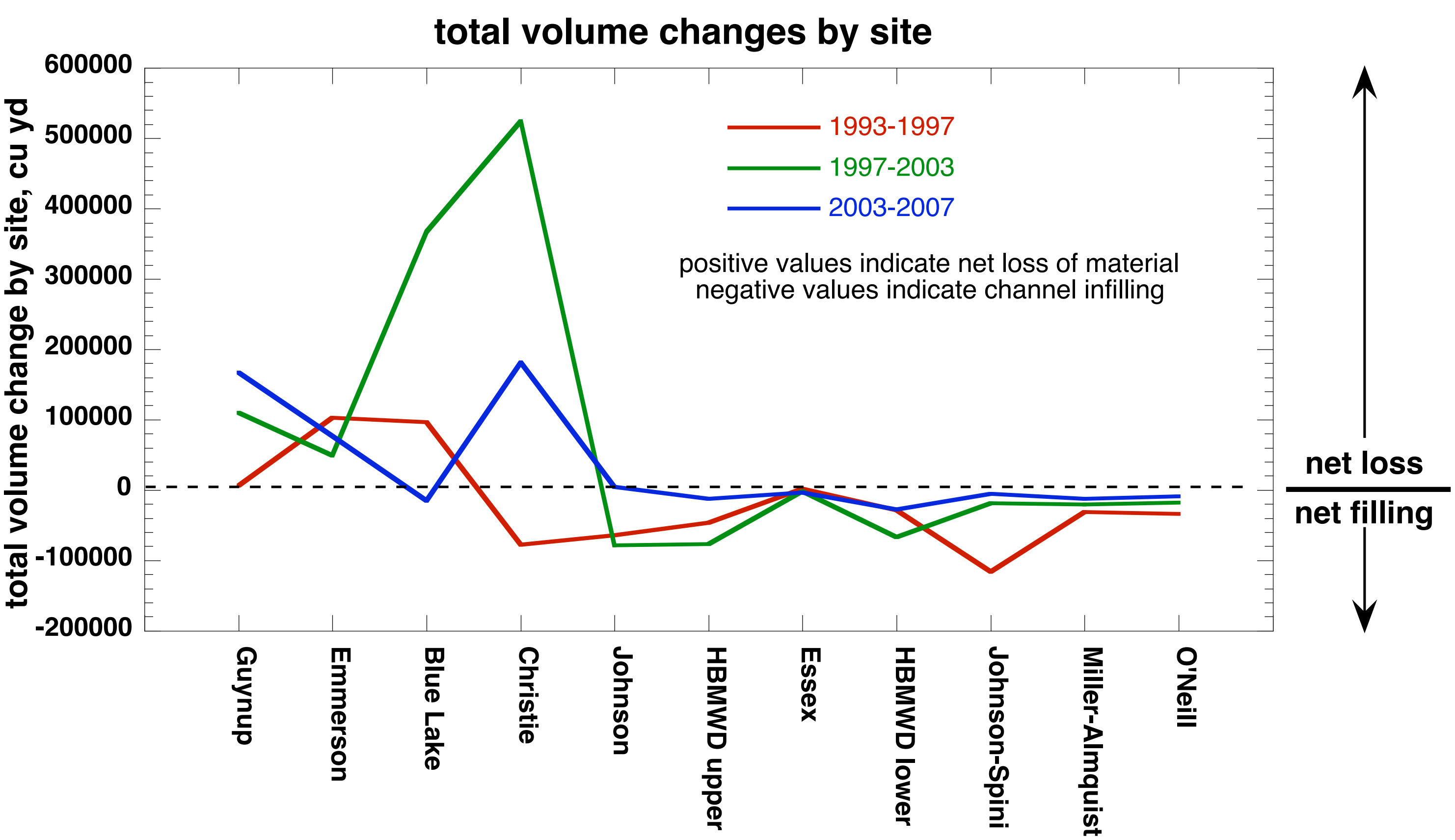




AK Lehre 14 Feb 2009



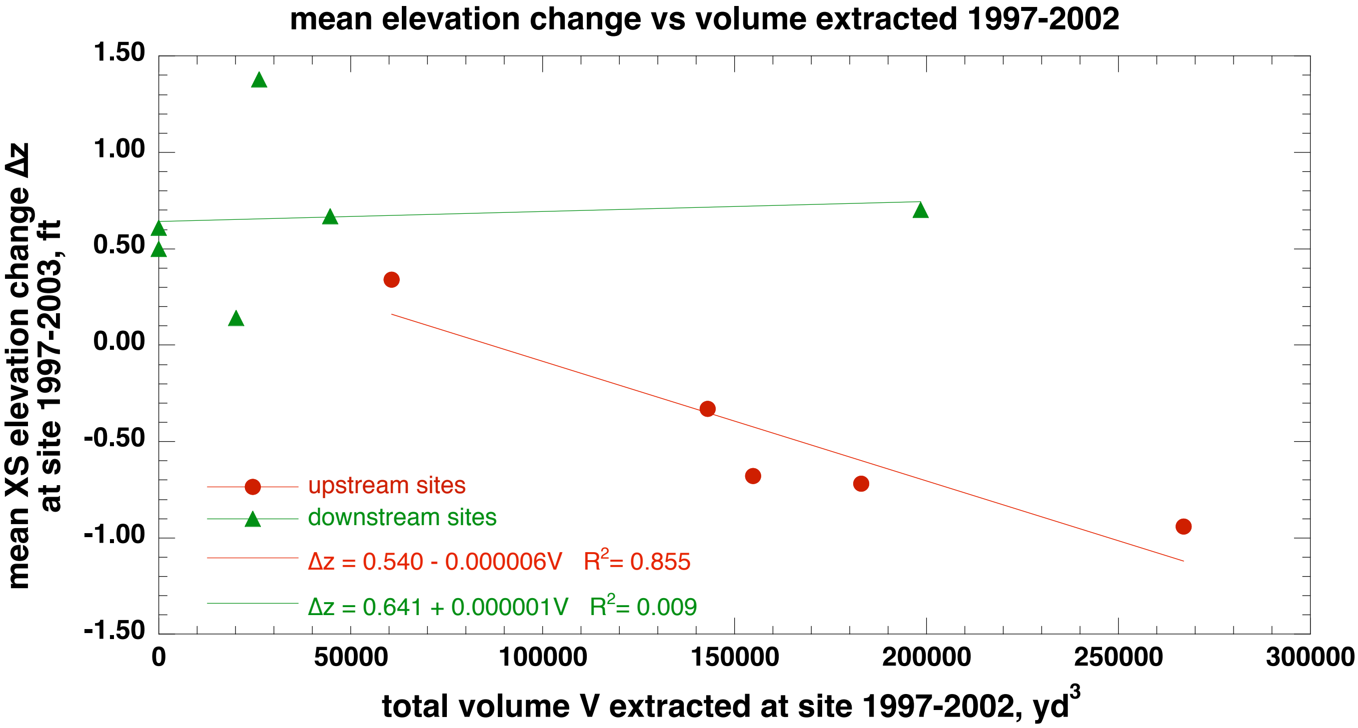


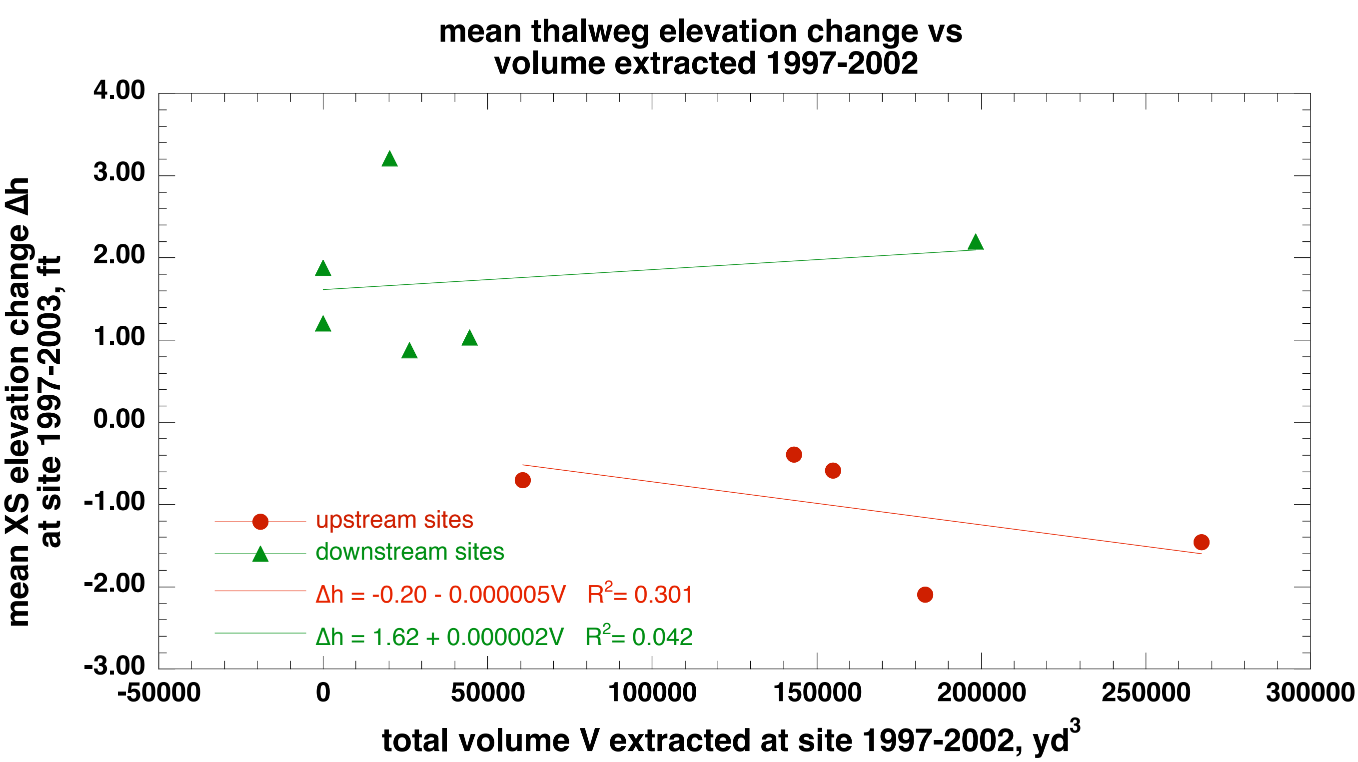
AK Lehre 13 Feb 2008

Appendix C

Revised regressions of changes in channel properties on volume extracted for 1997-2003

mean XS elevation
thalweg elevation
confinement
width
XS area
channel volume





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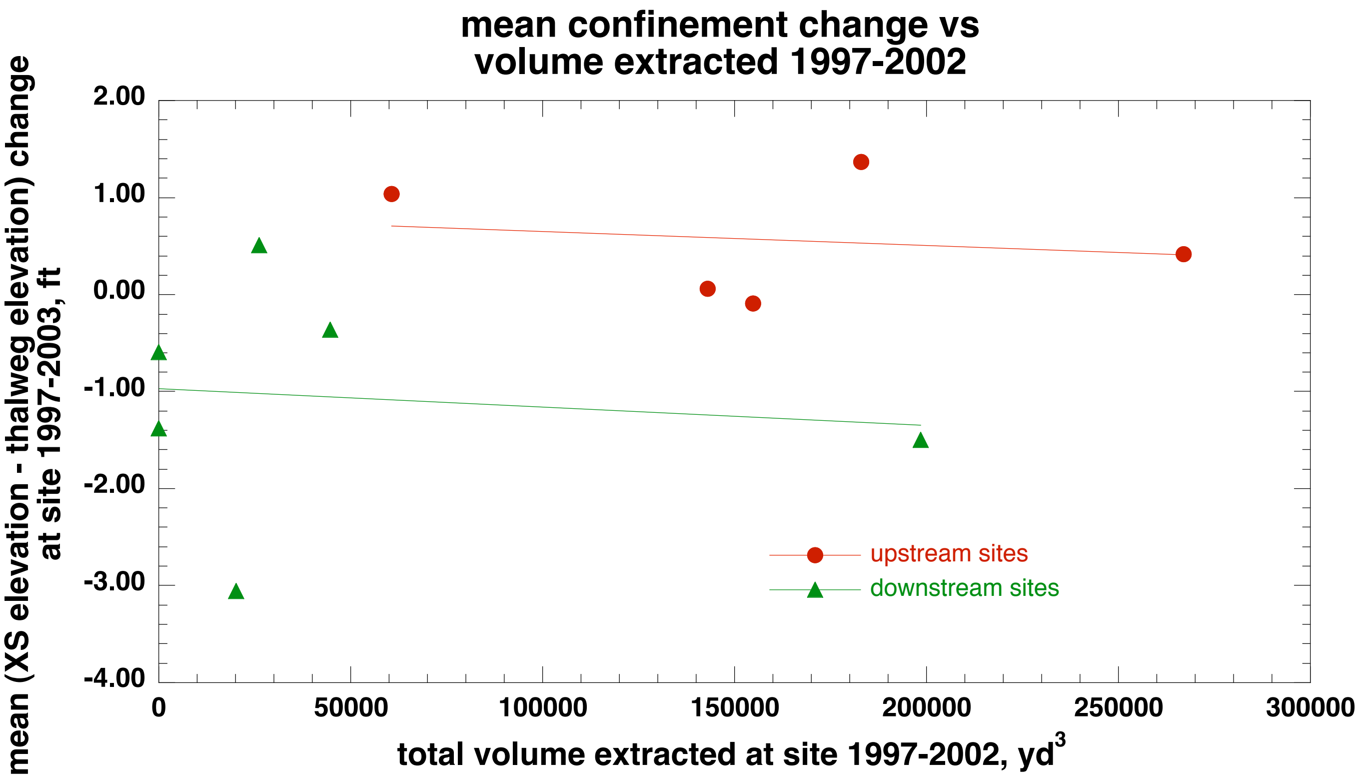

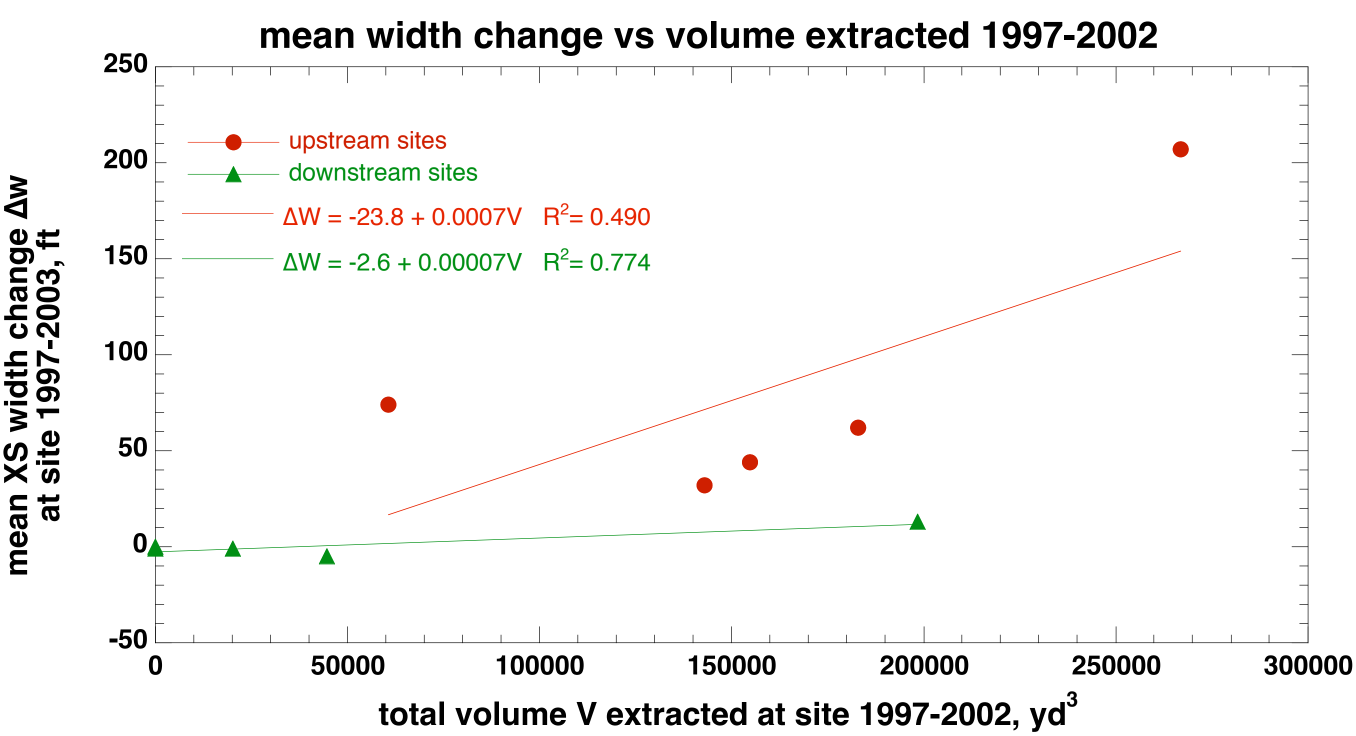

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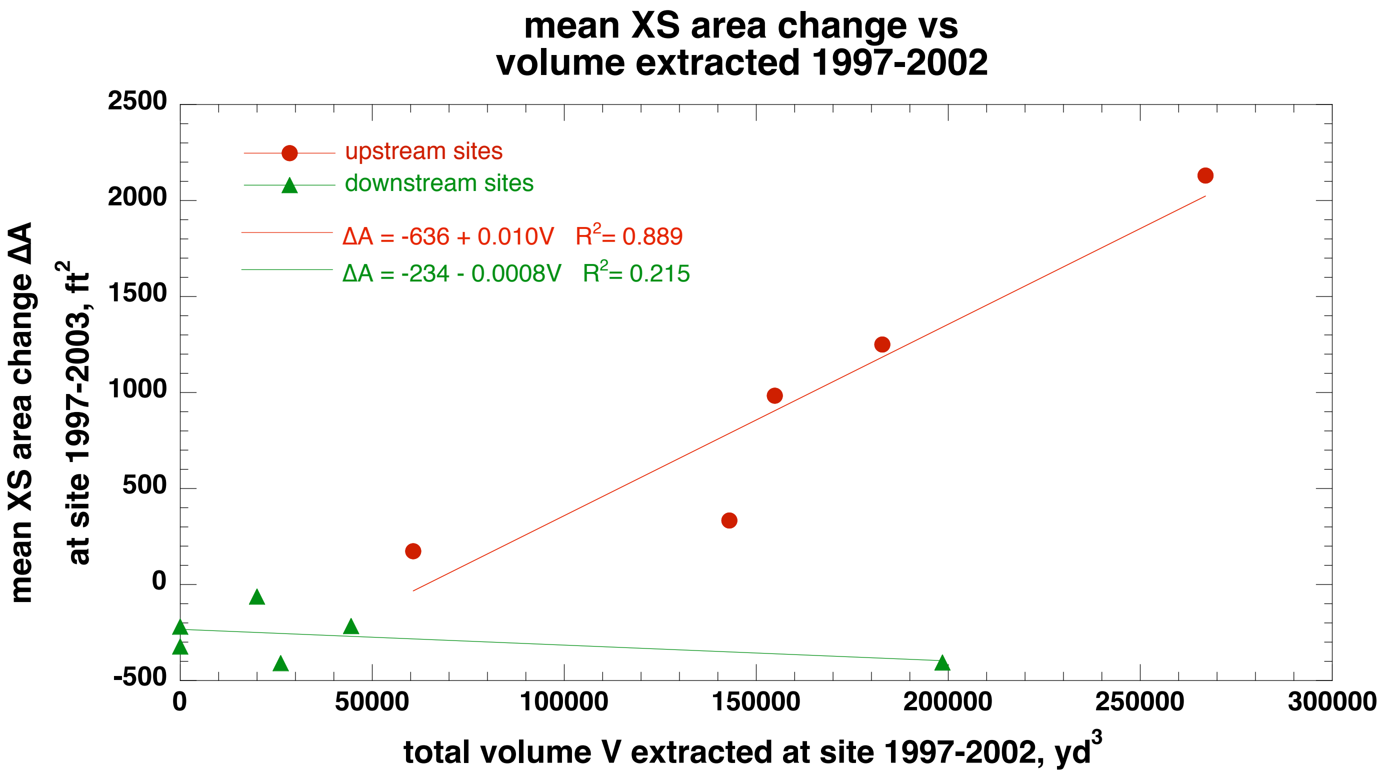

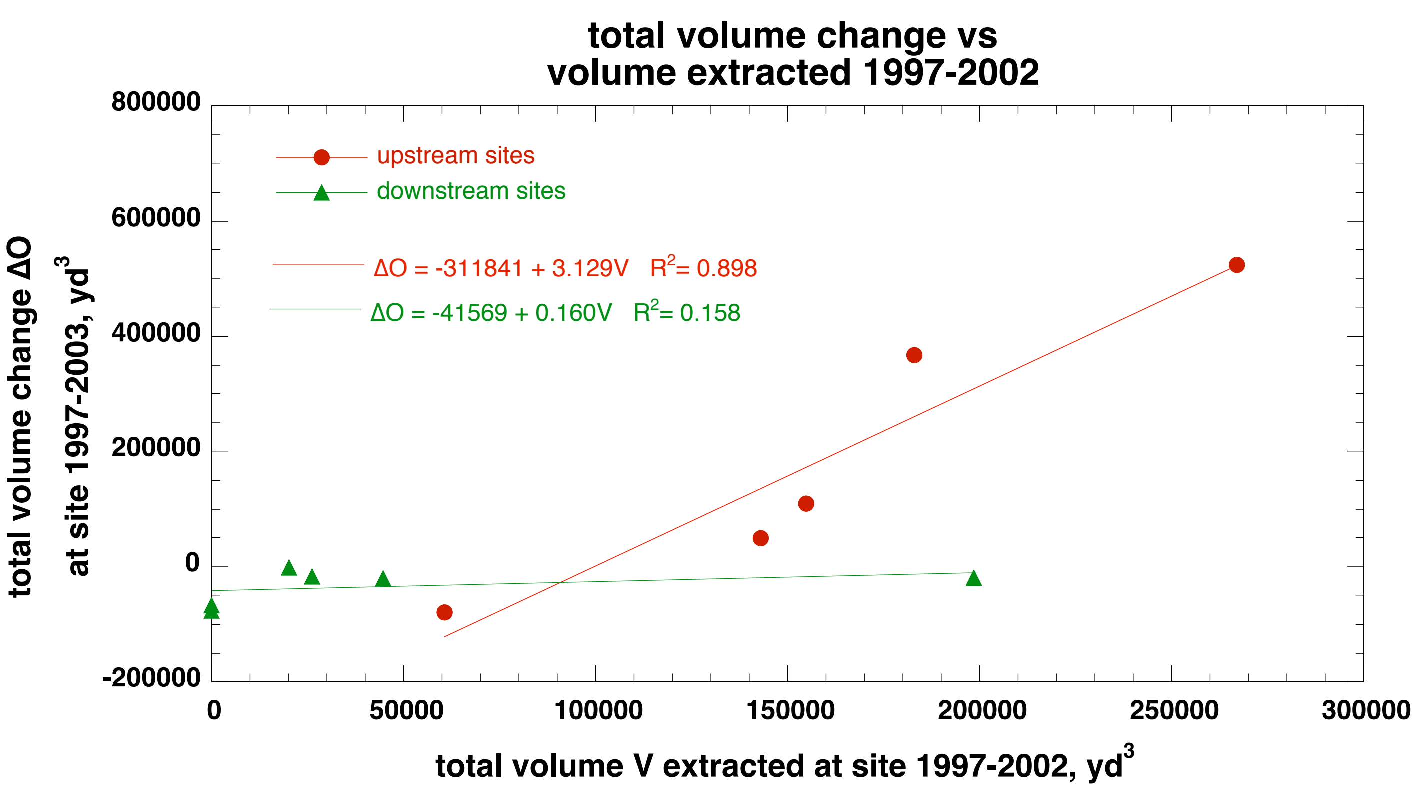

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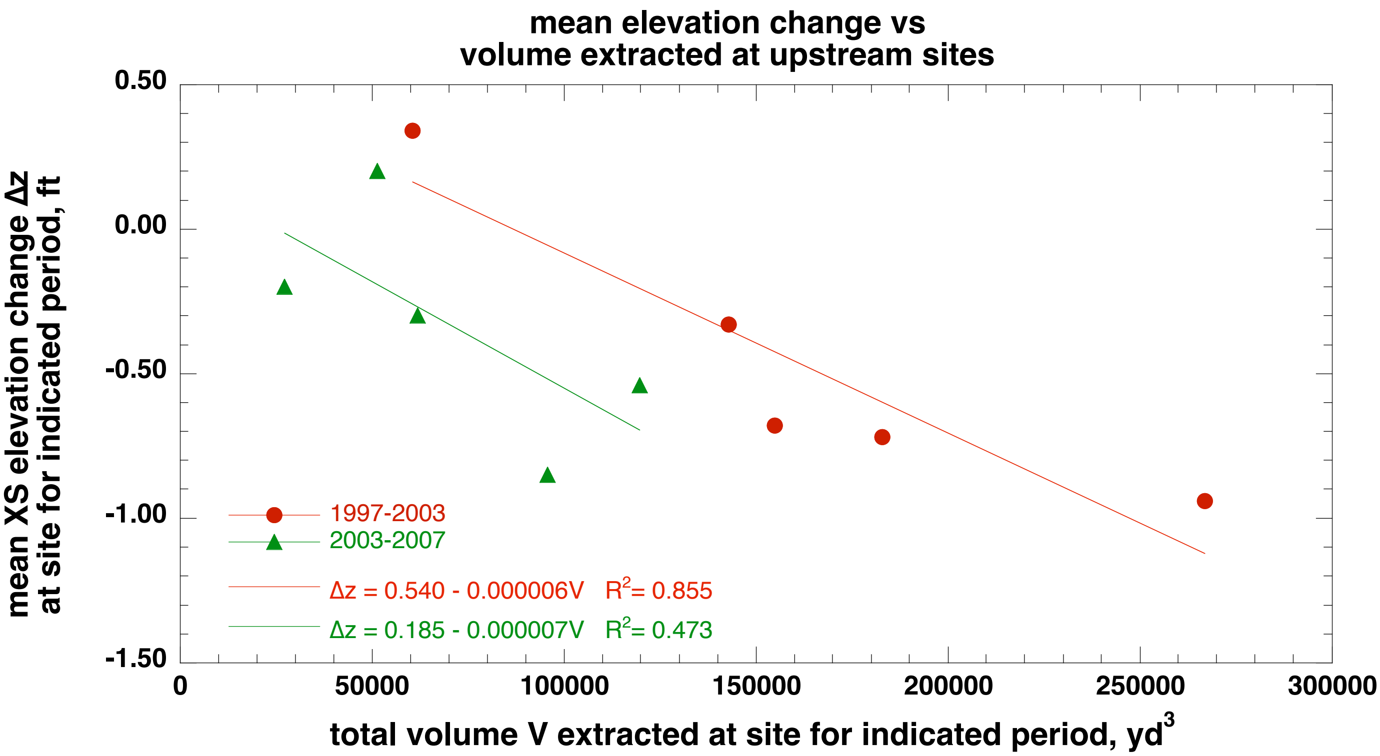
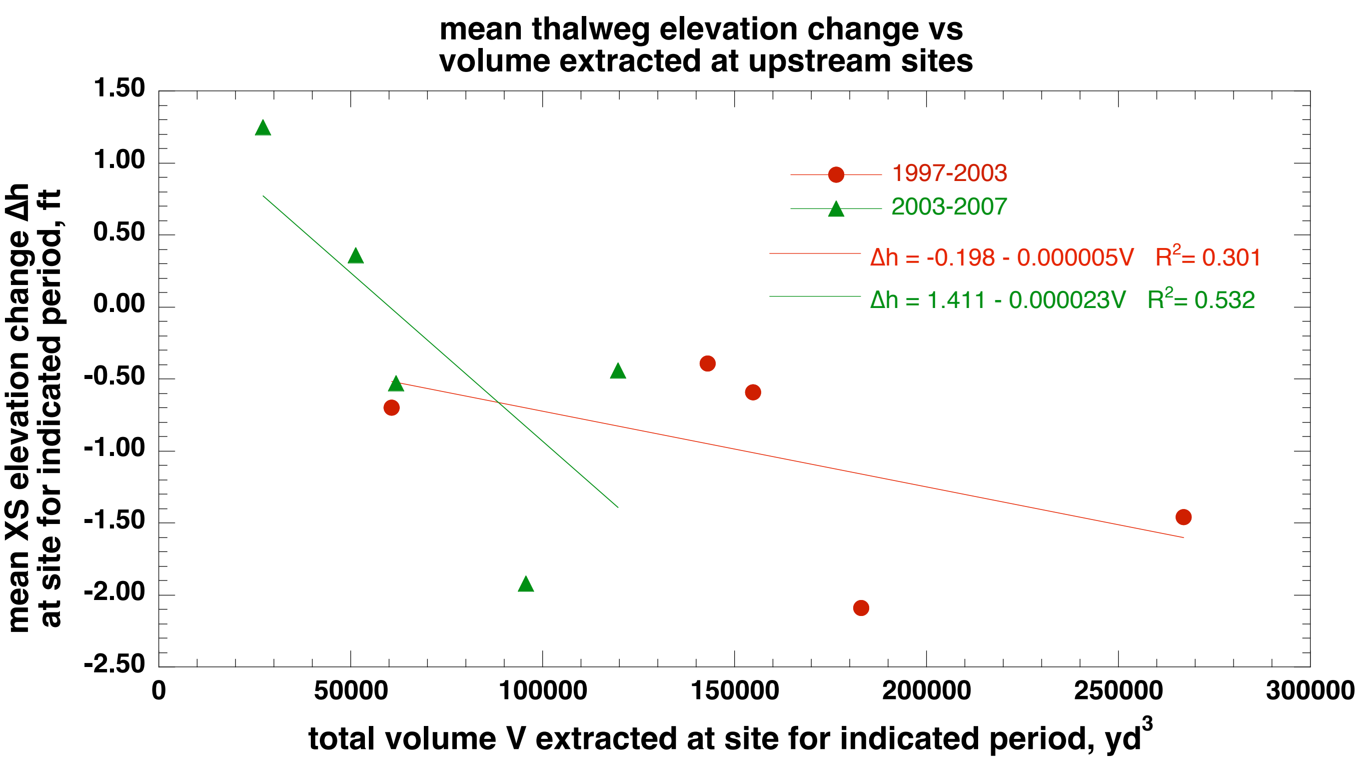
Appendix D

Comparison of regressions on volume extracted for 1997-2003 and 2003-2007 for upstream sites

mean XS elevation
thalweg elevation
confinement
width
XS area
channel volume





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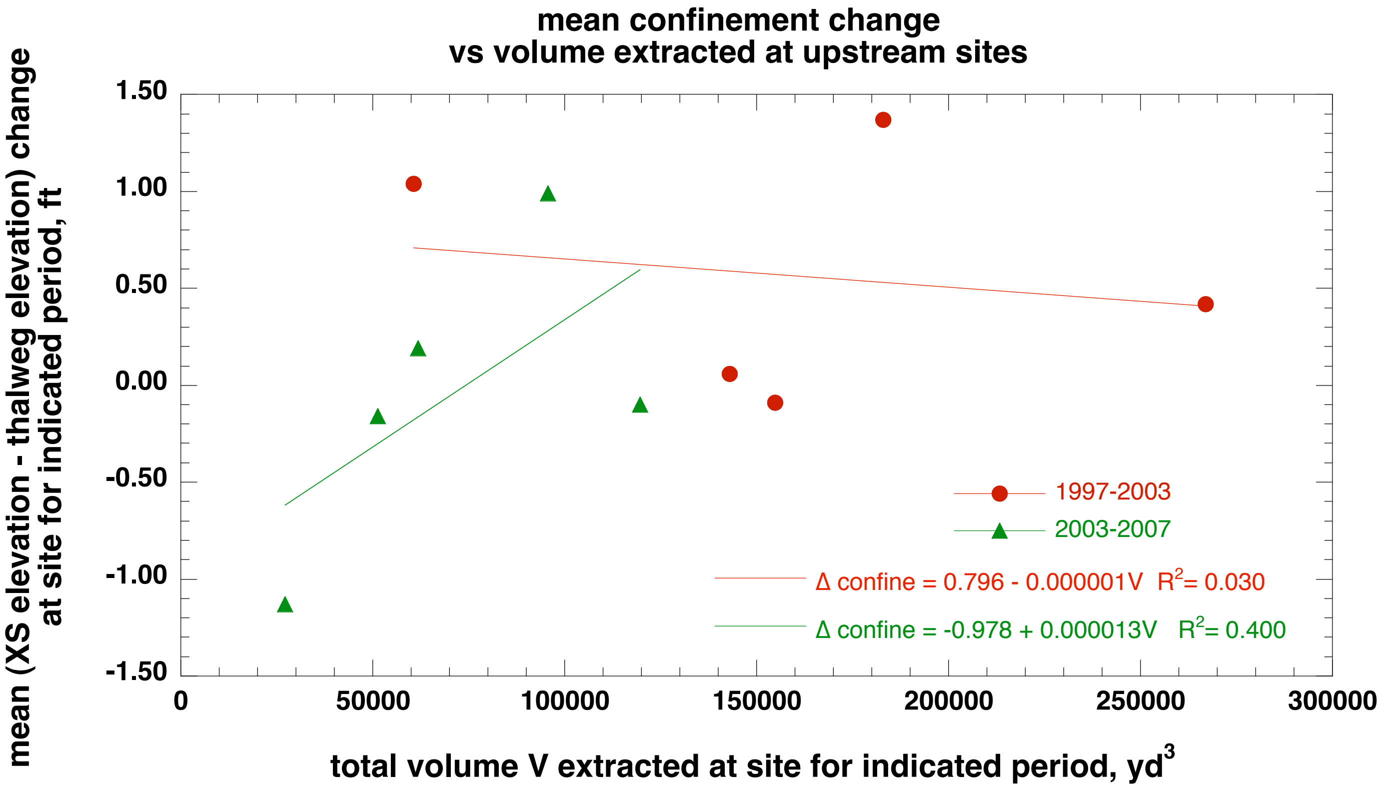
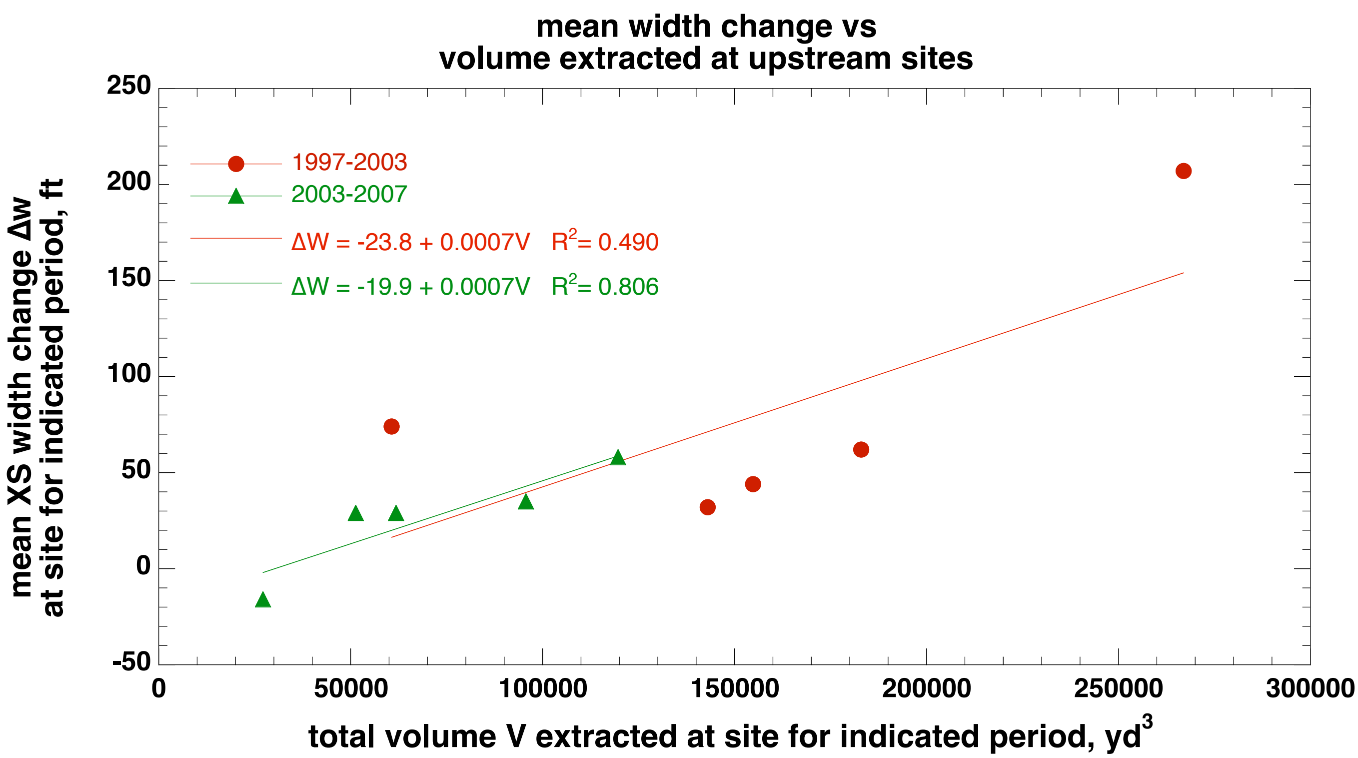
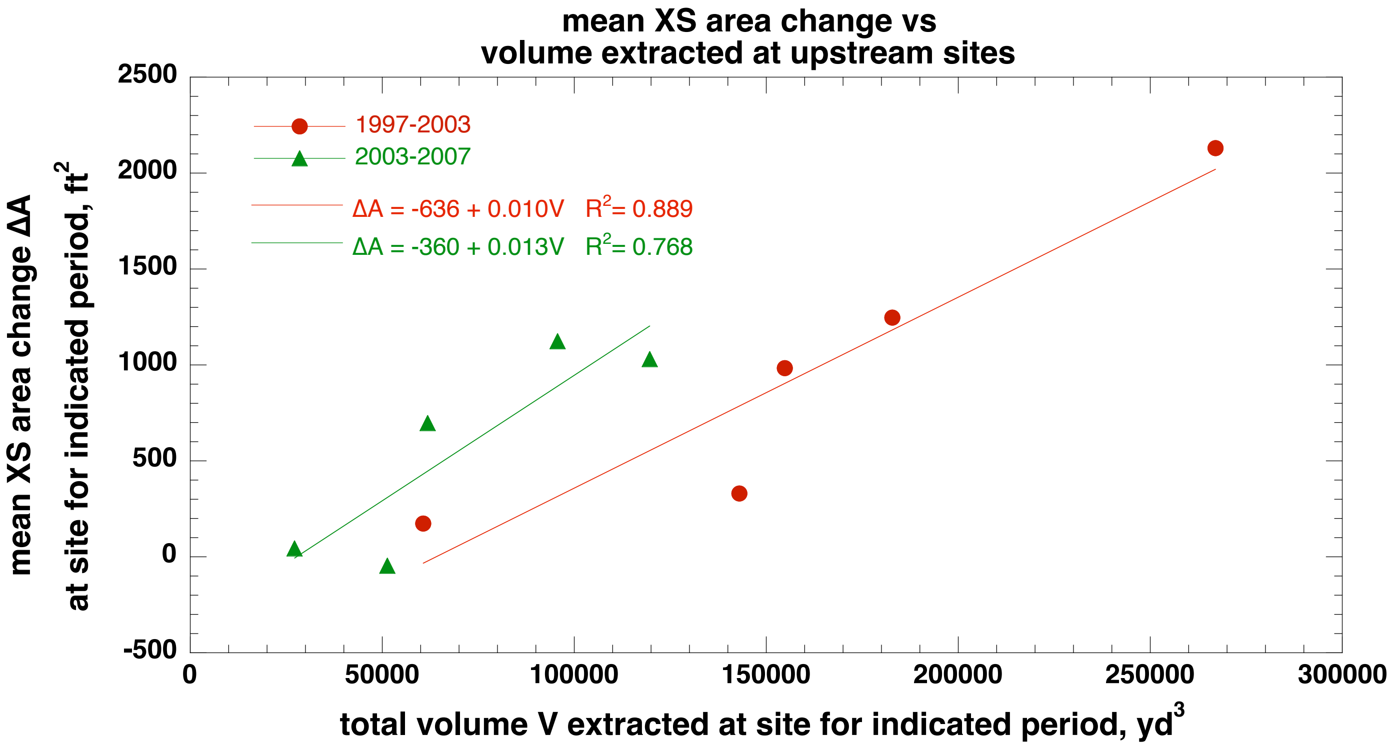
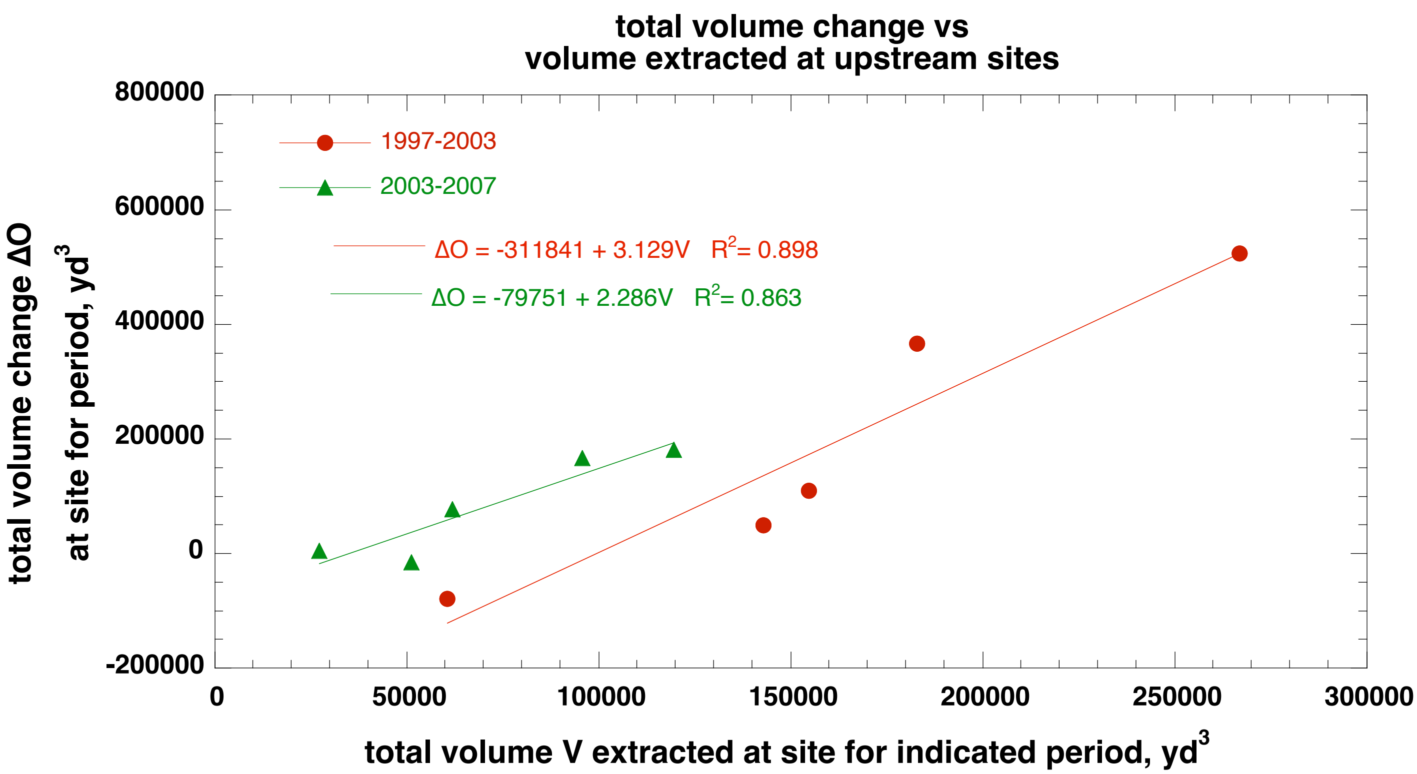




AK Lehre 16 Feb 2009





AK Lehre 15 Feb 2009