United States Department of the Interior
California Department of Parks and Recreation

Redwood National and State Parks
1655 Heindon Road
Arcata, California 95521

CALIFORNIA STATE PARKS

2002 303(d) List Update
Reference #26

IN REPLY REFER TO
Y34

May 7, 2001

Mr. Matt St. John
California Regional Water Quality Control Board
North Coast Region
5550 Skylane Boulevard, Suite A
Santa Rosa, Californian 95403

Dear Mr. St. John,

The following information is being submitted in response to the North Coast Regional Water Quality Control Board's request for new water quality data and information. The information relates specifically to the Redwood Creek basin, Humboldt County, and we believe that Redwood Creek should continue to be listed as 303(d) sediment impaired.

The enclosed information relates specifically to suspended sediment and channel conditions. Data attached to this correspondence are derived from suspended sediment measurements and channel surveys on Redwood Creek. This correspondence complements the data and information being submitted by Dr. Mary Ann Madej from the U.S. Geological Survey.

While general channel conditions in Redwood Creek may have greatly improved over past decades, the lower channel reaches in the parks are still sediment impaired. We also believe that the recently observed channel and sediment recovery trends can be reversed during the next major flood. For the past several decades the basin has experienced only low to moderate flows and has not been tested by a large storm. The last large flood occurred in 1975 (Recurrence Interval (RI) = 25-30 years) and flows since then, with the exception of a moderate flood in WY 97 (RI = 12 years), have all been less than a 5-year recurrence interval (Attachment 1).

Our concern for water quality in Redwood Creek is based on the Congressional mandate that the National Park Service protect the aquatic and riparian ***public trust resources*** in Redwood National and State Parks (RNSP). RNSP occupies the lower-third of the Redwood Creek basin and its resources are vulnerable to sediment impacts from erosion that occurs on private lands upstream of the park. These nationally significant resources received international recognition as both a designated World Heritage Site and International Biosphere Reserve in 1982. A brief discussion of roads in the Redwood Creek basin is necessary to explain our concerns.

Roads on private forestlands in the Redwood Creek basin have been and continue to be a major threat to water quality. In a watershed analysis of the Redwood Creek basin, roads on private lands in the upper basin were identified as a major cause of accelerated erosion and resultant loss of habitat for salmonid populations (NPS, 1997). Over 1,000 miles of logging roads exist on private lands upstream of the park. The road mileage in the upper basin of Redwood Creek is almost 5 times higher and road density is about 3.5 times higher than on parklands (Table 1). Roughly 80 percent of the road network in Redwood Creek was built before 1978 and prior to forest practice rules as amended in 1982. Current forest practice rules still do not require long-term maintenance of roads. Unmaintained roads, especially those previously built to lower-grade standards, represent significant potential sediment sources during large storm events.

Table 1. Roads in the Redwood Creek Basin

Basin Location	Drainage Area ($mile^2$)	Length (miles)	Road Density ($mile/mile^2$)
Upstream of Orick	278	1345	4.8
Parklands, including Prairie Creek	115	230	2.0
Private lands upstream of park	163	1115	6.8

Cooperative efforts between the private landowners in Redwood Creek and RNSP are currently addressing potential sediment sources from roads on private lands. A basin-wide inventory of roads that will identify potential sediment sources on private lands is underway and will be completed in 2003. The parklands road inventory is completed. The upper basin and parklands road assessments will be used to develop a basin-wide erosion prevention plan. On private lands, implementation of road treatments will occur based on the availability of funds and as specific road assessment areas are completed or as roads are used during timber harvest. However, roads will continue to be a significant threat to water quality during future large floods until the road treatments identified in the erosion prevention plan are fully implemented at the basin scale.

The new information and data that we would like to submit to the Board are as follows:

1. Reversal of Suspended Sediment Trends (Attachment 1)
The January 1, 1997 flood illustrates that existing watershed conditions are not favorable and the previously observed declining suspended sediment trends can be reversed during even a moderate flood event. A plot of the 10-year rolling average for suspended sediment yield at Orick shows that the declining suspended sediment trends, established during years of low to moderate streamflow, reversed in 1997. Due to the uncertainties associated with bedload measurements and incomplete bedload records, we recommend using suspended sediment yield rather than total load to track long-term sediment trends in Redwood Creek.

2. Redwood Creek Salmon Report (Attachment 2)
The Redwood Creek Landowners Association (RCLA) prepared a report entitled, *A Study in Change: Redwood Creek and Salmon.* RCLA has presented the document to various state agencies and boards as a "compendium" or "library" of information on Redwood Creek. By definition, a "compendium" is a short complete summary of all essential facts and details. In our opinion, the report does not meet that criterion and does not accurately relate the findings of research performed by various agencies and universities. We recommend the report be reviewed for scientific credibility before any board uses the report's conclusions for action or policy decisions.

3. Chronic Turbidity (Attachment 3)
Past studies on Redwood Creek focused on impacts from catastrophic input of coarse sediment to streams but not the effects of chronic turbidity on aquatic organisms. However, studies have shown extended exposure to suspended sediment concentrations above 27 mg/l can significantly affect the ability of juvenile salmonids to forage, and ultimately reduce their survival (Newcombe and Jensen, 1996). To address this issue Randy Klein, RNSP hydrologist, has completed a preliminary evaluation of WY 99 suspended sediment concentration/duration regimes from managed and reference watersheds in Redwood Creek tributaries. Preliminary results indicate managed streams exhibit much higher suspended sediment concentrations at a given discharge than reference streams. The duration that a suspended sediment concentration threshold of 27 mg/l was exceeded was also much lower in reference streams (11-25 consecutive days) than in the managed streams (101-135 consecutive days). Preliminary analysis of the WY 99 suspended sediment strongly suggests that management is having a significant effect on suspended sediment production in the Redwood Creek watershed, even in a relatively moderate winter runoff period. Current research is addressing the connection between exposure and salmonid growth and survival.

4. Redwood Creek Long-Term Channel Stability Monitoring (Attachment 4)
Channel cross sections continue to document sediment impacts associated with the 1964 and 1970's floods on the main channel of Redwood Creek. Cross section data indicate that channel aggradation below the Tall Trees Grove (lower reaches in parklands) peaked in the early 1990s. Channel changes observed in 1995 suggest that the lower section of Redwood Creek may have begun to recover. However, no significant channel down cutting has occurred since then and the channel remains elevated above 1973 levels. Madej (1999) documented the increase in residual pool depth on sections of Redwood Creek from 1975 to 1995, but following the 1997 flood, residual pool depths decreased to depths typical of the early 1980s. This demonstrated that a moderate flood was capable of reversing channel recovery. The persistence of sediment in Redwood Creek for more than three decades has likely impacted many life cycles of steelhead and salmon.

We hope you find this information useful. Please contact Vicki Ozaki (707) 825-5142, Randy Klein (707) 825-5111 or Greg Bundros (707) 825-5145 if you have any questions or need additional information.

Sincerely,

Terrence D. Hofstra

Terrence D. Hofstra
Chief, Resource Management and Science

4 Attachments (including a list of attachments and filenames)

cc: Superintendent, Redwood National and State Parks
Research Geologist, Redwood Field Station

References

Madej, Mary Ann. 1999. Temporal and Spatial Variability in the Thalweg Profiles of a Gravel-Bed River. Earth Surface Processes and Landforms. V. 24. pp. 1153- 1169.

National Park Service, U.S. Department of Interior. 1997. Draft Redwood Creek Watershed Analysis. Redwood National and State Parks. Division of Resource Management and Science. On-file, Orick, California. 84 pp.

Newcombe, C.P. and Jensen, J.O.T. 1996. Channel Suspended Sediment and Fisheries: A Synthesis for Quantitative Assessment of Risk and Impact. North American Journal of Fisheries Management. V. 16. No. 4. pp. 693-727.

List of Attachments and Filenames

Attachment 1: Reversal of Suspended Sediment Trends

1) Graph: Annual Peak Flow for Redwood Creek at Orick, California
   Graph: 10-Year Rolling Average for Suspended Sediment Yield for Redwood Creek

2) Annual Water and Sediment Discharge for Redwood Creek.
   (Excel Filename: RWC-HYDRODATA.xls)

Attachment 2: Redwood Creek Salmon Report

Attachment 3: Chronic Turbidity

1) Abstract: Baseline Suspended Sediment Characteristics And Juvenile Salmonids, North Coastal California. (Word Filename: Turbidity Abstract-Klein NSA.doc)

2) Paper: Suspended Sediment Concentrations and Fluxes in Redwood Creek Tributaries (Word Filename: TurbidityRWCTribs.doc)

3) Figures for paper (Word Filename: Turbidity Fig1-7.doc)

Attachment 4: Redwood Creek Long-Term Channel Stability Monitoring

1) RNSP Progress Report: Long-Term Channel Stability Monitoring on Redwood Creek, 1995-1997 (Word Filename: RWCXS95-97 RPT.doc)

2) Summary of Channel Changes at Redwood Creek Cross Sections (Tables 1-3).
   (Word Filename: RWCXS Summary 98-00.doc)

3) Plots of Redwood Creek cross sections surveyed in WY 00.
   (Word Filename: RWCXS-plots00.doc)

ATTACHMENT 1: Reversal of Suspended Sediment Trends

1) Graph: Annual Peak Flow for Redwood Creek at Orick, California
   Graph: 10-Year Rolling Average for Suspended Sediment Yield for Redwood Creek

2) Annual Water and Sediment Discharge for Redwood Creek (Excel Filename: RWC-HYDRODATA.xls)

The January 1, 1997 flood illustrates that existing watershed conditions are not favorable and the previously observed decline in suspended sediment can be reversed during the next major flood.

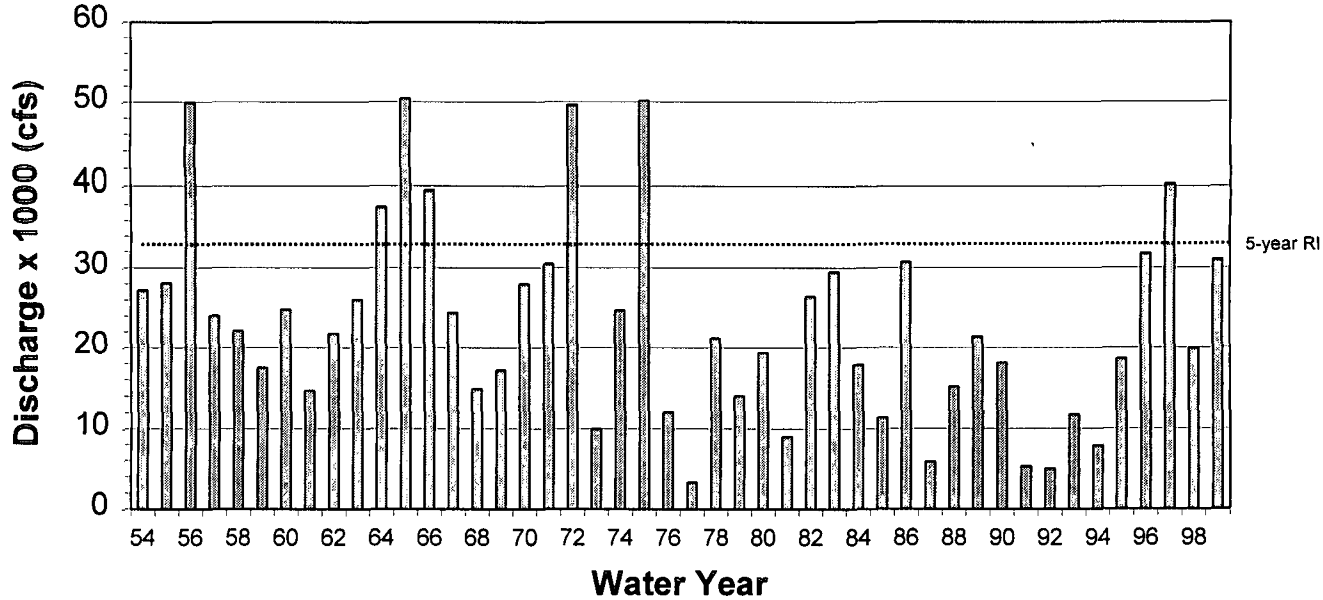
The first plot on the next page shows the annual peak discharges for Redwood Creek at Orick for the period of 1954-1999. It characterizes the 1997 flood as the largest runoff event since 1975. Based on flood frequency analysis, the 1997 flood had only a 12-year recurrence interval. The last large flood occurred in 1975 (RI = 25-30 years) and flows since then, with the exception of WY 97, have all been less than a 5-year recurrence interval. The Redwood Creek basin has not been tested by a large flood (>25-year recurrence interval) since 1975.

The second plot on the next page shows the 10-year rolling averages for suspended sediment at two stream gaging locations on Redwood Creek. The O'Kane gaging station captures the upper-third of the watershed and the Orick gaging station (below the confluence of Prairie Creek) captures the entire watershed. Since 1975, the 10-year rolling average for suspended sediment yield had a downward trend. However, a moderate flood in 1997 reversed that downward trend, and the upper portions of the watershed, as measured at the O'Kane gaging station, began to produce higher suspended sediment yields per unit drainage area than at Orick. The suspended sediment relationships at these two stations, established during periods of low to moderate stream flow, were reversed by this single storm.

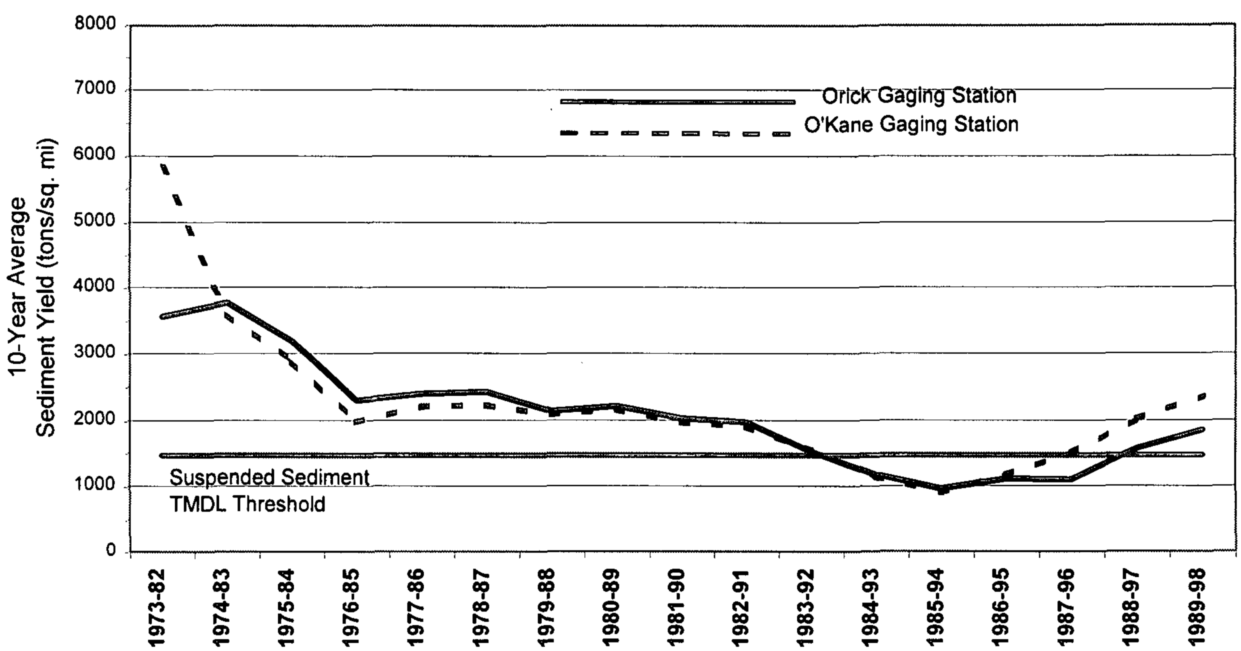
In the Total Maximum Daily Load for Redwood Creek, the U.S. Environmental Protection Agency established a threshold of 1900 tons/mile^2 based on total load (suspended and bedload sediment). Due to the uncertainty associated with bedload measurements and incomplete bedload records, we recommend using suspended sediment to track long-term sediment trends in Redwood Creek. The suspended sediment load threshold (1460 tons/ mile^2) was estimated based on the ratio of bedload to total load. Bedload is estimated to be 23 percent of the total sediment load based on sediment data collected at Orick from 1978-1992.

This attachment also includes an Excel sheet with the most accurate and complete record of peak flow and sediment data for the Orick and O'Kane stations. These data supercede previous sediment data from RNSP.

ANNUAL PEAK FLOW: Redwood Creek at Orick



TMDL: Ten-Year Rolling Average for Suspended Sediment Yield Redwood Creek, Humboldt County, California



STATION NAME: 11482500 REDWOOD CREEK AT ORICK, CA

LOCATION: There have been two gaging stations for this site. In 1987 the gaging station was moved. The current location is Lat 41°17'58", long 124°03'00", in NE 1/4 NE 1/4 sec. 34, T.11 N., R.1 E., Humboldt County Hydrologic Unit 18010102, on right bank,

DRAINAGE AREA: 277 sq. mi.

PERIOD OF RECORD: September 1911 to Sept 1913, October 1953 to current. Monthly discharge only for some periods, published in WSP

EXTREMES FOR PERIOD OF RECORD: Maximum discharge, 50,500 cfs, Dec. 22, 1964, former site, from outside high-water marks, maximum gage height, 28.22 ft, Jan. 1 1997; minimum daily, 2.1 cfs, Oct. 20-22, 1987.

REMARKS: Records good except for estimated daily discharges, which are fair. No regulation or diversion upstream from station.

WATER YEAR	Annual Water Discharge: PEAK FLOW (cfs)	ANNUAL RUNOFF (cfs-days)	(acre feet)	(m^3)	(mm)	Annual Sediment Discharge: Streamflow (cfs-days)	Suspended (Qss) (tons)	(tons/mi²)	Bedload (Qbd) (tons)	Total Load (Qs) (tons) [b]	Qs/Qw (tons/cfs-days)
1912	19500	336274	667000	822411000							
1913	12500	397278	788000	971604000							
54	27200	454853	902200	1112412600							
55	28100	278447	552300	680985900							
56	50000	591883	1174000	1447542000							
57	24100	386791	767200	945957600							
58	22200	495185	982200	1211052600							
59	17500	268818	533200	657435600							
60	24900	305571	606100	747321300							
61	14700	395303	784100	966795300							
62	21800	282347	560000	690480000							
63	26100	446088	884800	1090958400							
64	37700	383759	761200	938559600							
65	50500	535431	1062000	1309446000							
66	39600	320296	635300	783324900							
67	24500	381693	757100	933504300							
68	14900	243019	482000	594306000							
69	17200	434122	861100	1061736300							
70	28000	365955	725900	895034700							
71	30500	514592	102100	125889300		514592	2177713	7862			
72	49700	536198	1064000	1311912000		536198	3799775	13718			
73	10000	281803	559000	689247000		281843	757634	2735			
74	24800	629915	1249000	1540017000		629915	2228626	8046	371804	2600319	4
75	50200	476089	944300	1164321900		476089	2768664	9995	251070	3020223	6
76	12100	308627	612200	754842600		308627	745314	2691	100551	846074	3
77	3310	70117	139100	171510300		70117	22567	81	2277	24802	0
78	21200	425877	844700	1041515100		425877	948518	3424	330195	1278345	3
79	14100	231035	458300	565083900		231035	292989	1058	52100	345200	2
80	19400	404268	801900	988742700		404268	704585	2544	190778	895065	2
81	9030	235647	467400	576304200		235647	187877	678	174021	361920	2
82	26500	584844	1160000	1430280000							
83	29500	600654	1191000	1468503000							
84	17900	518881	1029000	1268757000							
85	11400	279552	554500	683698500							
86	30700	397838	789100	972960300							
87	5870	211455	419400	517120200							
88	15200	219713	435800	537341400							
89	21400	375540	744900	918461700							
90	18100	239769	475600	586414800							
91	5280	156443	310300	382599900							
92	5000	113686	225500	278041500							
93	11800	433171	859200	1059393600		433132	388111	1401			
94	7890	167244	331700	408986100		167403	73070	264			
95	18600	461145	914700	1127825100		461206	751906	2714			
96	31800	490776	973500	1200325500		490647	1080307	3900			
97	40300	461327	915000	1128195000		459449	1563727	5645			
98	19900	467432	927200	1143237600		465682	1004797	3627			
99	31000	474068	940300	1159389900		473750	1099292	3969			
2000	No Data Available Yet										

DATA SOURCES:
Data from USGS Water Resource Data Publications, Volume 2
Data from RNSP Data Release on Rainfall, Streamflow and Suspended Sediment Transport in the Redwood Creek Watershed Humboldt County, California 1990 through 1998

[a] Discrepancy in published USGS data.
[b] USGS published values for total load is differs from the sum of the suspended and bedload load due to rounding errors in the program.

WATER YEAR	Sediment Discharge (October-April): Streamflow (cfs-days)	Suspended (Qss) (tons)	(tons/mi²)	Bedload (Qbd) (tons)	Total Load (tons) [b]	Qs/Qw (tons/cfs-days)
1912						
1913	96617					
54	431177					
55	246363					
56	567527					
57	335588					
58	474393					
59	254514					
60	231258					
61	666090					
62	259572					
63	392543					
64	360947					
65	517548					
66	305607					
67	335630					
68	225364					
69	409598					
70	338009					
71	915908	2176062	7856			
72	516835	3798291	13712			
73	257848	756681	2732			
74	612822	2228311	8044	371800	2600000	4
75	440639	2750254	9929	249010	2999779	7
76	292100	745040	2690	10550	845800	3
77	49428	20372	74	2049	22382	0
78	397659	947110	3419	325620	1272360	3
79	181212	259908	938	43459	303440	2
80	380617	704048	2542	188250	892000	2
81	214127	187282	676	170350	357659	2
82	563407	1276880	4610	377890	1653970	3
83	600462	1327107	4801	370050	1697600	3
84	458970	625810	2259	279372	905952	2
85	265181	280541	1013	139376	420178	2
86	362162	1010226	3647	148237	1157760	3
87	201675	103782	375	61790	165606	1
88	176750	156514	565	62255	219072	1
89	353450	463771	1674	60950	525002	1
90	184274	191317	691	62215	253805	1
91	127467	34965	126	22967	57939	0
92	102919	18184	66	10884	29038	0
93	344244	344869	1245			
94	147580	66006	238			
95	416062	682271	2463			
96	450522	977452	3529			
97	431789	1401751	5060			
98	430922	962413	3474			
99	442105					
2000						

STATION NAME: 11481500 REDWOOD CREEK NEAR BLUE LAKE

LOCATION: Lat 40°54'22", long 123°48'51", in SE1/4 NE1/4 sec. 15, T.6 N., R.3 E., Humboldt County, Hydrologic Unit 18010102, on right bank, 400 ft upstream from Lupton Creek, and 9.1 mi east of town of Blue Lake.

DRAINAGE AREA: 67.7 sq. mi

PERIOD OF RECORD: June 1953 to September 1958, October 1972 to September 1993, October 1997 to September 1998.

EXTREMES FOR PERIOD OF RECORD: Maximum discharge, 12,200cfs, Mar. 18, 1975, gage height, 13.70 ft, from rating curve extended above 6,400 cfs; minimum daily, 0.69cfs, Sept. 30, 1993.

REMARKS: Records fair. No regulation or diversion upstream from station.

WATER YEAR	Annual Water Discharge					Annual Sediment Discharge					
	PEAK FLOW	ANNUAL RUNOFF				Streamflow	Suspended (Qss)		Bedload (Qbd)	Total Load (Qs)	Qs/Qw
	(cfs)	(cfs-days)	(acre feet)	(m^3)	(mm)	(cfs-days)	(tons)	(tons/mi²)	(tons)	(tons) [b]	ons/cfs-days)
54	8310		199000	245367000							
55	9200		114200	140808600							
56	12100		307100	378654300							
57	5890		182800	225392400							
58	7960		285600	352144800							
59	NOT IN SERVICE										
60	NOT IN SERVICE										
61	NOT IN SERVICE										
62	NOT IN SERVICE										
63	NOT IN SERVICE										
64	NOT IN SERVICE										
65	NOT IN SERVICE										
66	NOT IN SERVICE										
67	NOT IN SERVICE										
68	NOT IN SERVICE										
69	NOT IN SERVICE										
70	NOT IN SERVICE										
71	NOT IN SERVICE										
72	NOT IN SERVICE										
73	2980	70264	139400	171880200		70264	184689	2728			
74	5720	149735	297000	366201000		149725	657618	9714	301502	959906	6
75	12200	124174	246300	303687900		124160	695296	10270	243860	939725	8
76	4100	67860	134600	165961800		67873	81189	1199	21295	102495	2
77	827	16118	31970	39419010		16117	1217	18	724	1942	0
78	3490	95387	189200	233283600		95406	122233	1806	65950	188192	2
79	4760	51071	101300	124902900		51081	54296	802	28436	82761	2
80	4840	98563	195500	241051500		98573	162674	2403	36152	198810	2
81	3410	50769	100700	124163100		50793	46873	692	7143	53963	1
82	5730	132039	261900	322922700							
83	6750	143635	284900	351281700							
84	3950	120544	239100	294810300							
85	4390	67204	133300	164358900							
86	6470	91707	181900	224282700							
87	2020	47739	94690	116752770							
88	3900	46811	92850	114484050							
89	5980	87270	173100	213432300							
90	5980	54348	107800	132917400							
91	1430	33431	66310	81760230							
92	1370	25245	50070	61736310							
93	5340	93550	185600	228844800		186854	111899	1653			
94	2209	37713	74804	92233788		37713	12642	187			
95	6205	130842	259525	319994646		129757	259525	3833			
96	8884	118505	235056	289823432		118505	469165	6930			
97	7052	102062	202440	249609050		102062	365461	5398			
98	7000	122065	242100	298509300		122197	264146	3902			
99	4470	108157	214500	264478500		107811	90431	1336			
2000		No Data Available Yet									

DATA SOURCES:
Data from USGS Water Resource Data Publications, Volume 2
Data from RNSP Data Release on Rainfall, Streamflow and Suspended Sediment Transport in the Redwood creek Watershed Humboldt County, California 1990 through 1998

[a] Discrepancy in published USGS data.
[b] USGS published values for total load is differs from the sum of the suspended and bedload load due to rounding errors in the program.

WATER YEAR	Sediment Discharge (October-April)					
	Streamflow	Suspended (Qss)		Bedload (Qbd)	Total Load	Qs/Qw
	(cfs-days)	(tons)	(tons/mi²)	(tons)	(tons) [b]	ons/cfs-days)
54						
55						
56						
57						
58						
59						
60						
61						
62						
63						
64						
65						
66						
67						
68						
69						
70						
71						
72						
73	65540	1884485	27836			
74	145305	657414	9711	301500	959700	7
75	113887	694218	10254	242700	937514	8
76	63170	81155	1199	21284	102450	2
77	11620	1162	17	717	1880	0
78	88920	122146	1804	65950	188104	2
79	40719	41315	610	26026	78769	2
80	91912	162566	2401	36110	198660	2
81	45713	46792	691	7140	53877	1
82	124268	255056	3767	74039	328605	3
83	131297	373940	5523	85292	458310	3
84	120542	173401	2561	56666	230360	2
85	63422	81351	1202	8956	90234	1
86	83886	239826	3542	24563	264261	3
87	44747	12310	182	3654	15967	0
88	37076	28769	425	5623	34342	1
89	82174	89666	1324	6385	96095	1
90	41912	32804	485	1618	34411	1
91	25986	5108	75	420	5527	0
92	22295	2870	42	176	3049	0
93	74178	106057	1567			
94	32548	12517	185			
95	114777	258249	3815			
96	109156	464757	6865			
97	105941	365345	5397			
98	111802	263569	3893			
99						
2000						

ATTACHMENT 2: Redwood Creek and Salmon Report

We recommend the report *A Study in Change: Redwood Creek and Salmon* be reviewed for scientific credibility before any board uses the report's conclusions for action or policy decisions. Our primary issues with the Redwood Creek and Salmon report (herein referred to as the RCLA report) are:

1. The report does not accurately relate the finding of research performed by various agencies and universities. Many study results and citations are used out of context or conclusions are distorted and misinterpreted. In some cases, the report presents only selected portions of the study and fails to disclose all the relevant conclusions reached by the original researchers (see example next page).

2. The report dismisses decades of research by U.S. Geological Survey, the National Park Service and universities documenting the effects of land use and cumulative watershed effects from timber harvesting and road building in the Redwood Creek basin. Throughout the RCLA's report, words such as "perceptions", "assumptions", "past speculations", and "mere speculation" are frequently used to discredit past scientific, quantitative, peer-reviewed studies.

3. The report concludes that timber harvest and road building had little effect on the erosional processes and watershed response in the Redwood Creek basin during past large floods. They suggest that the watershed response to past large floods, such as the 1964 flood, was within the "range of natural variability" for unmanaged watersheds where erosional processes are naturally affected by natural climatic or geologic events, stand replacement forest fires, and even indigenous use. However, widespread timber harvest and road building can change the frequency and timing of disturbances compared to natural disturbance regimes. In addition, chronic alterations of lower-magnitude processes (seasonal or diurnal patterns of discharge, temperature and sediment mobility) can result in more severe effects on the integrity and resilience of aquatic ecosystems than large floods and other catastrophic events (see Frissel and Bayles (1996) and Yount and Niemi, 1990 for further discussion).

4. The report does not address past cumulative watershed response or the potential basin response to future large storms. Since 1975, Redwood Creek has experienced a relatively low to moderate flow regime. With the exception of the 1997 flood (12-year recurrence interval), peak flows during the last 26 years have all been less than a 5-year recurrence interval. The landscape and roads have not been tested by a large flood, and monitoring and data collection have occurred during a fairly benign storm period.

EXAMPLE: Landslide Processes in Redwood Creek.

In a discussion of landslide processes in Redwood Creek, the RCLA's report describes landslides as being common and naturally widespread throughout the basin with little connection to land use. The RCLA's report states, "*one report puts the number of active landslides in the Redwood Creek basin at 551, covering 10-16 percent of the total basin area*" (RCLA's report page 9, paragraph 1). The author cites Harden, Colman and Nolan (1995). The statement is partially true, but the reference is used out of context and doesn't capture the complete conclusion of the original authors.

In a discussion of landslide history, Harden, and others (1995) state, "*About 100 unvegetated landslides, mainly debris slides, can be seen along the Redwood Creek channel on 1947 aerial photographs, whereas 415 active landslides appear on the 1976 photographs*" (page G6). Harden, and others (1995) point out that this was a four-fold increase in landsliding along the main stem of Redwood Creek between 1947-1976 (page G11) and a similar increase of streamside landslides along many tributaries in the basin have been documented (page G6). They also concluded that the "*increased streamside debris slides adjacent to the Redwood Creek channel from 1947-1975 can be attributed to the combined impacts of major floods, particularly the flood of 1964, and to intensive timber harvesting.*"

The discussion of landslides, or "agents of change," in RCLA's report avoids reference to timber harvest and cumulative effects. The RCLA's report states, "*the probability that a landslide or debris flow occurs in Redwood Creek increases in the downstream direction of the channel due to an increase in the number of potential landslide source areas and increased probability of large storms with larger drainage area*" (RCLA's report page 9, paragraph 3). No citation is included to support this conclusion and it represents the author's reinterpretation of the research and conclusions of Harden, and others (1995).

Harden, and others (1995) documented and reported the trend of landslide activity increasing in a downstream direction between 1947 and 1975, and provided a very different conclusion. For the landsliding observed during the 1972 and 1975 floods, they described the trend as follows: "*Several factors may have contributed to this shift. First, most unstable slopes in upper reaches already may have failed by 1966, presumably during the intense rainfall of 1964. Second, streamside timber harvesting was concentrated in the lower Redwood Creek basin after 1966. Finally sediment deposited in the upper reaches during the 1964 flood has migrated to the lower channel since that time. The increased sliding in the lower reaches since 1966 may be partly a response to the channel widening and under cutting of slopes that resulted from the massive influx of sediment related to the 1964 flood.*"

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Yount J.D., and Niemi, G.J. 1990. Recovery of Lotic Communities and Ecosystem from Disturbance-A Narrative Review of Case Studies. Environmental Management. V. 14. No. 5. pp. 547-569.

ATTACHMENT 3: Chronic Turbidity

1) Abstract: Baseline Suspended Sediment Characteristics and Juvenile Salmonids, North Coastal California (Word Filename: Turbidity Abstract-Klein NSA.doc)

2) Paper: Suspended Sediment Concentrations and Fluxes in Redwood Creek Tributaries (Word Filename: TurbidityRWCTribs.doc)

3) Figures for paper (Word Filename: Turbidity Fig. 1-7.doc)

ATTACHMENT 3: CHRONIC TURBIDITY

BASELINE SUSPENDED SEDIMENT CHARACTERISTICS AND JUVENILE SALMONIDS, NORTH COASTAL CALIFORNIA

Randy Klein
Redwood National and State Parks

Bill Trush
McBain and Trush, Inc.

Extended exposure to suspended sediment concentrations above 20 mg/l can significantly affect the ability of juvenile salmonids to forage, and ultimately reduce their survival. This connection between exposure and survival may be the best available quantitative linkage for objectively assessing cumulative watershed effects on a biological 'beneficial use.' Although data characterizing suspended sediment transport conditions in streams draining unmanaged basins in north coastal California are scarce, several stream gaging stations in Redwood National and State Parks provide such data. The objectives of this study were to: 1) establish a baseline condition for suspended sediment concentration/duration regimes in unmanaged, predominantly old-growth redwood basins, 2) compare similar data from managed streams, and 3) assess potential reduction in salmonid survival attributable to cumulative watershed effects. Chronic exposure to relatively low suspended concentrations over extended periods (e.g., winter baseflow periods between storms) may affect salmonid survival more than much higher suspended concentrations occurring over short durations (during storms). Focusing suspended sediment (or turbidity) sampling on the hydrograph component(s) with particular biological significance provides a 'minimalist' sampling strategy, one that lowers costs relative to more complete monitoring of the winter hydrograph. Consequently, for an equivalent amount of money, more streams can be sampled, suspended sediment regimes can be developed relatively quickly (often in one season), and monitoring results can more quantitatively address management thresholds.

Presented at: Northwest Scientific Association 2001 Annual Meetings,
Humboldt State University, Arcata, CA,
March 21-24, 2001

http:// www.humboldt.edu/~scs6/session2abs.html#7

ATTACHMENT 3: Chronic Turbidity

Suspended Sediment Concentrations and Fluxes in Redwood Creek Tributaries

Randy Klein
Hydrologist
Redwood National and State Parks

May 8, 2001

Introduction

Increased erosion and sedimentation from land management activities has long been an issue of concern with regard to the health and sustainability of aquatic ecosystems. Until recently, the primary issues of concern have centered on stream channel geomorphic changes (bank erosion, aggradation, loss of channel complexity, etc.) and streambed textural changes (fine sediment filling pools and infiltrating the channel bed, fining of riffles, etc.); things we can see and measure when we visit streams during low flow periods. Contemporary views of the effects of sedimentation have strong biases toward the dramatic, i.e., large storms causing large inputs of sediment to channels, such as occurred during and after the infamous 1964 flood. Sediment budgets have been employed as an effective tool to quantify sediment inputs and the role of management in such large events. The yardstick by which we typically evaluate the magnitude of effects is the volumetric proportion of the sediment budget accounted for by a particular erosion process or management practice. However, while geomorphically large events are certainly important determinants of the health of aquatic ecosystems and sediment budgets are fundamental tools for evaluating such events, they do not tell the whole story.

Between-storm suspended sediment transport at low concentrations (compared to storm transport), although representing a small fraction of the sediment budget, can have disproportionately large effects on aquatic biota. Suspended sediment concentrations above about 27 mg/l (a relatively low concentration compared to what most of us would consider turbid) affect the ability of juvenile salmonids to forage for food. Concentrations exceeding such a threshold for extended periods suppress feeding ability and growth and ultimately reduce the chances for successful completion of the salmonid reproductive cycle (Newcombe and Jensen, 1996). Large smolt outmigrant size has been shown to lead to higher chances of a fish returning as a spawning adult, so suppression of feeding and growth for a cohort can result in poor escapement, even if smolt outmigration numbers are relatively high.

By adding very fine (suspendable) sediment to the stream channel system over and above background levels, land management has a tendency to both elevate suspended sediment concentrations during winter storms and increase the duration of turbid flows between storms. In addition to effects on juvenile fish feeding ability, turbid water diminishes the amount of sunlight reaching the streambed which depresses primary production. Thus, chronic turbidity both diminishes the time fish are able to forage for food and may also reduce the supply of food during those times. When considered in combination (either additively or synergistically) with other impacts to freshwater habitat (e.g., loss of LWD, streambed sedimentation, elevated summer water temperatures, elimination of refugia, etc.), the net effect may be conditions quite hostile to salmonid reproduction.

Suspended sediment concentrations for unmanaged and managed streams

Although data characterizing suspended sediment concentrations in streams draining unmanaged basins in north coastal California are scarce, several stream gaging stations in the Redwood Creek basin provide such data. Several other gages, also on Redwood Creek tributary basins, provide data on managed streams for comparison. Tributary basins within the Redwood Creek watershed that provide suspended sediment data useful for characterizing near-pristine conditions are Little Lost Man Creek and Upper Prairie Creek. Panther Creek, Coyote Creek, and Lacks Creek provide data from streams draining watersheds that have historically been, and continue to be, managed primarily for timber production. In addition to the Redwood Creek tributaries, Elder Creek, a pristine tributary to the South Fork Eel River possessing a long record of discharge and suspended sediment data, was included to augment the data base for unmanaged streams for comparison with unmanaged streams. Basic watershed information for each stream is presented in Table 1.

Table 1. Watershed characteristics for gaged Redwood Creek tributaries and Elder Creek.

Stream	Drainage Area (mi^2)	Basin Elev. Range (ft., NGVD)	Mean Annual Precip. (in.)	Mean Basin Slope (%)	Primary Geologic Units (ratio)
Upper Prairie	4.0	250-870	68	2.82	Gold Bluffs formation/Coherent Unit of Lacks Creek (80/20%)
Little Lost Man	3.5	50-2130	61	8.67	Coherent Unit of Lacks Creek
Panther	6.1	400-2450	73	10.79	Redwood Creek Schist
Coyote	7.8	450-3260	70	16.53	Incoherent Unit of Coyote Creek
Lacks	16.9	480-4100	70	9.05	Incoherent Unit of Coyote Creek/ Coherent Unit of Lacks Creek (60/40%)
Elder	6.5	1391-4200	52	11.24	

Natural variability in suspended sediment characteristics

Suspended sediment concentration-duration characteristics of streams are subject to natural variability, both within and among different basins, and this natural variability can confound attempts to isolate effects of management. Generally, the duration of turbid flow is directly correlated with basin size (streams draining larger basins tend to remain turbid longer following cessation of rainfall). Three possible reasons for this are: 1) as basin size increases, travel time from source areas to the outflow (measurement) point is greater (longer suspended sediment flushing time required once source areas become inactive following cessation of rainfall), 2) the proportion of wetted channel area composed of transient storage zones (backwater areas that recirculate turbid flow into the main current) probably increases with stream size, and 3) there is a greater prevalence of fine sediment source areas that remain active once rainfall has ceased in larger basins (in-channel sources such as landslide toes and flood terraces which, because they are in direct contact with flowing water, can continue to provide suspendable sediment long after rainfall ceases). Thus, expecting suspended sediment concentration-duration characteristics between basins of vastly different size is inappropriate and will result in an inability to isolate land use effects. The basins examined here fall within a narrow range of sizes and consequently basin scale influences, if they exist at all, are minimal.

Obviously, the geologic and soils makeup of a basin has a large effect on erodibility of hillslopes and consequently on suspended sediment concentrations of basin outflows. Soils and bedrock in the northcoast region as a whole are generally considered to be highly erodible, but there is considerable within-region variability. Similarly, hillslopes are generally steep, but average watershed slopes can be quite variable. Climate within the region is also variable, as suggested by the variations in mean annual precipitation shown in Table 1. With varying rainfall characteristics, surface runoff will vary as well in terms of flood frequencies, flow durations, and other expressions of runoff.

Clearly, using a single reference basin for evaluating the effects of land use on suspended sediment concentration-duration characteristics will severely limit opportunities for evaluating land use effects to a small number of similar basins. In this study, we attempted to make a broader evaluation by using three reference basins that spanned a considerable range of natural variability in factors that control suspended sediment concentrations.

Suitability of selected reference streams as controls

While natural variability in factors that determine the suspended sediment transport characteristics of streams in the northcoast region is potentially large, this variability can be captured and quantified if representative control basins reflecting this variability are monitored. The characteristics given in Table 1 indicate that the reference basins included here span a wide range of natural factors that control suspended sediment characteristics. For example, Upper Prairie Creek is a relatively low gradient watershed with relatively non-erodible soils and geology, thus representing a relatively 'clean' reference stream. In contrast, Little Lost Man Creek is a steep basin underlain by fairly erodible geology and soils, and the main channel follows a fault lineament; characteristics that indicate a relatively 'dirty' reference condition.

The geologic makeup of Elder Creek is typical of erodible terrain in the upper Eel River watershed, but has lower rainfall than the Redwood Creek tributaries. Also, Elder Creek is truly pristine, whereas Upper Prairie and Little Lost Man Creeks have had low levels of disturbance (limited road construction, minor timber harvest). Because the reference basins included in this analysis span much of the range of natural variability in baseline suspended sediment characteristics found in the northcoast region, managed basins with suspended sediment and turbidity characteristics that lie well above this range probably do so because of management effects.

Methods of data collection and analysis

Stream discharge and suspended sediment data are collected at established gaging stations on the Redwood Creek tributaries by RNSP staff. For the most part, USGS protocols are used in data collection and quality control. Stream stage is automatically recorded on 0.5 hour intervals (essentially continuous) using pressure transducers and data loggers. Stage-discharge rating curves, developed from discharge measurements and simultaneous stage readings, allow calculation of continuous discharge from the stage record. Data are downloaded in the field at approximately two-week intervals. Stream water sampling for suspended sediment concentration is done both manually, during station visits, and using an automated pumping sampler controlled by the data logger. A stage-based sampling routine is used to control the pumping sampler that increases sampling frequency with increasing stage above a pre-set threshold. Manual, depth-integrated, full-width samples are also collected. These samples are used, along with automated samples, for determining suspended sediment flux and defining rating curves, but are also used for calibrating samples collected automatically.

Suspended sediment concentration ('SSC', mg/l) was determined from the samples using a standard vacuum filtration technique and 1.5 micron filters. Regression of SSC on discharge provided SSC rating curves Fig. 1) that were used to estimate continuous SSC data from the discharge record. When plotted, these data compose a 'sedigraph' reflecting the variation of SSC over a period of interest. From a sedigraph, or the data used to construct one, the length of time concentrations exceed some threshold of interest can be determined. Sedigraphs for tributaries to Redwood Creek were computed using instantaneous discharge data, but the sedigraph for Elder Creek was developed from daily average flows (readily available).

For the five streams included here, the chosen threshold of 27 mg/l was plotted on each stream's sedigraph and storm periods where this concentration was exceeded were delineated. The number of days above threshold were tallied by period and for the year as a whole. For the time being, only data from water year (WY) 1999 were examined. Similar data from other years will be compiled as time allows.

In addition to the sedigraphs, the annual suspended sediment flux for the four Redwood Creek tributaries plus Coyote Creek (abandoned after WY 1995) was calculated for the period of WY 1992-2000. Unlike the sedigraphs, which relied on suspended sediment rating curves, annual flux was calculated by integrating measured concentrations from WY 1999 samples with the WY 1999 discharge record using the subdivided day method (USGS, 1972). In applying this method, estimated concentrations were added into the record to supplement the measured concentrations to develop a more complete sediment concentration data set. Most estimated points were added during stormflow recession to bring concentrations down after storm sampling had ceased. Without adding estimated concentrations between storms, interpolation between storm samples would have resulted in gross overestimation of suspended sediment flux. With complete suspended sediment concentration and water discharge data, suspended sediment flux was calculated by multiplying the two for periods bracketed by either measured or estimated concentrations using linear interpolation. Total annual flux was calculated by summing the individual fluxes bracketed by measured or estimated concentrations, and is expressed as both total flux in tons transported past the gaging stations and as tons per square mile of basin area.

Results of Data Analysis

The suspended sediment rating curves shown in Figure 1 show the differences in SSC as a function of stream discharge for the five streams. Despite the scatter of rating points, clear differences are evident between the two managed streams (PAN and LAC) and the three reference streams (ELD, PRU, and LLM), with the two managed streams exhibiting much higher SSC at a given discharge (note: discharge is shown in cfs/mi^2 to better compare streams with different drainage areas).

Sedigraphs for WY 1999 are shown in Figures 2-6. The 27 mg/l threshold is shown on each sedigraph along with the number of days exceeding the threshold. Figure 7 shows the number of days each of the streams was above threshold in WY 1999, both for individual storm periods and for the year as a whole. Table 2 lists the numbers of consecutive days above 27 mg/l calculated from the sedigraphs.

Table 2. Consecutive days suspended sediment concentration above 27 mg/l for water year (WY) 1999 in four Redwood Creek tributaries and Elder Creek.

Storm Period in Water Year 1999	Consecutive Days Above 27 mg/l				
	ELD	PRU	LLM	PAN	LAC
Nov. 6-10	0	0	0	0	3
Nov. 17-19	0	1	1	0	2
Nov. 21-Dec. 17	2	9	17	18	26
Jan. 15-Feb. 2	1	7	1	16	13
Feb. 6-Feb. 16	4	8	6	10	10
Feb. 16-Mar. 7	4	0	0	20	20
Mar. 7-Mar. 24	0	0	0	8	18
Mar. 24-Apr. 25	0	0	0	28	32
May 2-9	0	0	0	1	7
May 16-19	0	0	0	0	4
Year Total	**11**	**25**	**25**	**101**	**135**

As shown in Figure 7 and Table 2, the amount of time when the threshold SSC of 27 mg/l was exceeded was much lower in the reference streams (ELD, PRU, LLM) than in the managed streams (PAN and LAC). While some of the differences may be explained by natural sediment-producing characteristics between streams, we believe a large source of the difference is due to timber harvest and related activities. As mentioned earlier, the reference streams drain watersheds that span a range of inherent (natural) sediment-producing characteristics, thus there is likely some overlap in inherent sediment-producing characteristics (geology, soils, rainfall, etc.) between the reference and managed watersheds. However, there is no corresponding overlap in the time above threshold SSC, indicating that management likely explains a good part of the disparity in WY99 suspended sediment durations.

Implications for watershed management

The results above clearly show that land management is having dramatic effects on suspended sediment concentrations and fluxes. However, before deciding on a course of action to correct the problem, we must first ask and answer this question: what are the main sources and land use practices responsible for chronic turbidity? Are they derived from: 1)current practices, such as winter use of roads, broadcast burning, tractor yarding, 2) fresh erosion on relict features from past land uses, such as old, abandoned roads and skid trails, 3) secondary erosion processes (surface, rill, and gully erosion) on active landslides, 4) remobilization of fine sediment contained in flood terraces deposited in the 1964 and other large floods, or 4) particle attrition as bedload-sized material moves downstream? Answering such questions is pre-requisite to determining if/how management practices and intensities should be changed to deal with chronic turbidity. In any case, the WY99 suspended sediment example strongly suggests that management is having a significant effect on suspended sediment production in the Redwood Creek watershed, even in a relatively moderate winter runoff period.

Figure 1. Suspended Sediment Rating Curves for Five Northcoast Streams

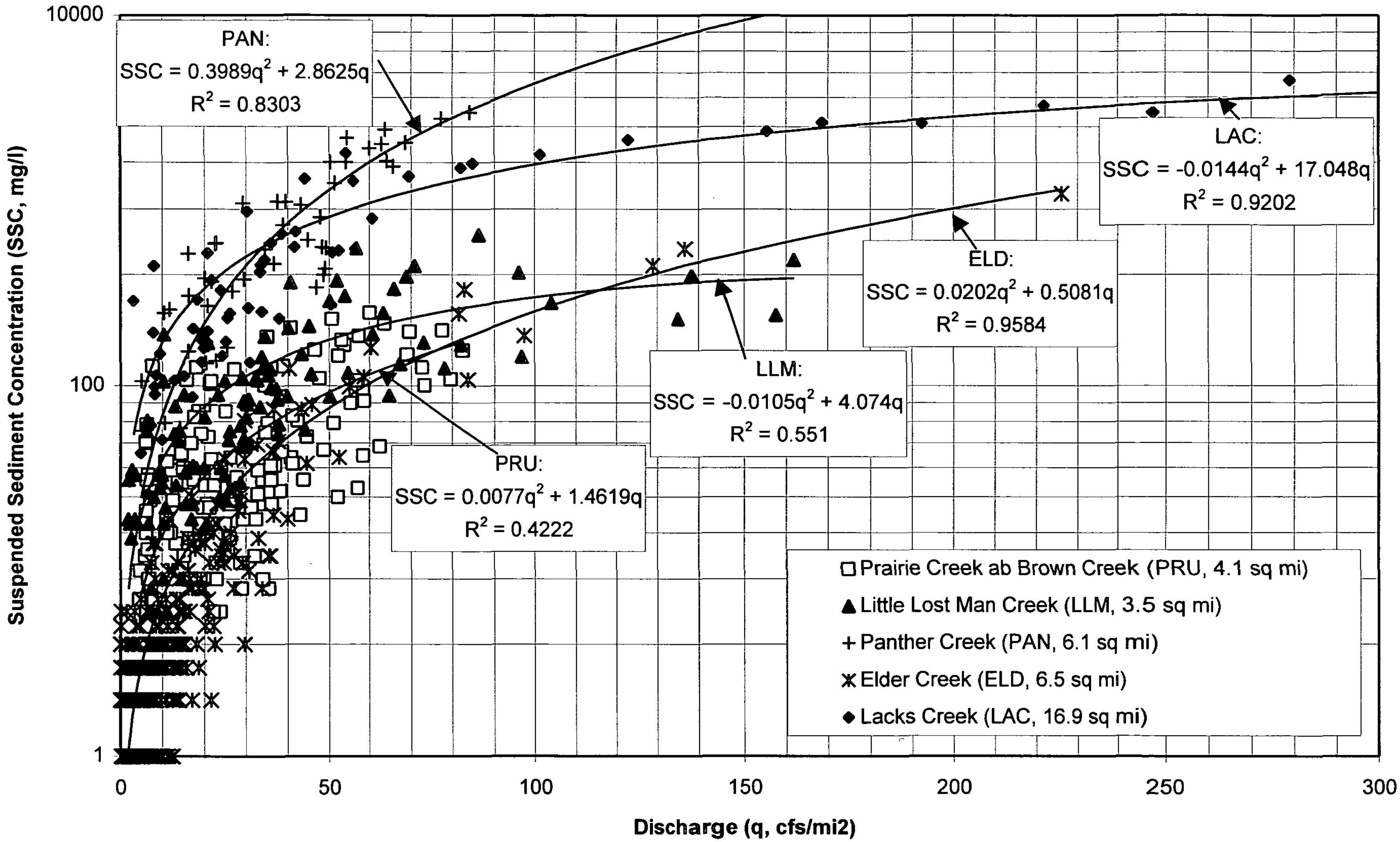


Figure 2. Sedigraph for Elder Creek near Branscomb, WY99 (unmanaged; DA = 6.5 mi^2; rating points from WY71-96)

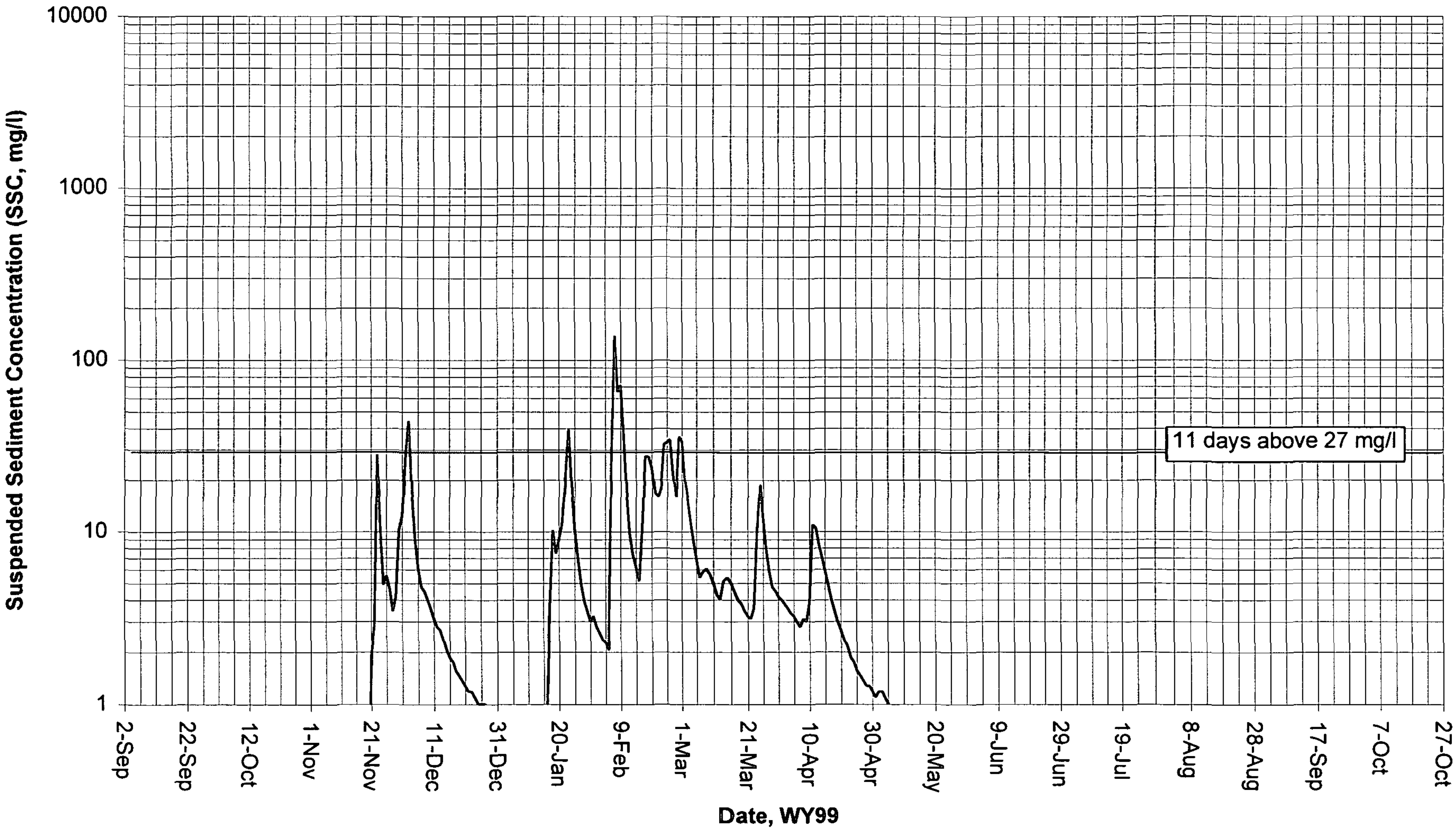


Figure 3. Sedigraph for Upper Prairie Creek, WY99 (unmanaged; DA = 4.02 mi^2)

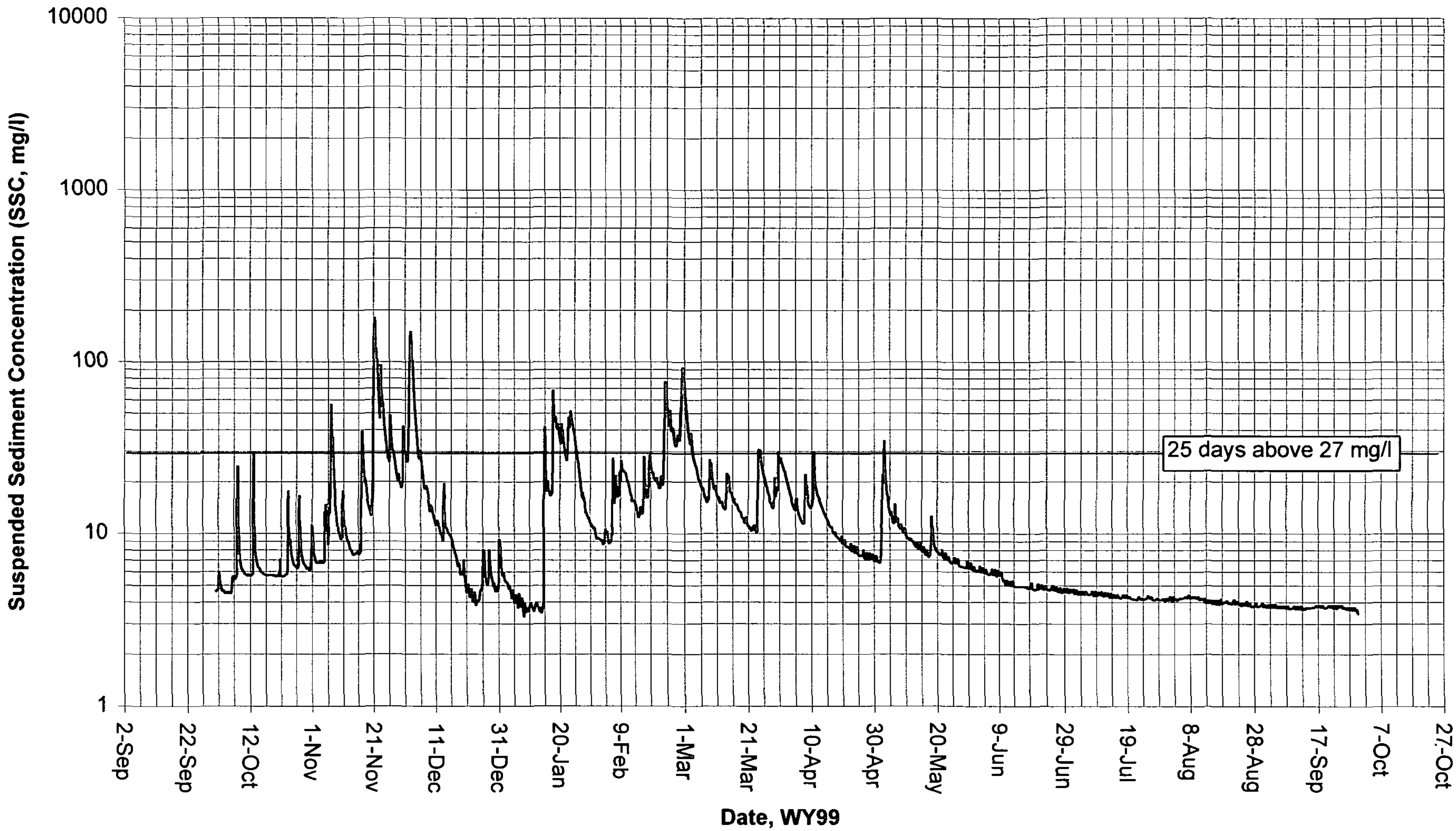


Figure 4. Sedigraph for Little Lost Man Creek, WY99 (unmanaged; DA = 3.46 mi^2)

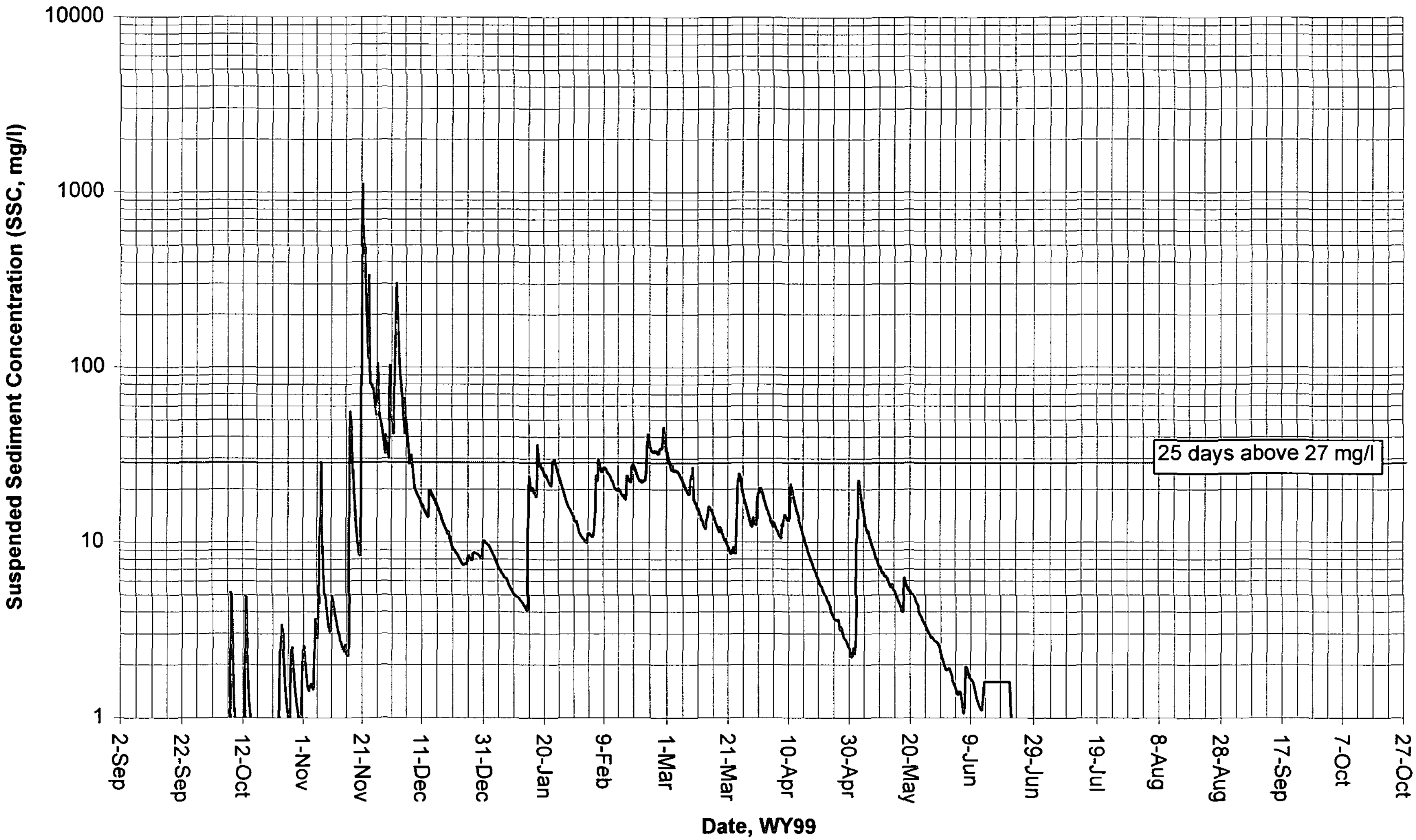


Figure 5. Sedigraph for Panther Creek, WY99 (managed; DA = 6.07 mi^2)

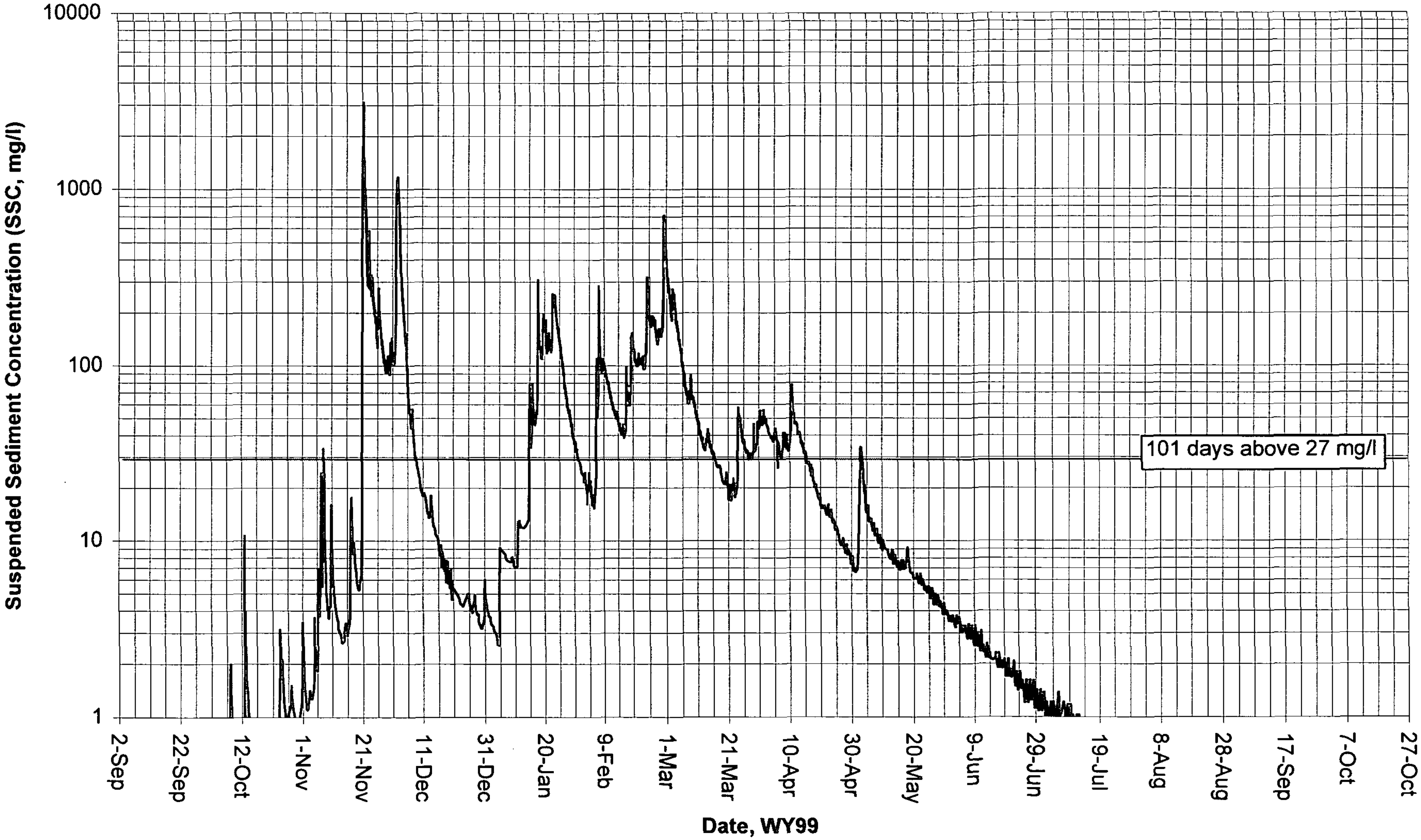


Figure 6. Sedigraph for Lacks Creek, WY99 (managed; DA = 16.9 mi^2)

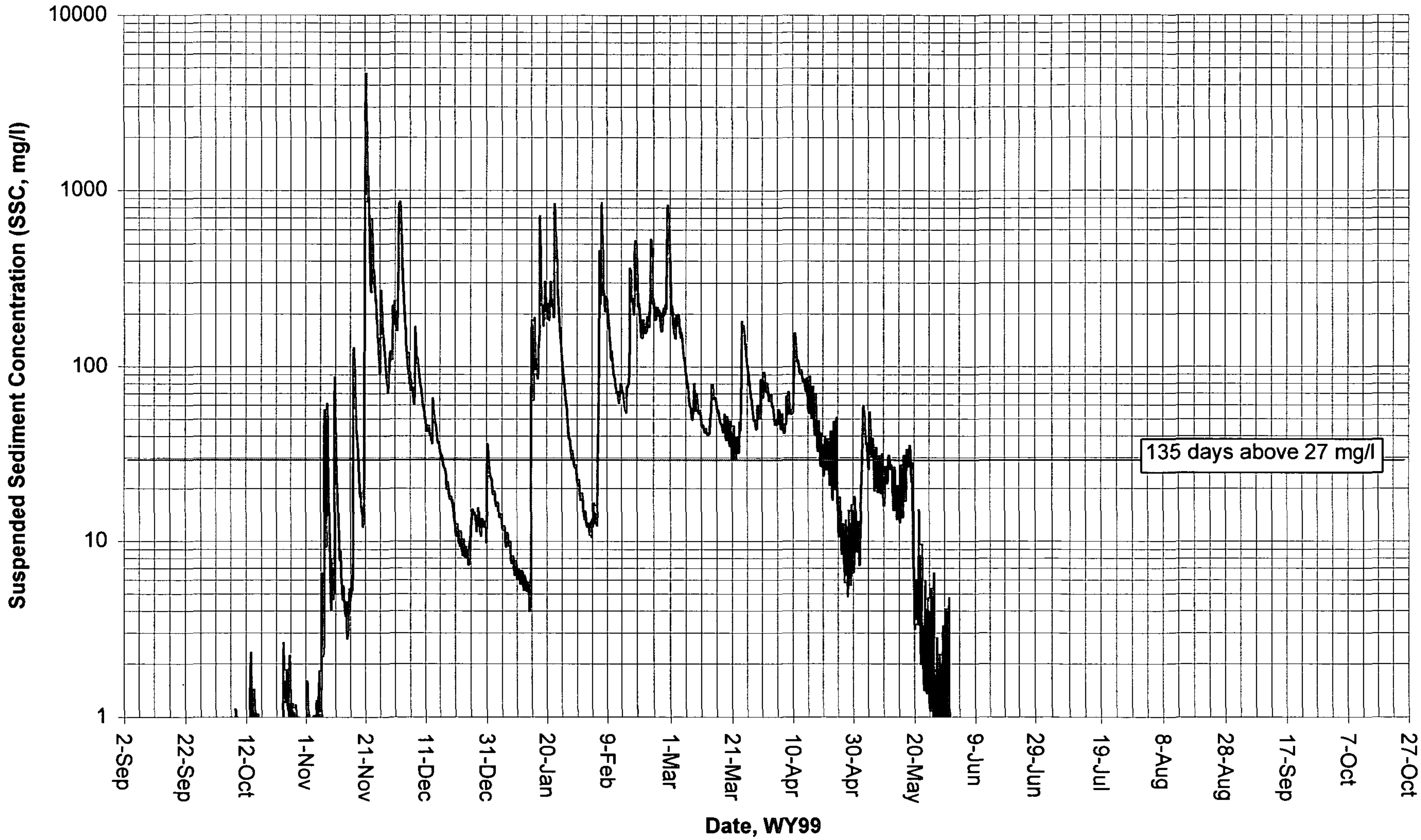
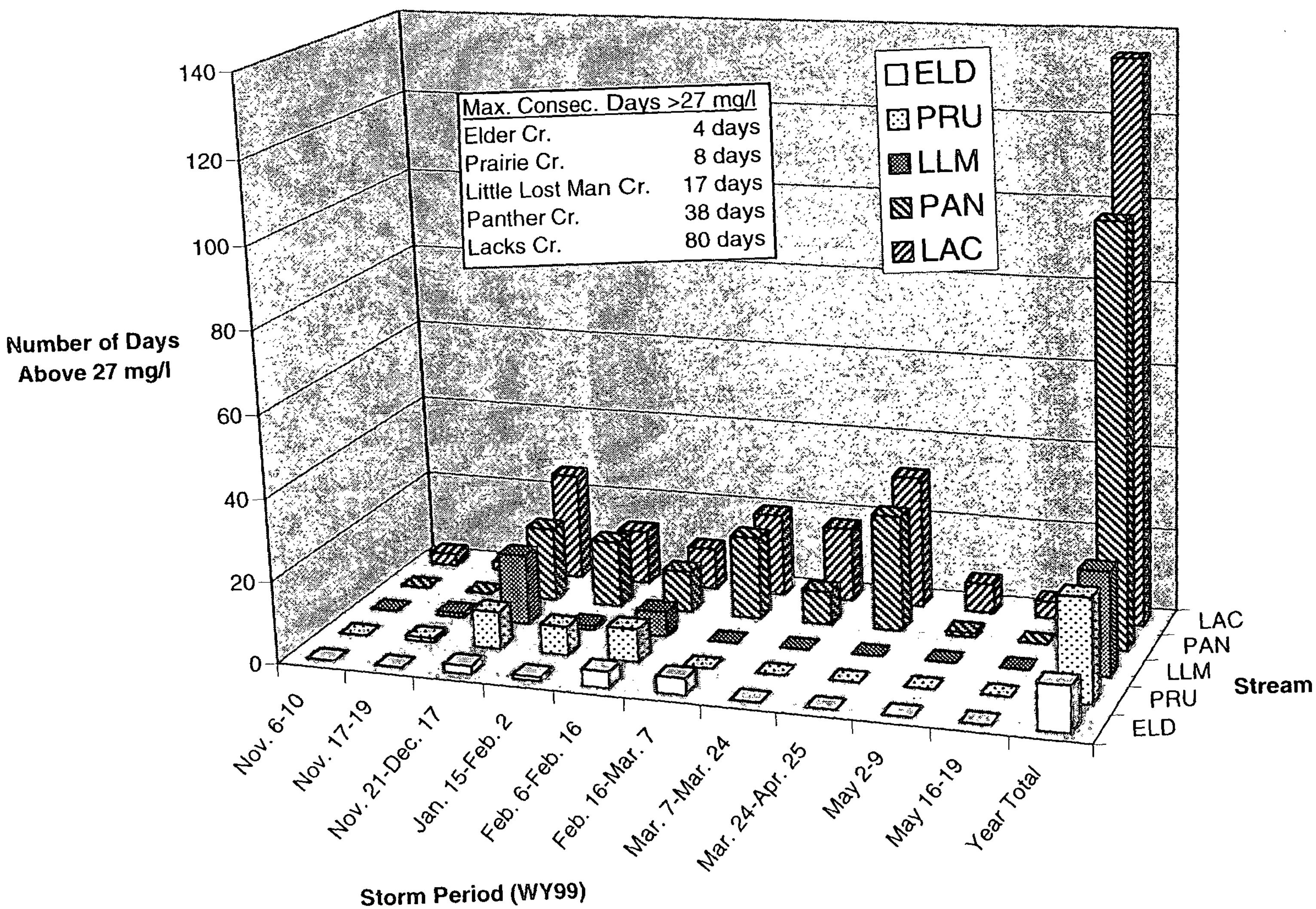


Figure 7. Number of Days SSC Above 27 mg/l for Five Northcoast Streams, WY99



ATTACHMENT 4: Redwood Creek Long-Term Channel Stability Monitoring

1. RNSP Progress Report: Long-Term Channel Stability Monitoring on Redwood Creek, 1995-1997 (Word Filename: RWCXS95-97 RPT.doc)

2. Summary of Channel Changes at Redwood Creek Cross Sections (Tables 1-3) (Word Filename: RWCXS Summary 98-00.doc)

3. Plots of Redwood Creek Cross Sections Surveyed in WY 00 (Word Filename: RWCXS-plots00.doc)

A network of 58 channel cross sections has been monitored on Redwood Creek since 1973, and these surveys quantify changes in channel geometry (width, bed elevation, thalweg depth and position), net changes in area (scour and fill) and document long-term channel trends. Twenty-seven years of data currently exist to: 1) quantify channel response since 1973, 2) describe the movement of streambed sediment through the channel and, 3) provide baseline data for the next large flood. This attachment contains a progress report on Long-Term Channel Stability Monitoring on Redwood Creek, 1995-1997, a summary of channel changes from WY 98-00, and cross section plots from WY 00. Cross sections plots from 1997-1999 are available on request.

Channel cross sections document how high influxes of sediment from hillslopes and stream channels during large storm events in the Redwood Creek basin have persisted for decades. After more than 35 years, the effects of the 1964 flood continue to impact the main channel on park lands in lower Redwood Creek. Cross section data indicate that channel aggradation peaked in the early 1990's in this lower most section. However, no significant channel scouring has occurred in recent years and the channel remains sediment impaired. Madej (1999) documented the increase in residual pool depth on sections of Redwood Creek from 1975 to 1995, but following the 1997 flood, residual pool depths decreased to depths typical of the early 1980's. Madej (1999) demonstrated that even a moderate flood was capable of reversing channel recovery. The persistence of sediment in Redwood Creek for more than 3 ½ decades has likely impacted many life cycles of steelhead and salmon.

While the channel bed has returned to a probable pre-disturbance elevation in some sections of upper reaches, bed elevation is just one measure of channel recovery. For most of its length, the channel still remains wider than pre-1964 conditions. In addition, the original characteristics of the riparian vegetation (old-growth coniferous forest) have not been reestablished. The current riparian forests along many of the main stem and tributary reaches are dominated by alders and other hardwoods.

Long-Term Channel Stability Monitoring on
Redwood Creek, 1995-1997
Progress Report

September 1998

Vicki Ozaki and Carrie Jones
Geologic Services Branch, Resource Management & Science Division

I. Introduction

Redwood Creek, like many streams in north coastal California, has experienced dramatic changes in channel configuration and sediment load since the mid-1950's. During the last four decades, a series of large floods (in 1953, 1955, 1964, 1972 and 1975) combined with the advent of widespread timber harvesting and road building caused extensive erosion which contributed high volumes of sediment (sand and gravel) to Redwood Creek and its tributaries. Channel characteristics reflecting this increase of sediment include channel widening, increased stored sediment in the channel, increased streambed elevation, and decreased streambed material size (Janda, 1977, Nolan and Marron, 1995).

Concern about the effects of channel changes on the riparian and aquatic resources of Redwood National Park prompted the initiation of many studies in 1973 to document the magnitude and cause of change in the Redwood Creek basin (Nolan and Marron, 1995). Monitoring of long-term channel stability in Redwood Creek was initiated by the U.S. Geological Survey (USGS) in cooperation with the National Park Service in 1973. The purpose of the study was to document channel response to large storm events and land-use in the Redwood Creek basin.

Surveys at channel cross sections were used to document and quantify changes in channel geometry (width, bed elevation, thalweg depth and position), net changes in area (scour and fill) and determine long-term channel trends. Twenty-four years of data currently exist to: 1) quantify channel response since 1973, 2) describe the movement of streambed sediment through the channel and, 3) provide baseline data for the next large flood. This report provides a brief overview of past channel response and summarizes the most recent channel changes observed at Redwood Creek cross sections from 1995 to 1997.

II. Study Area

The Redwood Creek basin drains an area about 738 km^2 (285 mi^2) in north coastal California (Figure 1A). The main channel is 108 km (65 mi) long and roughly bisects the basin. Channel gradient decreases from 12 percent in the headwaters to 0.10 percent near the mouth (Figure 1B). Total basin relief is 1615 m (5,300 ft) and the average hillslope gradient is 26 percent. The basin receives about 200 cm (80 in) of rainfall annually, most of which falls as rain between October and March.

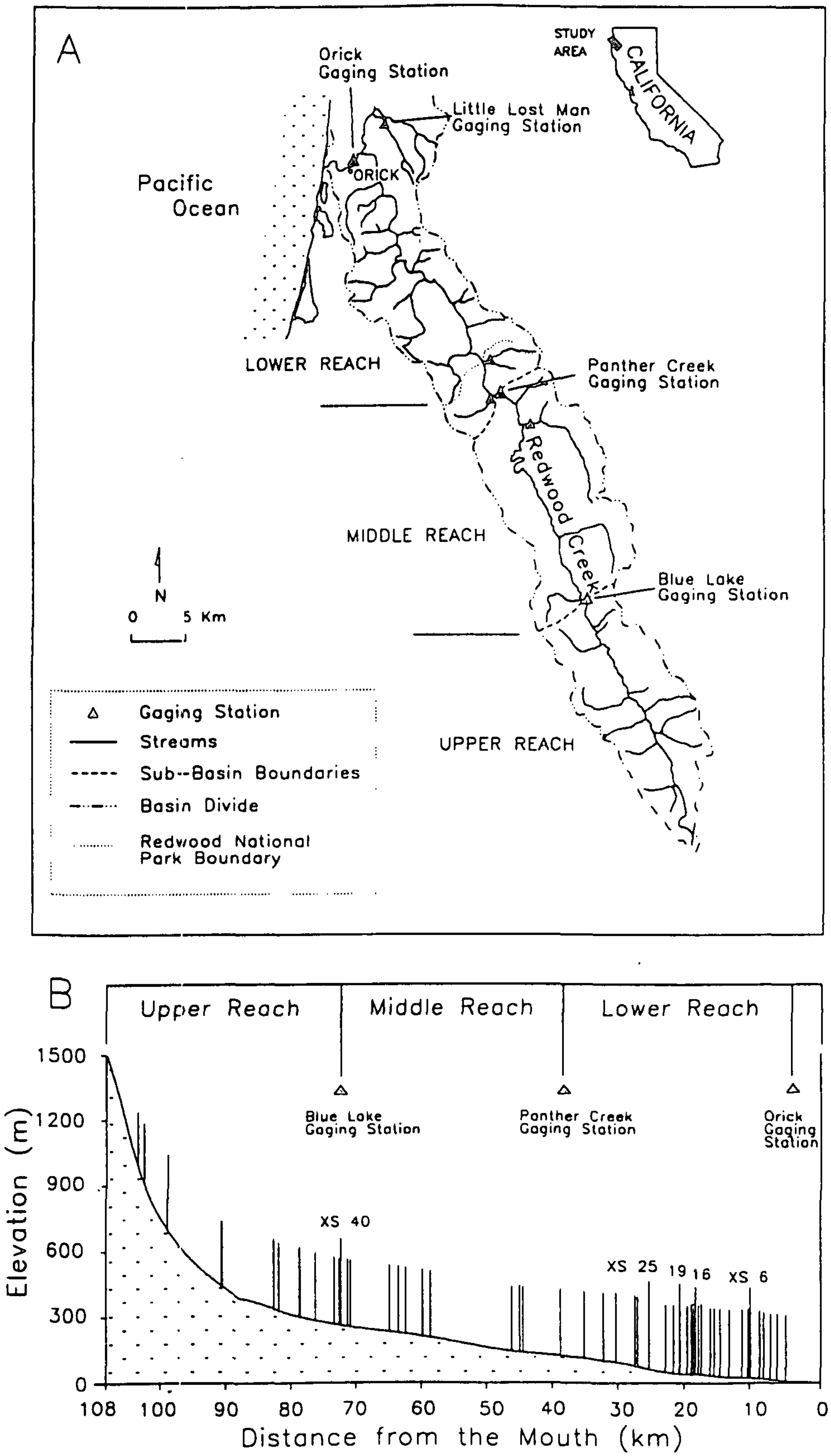


Figure 1. (A) Location map showing Redwood Creek drainage basin, study reaches and gaging stations. (B) Longitudinal profile of Redwood Creek. Cross section locations are represented by vertical lines on the profile.

For most of its length, Redwood Creek follows the trace of the Grogan Fault which juxtaposes sandstones and siltstones on the east side of the basin against schist on the west side. The bedrock is part of the Franciscan Assemblage of Jurassic and Cretaceous age (Bailey *et al.* 1970) and is pervasively sheared and fractured. As a result of periodic large floods and highly fractured bedrock, the landscape is highly susceptible to landslides and gullying. Annual suspended sediment discharge of Redwood Creek (1000 to 2500 Mg/km^2/yr of fine sand, silt and clay) is among the highest measured in the United States for basins of this size, outside of rivers draining active glaciers or volcanoes.

Aerial photographs from 1936 and 1947 show that prior to the advent of commercial timber harvesting, 82 percent of the basin was covered with old-growth redwood and Douglas fir forest and the remaining acreage was oak woodlands and prairie grasslands (Best, 1984). Redwood Creek was narrow and sinuous in most reaches, with a thick canopy of trees over much of its length. Large-scale timber harvesting began in the early 1950's (Figure 2). By 1966, 55 percent of the coniferous forest had been logged, and by 1992, about 80 percent of the forest was logged, largely by clear cutting. Thousands of kilometers of logging roads were built during the last forty years and the vast majority was built prior to forest practice rules dealing with road standards.

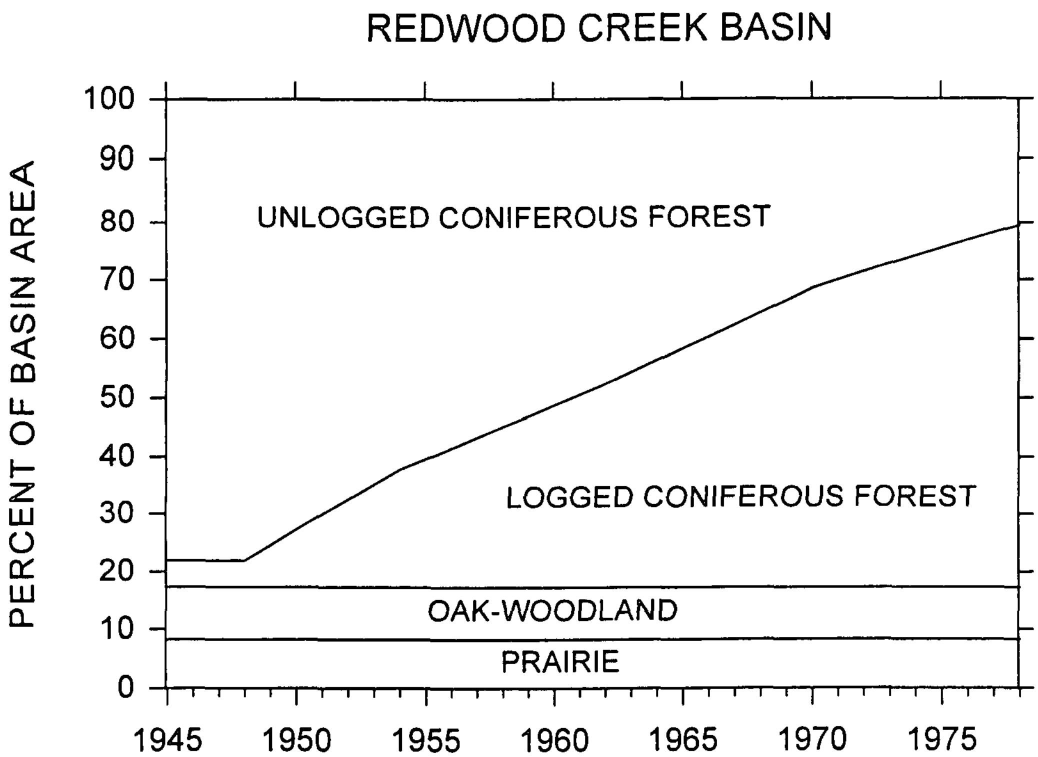


Figure 2. Change in basin area covered by old-growth coniferous forest from 1945 to 1978 in the Redwood Creek basin.

Large floods in 1953, 1955, 1964, 1972, and 1975 (15-20 year recurrence interval (RI) or roughly 50,000 ft^3/s) initiated widespread road and stream crossing failures, gullying, and streamside landsliding in the basin. These floods caused extensive infilling and bank erosion in Redwood Creek. Channel changes were most extensive in the upstream half of the basin, where both the storms and previous logging activity had been most intense. Aerial photographs, field observations and accounts by local residents document that the channel widened, pools filled in, channel bed material became finer, and the channel bed aggraded up to nine meters at some sites (Madej, 1992).

Since 1975 annual peak flows measured on Redwood Creek near Orick have been low to moderate (Figure 3), and annual peak flows from 1975-1996 were all less than a 5-year recurrence interval. However, during January 1997, Redwood Creek experienced the highest peak flows since 1975 with a recurrence interval of 12 years.

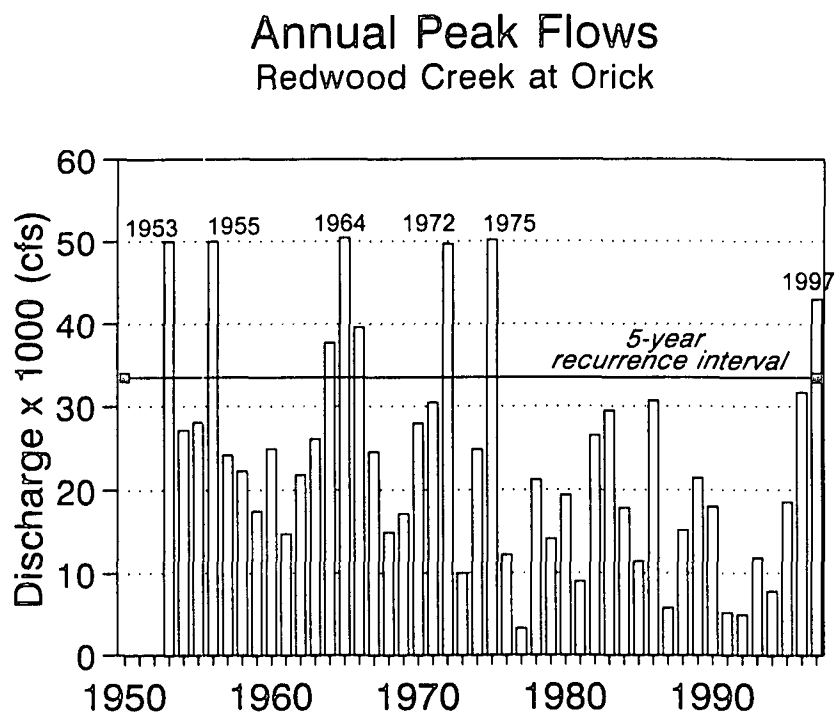


Figure 3. Annual peak flows on Redwood Creek at Orick from 1953 to 1997.

III. Methods

Since initiation of the monitoring program in 1973, a network of 58 channel cross sections has been established on Redwood Creek. Channel cross sections are located on Redwood Creek from the headwaters (Cross Section (X/S) 45) downstream to the flood control levees near Prairie Creek (X/S 1; Figure 4). Figure 1B shows the distribution of channel cross sections longitudinally along Redwood Creek. The USGS surveyed cross sections from 1973 to 1981.

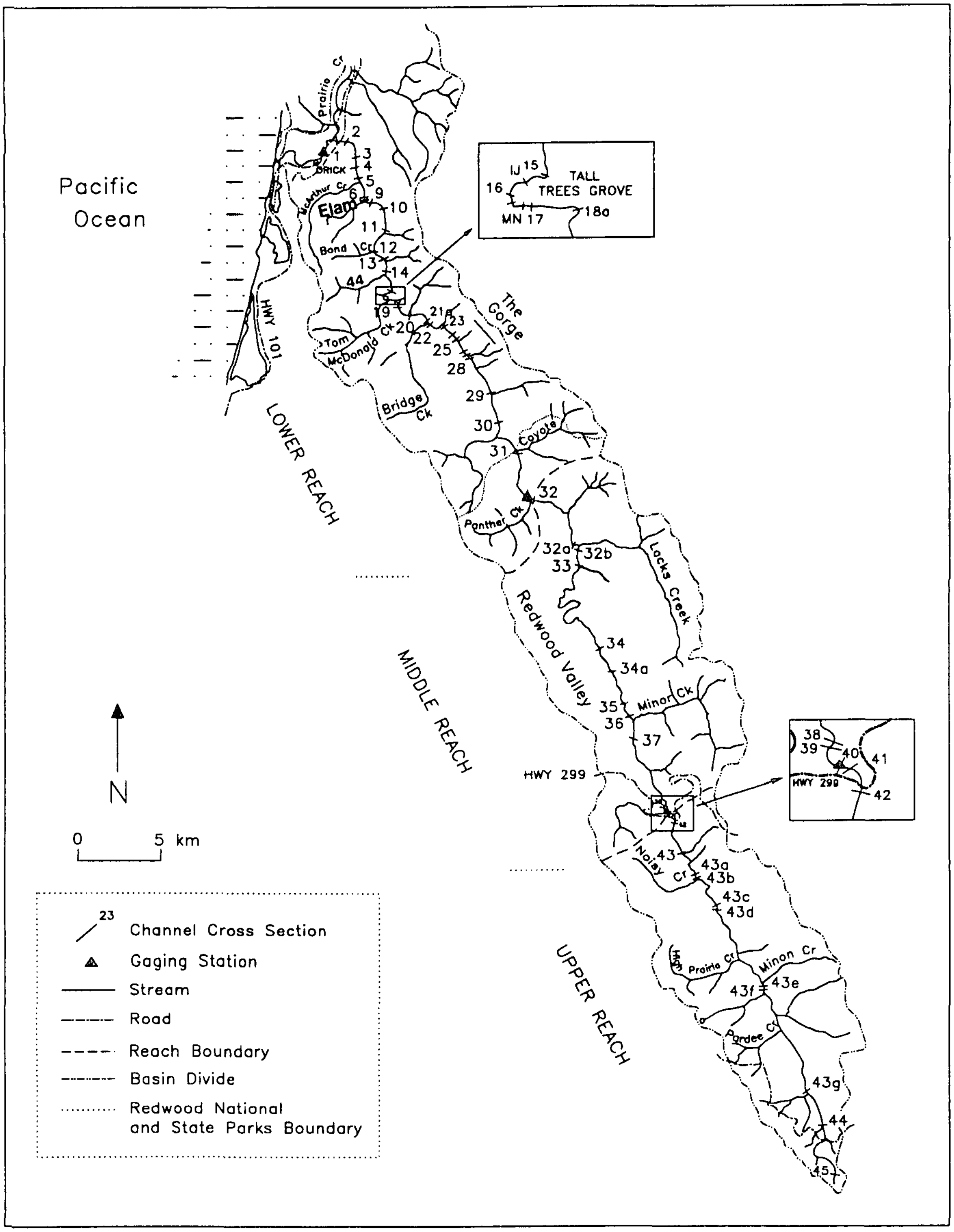


Figure 4 Cross section location map for Redwood Creek, California.

In the summer of 1982, the park service acquired responsibility for monitoring the cross section network. The cross section network has been surveyed annually since 1974 with the exception of 1978 and 1988 when no cross sections were surveyed. Since 1988, if moderately high winter flows occurred all accessible cross sections were surveyed during the summer months. Otherwise, only selected cross sections were surveyed.

Cross sections were monumented with steel rebar reinforced by concrete, and referenced to at least two other triangulation points. Relative elevations between end points were established by leveling (Emmett, 1974). Cross sections were surveyed during the summer months with either an automatic level or an electronic total station. Photo-points of the channel and bank conditions at cross section were also taken. Cross sections are referenced to channel distance with the zero distance (Km 0) starting at the headwaters and increasing downstream.

IV. Terminology

The terminology of Varnum and Ozaki (1986) was used in this report (Figure 5). The thalweg (T) is defined as the lowest point in the streambed in a cross-sectional profile. Active channel width is the channel width occupied by the effective discharge and is identified in Redwood Creek by highwater marks, vegetation breaks and breaks-in-slope. Nolan and others (1987) defined the effective discharge as the discharge that transports the majority of sediment due to its high frequency of occurrence (RI = 1.8 years on Redwood Creek or 425 m^3/s or 15,000 ft^3/s).

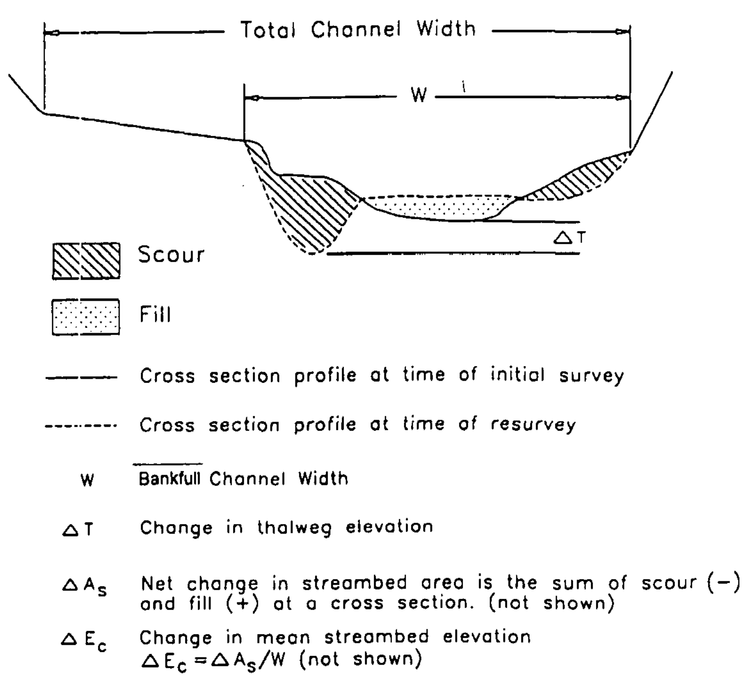


Figure 5. Definitions of cross sections terminology used in this report (from Varnum and Ozaki, 1986)

Net change in streambed area (ΔA_s) is the difference between the area of fill and area of scour across the streambed. Mean change in streambed elevation (ΔE_c) is a normalized value that compares the relative importance of changes at cross sections of different widths and is derived by dividing the net change in streambed area (ΔA_s) by the active channel width (W).

Change in Mean Streambed Elevation: $\Delta E_c = \Delta A_s / W$

Thus, a lowering of the mean streambed elevation by 0.15 m (ΔE_c = -0.15) produces the same percent change in a 10 m wide cross section as it does in a 100 m wide cross section, even though more material has moved through the wider cross section. A change in mean streambed elevation of 0.05 m or less is within the survey measurement error and cross section changes within this range are considered to show no change.

For each survey year, the cumulative change in mean streambed elevation is calculated. The cumulative change in mean streambed elevation is plotted by year to show trends at individual cross sections over time and can depict general trends in infilling, scouring, or stability at the cross section.

V. Past Studies: Overview of Channel Response

Annual cross-sectional surveys from 1973 to 1994 have been analyzed by other researchers (Iwatsubo *et al.*, 1975 and Iwatsubo *et al*, 1976; Nolan and Janda, 1979; Varnum, 1984; Varnum and Ozaki, 1986; Potter *et al.*, 1987; Ozaki, 1991; and Ozaki, 1992; Nolan and Marron, 1995; Madej and Ozaki, 1996). Nolan and Marron (1995) interpret channel response based on cross section data from 1973 to 1981. Madej and Ozaki (1996) describe in detail the movement of a sediment wave through the lower 26 kilometers (16 mi) of Redwood Creek and channel changes through 1994.

The following is an overview of channel response from Madej and Ozaki (1996) and summarizes channel changes in Redwood Creek that occurred in response to large floods and altered sediment loads of the last three decades. The three reaches used in this discussion (upper, middle and lower reach) are defined by the location of USGS gaging stations (Figure 1A). Also included is a brief discussion of the sediment wave in the lower reach.

Upper Reach - *Headwaters Redwood Creek downstream to near HWY 299*
(X/S 45 - X/S 40)

The 35 kilometer long upper reach extends from the headwaters of Redwood Creek to the Blue Lake (O'Kane) gaging station near Highway 299. Thirteen cross sections are located in this reach and have bankfull widths ranging from 12 to 84 m. Stream gradient ranges from 12 percent to 0.6 percent, and averages 3 percent.

This reach was the most adversely affected by the 1964 flood. Kelsey *et al.* (1981) mapped over 600 streamside landslides in this reach, most of which failed in 1964 and contributed over 5 million cubic meters of sediment to the channel. A comparison of aerial photographs in 1954 and 1966 reveals that channel widths increased by 150 to 350 percent. Up to nine meters (29 feet) of sand and gravel buried the channel above the 1994 thalweg elevation (Figure 6). The presence of roughness elements, such as boulders, riparian vegetation, and pool/riffle sequences was greatly reduced. The 1964 flood increased channel-stored sediment in this reach by more than 90 percent (1.5 x 10^6 m^3), and over half of the added sediment (800,000 m^3) was subsequently eroded from this reach between 1965 and 1980 (Madej, 1992). No estimate of the current channel-stored sediment has been determined.

Long-term records at the Blue Lake gaging station (X/S 40) indicate that between 1953 and 1973 the increase in mean streambed elevation was at least one meter, and the thalweg rose more than 1.2 meters (Nolan and Janda, 1979). The total amount of aggradation following the 1964 flood was probably greater than this, but documentation is lacking because the gaging station was discontinued between 1958 and 1973. The channel bed in this reach has degraded since 1974 (Figure 7). By 1985, the streambed at Cross Section 40 had returned to near 1953 levels and has been relatively stable since then. Other upper basin cross sections reflect similar trends. In places, the low flow channel has incised into remnants of the 1964 flood deposits, and bedrock is now exposed locally in the streambed. However, for most of the channel length, a return to a former channel width has not occurred nor the original quality of riparian vegetation reestablished.

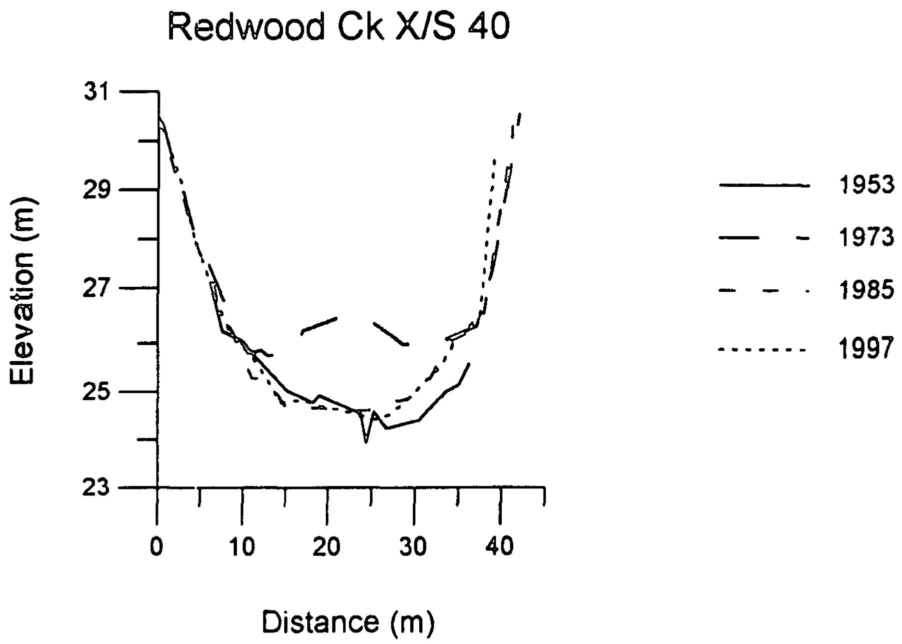
<u>Middle Reach</u> - *Near Chezem Bridge downstream to the confluence with Panther Creek* (X/S 39 - X/S 32)

Between the Blue Lake and Panther Creek gaging stations Redwood Creek flows through a wide valley floor at the upper end, and a narrow gorge at the downstream end, but channel gradient is about the same in both portions (0.4 percent). There are eleven cross sections in this 34-km long reach. In the upper portion, bankfull widths range from 23 to 127 m, and floodplain widths extend up to 200 m. The channel pattern here was dramatically modified during the 1964 flood and has not been changed by subsequent high flows. Bankfull widths in the downstream portion range from 25 to 35 m, and the floodplain is generally less than 50 m wide. Channel-stored sediment in the middle reach increased by 1.4 x 10^6 m^3 after the 1964 flood, a 32 percent increase over previous levels. By 1980, 62 percent of those flood deposits had eroded (Madej, 1992). Cross section surveys display similar channel response as in the upper reach; that is, the channel widened and aggraded as a result of the 1975 flood and has degraded since then (Figure 8).

<u>Lower Reach</u>

Between the Panther Creek and Orick gaging stations, the Redwood Creek channel showed four patterns of channel response. Monitoring of the lower 38 kilometers of Redwood Creek document complex channel response and recovery. The most dramatic channel changes were observed in the downstream portion of this reach where the channel widens abruptly. Cross section monitoring has documented the movement of a sediment wave throughout the lower 26 kilometers of Redwood Creek (see below).

Figure 6 Remnants of sediment deposited in the channel in the 1964 flood which buried and killed these riparian trees. Subsequent floods (in 1972 and 1975) and winter flows flushed much of this sediment downstream and reexposed these dead trees. The channel bed elevation has regained its previous level.



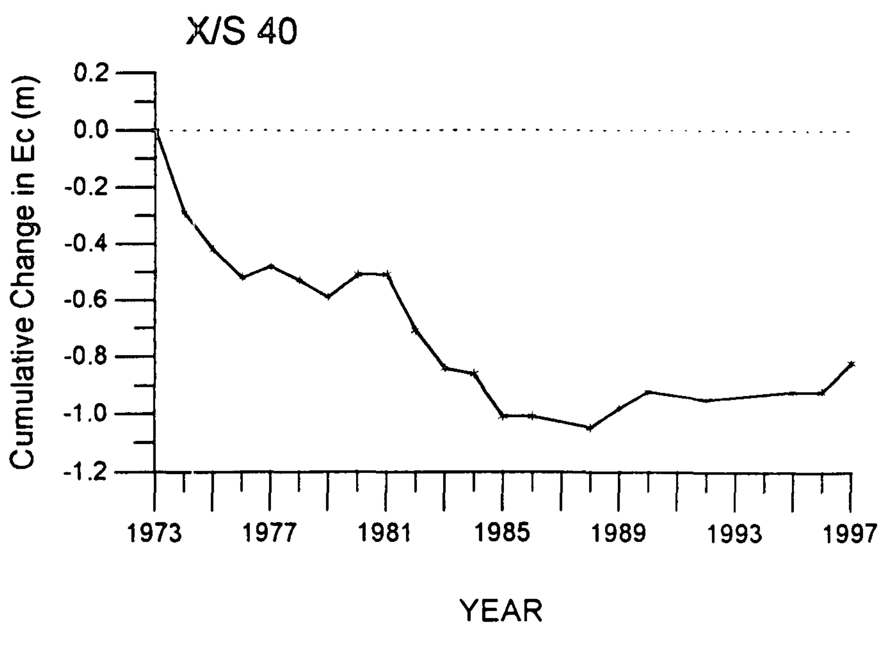


Figure 7. Plot of Cross Section 40 (Blue Lake gaging station). The channel bed at this cross section has downcut to a pre-disturbance level (1953). Recovery of the streambed to a former pre-flood elevation had occurred by 1985 and has been relatively stable since then.

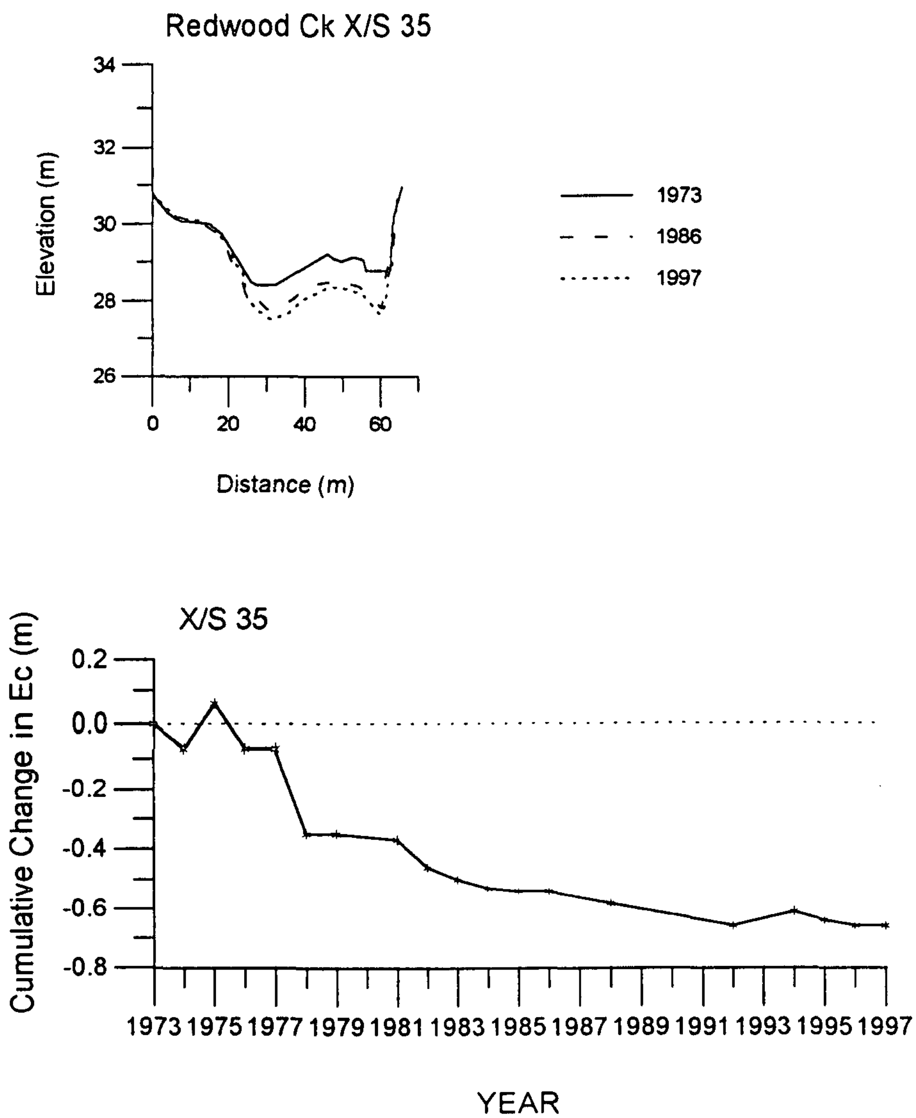


Figure 8. Plot of Cross Section 35 (Redwood Valley).

Confluence with Panther Creek downstream to the Tall Trees Grove (X/S 31 - X/S 19)

In the upstream portion, Km 72.5 to 86.7 (14 cross sections) bankfull widths range from 28 to 128 m and average channel gradient is 0.31 percent. Km 82.1 marks the beginning of a wide alluvial channel typical of lower Redwood Creek. Channel gradient decreases abruptly from 1.4 percent to 0.3 percent, and channel width increases from 30 m to 50 m. The channel in this portion of the river aggraded greater than one meter after the 1975 flood. Since 1980 the river has degraded, and by 1994 the channel bed was an average of 0.7 m lower than 1974 levels.

Tall Trees Grove (X/S 18a - X/S 15)

A second type of response occurred from Km 86.7 to 89.8 (6 cross sections) where the river flows around the Tall Trees Grove. Here, bankfull widths are large (up to 150 m) and channel gradient is 0.21 percent. Since monitoring began, the channel bed has fluctuated between aggradation and degradation. Until the late 1980's, this channel segment was considered a transitional reach between the upstream degrading and downstream aggrading portions of the channel bed. Since then, the channel bed has generally scoured or stayed the same.

Tall Trees Grove downstream to the McArthur Creek confluence (X/S 14 - X/S 5)

Farther downstream, from Km 89.9 to 98.8 (10 cross sections), Redwood Creek responded in a third way, by continual aggradation since 1973. In this aggrading reach, bankfull widths range from 61 to 114 m, and channel gradient averages 0.18 percent. Aerial photographs show that this area had aggraded between 1964 and the early 1970's, and cross-sectional surveys show the streambed had increased an average of 0.6 m in elevation from 1973 to 1994. Aggradation was accompanied by frequent shifting of the low flow channel and formation of mid-channel bars. The elevations of the mid-channel bar surfaces are higher than the roots of perennial streambank vegetation, an observation that is also consistent with a rapid rise in streambed elevation.

McArthur Creek to the confluence with Prairie Creek (X/S 4 - X/S 1)

The fourth type of response is apparent in the four-km reach immediately downstream of Cross Section 5 to the Orick gaging station, where the river has fluctuated between aggradation and degradation. Several factors influence river behavior there. The river becomes unconstrained at this point, and valley widths are greater than 500 m, however, construction of flood levees in 1968 artificially confined part of the channel reach. In addition, extraction of gravel from the streambed in the late 1980's artificially lowered streambed elevations in some areas. The results of cross-sectional survey in this area are not considered typical of the lower reach.

SEDIMENT WAVE (X/S 25 - X/S 5)

More than twenty years of cross-sectional survey data document the downstream movement of a sediment wave on park lands in the lower 26 kilometers of Redwood Creek (from the base of the gorge downstream). As the wave moved downstream, it spread out in both space and time resulting in both slower travel rates and lower wave heights the farther it moved. As it traveled downstream, transit rates of the sediment wave decreased from 1700 m/yr to 700 m/yr (1 to 0.5 mi/yr). Plots of the mean change in streambed elevation indicate that the height of the wave decreased more than one meter as it moved downstream. Peak sedimentation at downstream cross sections (downstream of Bond Creek, X/S 11) lagged at least 18 years behind upstream sites (near the base of the gorge, X/S 25).

In all the reaches described above, the channel aggraded and degraded across the entire active channel width (including the thalweg and low, unvegetated bars) rather than becoming incised and narrower (Madej and Ozaki, 1996).

VI. Results and Discussion

This report presents the results of cross section changes observed from Water Year (WY) 95 – 97 (a water year extends from October to September; that is, WY 97 began on October 1, 1996 and ended on September 30, 1997). During the summer of 1995, 23 selected cross sections were surveyed. In 1996 and 1997, 16 and 26 cross sections were surveyed respectively. Cross sections were spread out in the upper, middle and lower basin. However, about 70 percent of the surveyed cross sections in each year were located in the lower 26 kilometers of Redwood Creek within Redwood National and State Parks (Cross Section 3 - 25). These cross sections are located in a reach of stream responding to the passage of a sediment wave in lower Redwood Creek.

Changes at cross sections on Redwood Creek from WY 95 to WY 97 are quantified in Table 1, 2, and 3 respectively. The net change in cross-sectional area, mean change in streambed elevation, and the change in thalweg elevation (lowest point in the channel) are calculated for each cross section. Cross sections changes and cumulative change in mean streambed elevation for all cross sections are plotted in Appendix A.

<u>Upper and Middle Reaches (X/S 45- X/S 26)</u>

During WY 95-97, no significant changes occurred at cross sections in the upper and middle basin and support previously identified trends. Except for a few site specific changes, the mean change in streambed elevation for cross sections in the upper and middle basin were less than 0.05 m and within measurement error. These cross sections are generally considered stable.

Plots of the cumulative change in mean streambed at selected cross sections indicate that since 1973 most cross sections have scoured and by 1985 the greatest amount of scour or channel recovery had occurred (Figure 9). Since the mid-1980's, cross sections in the upper and middle basin in general have recovered to a stable bed elevation. Part of the observed trends may be an artifact of the drought years (1985-1992) and the moderately low winter flows. However, observations of bedrock in the channel and long-term data at one cross section indicate that the channel has probably reached a pre-disturbance elevation (Figure 9b). I would like to reiterate that while the bed elevation has returned to a probable pre-disturbance elevation, it is just one measure of channel recovery. For most of the channel length, a return to a former channel width has not occurred nor the original riparian vegetation characteristics and quality reestablished.

TABLE 1: Summary of Channel Change at Redwood Creek Cross Sections, 1995.

	Cross Section Number	Year Estab.	Change in Thalweg Elev. (m)	Scour (-) (m2)	Fill (+) (m2)	Net Change in Area (m2)	Active Channel Width (m)	Ec* (m)	Comparison Year
LOWER REACH	3	9/73	-0.21	62.88	50.19	-12.69	127	-0.10	1992
	5	10/73	-1.22	51.73	30.19	-21.54	114	-0.19	1994
	6	10/73	-0.25	11.57	6.25	-5.32	112	-0.05	1994
	10	10/73	-0.35	26.81	5.08	-21.73	99	-0.22	1988
	11	10/73	0.05	5.83	7.31	1.48	71	0.02	1991
	12	10/73	-0.40	13.81	8.17	-5.64	75	-0.08	1991
	14	10/73	-1.23	29.50	10.25	-19.25	61	-0.32	1991
	15	10/73	-0.02	19.53	3.28	-16.25	62	-0.26	1991
	16	10/73	0.68	20.06	3.87	-16.19	85	-0.19	1994
	17	10/73	-0.22	6.68	3.63	-3.05	87	-0.04	1994
	19	10/73	0.41	27.90	15.99	-11.91	128	-0.09	1991
	20	10/73	-0.33	11.40	2.20	-9.20	58	-0.16	1989
	21a	10/82	-0.55	17.98	0.69	-17.29	71	-0.24	1990
	22	10/73	0.58	11.20	8.01	-3.19	58	-0.06	1989
	23	10/73	-1.06	227.78	10.43	-217.35	77	-2.82	1991
	25	10/73	-0.20	3.84	0.23	-3.61	49	-0.07	1991
MIDDLE REACH	32	10/73	-0.06	0.73	0.90	0.17	35	0.00	1991
	34	10/73	-0.07	2.15	0.99	-1.16	67	-0.02	1992
	35	10/73	0.03	3.17	1.59	-1.58	51	-0.03	1992
UPPER REACH	40	10/73	0.09	0.52	1.60	1.08	34	0.03	1993
	41	10/73	-0.02	1.94	0.08	-1.86	29	-0.06	1993
	43e	10/78	-0.05	3.19	2.24	-0.95	54	-0.02	1989
	43f	10/78	-0.13	2.14	2.23	0.09	31	0.00	1989

* Ec is the mean change in streambed elevation. A patterned box indicates that Ec ≤ 0.05 are within measurement error. As a result, changes at these cross sections document no particular trend and are considered stable.

TABLE 2. Summary of Channel Changes at Redwood Creek Cross Sections, 1996.

	Cross Section Number	Year Estab.	Change in Thalweg Elev. (m)	Scour (-) (m^2)	Fill (+) (m^2)	Net Change in Area (m^2)	Active Channel Width (m)	Ec* (m)	Comparison Year
LOWER REACH	5	10/73	1.19	26.33	36.95	10.62	114	0.09	1995
	6	10/73	-0.23	9.06	9.00	-0.06	112	0.00	1995
	10	10/73	0.04	17.39	20.21	2.82	99	0.03	1995
	11	10/73	-0.10	5.47	15.08	9.61	71	0.14	1995
	12	10/73	0.20	6.22	15.18	8.96	75	0.12	1995
	14	10/73	0.34	0.85	7.18	6.33	61	0.10	1995
	16	10/73	0.04	21.10	9.97	-11.13	85	-0.13	1995
	MN	12/82	-0.10	10.63	11.14	0.51	120	0.00	1991
	17	10/73	0.00	7.05	4.99	-2.06	87	-0.02	1995
	19	10/73	0.35	46.10	29.84	-16.26	128	-0.13	1995
	20	10/73	-0.42	15.22	0.09	-15.13	58	-0.26	1995
MIDDLE REACH	34	10/73	-0.12	18.85	7.31	-11.54	67	-0.17	1995
	34a	10/74	0.13	4.61	7.44	2.83	127	0.02	1994
	35	10/73	-0.07	4.28	3.14	-1.14	51	-0.02	1995
UPPER REACH	40	10/73	-0.03	1.10	1.08	-0.02	34	0.00	1995
	41	10/73	-0.02	2.60	0.72	-1.88	29	-0.06	1995

* Ec is the mean change in streambed elevation. A patterned box indicates that Ec $\leq$ 0.05 m are within measurement error. As a result, changes at these cross sections document no particular trend and are considered stable.

TABLE 3: Summary of Channel Changes at Redwood Creek Cross Sections, 1997.

	Cross Section Number	Year Estab.	Change in Thalweg Elev. (m)	Scour (-) (m^2)	Fill (+) (m^2)	Net Change in Area (m^2)	Active Channel Width (m)	Ec* (m)	Comparison Year
LOWER REACH	2	10/73	0.36	49.05	130.91	81.86	141	0.58	1994
	3	9/73	-0.07	44.63	39.60	-5.03	127	-0.04	1995
	5	10/73	-0.05	13.37	15.53	2.16	114	0.02	1996
	6	10/73	-0.30	17.29	6.96	-10.33	112	-0.09	1996
	10	10/73	0.23	14.48	18.13	3.65	99	0.04	1996
	11	10/73	0.94	12.3	20.5	3.65	71	0.05	1996
	12	10/73	0.28	11.34	10.52	-0.82	75	-0.01	1996
	14	10/73	0.72	10.47	12.44	1.97	61	0.03	1996
	15	10/73	-0.43	11.67	17.99	6.32	62	0.10	1995
	IJ	11/82	-0.66	183.55	44.61	-138.94	141	-0.99	1989
	16	10/73	0.41	2.87	31.31	28.44	85	0.33	1996
	MN	12/82	0.26	9.41	22.76	13.35	120	0.11	1996
	17	10/73	1.31	11.45	22.23	10.78	87	0.12	1996
	19	10/73	-0.37	47.45	64.68	17.23	128	0.13	1996
	20	10/73	0.22	9.62	24.30	14.68	58	0.25	1996
	21a	10/82	0.71	26.24	7.93	-18.31	71	-0.26	1995
	23	10/73	-0.31	59.20	39.38	-19.82	77	-0.26	1995
	25	10/73	-0.73	8.60	0.60	-8.00	49	-0.16	1995
MIDDLE REACH	32	10/73	0.14	0.75	2.00	1.25	35	0.04	1995
	34	10/73	-0.03	6.94	3.73	-3.21	67	-0.05	1996
	34a	10/74	0.16	0.49	15.72	15.23	127	0.12	1996
	35	10/73	-0.14	1.11	1.32	0.21	51	0.00	1996
UPPER REACH	40	10/73	0.07	0.16	3.49	3.33	34	0.10	1996
	41	10/73	-0.17	4.29	2.22	-2.07	29	-0.07	1996
	44	10/74	-0.40	5.29	0.00	-5.29	15	-0.35	1994
	45	10/74	0.03	0.71	0.22	-0.49	12	-0.04	1994

* Ec is the mean change in streambed elevation. A patterned box indicates that Ec $\leq$ 0.05 m are within measurement error. As a result, changes at these cross sections document no particular trend and are considered stable.

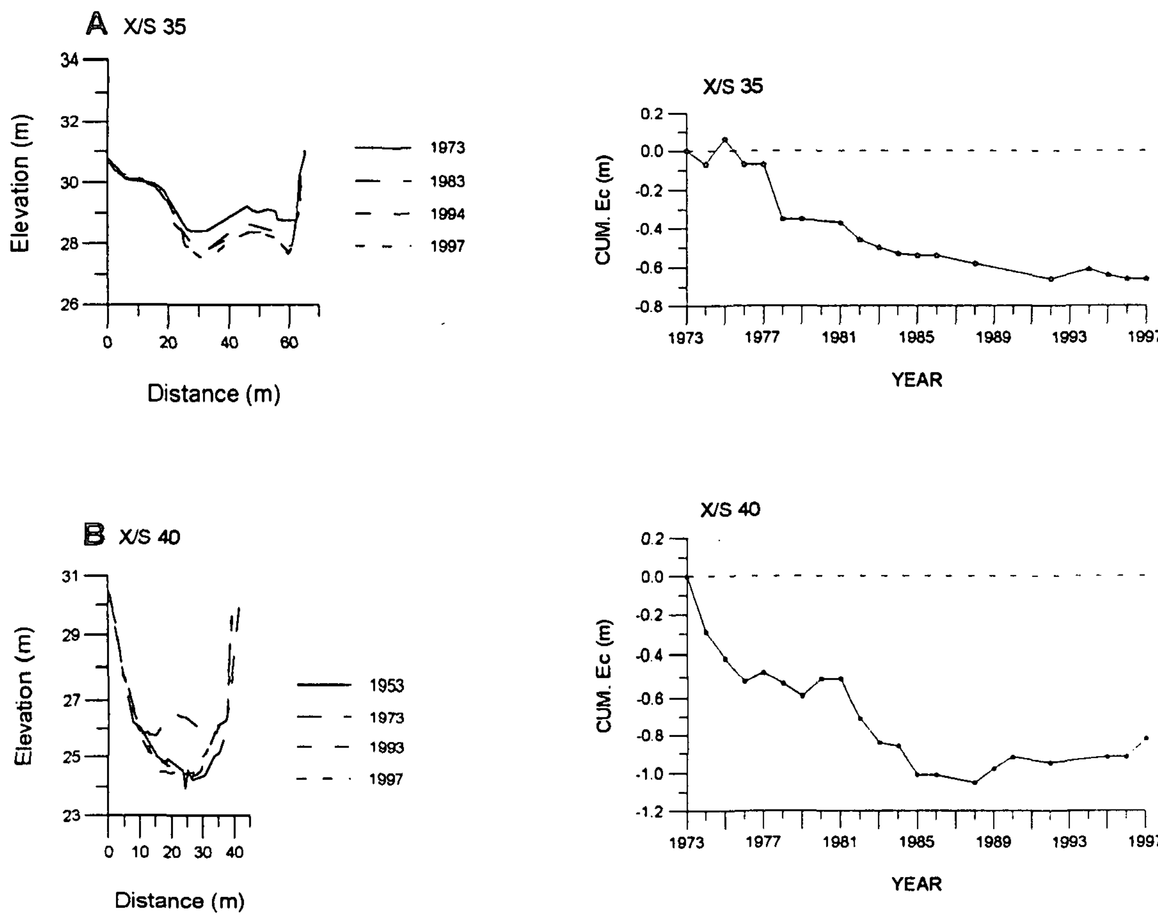


Figure 9. Cross section plots and cumulative change in mean streambed elevation for Cross Sections 35 (A) and 40 (B).

Lower Reach (Park lands; X/S 25 – X/S 1)

It is interesting to note that during the entire monitoring period (1973 to present), the most dramatic channel changes occurred on park lands in the lower 26 kilometers of Redwood Creek. Cross sections in this reach have documented passage of a sediment wave through the lower most portions of Redwood Creek (Figure 10).

At Cross Section 25, located at the base of the gorge, peak aggradation occurred in the mid-1970's (Figure 10d) and since then the channel has scoured. However, 4.5 kilometers downstream, at Cross Section 19, aggradation lagged in time and channel infilling peaked in the early 1980's (Figure 10c). Farther downstream, around the Tall Trees Grove, Cross Section 16 experienced peak aggradation a few years latter in the early to mid-1980's (Figure 10b). However, downstream of the Tall Trees Grove, channel cross sections have documented aggradation since monitoring began (Figure 10a). Aggradation of the streambed continues between Bond and Elam Creek (X/S 10-5). Data indicate that the leading edge of this "wave" of sediment is located between Elam (X/S 6) and McArthur Creek (X/S 5) and hasn't changed positions over time.

During WY 95-97, cross sections indicate that the channel bed in lower Redwood Creek responded differently from year to year.

In WY 1995, all cross sections in lower Redwood Creek from the base of the gorge downstream (X/S 25 – 3) scoured or had no significant changes. For the first time in more than 22 years, all cross sections in lower Redwood Creek showed channel bed scouring. However, these channel changes observed in a single year do not indicate that aggradation in this portion of the channel has peaked or is no longer occurring.

In WY 96, channel cross sections around and upstream of the Tall Trees Grove showed no change or scoured. In contrast to the previous year, the channel downstream of the Tall Trees Grove, filled in or showed no significant changes.

In WY 97, the channel continued to scour or was stable from the headwaters downstream to Bridge Creek. However, downstream of Bridge Creek to the Tall Trees Grove, the channel aggraded or filled in. This is most likely in response to streambed scour and erosion of a large storage bar (X/S 23) from upstream of this cross section. Also a debris torrent released a large quantity of sediment directly into Bridge Creek, a tributary immediately upstream of this reach. During the high winter flows, some of this sediment was possibly redistributed to the main channel of Redwood Creek downstream of Bridge Creek. Downstream of the Tall Trees Grove the channel generally showed no change. Large sand sheets were observed in the channel covering the bed and gravel bars downstream of Forty-Four Creek. Cross sections in this reach of stream generally showed no significant change in cross section area; however, thalweg elevations increased in places up to about one meter.

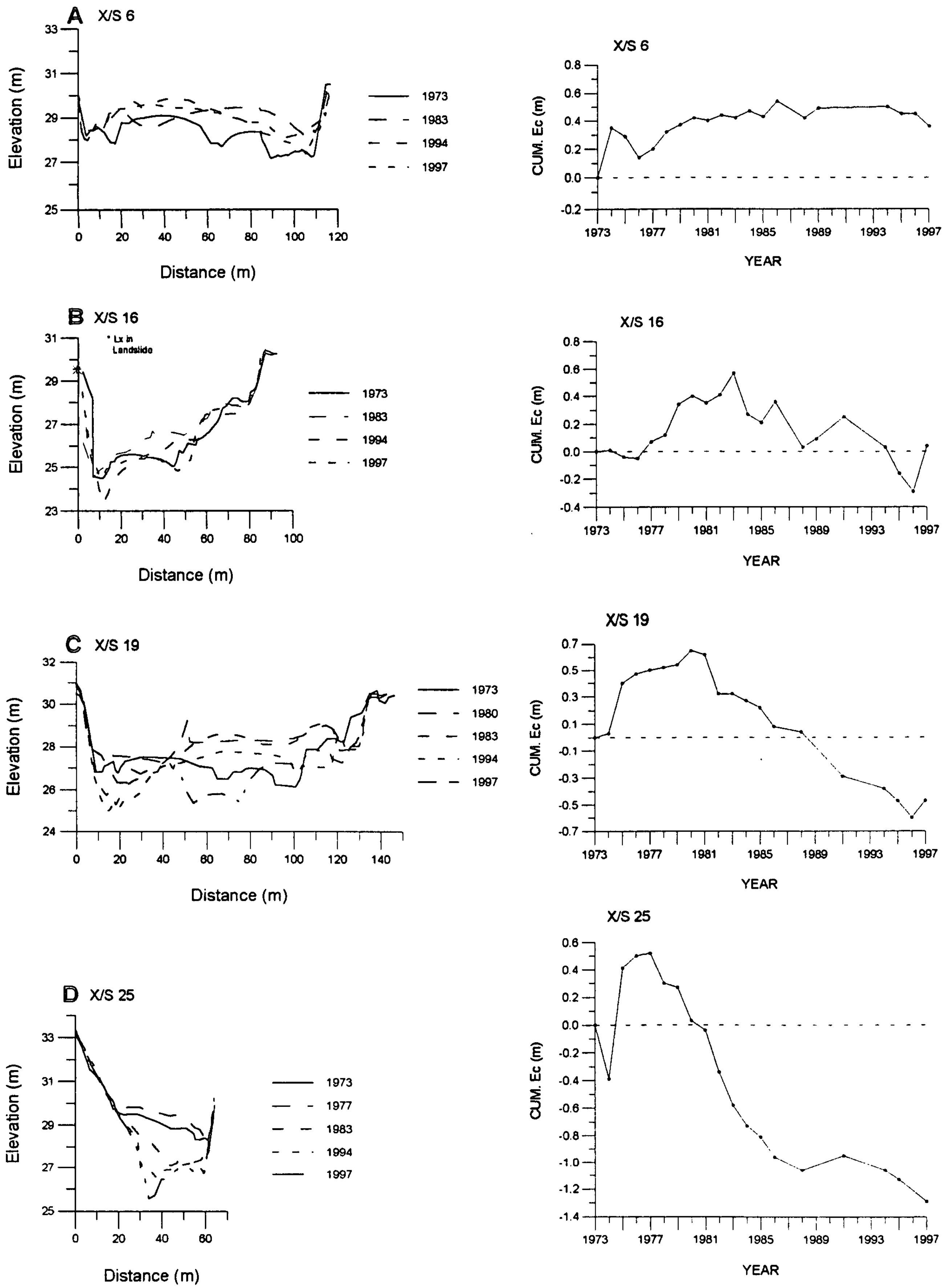


Figure 10. Cross section plots and the cumulative change in mean streambed elevations are plotted for Cross Sections 6 (A), 16 (B), 19 (C) and 25 (D) located in the lower 26 kilometers of Redwood Creek.

VII. Conclusions

Climatic conditions in the Redwood Creek basin have resulted in periodic large flood-producing storms accompanied by accelerated erosion from logged lands and road networks. These storm events have occurred in the past and will continue to be a process that shapes and influences Redwood Creek. The last large flood occurred in 1975 (RI = 25-30 years; Coghlan, 1984) and flows since then, with the exception of WY 97, have all been less than a 5-year recurrence interval. Consequently, the cross section network has been monitored during relatively low to moderately low flow years.

Channel cross sections document how high influxes of sediment from hillslopes and stream channels during large storm events in the Redwood Creek basin can persist for decades. After more than 30 years, the effects of the 1964 flood event continue to impact the main channel on park lands in lower Redwood Creek (Figure 11). As sediment is transported through the system, from the headwaters to the mouth, the sediment diminishes in both time and space. As the wave moves downstream the height of the wave decreases and the wave spreads out resulting in slower movement of the sediment wave. The persistence of the sediment wave in Redwood Creek for more than 20 years has impacted several life cycles of steelhead and salmon.

While the channel bed has returned to a probable pre-disturbance elevation in the upper reaches, bed elevation is just one measure of channel recovery. For most of its length, the channel still remains wider than pre-1964 conditions. In addition, the original characteristics of the riparian vegetation (old-growth coniferous forest) have not been reestablished. Instead, the current riparian forests are dominated by alders.

Cross sections continue to document channel recovery. If there are no large influxes of sediment to Redwood Creek in the next decade or two, we can expect to see continued flushing of channel stored sediment and channel recovery. Most changes will probably occur in lower Redwood Creek below the Tall Trees Grove as the sediment wave moves out of the Redwood Creek system.

Expected impacts from another large flood event are unknown. While the upper and middle basin appear to have recovered to a pre-disturbance bed elevation, studies indicate that channel-storage reservoirs are still partially full from the last series of large floods (Madej, 1992). The current volume of channel stored sediment has not been determined. Without an ability to store excess sediment, the channel bed will respond by filling with sediment, widening, and potentially repeating impacts observed from earlier floods.

VIII. Future Monitoring Efforts

Selected cross sections should be measured periodically every three years or after the next major flood event (RI=10 years) to assess general trends in the channel. Access in both the upper, mid and lower basin is getting more difficult due to poor road conditions. Also, moving to a more periodic monitoring schedule, means that it will take considerably more time to locate end points, and to clear cross sections of vegetation. Realistically, only selected cross sections will

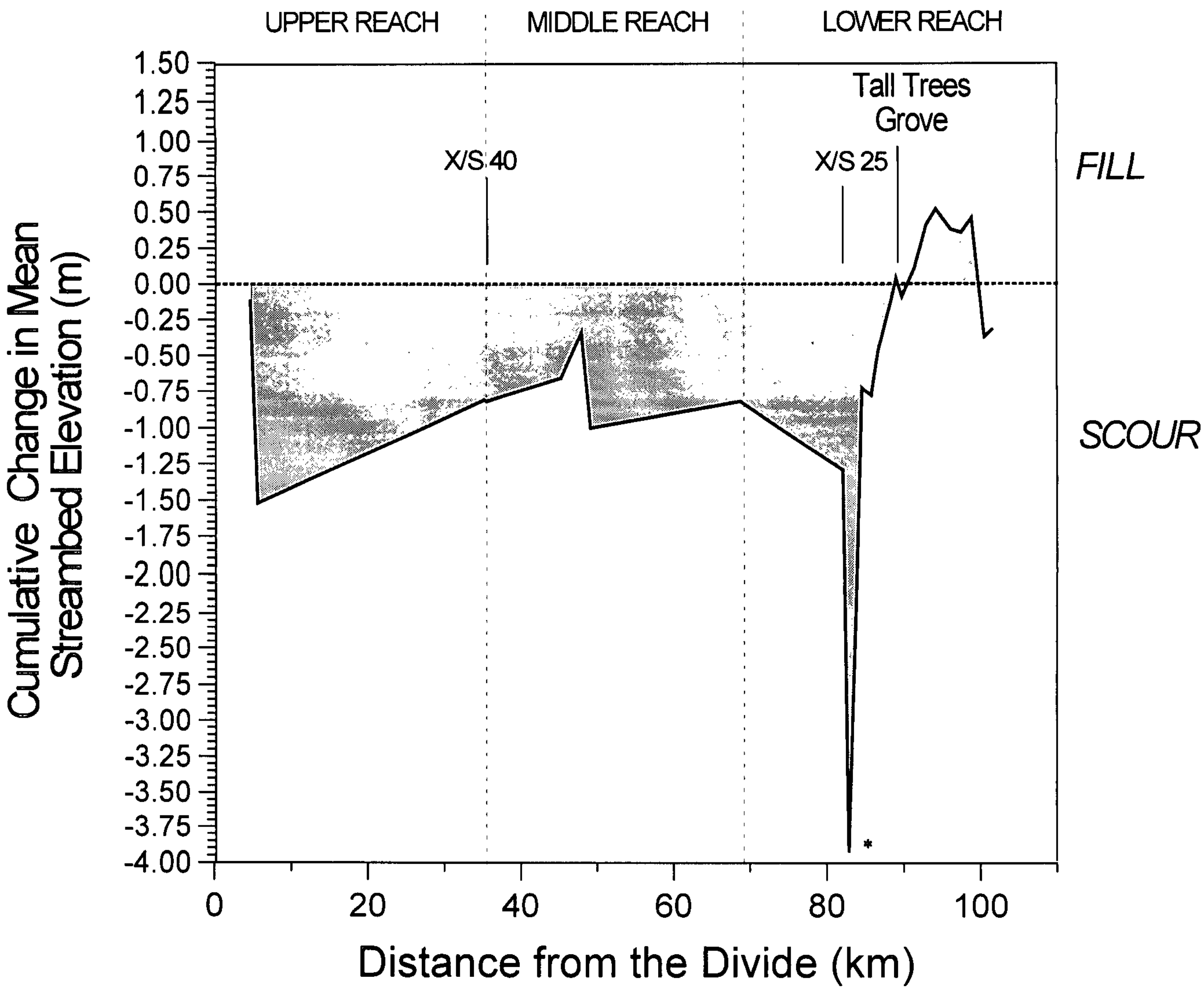


Figure 11. Longitudinal trend in channel changes at cross sections along Redwood Creek, 1973-1997.

be able to be maintained over time. If possible, cross section end points should be located with a GPS to ensure accurate relocation of cross sections after the next major flood and to help field teams unfamiliar with the cross section network to locate cross sections during long-term monitoring.

Emphasis of future channel monitoring should incorporate interdisciplinary aspects and include aquatic and riparian biology and ecology. Future studies should attempt to provide the linkages between the physical changes or trends observed and the biological response.

Future channel monitoring should dovetail with basin wide monitoring efforts such as the Redwood Creek Water Quality Attainment Strategy (TMDL) and Implementation Plans by the EPA and Regional Water Quality Control Board. Ideally, the park should: 1) work with upper basin landowners on a systematic monitoring plan for the Redwood Creek watershed, 2) develop standardized monitoring techniques, protocols, and data collection, and 3) analyze data from a basin wide perspective.

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APPENDIX A

TOP AND MIDDLE GRAPH

For each cross section surveyed in 1997, three plots are presented to show both the most recent changes and long-term channel changes at cross sections. The top graph depicts long-term cross-sectional changes over the last 22 years. The graph includes the earliest survey (solid line), one mid-1980's (dashed line) and the 1997 cross section survey (small dashed line). The middle graph is a plot of the two most recent channel surveys; the 1997 survey (dashed line) and the previous years survey (solid line).

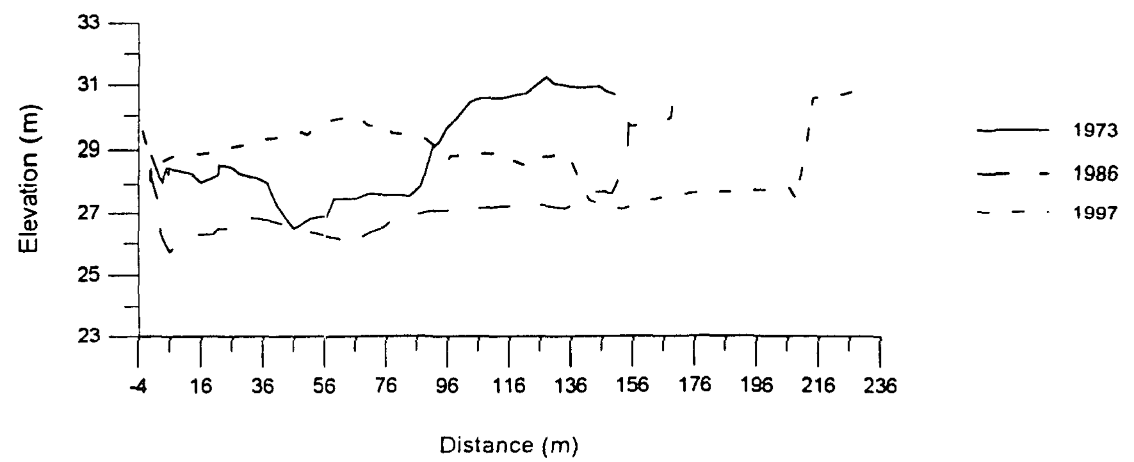
Both axes are plotted in meters. The x-axis is the distance measured from the left end point (that is the left monument distance = 0.0 meters). Left and right on a channel cross section are designated while looking in a downstream direction. The y-axis is elevation measured above an arbitrary datum.

The vertical exaggeration for each plot is either 5x or 10x. The scale on the y-axis (elevation) is five times the x-axis (distance) on plots with a vertical exaggeration of five. Likewise, the x-axis scale on plots with vertical exaggeration equal to ten is ten times that of the y-axis scale.

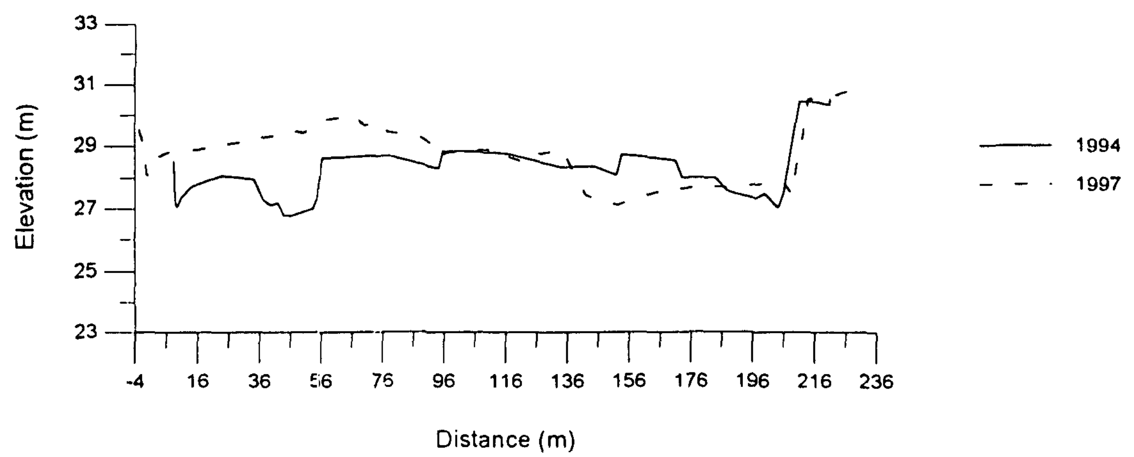
LOWER GRAPH

The cumulative change in streambed elevation (Cum. Ec; y-axis) is plotted by year (x-axis) for each cross section. The cumulative change in mean streambed elevation is plotted by year to show trends at individual cross sections over time and can depict general trends in infilling, scouring, or stability at the cross section.

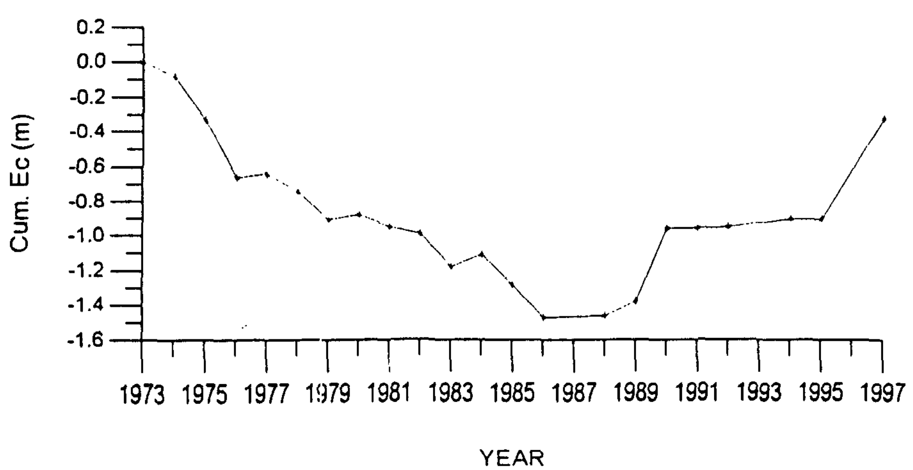
Redwood Ck X/S 2

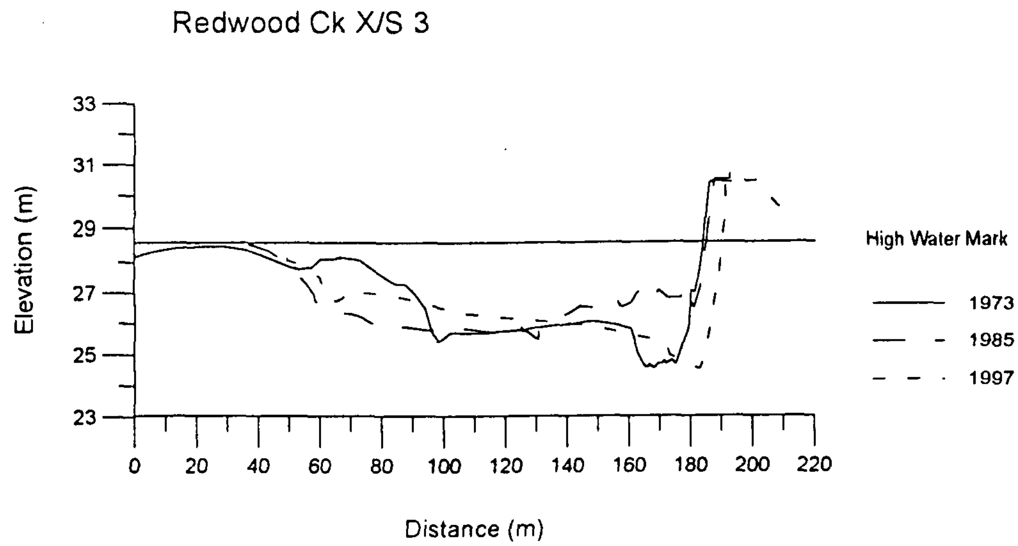


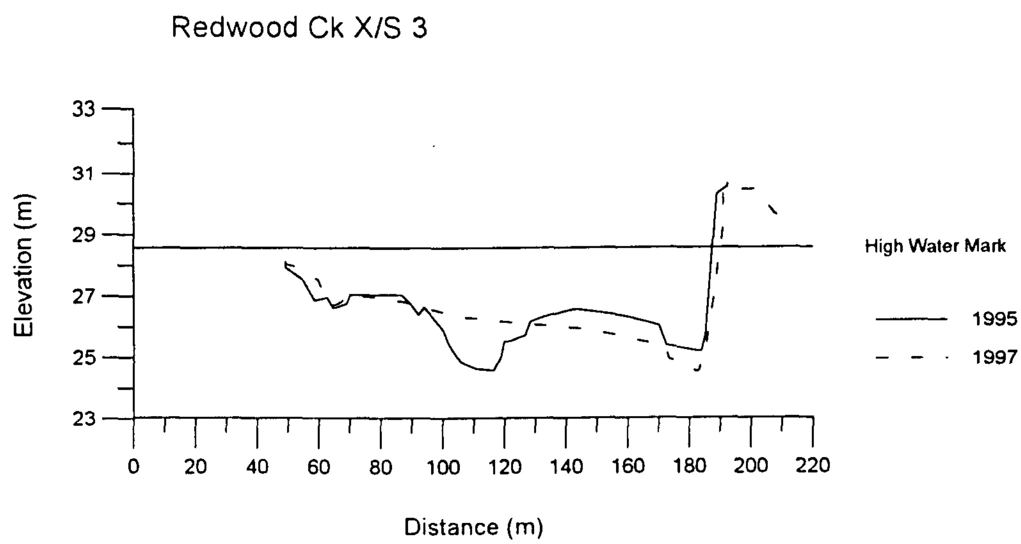
Redwood Ck X/S 2

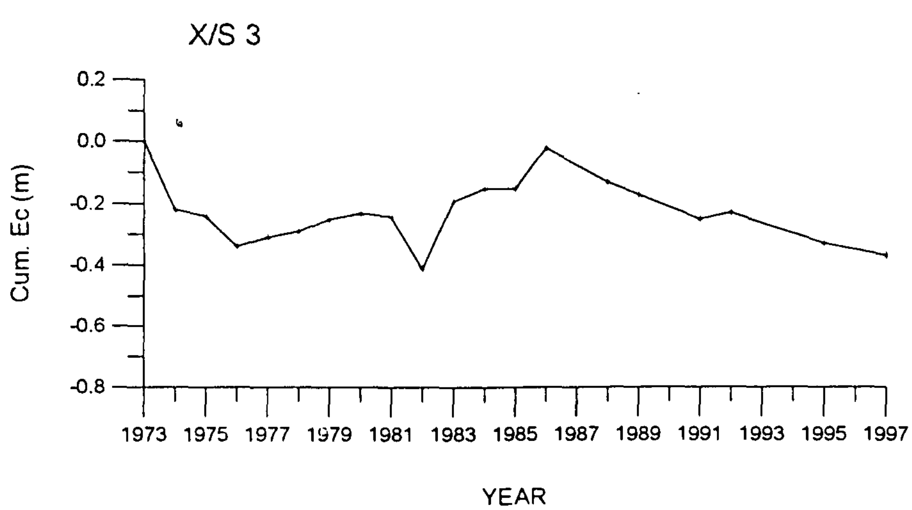


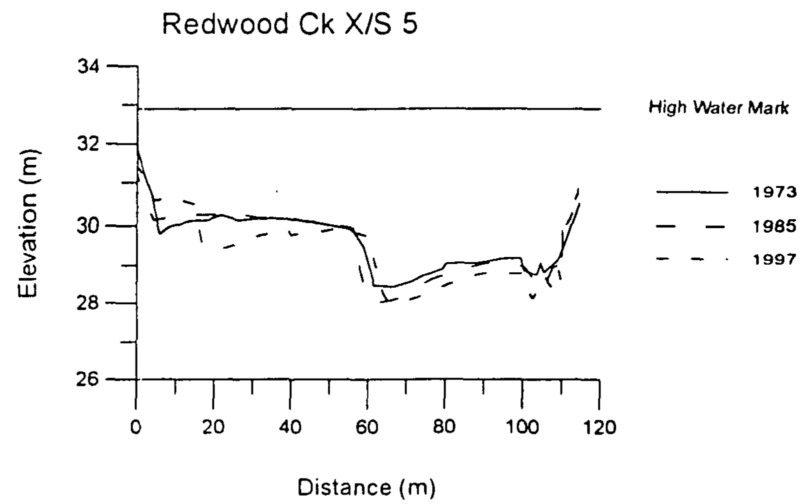
X/S 2

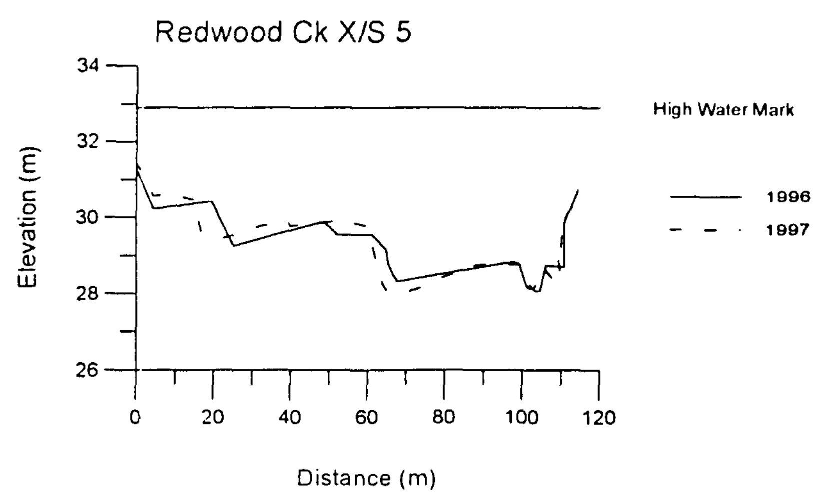


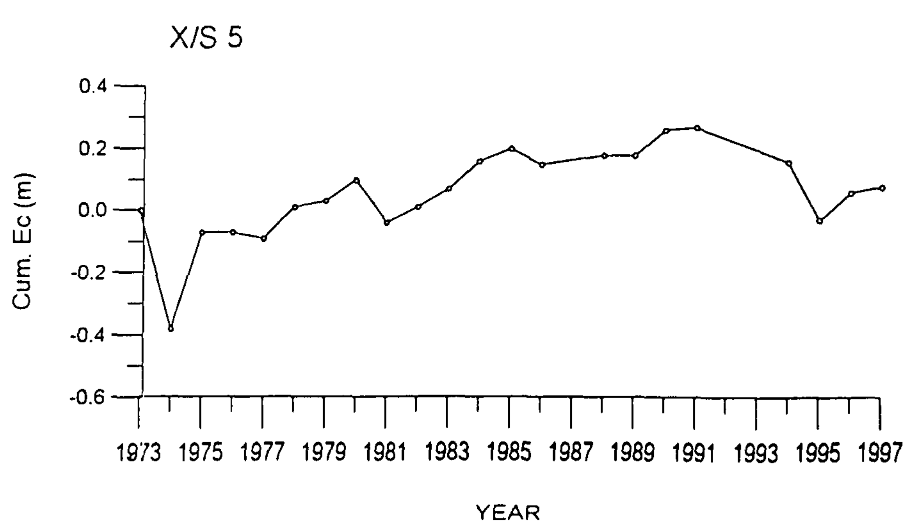

Redwood Ck X/S 3
Elevation (m)
33
31
29
27
25
23
0 20 40 60 80 100 120 140 160 180 200 220
Distance (m)
High Water Mark
1973
1985
1997

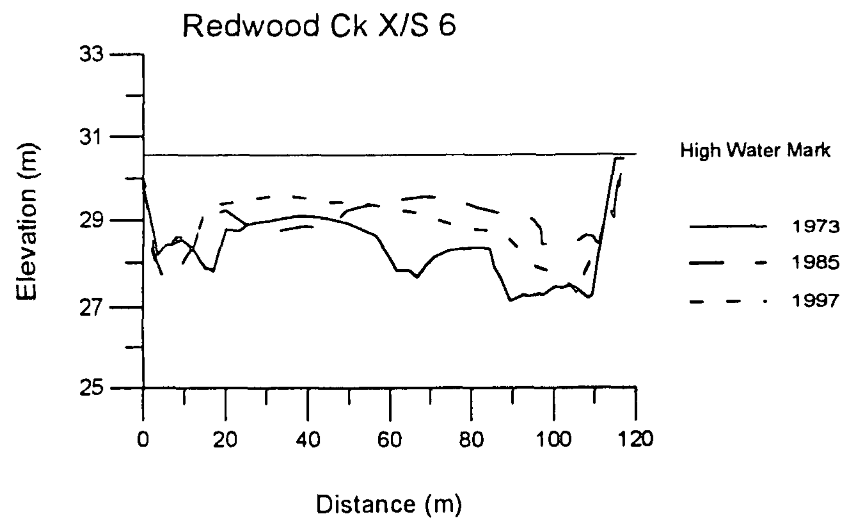

Redwood Ck X/S 3
Elevation (m)
33
31
29
27
25
23
0 20 40 60 80 100 120 140 160 180 200 220
Distance (m)
High Water Mark
1995
1997

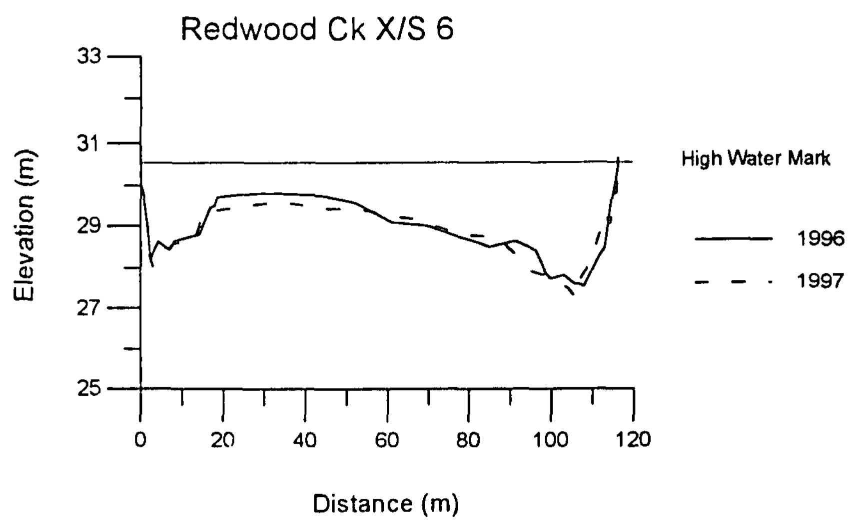

X/S 3
Cum. Ec (m)
0.2
0.0
-0.2
-0.4
-0.6
-0.8
1973 1975 1977 1979 1981 1983 1985 1987 1989 1991 1993 1995 1997
YEAR

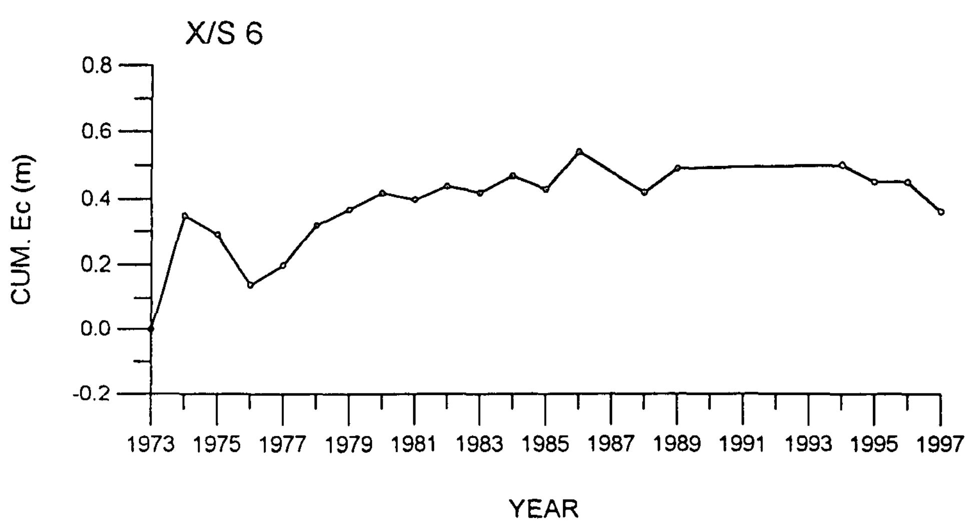

Redwood Ck X/S 5
High Water Mark
1973
1985
1997
Elevation (m)
34
32
30
28
26
0
20
40
60
80
100
120
Distance (m)

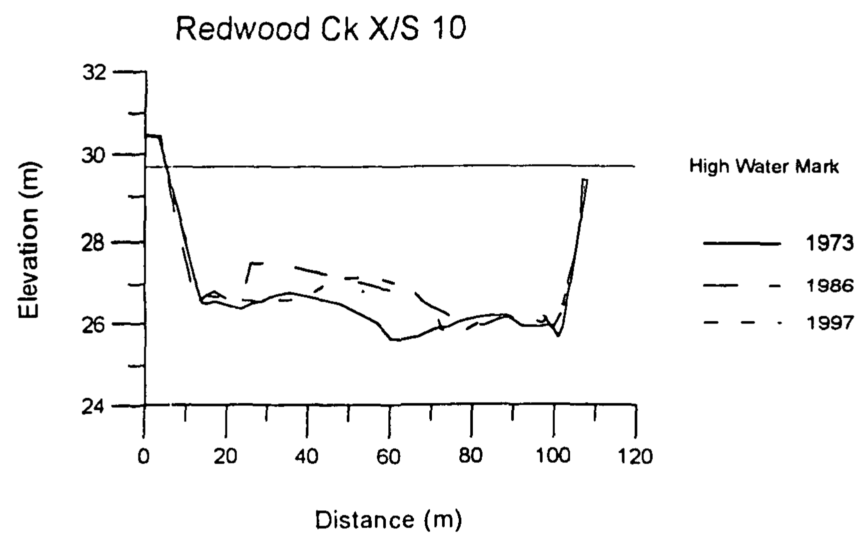

Redwood Ck X/S 5
High Water Mark
1996
1997
Elevation (m)
34
32
30
28
26
0
20
40
60
80
100
120
Distance (m)

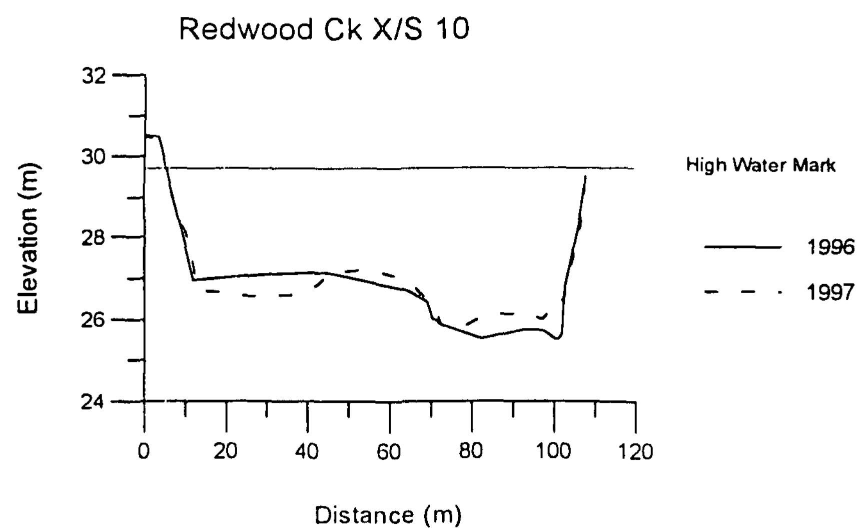

X/S 5
Cum. Ec (m)
0.4
0.2
0.0
-0.2
-0.4
-0.6
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
YEAR

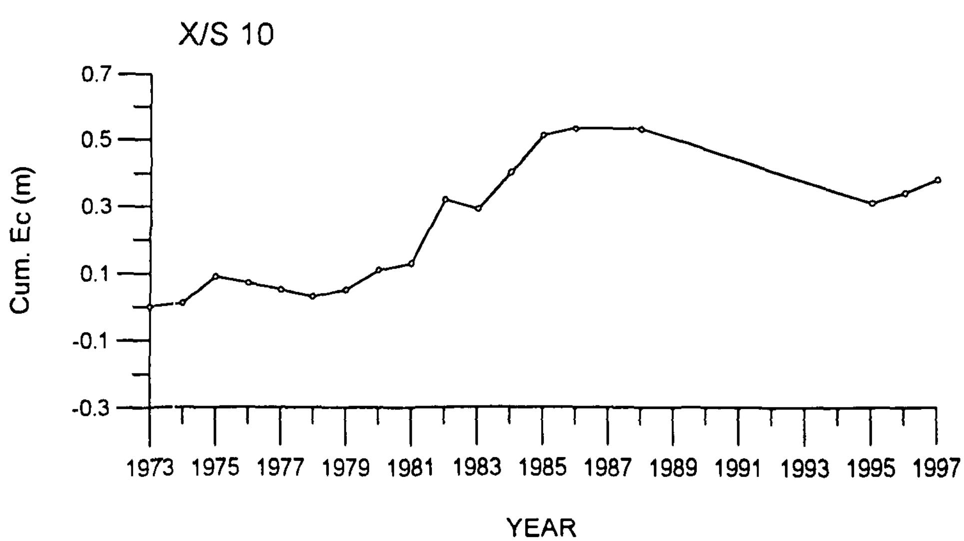

Redwood Ck X/S 6
Elevation (m)
33
31
29
27
25
0
20
40
60
80
100
120
Distance (m)
High Water Mark
1973
1985
1997

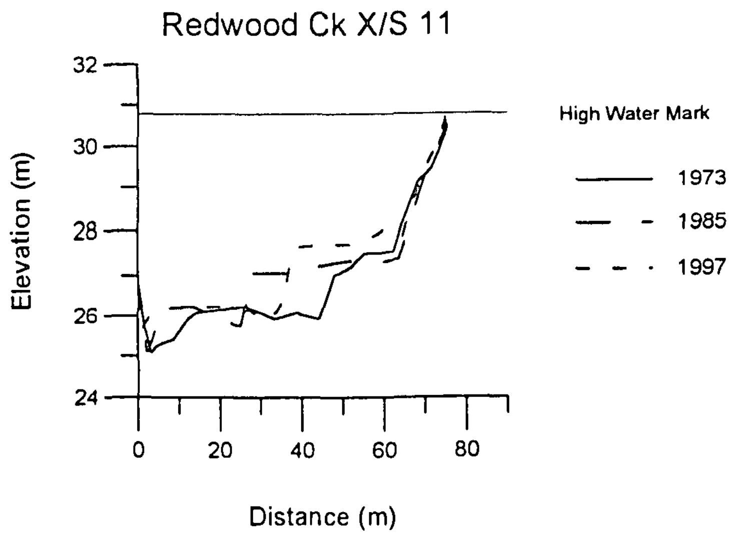

Redwood Ck X/S 6
Elevation (m)
33
31
29
27
25
0
20
40
60
80
100
120
Distance (m)
High Water Mark
1996
1997


X/S 6
CUM. Ec (m)
0.8
0.6
0.4
0.2
0.0
-0.2
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
YEAR

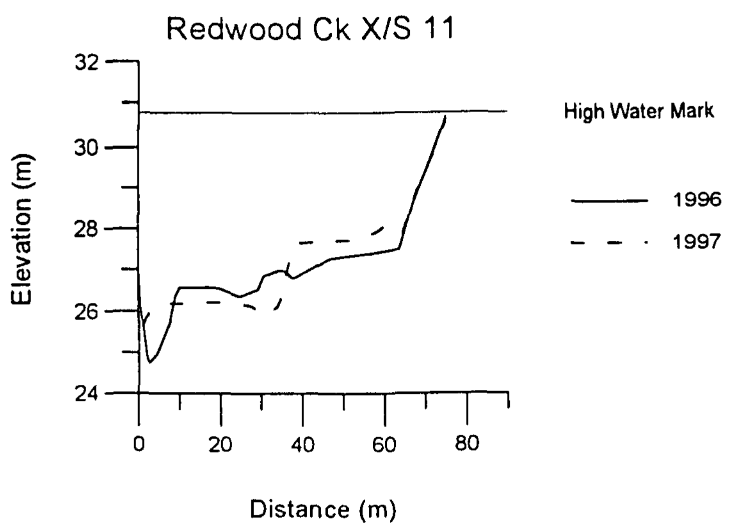

Redwood Ck X/S 10
Elevation (m)
32
30
28
26
24
0
20
40
60
80
100
120
Distance (m)
High Water Mark
1973
1986
1997


Redwood Ck X/S 10
Elevation (m)
32
30
28
26
24
0
20
40
60
80
100
120
Distance (m)
High Water Mark
1996
1997

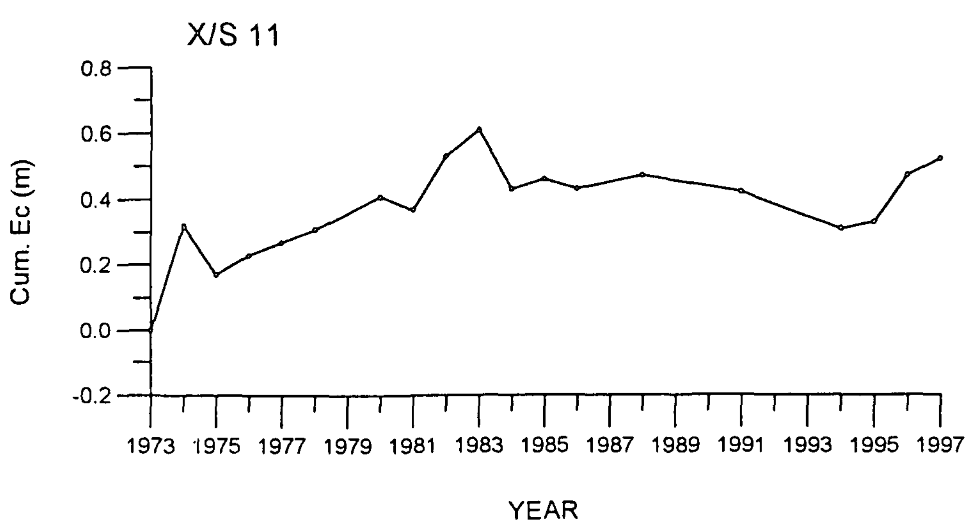

X/S 10
Cum. Ec (m)
0.7
0.5
0.3
0.1
-0.1
-0.3
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
YEAR



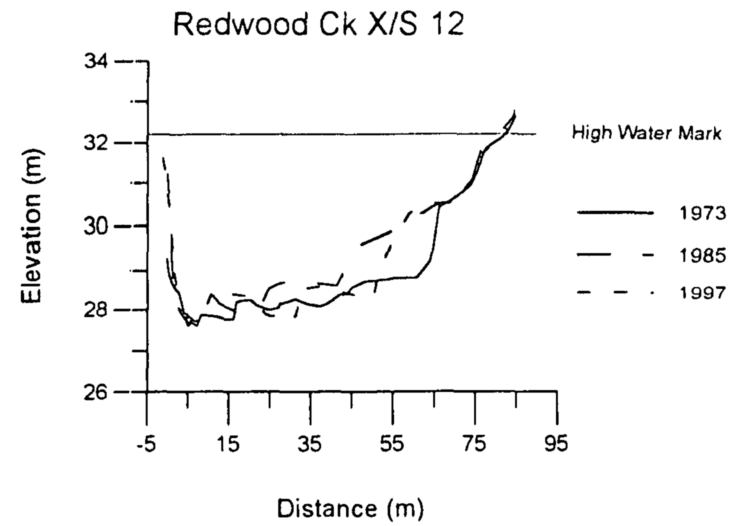
Redwood Ck X/S 11
Elevation (m)
Distance (m)
High Water Mark
1973
1985
1997

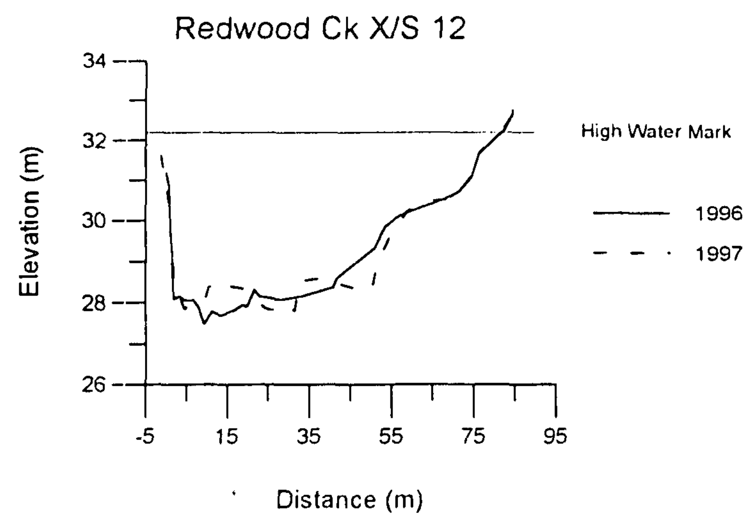


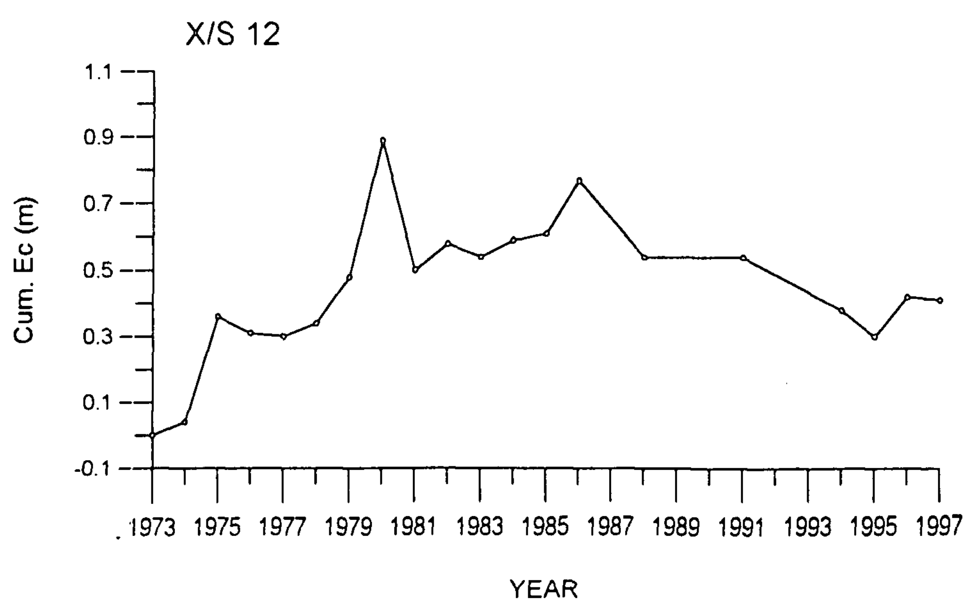
Redwood Ck X/S 11
Elevation (m)
Distance (m)
High Water Mark
1996
1997

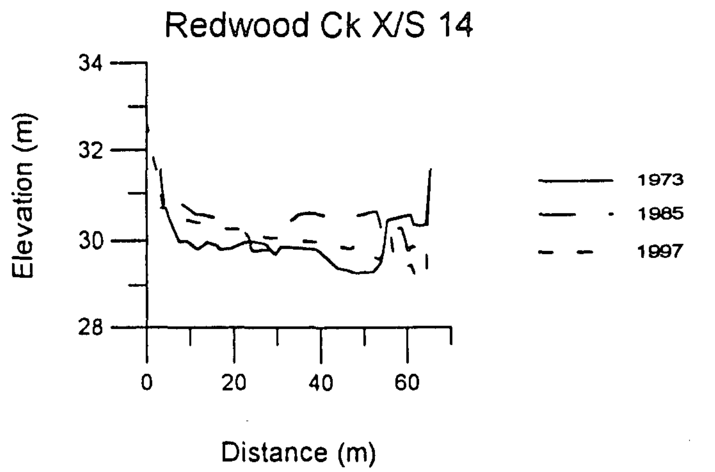


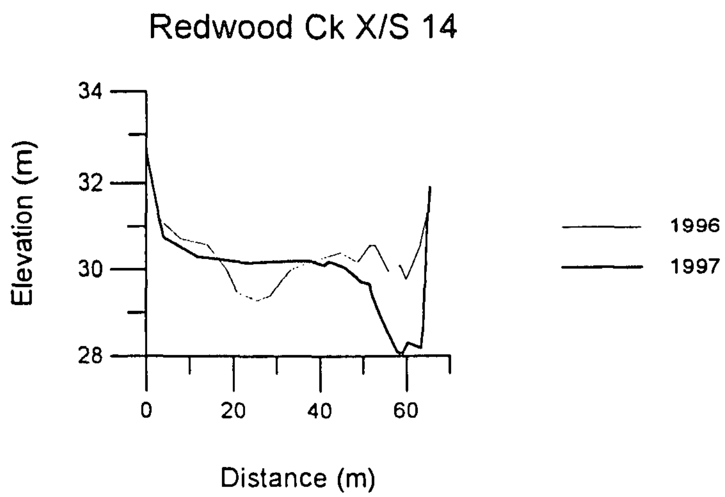
X/S 11
Cum. Ec (m)
YEAR

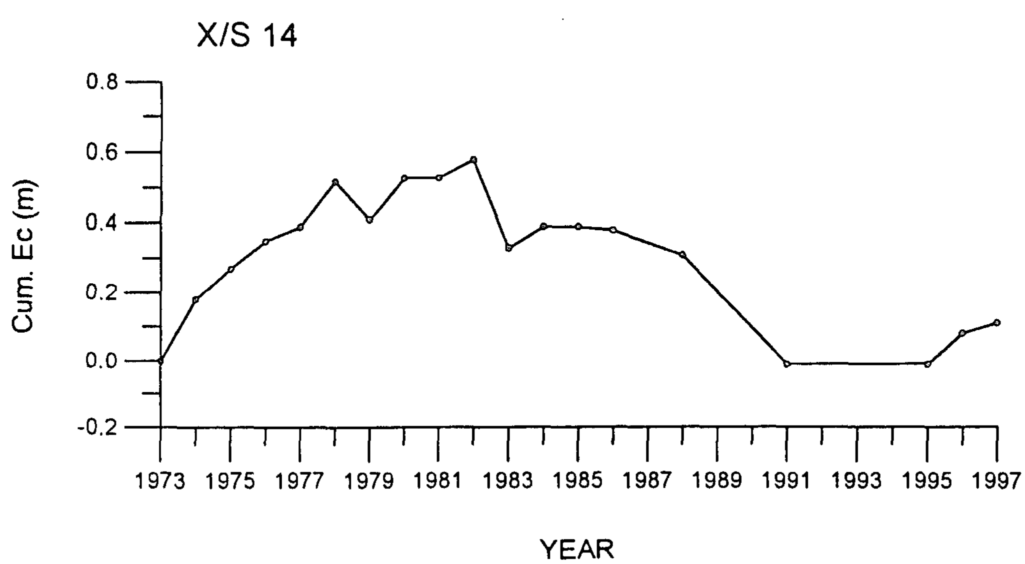

Redwood Ck X/S 12
34
32
30
28
26
Elevation (m)
-5
15
35
55
75
95
Distance (m)
High Water Mark
1973
1985
1997

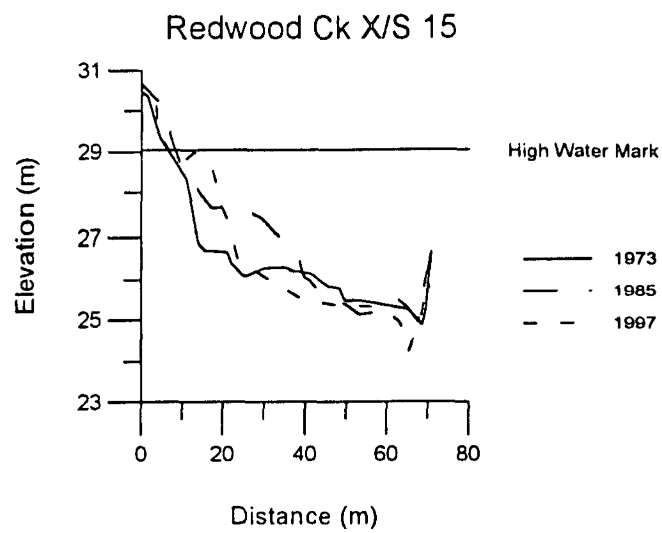

Redwood Ck X/S 12
34
32
30
28
26
Elevation (m)
-5
15
35
55
75
95
Distance (m)
High Water Mark
1996
1997

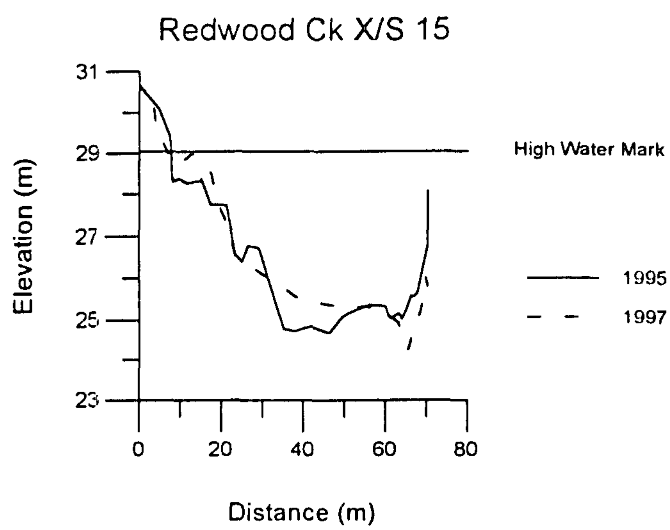

X/S 12
1.1
0.9
0.7
0.5
0.3
0.1
-0.1
Cum. Ec (m)
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
YEAR

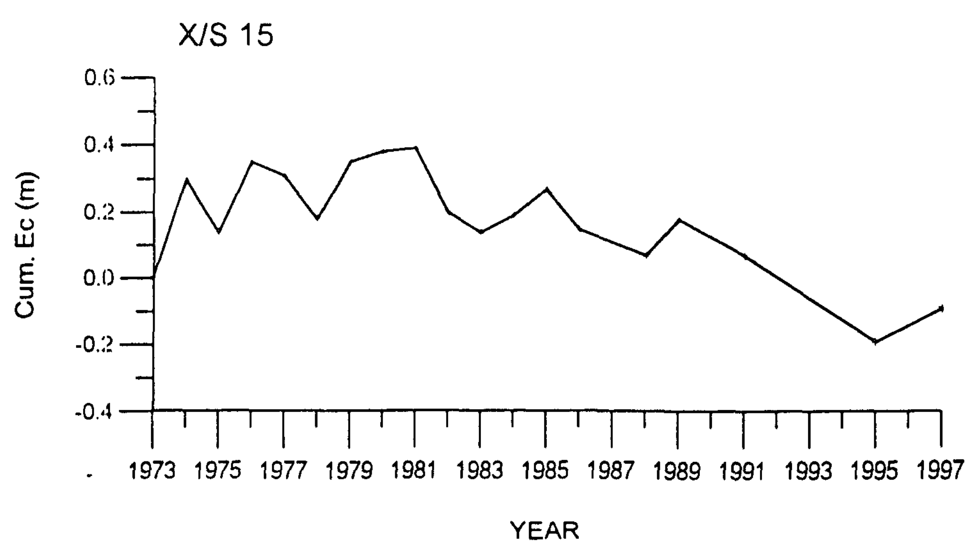

Redwood Ck X/S 14
Elevation (m)
34
32
30
28
0
20
40
60
Distance (m)
1973
1985
1997

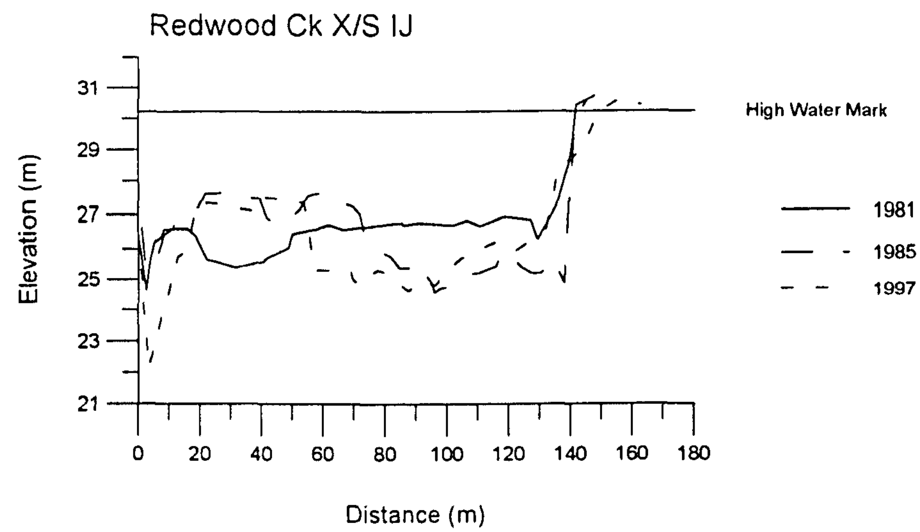

Redwood Ck X/S 14
Elevation (m)
34
32
30
28
0
20
40
60
Distance (m)
1996
1997

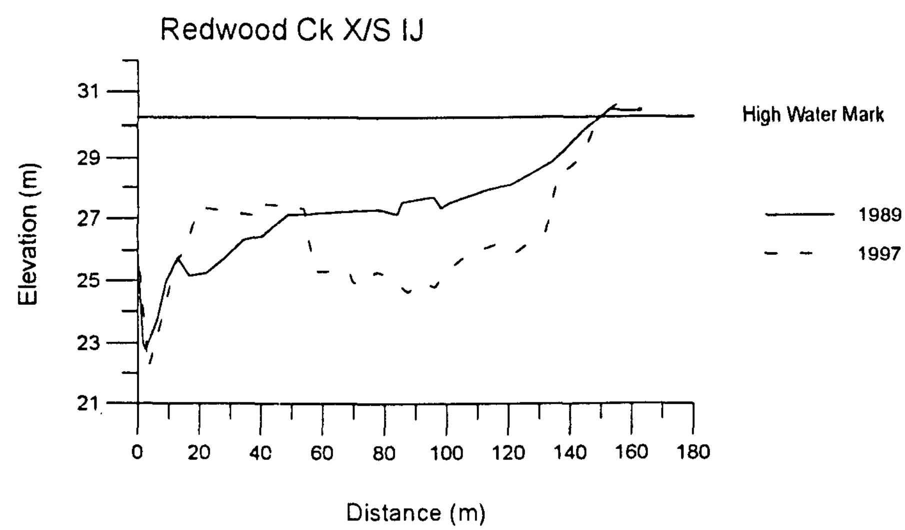

X/S 14
Cum. Ec (m)
0.8
0.6
0.4
0.2
0.0
-0.2
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
YEAR

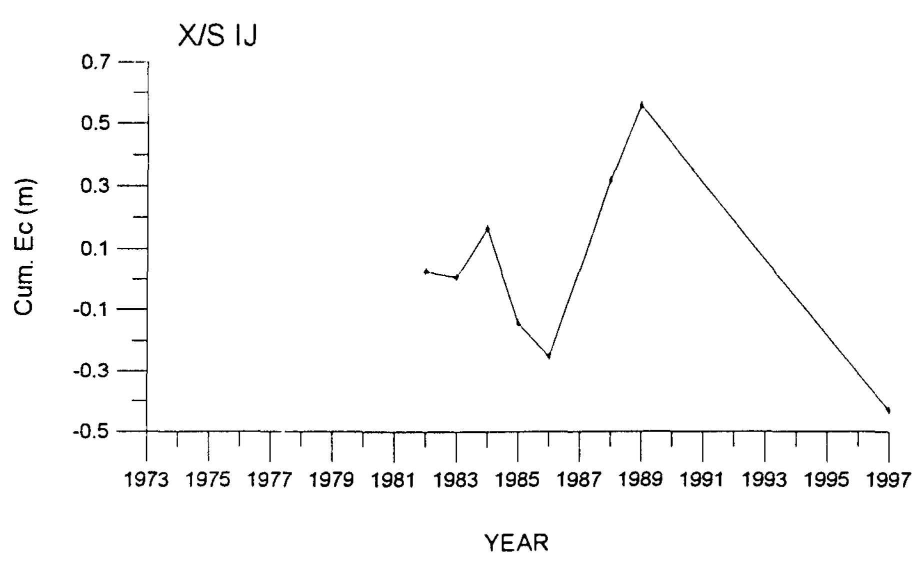

Redwood Ck X/S 15
Elevation (m)
31
29
27
25
23
0
20
40
60
80
Distance (m)
High Water Mark
1973
1985
1997

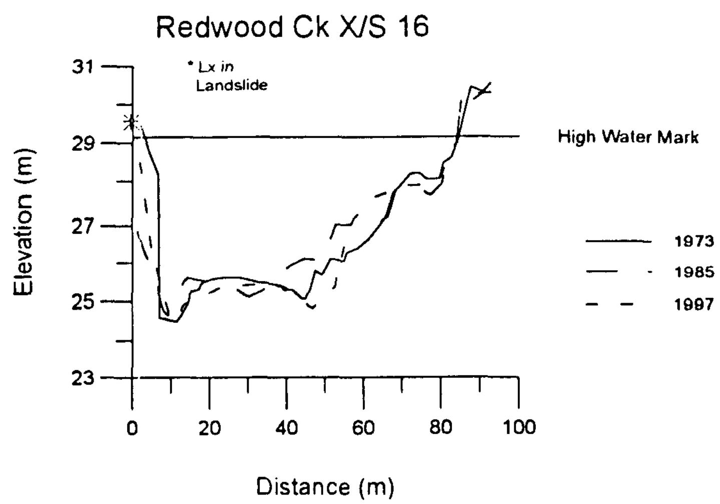

Redwood Ck X/S 15
Elevation (m)
31
29
27
25
23
0
20
40
60
80
Distance (m)
High Water Mark
1995
1997

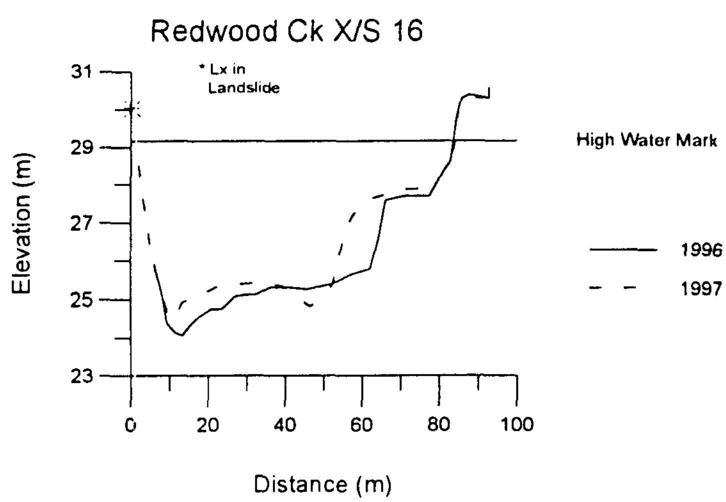

X/S 15
Cum. Ec (m)
0.6
0.4
0.2
0.0
-0.2
-0.4
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
YEAR

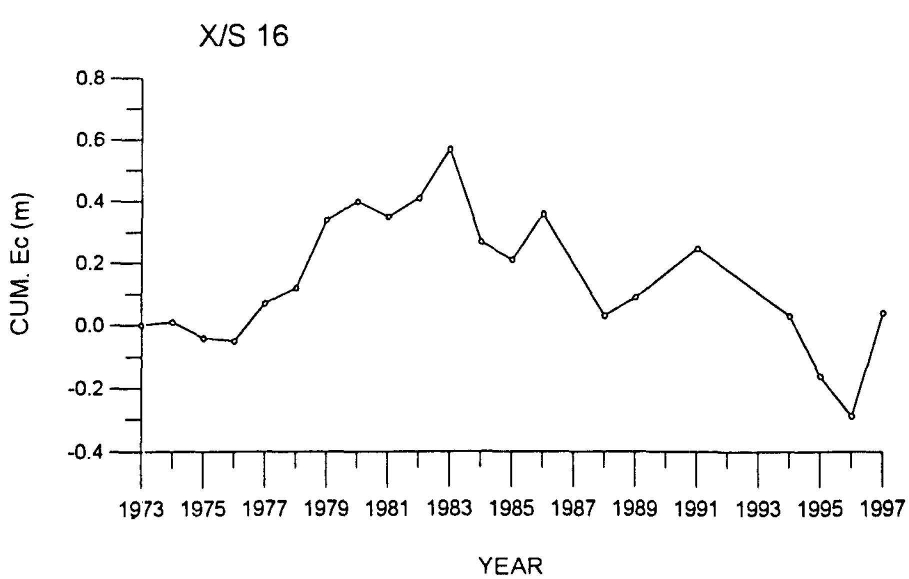

Redwood Ck X/S IJ
Elevation (m)
31
29
27
25
23
21
0
20
40
60
80
100
120
140
160
180
Distance (m)
High Water Mark
1981
1985
1997

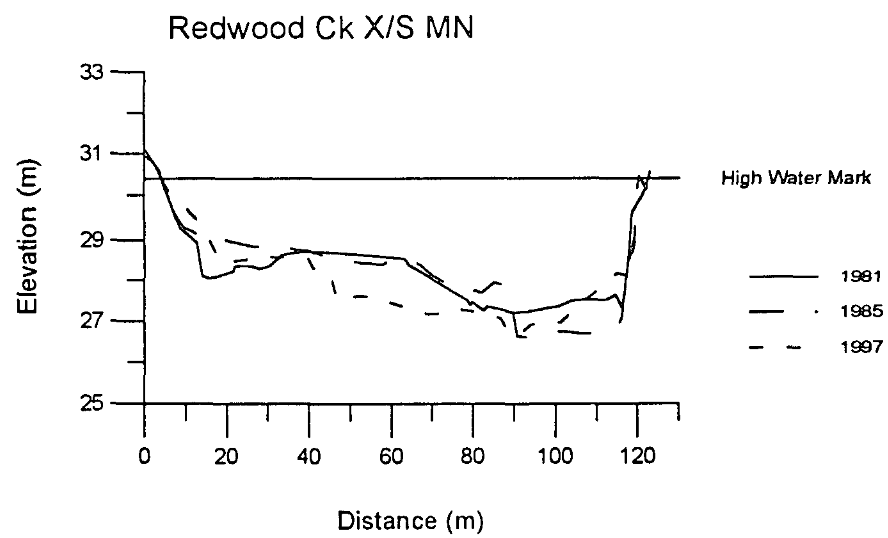

Redwood Ck X/S IJ
Elevation (m)
31
29
27
25
23
21
0
20
40
60
80
100
120
140
160
180
Distance (m)
High Water Mark
1989
1997

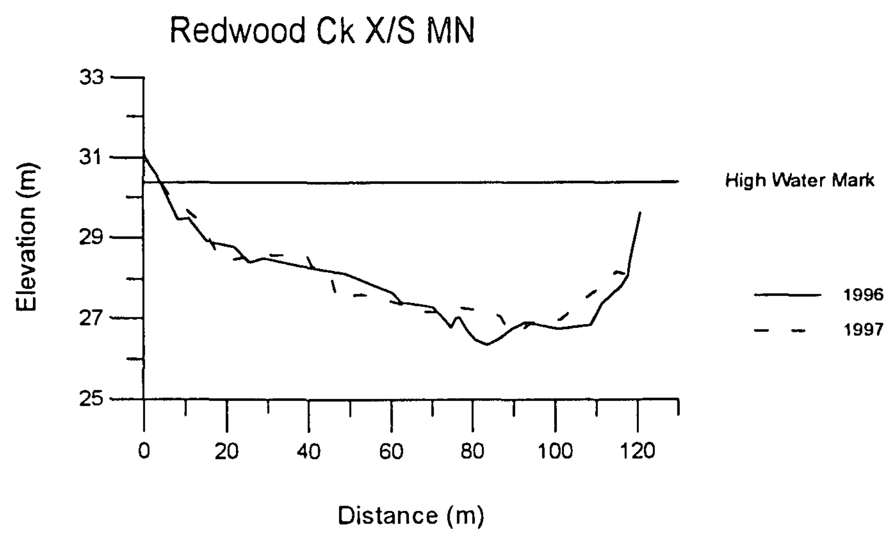

X/S IJ
Cum. Ec (m)
0.7
0.5
0.3
0.1
-0.1
-0.3
-0.5
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
YEAR

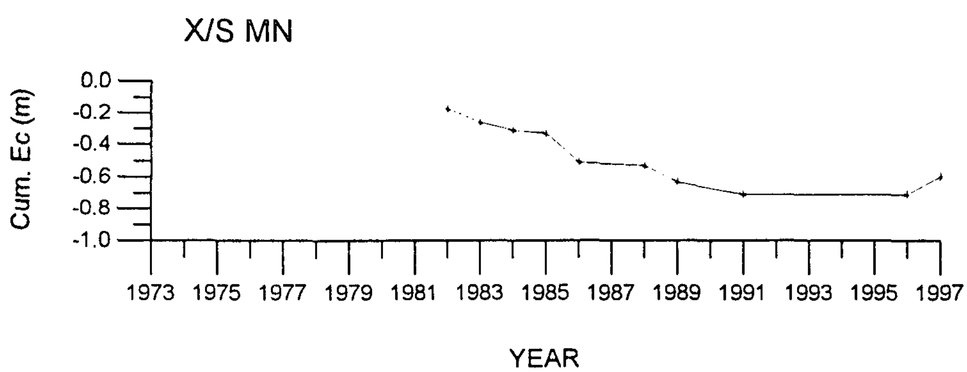

Redwood Ck X/S 16
* Lx in Landslide
High Water Mark
Elevation (m)
31
29
27
25
23
0
20
40
60
80
100
Distance (m)
1973
1985
1997

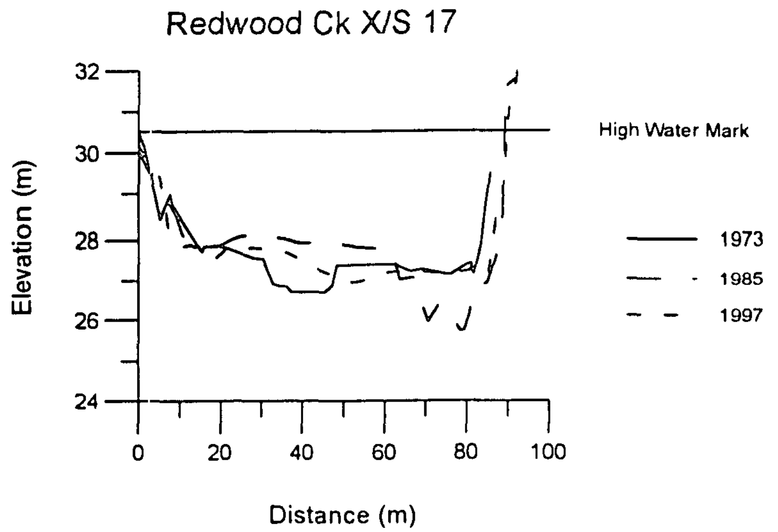

Redwood Ck X/S 16
* Lx in Landslide
High Water Mark
Elevation (m)
31
29
27
25
23
0
20
40
60
80
100
Distance (m)
1996
1997

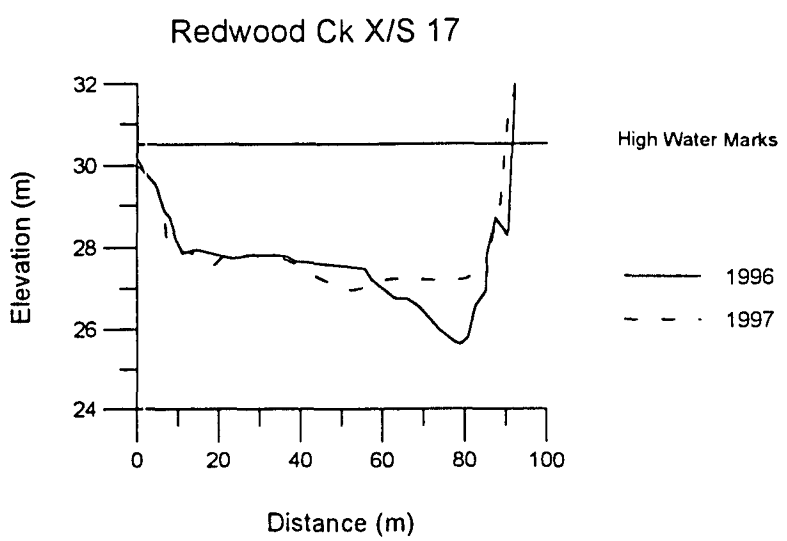

X/S 16
CUM. Ec (m)
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
YEAR

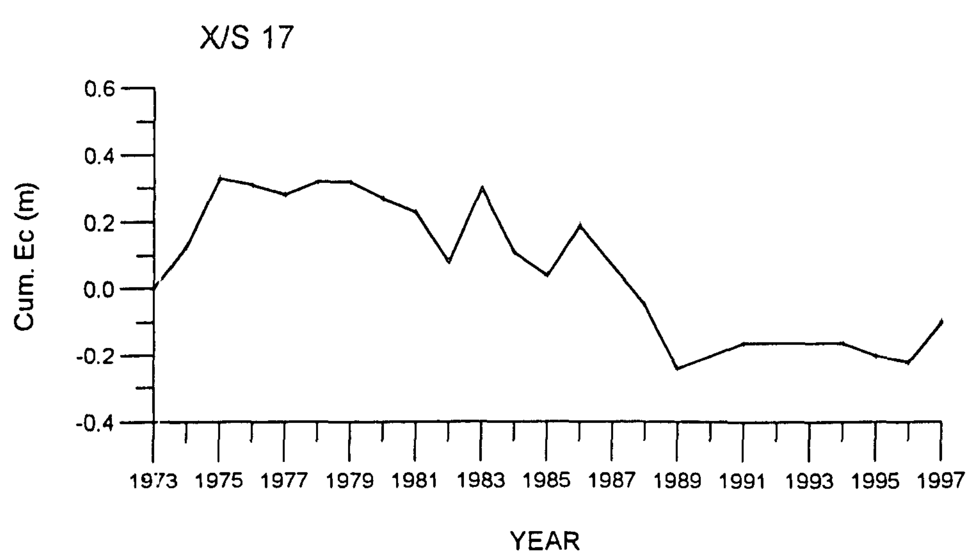

Redwood Ck X/S MN
Elevation (m)
33
31
29
27
25
0
20
40
60
80
100
120
Distance (m)
High Water Mark
1981
1985
1997

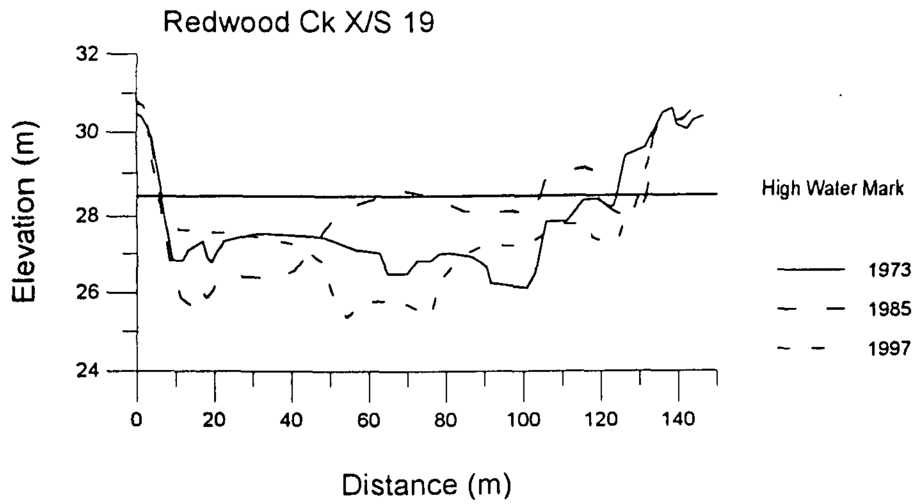

Redwood Ck X/S MN
Elevation (m)
33
31
29
27
25
0
20
40
60
80
100
120
Distance (m)
High Water Mark
1996
1997

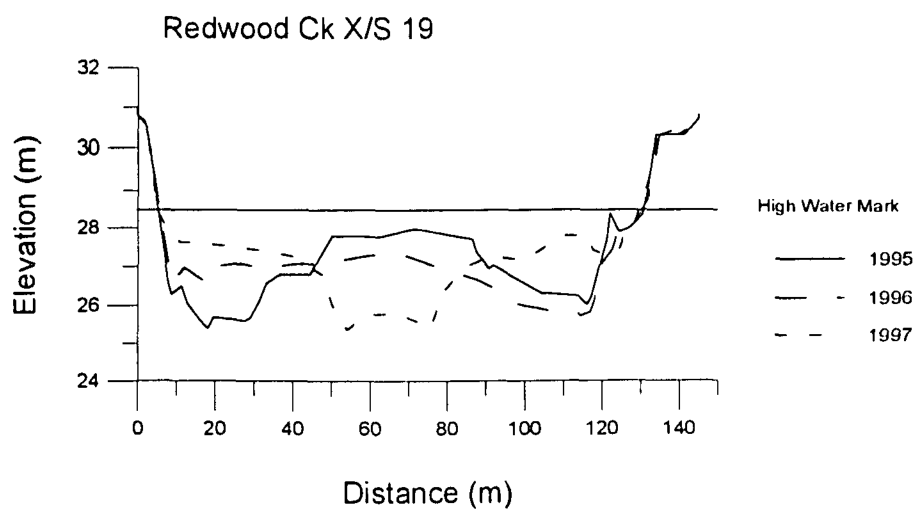

X/S MN
Cum. Ec (m)
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
YEAR

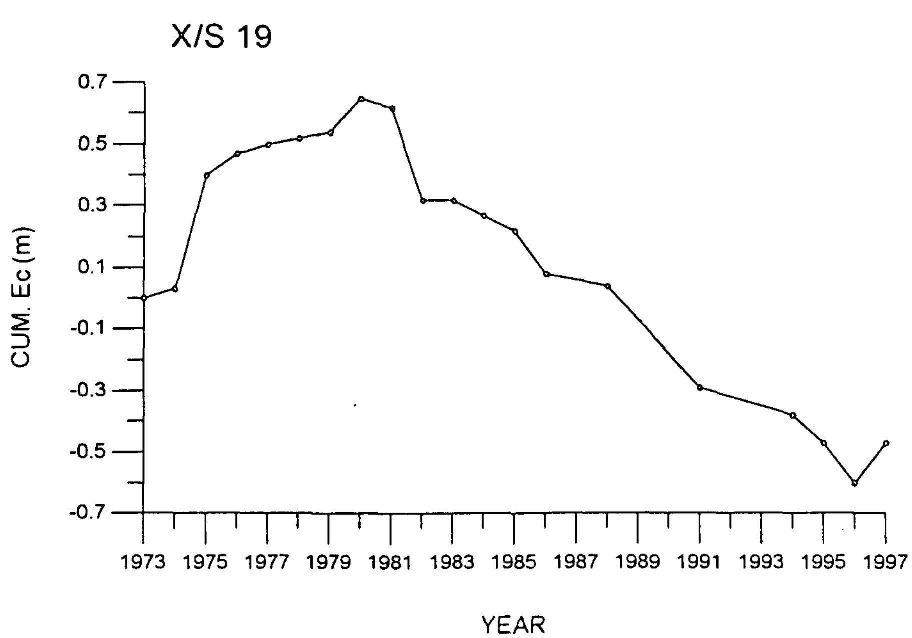

Redwood Ck X/S 17
Elevation (m)
Distance (m)
High Water Mark
1973
1985
1997
32
30
28
26
24
0
20
40
60
80
100

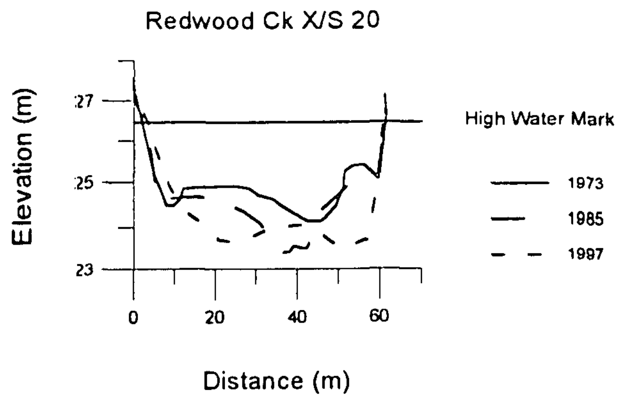

Redwood Ck X/S 17
Elevation (m)
Distance (m)
High Water Marks
1996
1997
32
30
28
26
24
0
20
40
60
80
100

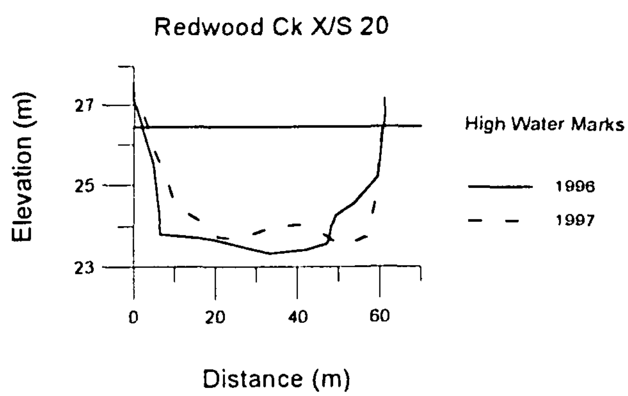

X/S 17
Cum. Ec (m)
YEAR
0.6
0.4
0.2
0.0
-0.2
-0.4
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997

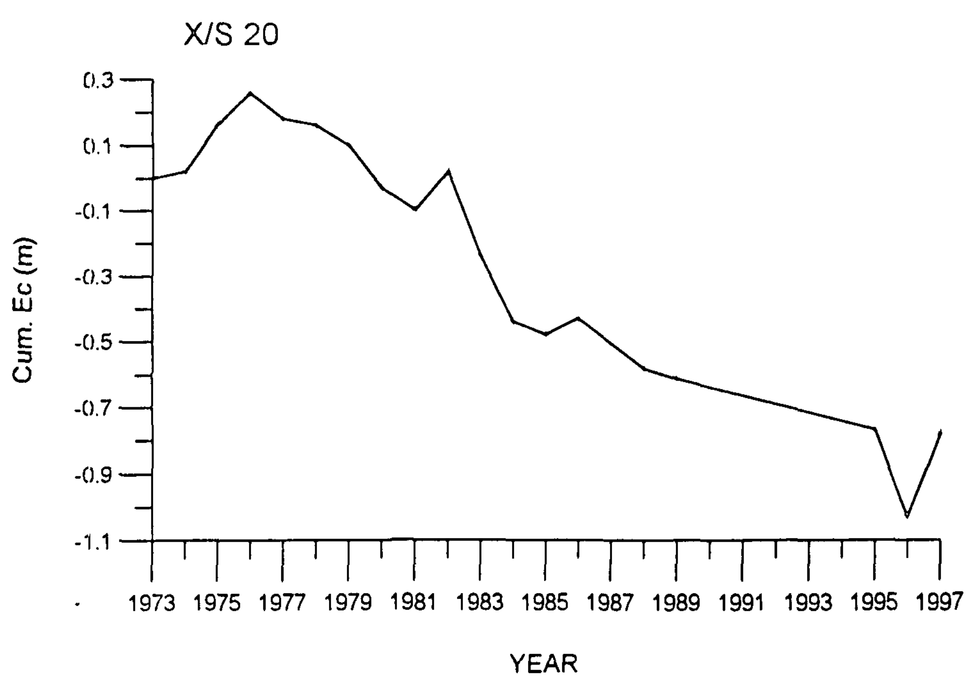

Redwood Ck X/S 19
Elevation (m)
Distance (m)
High Water Mark
1973
1985
1997
32
30
28
26
24
0
20
40
60
80
100
120
140

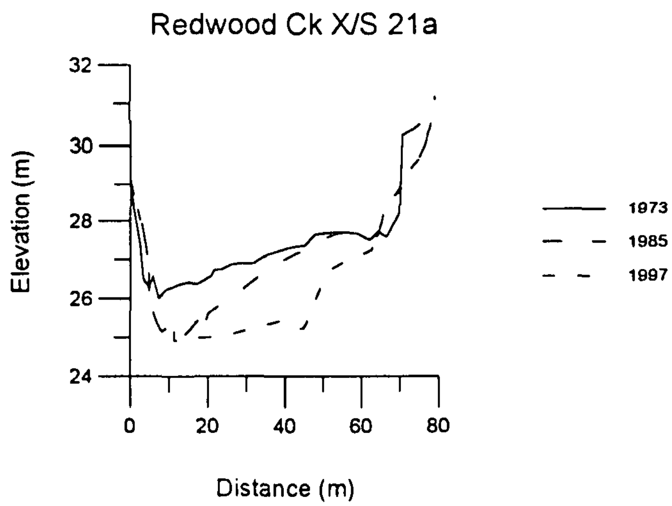

Redwood Ck X/S 19
Elevation (m)
Distance (m)
High Water Mark
1995
1996
1997
32
30
28
26
24
0
20
40
60
80
100
120
140


X/S 19
CUM. Ec (m)
YEAR
0.7
0.5
0.3
0.1
-0.1
-0.3
-0.5
-0.7
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997

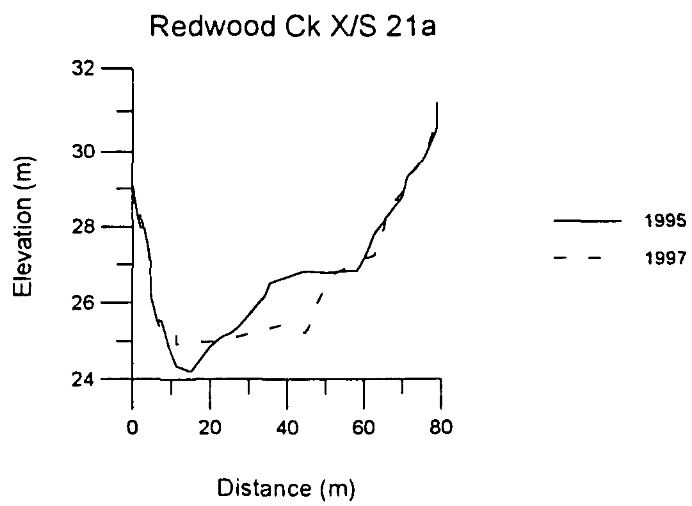

Redwood Ck X/S 20
Elevation (m)
27
25
23
0
20
40
60
Distance (m)
High Water Mark
1973
1985
1997


Redwood Ck X/S 20
Elevation (m)
27
25
23
0
20
40
60
Distance (m)
High Water Marks
1996
1997

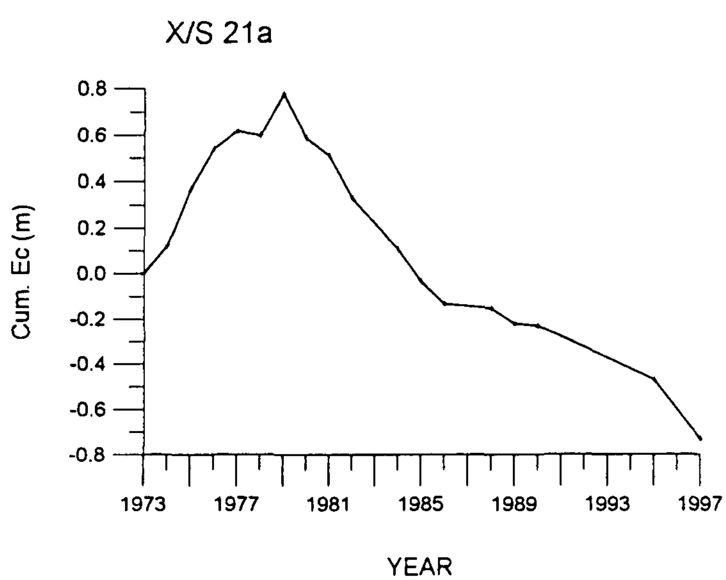

X/S 20
Cum. Ec (m)
0.3
0.1
-0.1
-0.3
-0.5
-0.7
-0.9
-1.1
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
YEAR



Redwood Ck X/S 21a
Elevation (m)
32
30
28
26
24
0
20
40
60
80
Distance (m)
1973
1985
1997

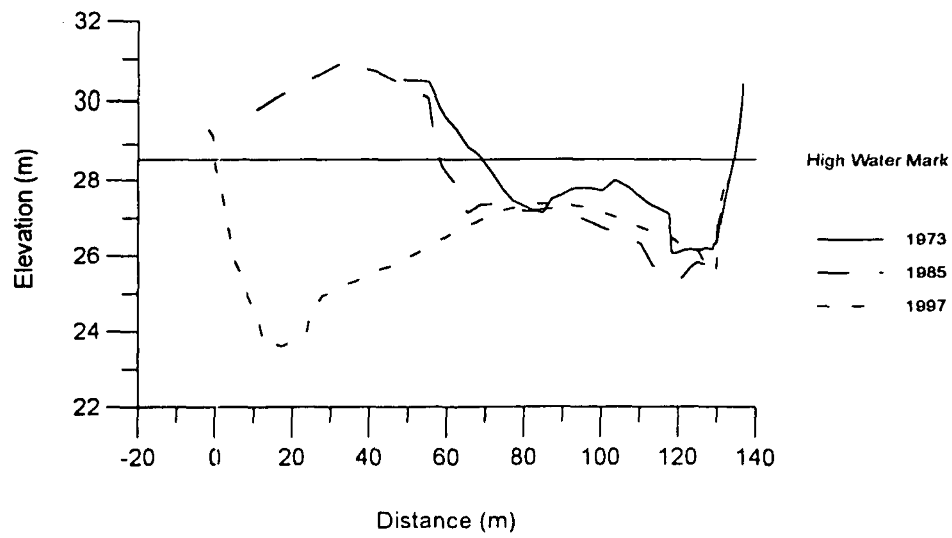


Redwood Ck X/S 21a
Elevation (m)
32
30
28
26
24
0
20
40
60
80
Distance (m)
1995
1997

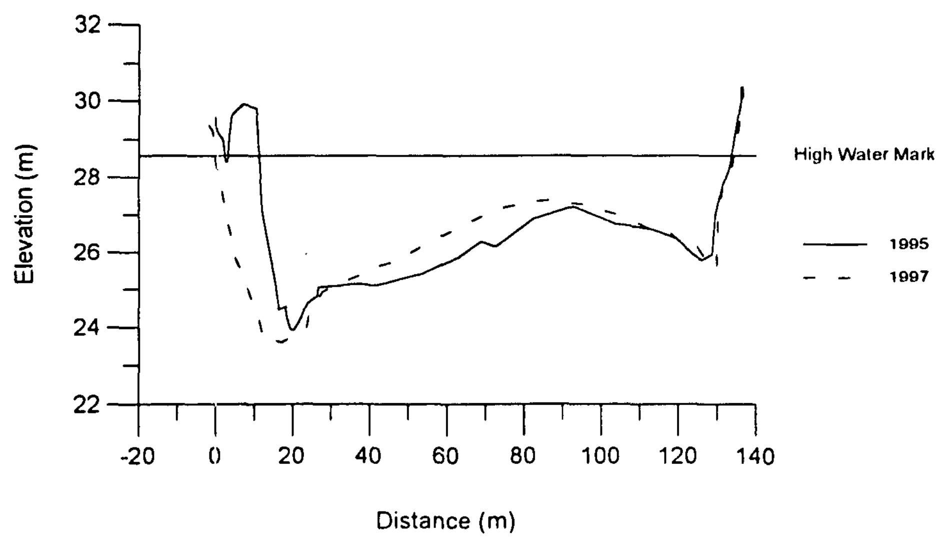


X/S 21a
Cum. Ec (m)
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
1973
1977
1981
1985
1989
1993
1997
YEAR

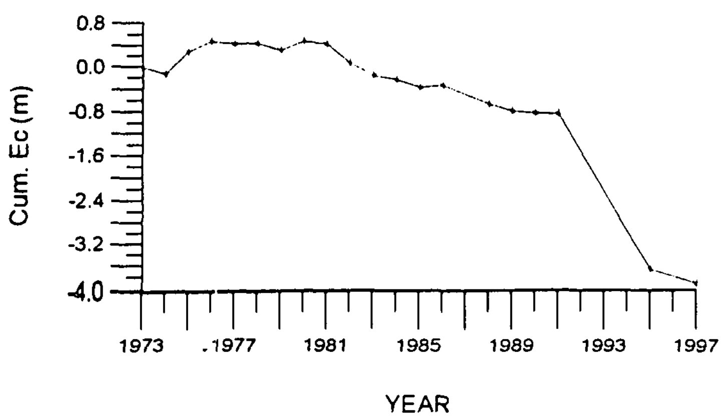
Redwood Creek X/S #23

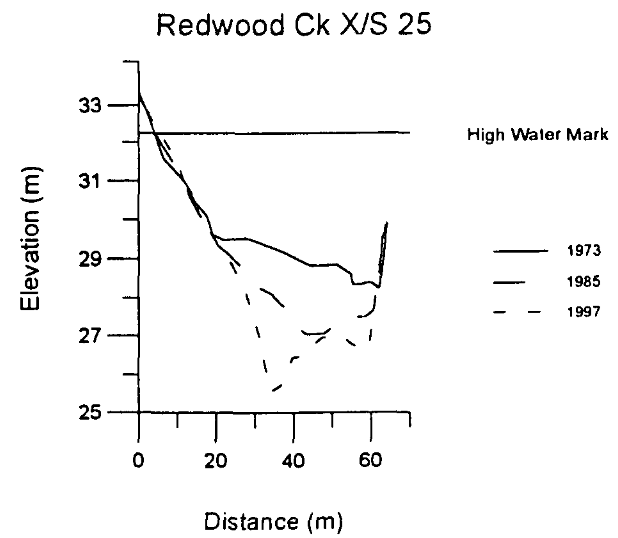


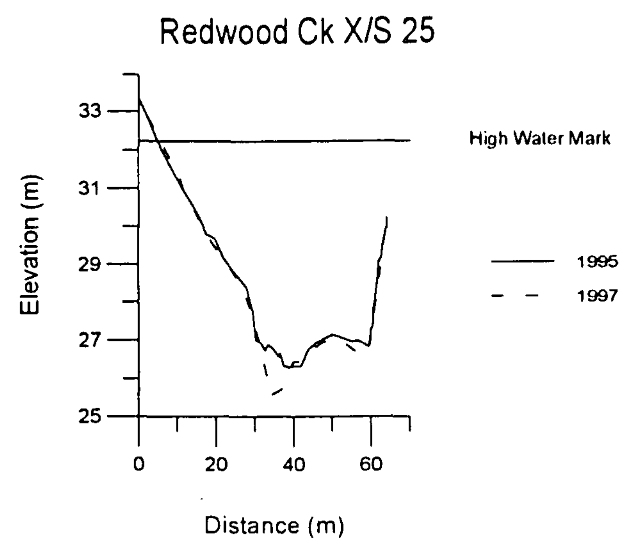
Redwood Creek X/S #23

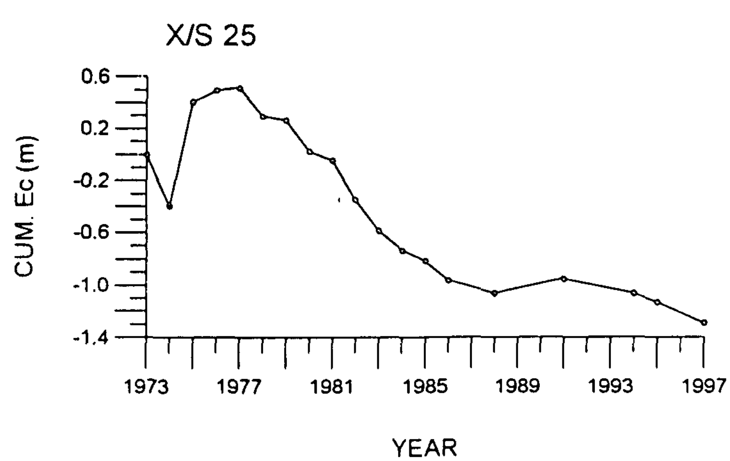


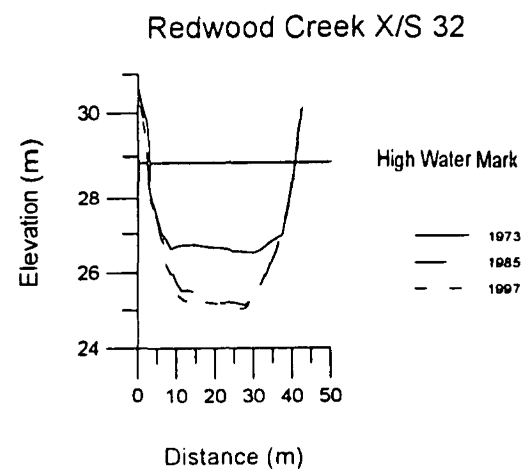
X/S 23

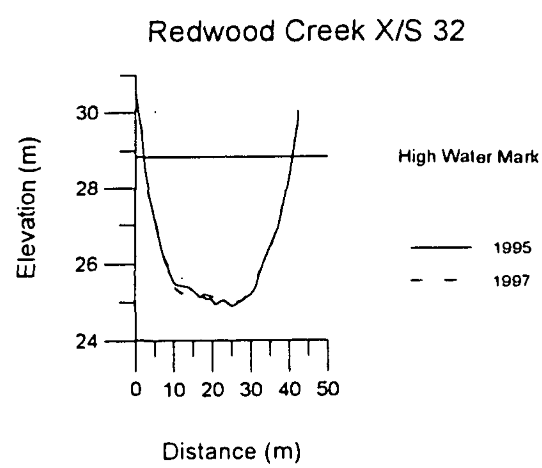


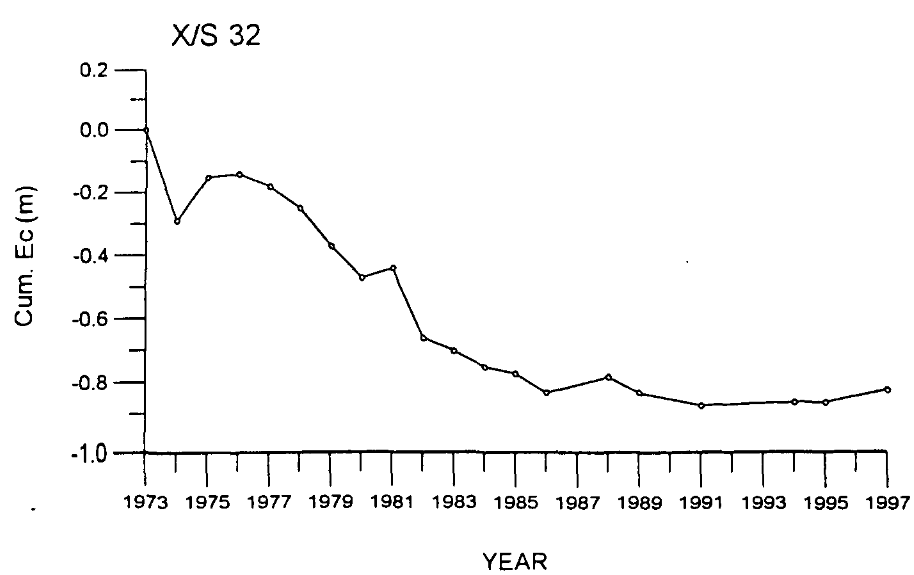

Redwood Ck X/S 25
Elevation (m)
33
31
29
27
25
0
20
40
60
Distance (m)
High Water Mark
1973
1985
1997

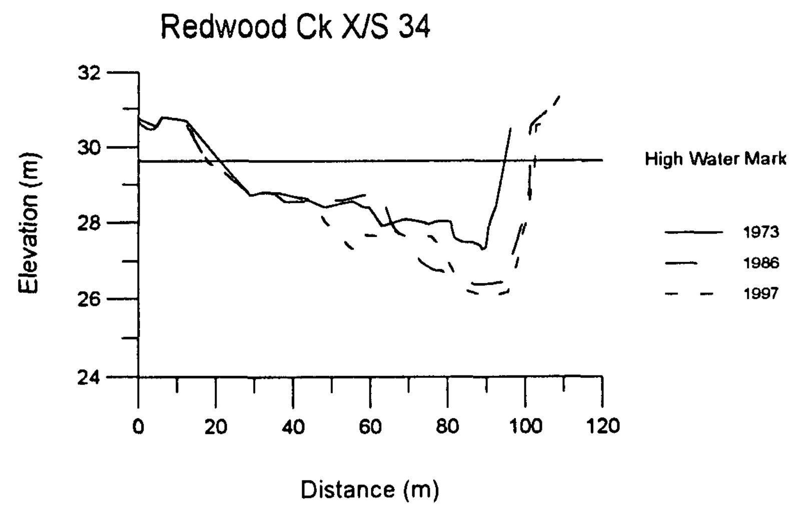

Redwood Ck X/S 25
Elevation (m)
33
31
29
27
25
0
20
40
60
Distance (m)
High Water Mark
1995
1997

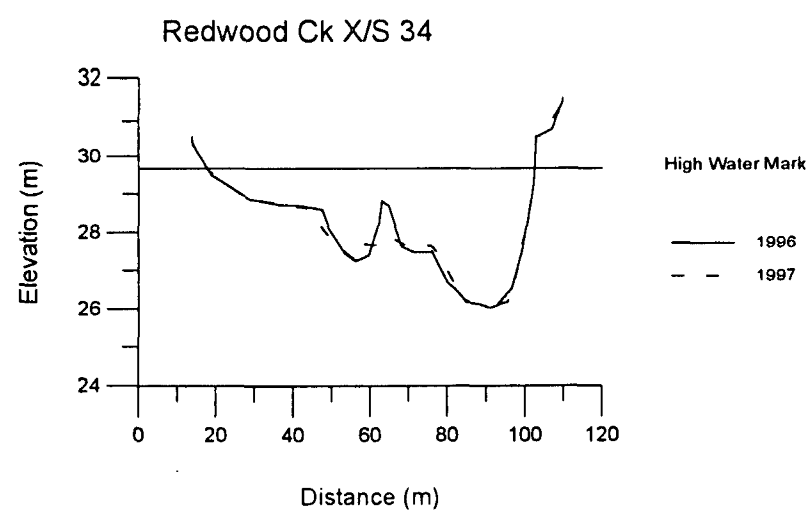

X/S 25
CUM. Ec (m)
0.6
0.2
-0.2
-0.6
-1.0
-1.4
1973
1977
1981
1985
1989
1993
1997
YEAR

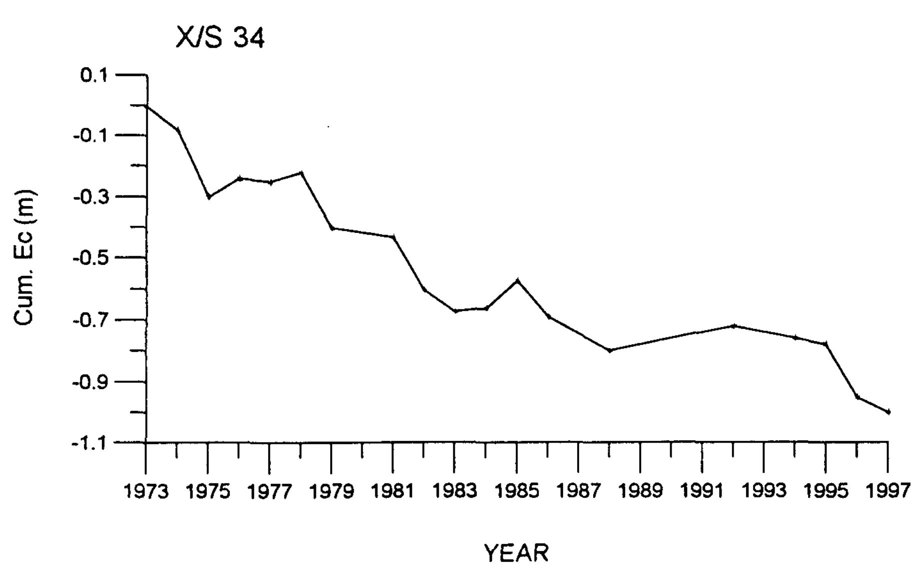

Redwood Creek X/S 32
Elevation (m)
30
28
26
24
0 10 20 30 40 50
Distance (m)
High Water Mark
1973
1985
1997

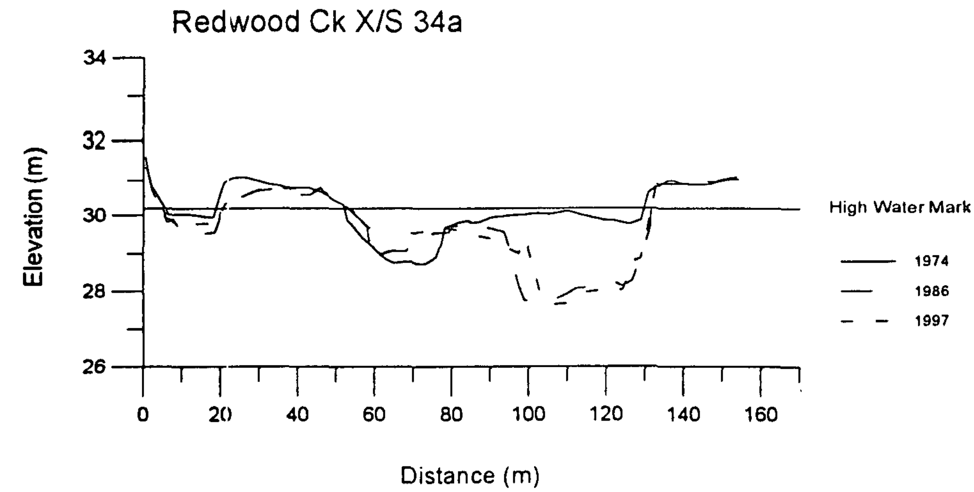

Redwood Creek X/S 32
Elevation (m)
30
28
26
24
0 10 20 30 40 50
Distance (m)
High Water Mark
1995
1997

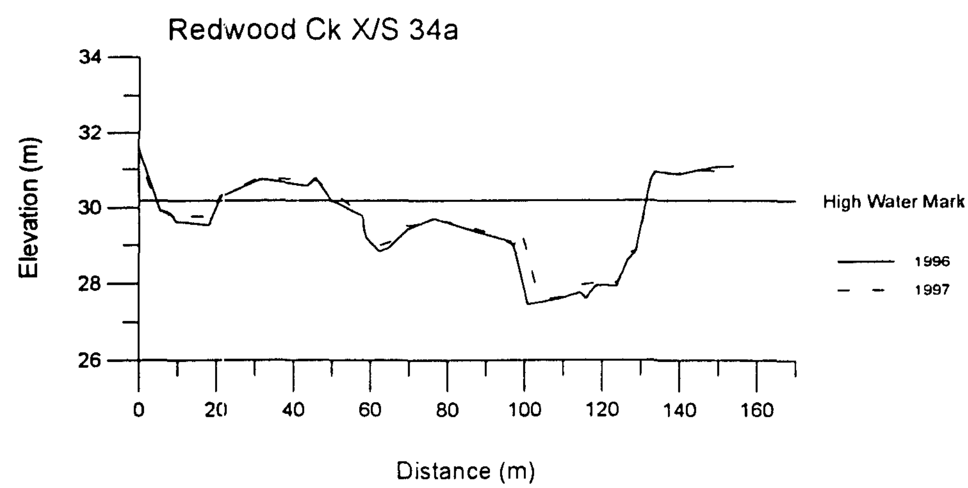

X/S 32
Cum. Ec (m)
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
1973 1975 1977 1979 1981 1983 1985 1987 1989 1991 1993 1995 1997
YEAR

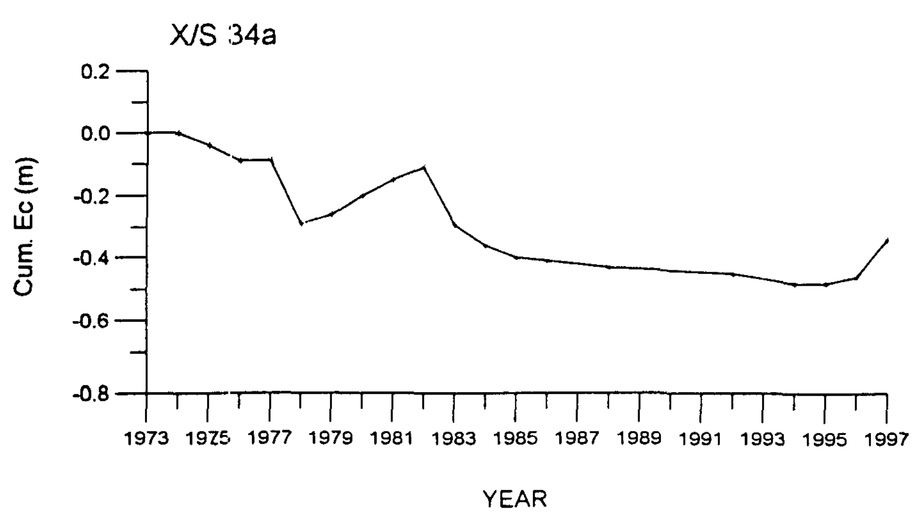

Redwood Ck X/S 34
Elevation (m)
Distance (m)
High Water Mark
1973
1986
1997

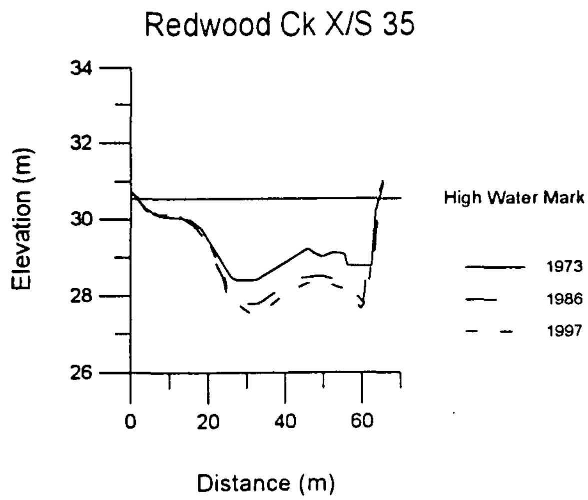

Redwood Ck X/S 34
Elevation (m)
Distance (m)
High Water Mark
1996
1997

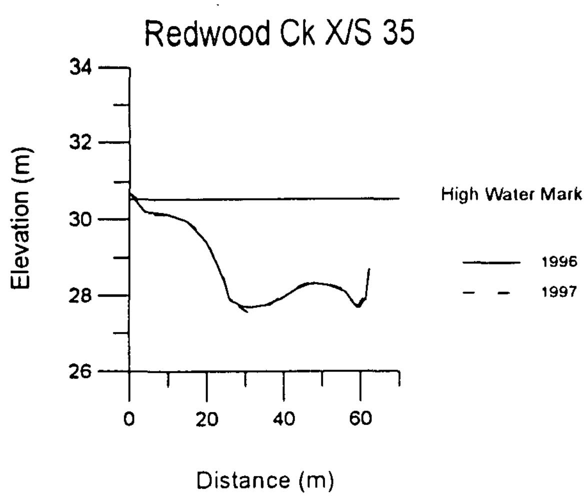

X/S 34
Cum. Ec (m)
YEAR

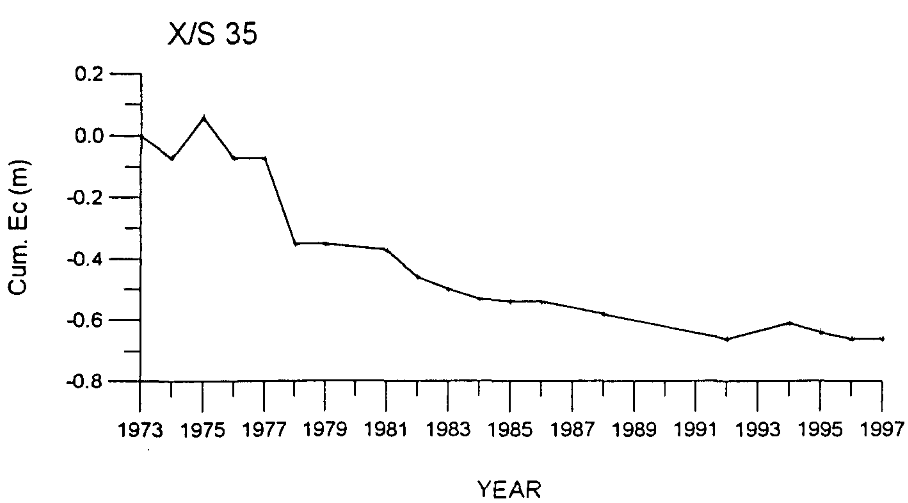

Redwood Ck X/S 34a
Elevation (m)
34
32
30
28
26
0
20
40
60
80
100
120
140
160
Distance (m)
High Water Mark
1974
1986
1997

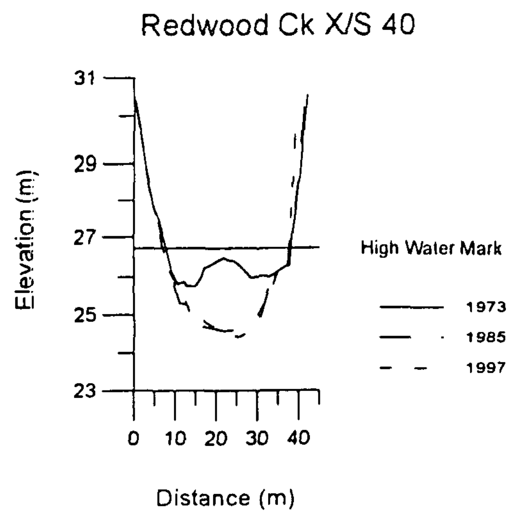

Redwood Ck X/S 34a
Elevation (m)
34
32
30
28
26
0
20
40
60
80
100
120
140
160
Distance (m)
High Water Mark
1996
1997

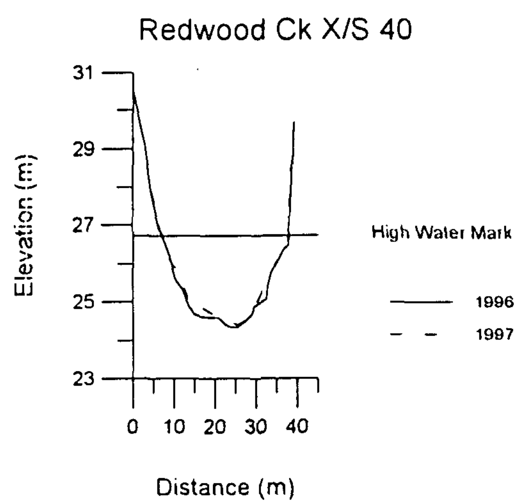

X/S 34a
Cum. Ec (m)
0.2
0.0
-0.2
-0.4
-0.6
-0.8
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
YEAR

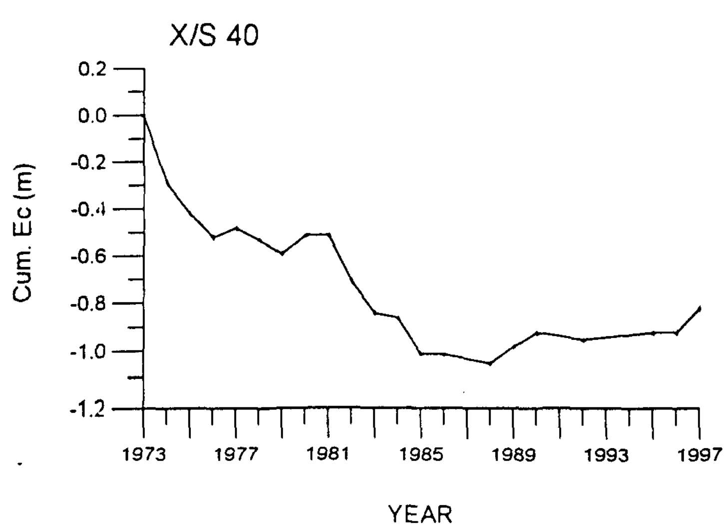

Redwood Ck X/S 35
Elevation (m)
34
32
30
28
26
0
20
40
60
Distance (m)
High Water Mark
1973
1986
1997

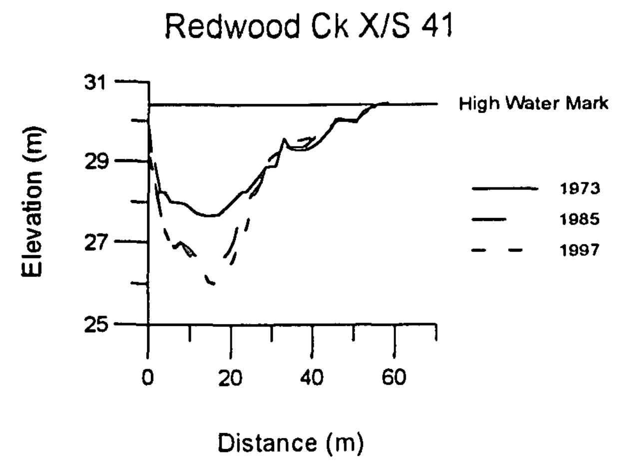

Redwood Ck X/S 35
Elevation (m)
34
32
30
28
26
0
20
40
60
Distance (m)
High Water Mark
1996
1997

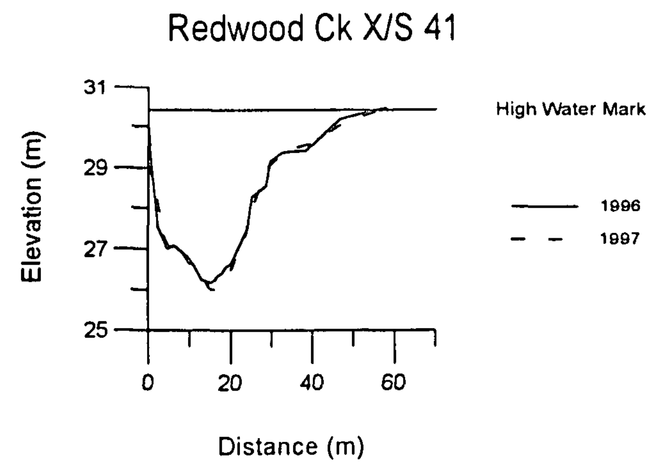

X/S 35
Cum. Ec (m)
0.2
0.0
-0.2
-0.4
-0.6
-0.8
1973 1975 1977 1979 1981 1983 1985 1987 1989 1991 1993 1995 1997
YEAR

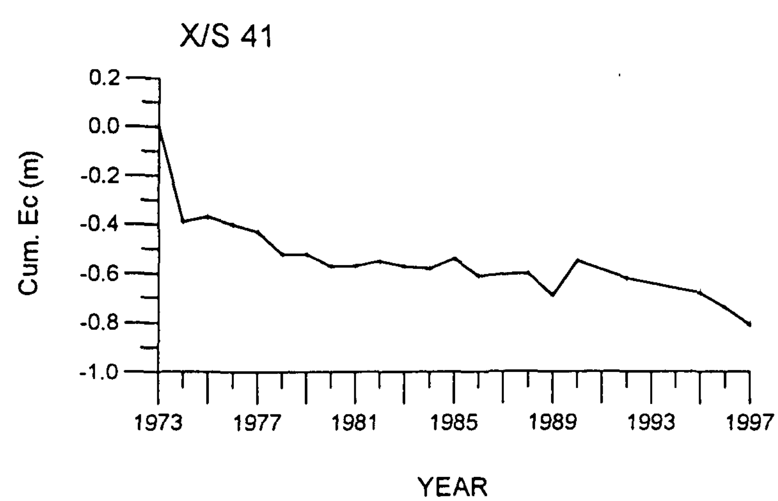

Redwood Ck X/S 40
31
29
27
25
23
Elevation (m)
0
10
20
30
40
Distance (m)
High Water Mark
1973
1985
1997

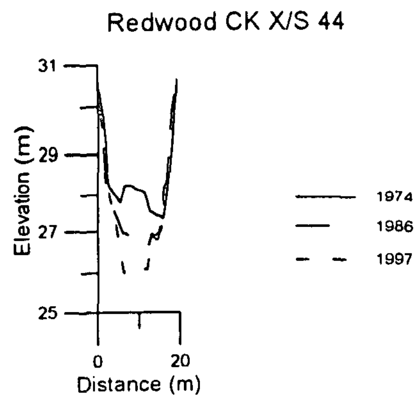

Redwood Ck X/S 40
31
29
27
25
23
Elevation (m)
0
10
20
30
40
Distance (m)
High Water Mark
1996
1997


X/S 40
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
Cum. Ec (m)
1973
1977
1981
1985
1989
1993
1997
YEAR

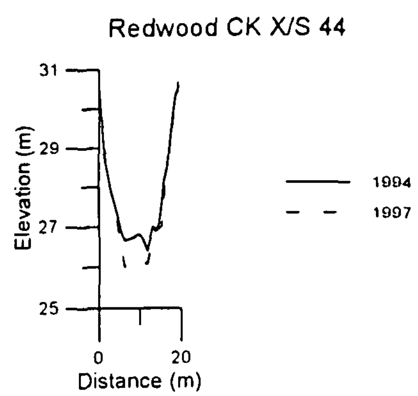

Redwood Ck X/S 41
Elevation (m)
31
29
27
25
0
20
40
60
Distance (m)
High Water Mark
1973
1985
1997


Redwood Ck X/S 41
Elevation (m)
31
29
27
25
0
20
40
60
Distance (m)
High Water Mark
1996
1997

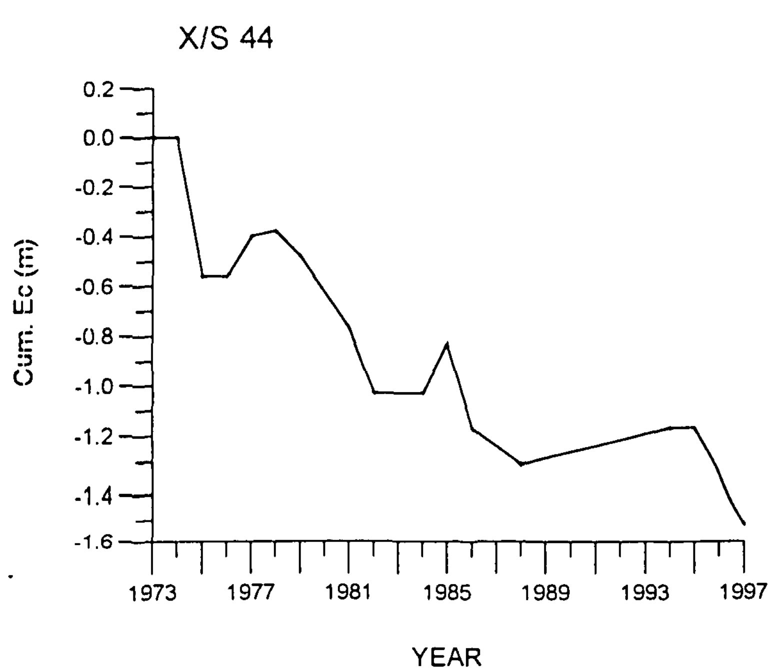

X/S 41
Cum. Ec (m)
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
1973
1977
1981
1985
1989
1993
1997
YEAR



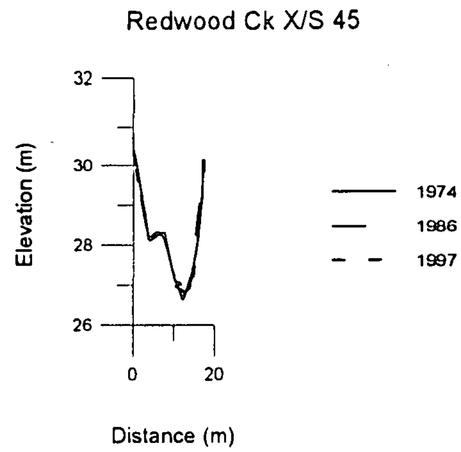
Redwood CK X/S 44
31
29
27
25
Elevation (m)
0
20
Distance (m)
1974
1986
1997

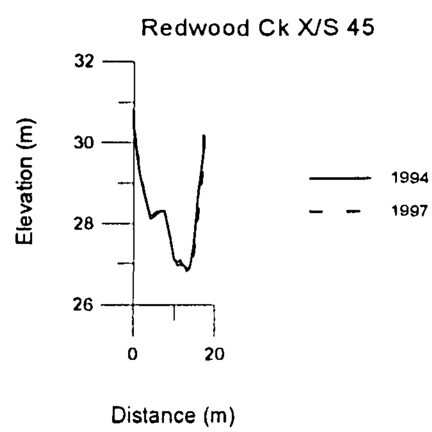


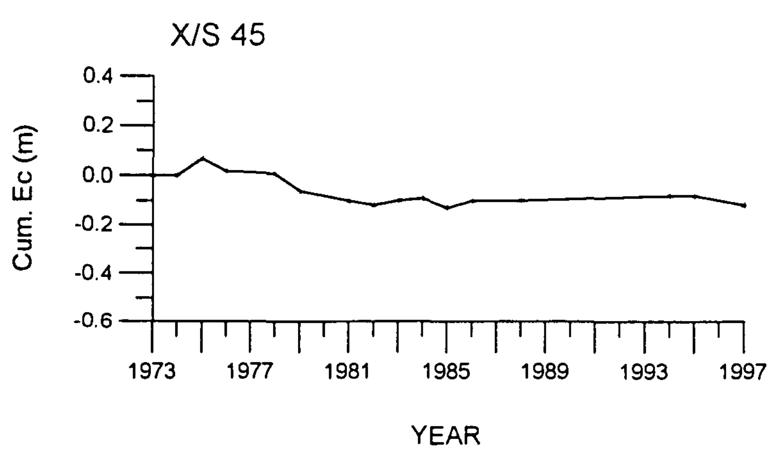
Redwood CK X/S 44
31
29
27
25
Elevation (m)
0
20
Distance (m)
1994
1997



X/S 44
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
Cum. Ec (m)
1973
1977
1981
1985
1989
1993
1997
YEAR


Redwood Ck X/S 45
Elevation (m)
32
30
28
26
0
20
Distance (m)
1974
1986
1997


Redwood Ck X/S 45
Elevation (m)
32
30
28
26
0
20
Distance (m)
1994
1997


X/S 45
Cum. Ec (m)
0.4
0.2
0.0
-0.2
-0.4
-0.6
1973
1977
1981
1985
1989
1993
1997
YEAR

Attachment 4: Redwood Creek Long-Term Channel Stability Monitoring

Redwood Creek Cross Section Plots for WY 2000

TOP AND MIDDLE GRAPH

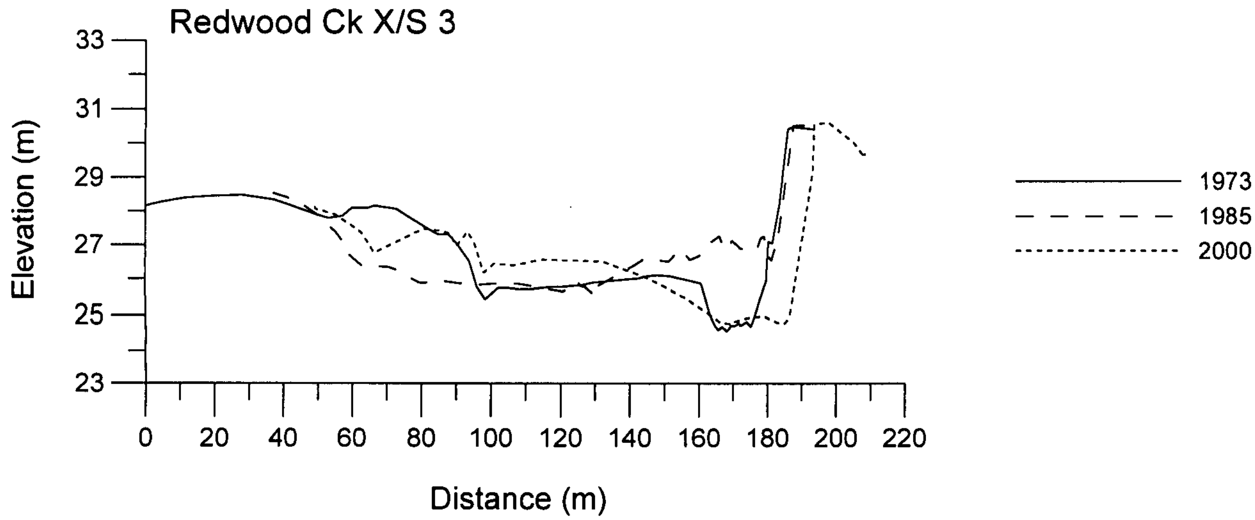
For each cross section surveyed in 2000, three plots are presented to show both the most recent changes and long-term channel changes at cross sections. The top graph depicts long-term cross-sectional changes over the last 25 years. The graph includes the earliest survey (solid line), one mid-1980's (dashed line) and the 2000 cross section survey (small dashed line). The middle graph is a plot of the two most recent channel surveys; the 2000 survey (dashed line) and the previous years survey (solid line).

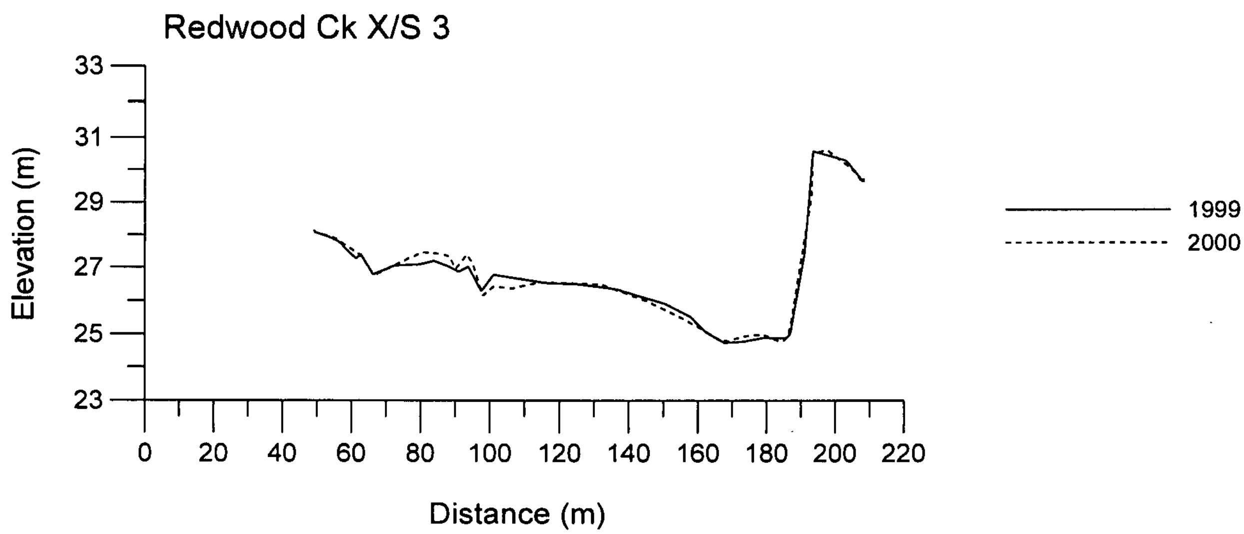
Both axes are plotted in meters. The x-axis is the distance measured from the left end point (that is the left monument distance = 0.0 meters). Left and right on a channel cross section are designated while looking in a downstream direction. The y-axis is elevation measured above an arbitrary datum.

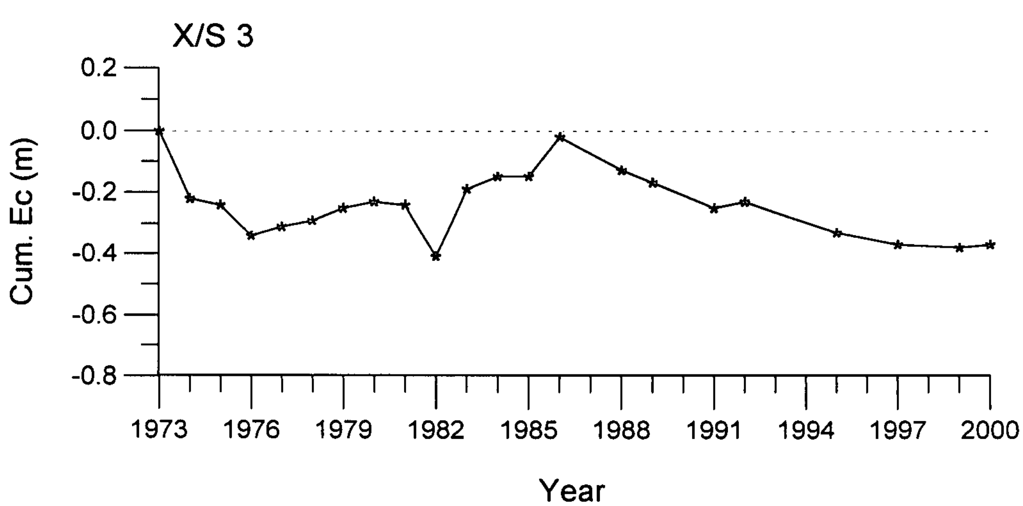
The vertical exaggeration for each plot is either 5x or 10x. The scale on the y-axis (elevation) is five times the x-axis (distance) on plots with a vertical exaggeration of five. Likewise, the x-axis scale on plots with vertical exaggeration equal to ten is ten times that of the y-axis scale.

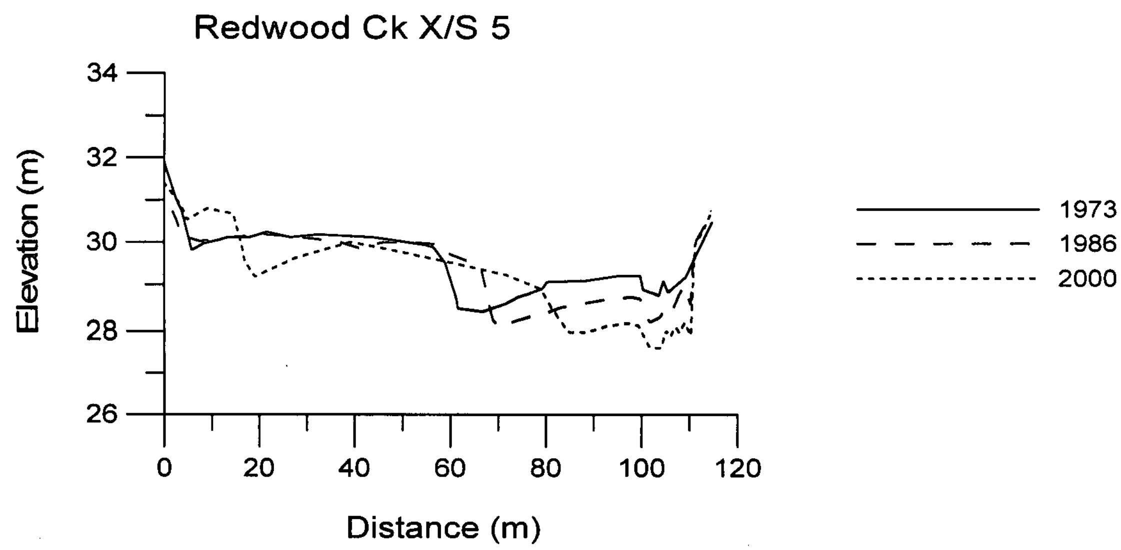
LOWER GRAPH

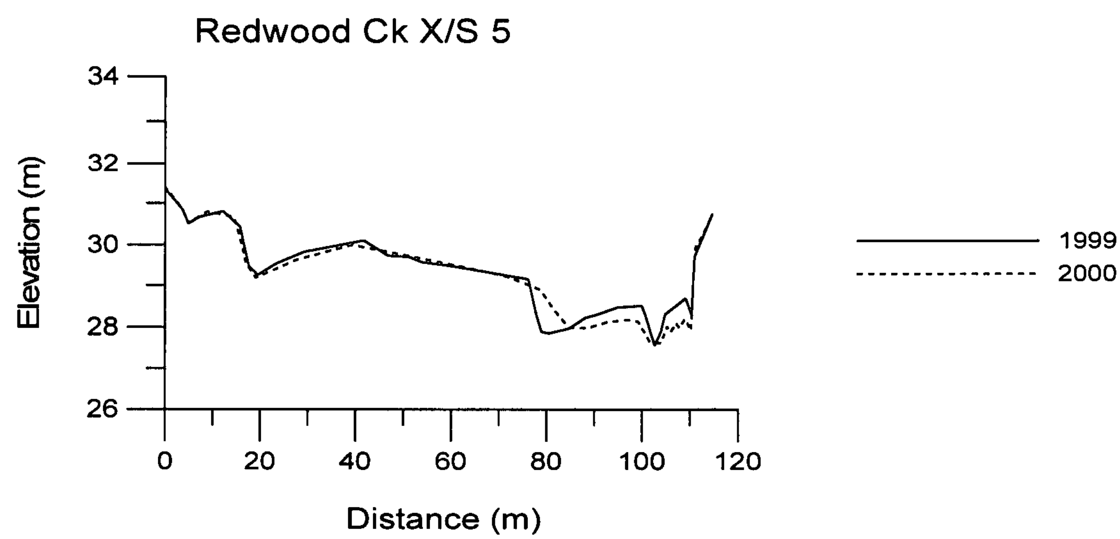
The cumulative change in streambed elevation (Cum. Ec; y-axis) is plotted by year (x-axis) for each cross section. The cumulative change in mean streambed elevation is plotted by year to show trends at individual cross sections over time and can depict general trends in infilling, scouring, or stability at the cross section.

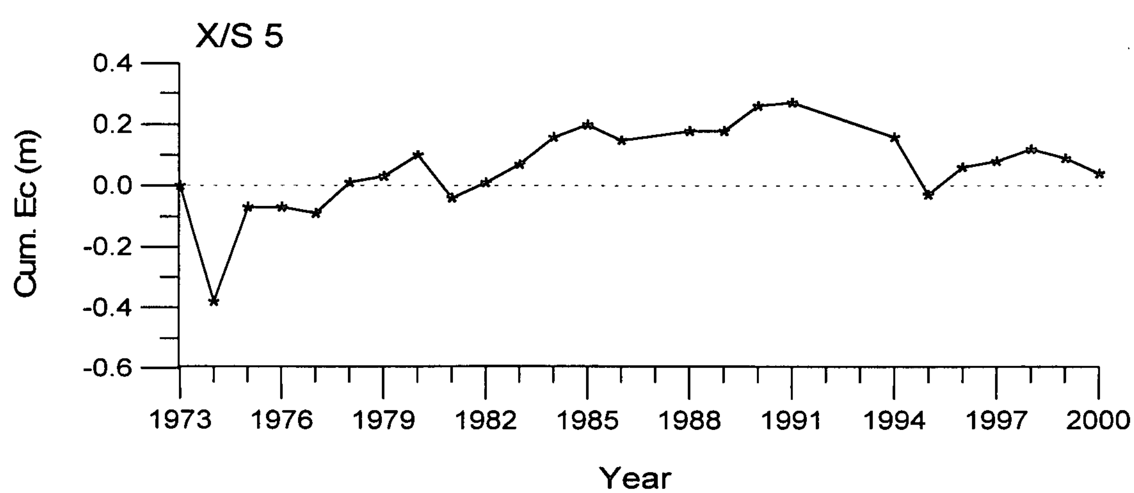

Redwood Ck X/S 3
Elevation (m)
Distance (m)
1973
1985
2000

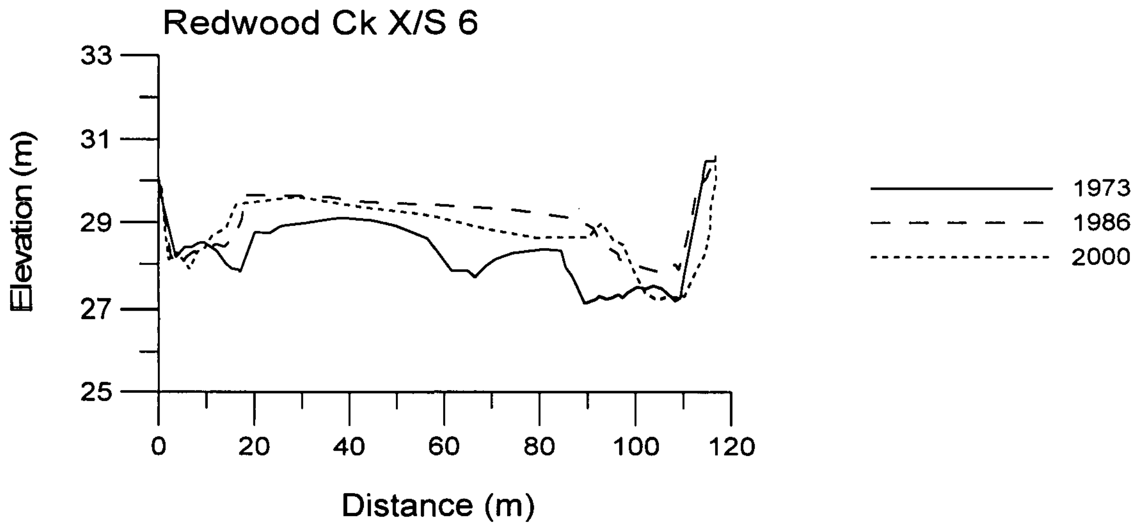

Redwood Ck X/S 3
Elevation (m)
Distance (m)
1999
2000


X/S 3
Cum. Ec (m)
Year

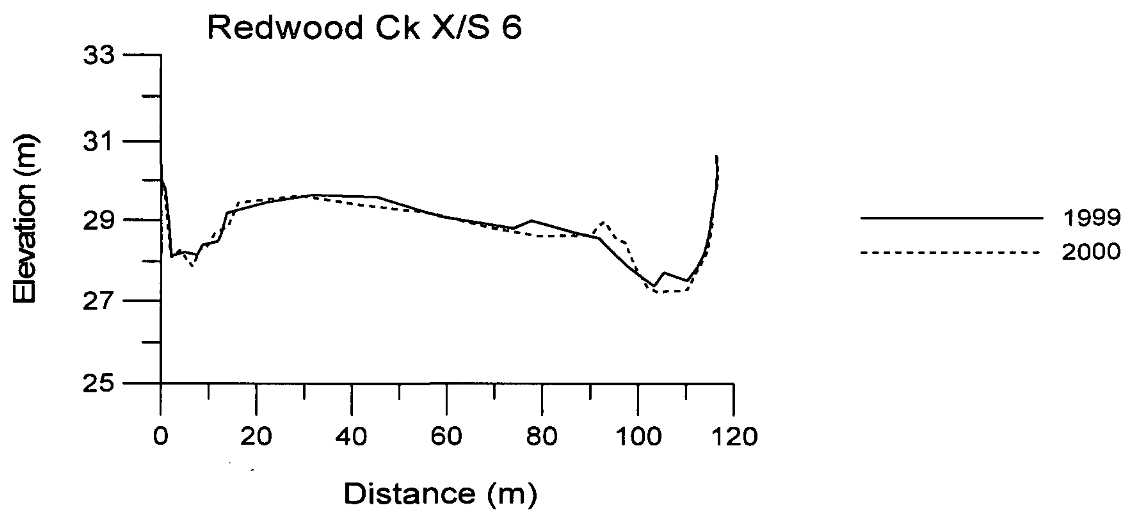

Redwood Ck X/S 5
Elevation (m)
34
32
30
28
26
0
20
40
60
80
100
120
Distance (m)
1973
1986
2000


Redwood Ck X/S 5
Elevation (m)
34
32
30
28
26
0
20
40
60
80
100
120
Distance (m)
1999
2000

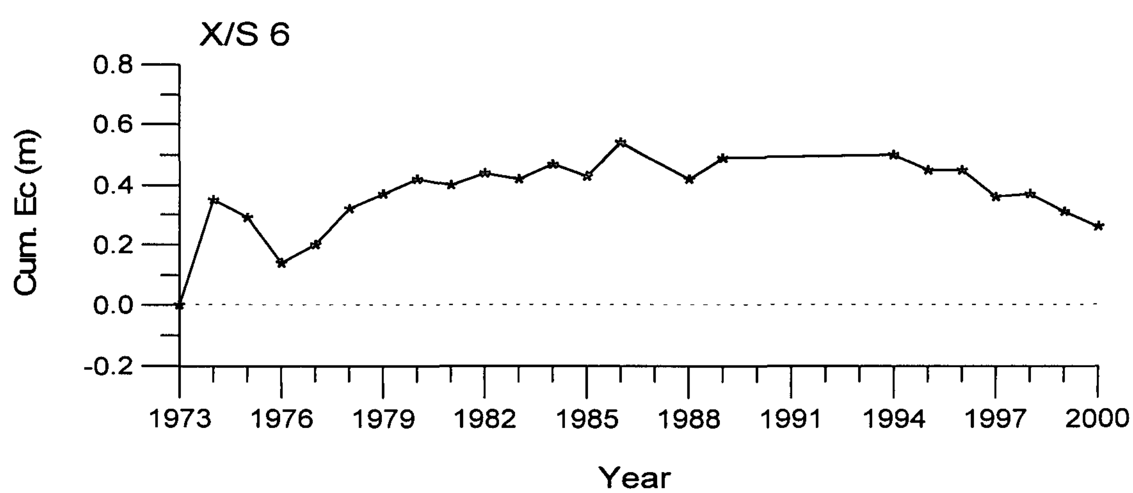

X/S 5
Cum. Ec (m)
0.4
0.2
0.0
-0.2
-0.4
-0.6
1973
1976
1979
1982
1985
1988
1991
1994
1997
2000
Year



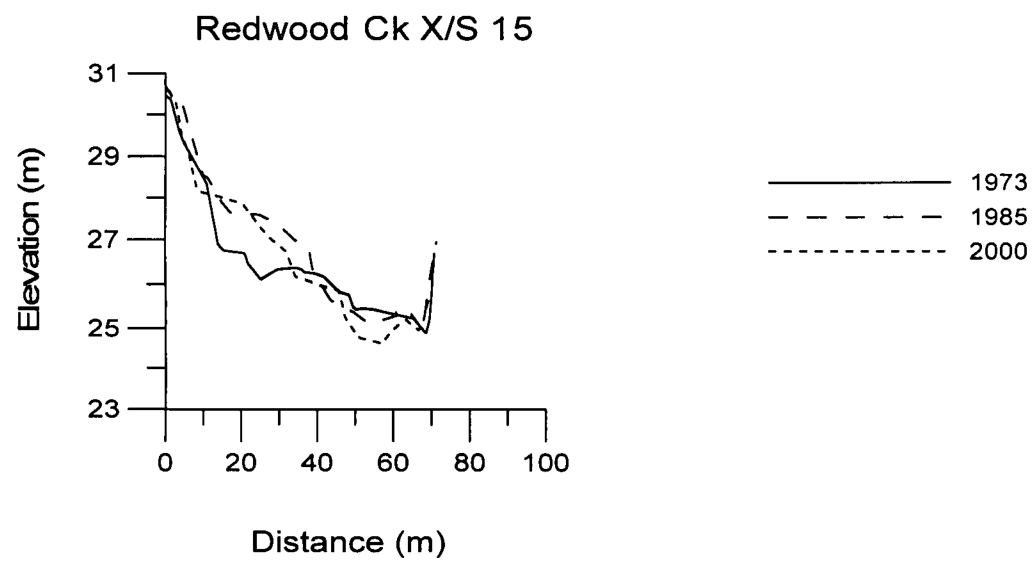
Redwood Ck X/S 6
Elevation (m)
Distance (m)
1973
1986
2000



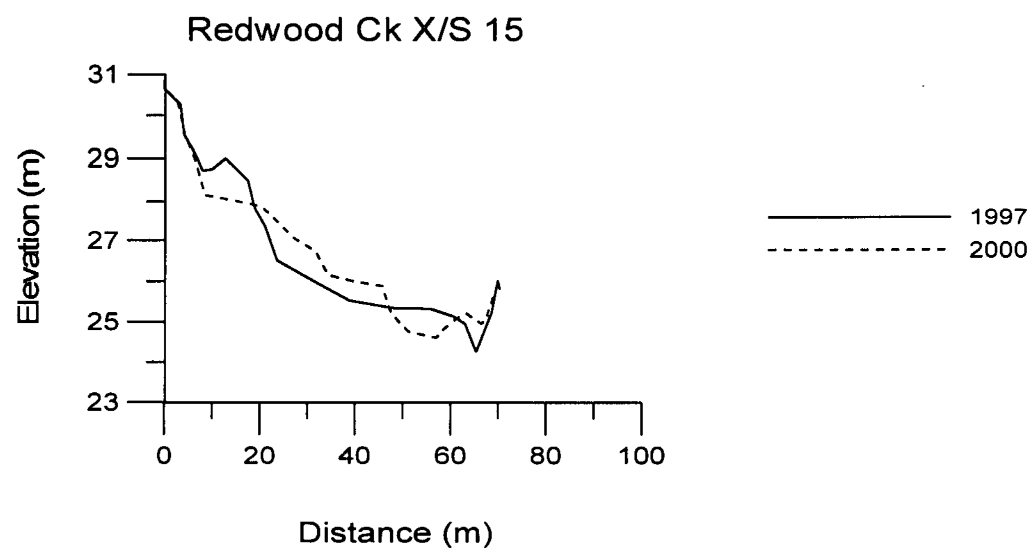
Redwood Ck X/S 6
Elevation (m)
Distance (m)
1999
2000



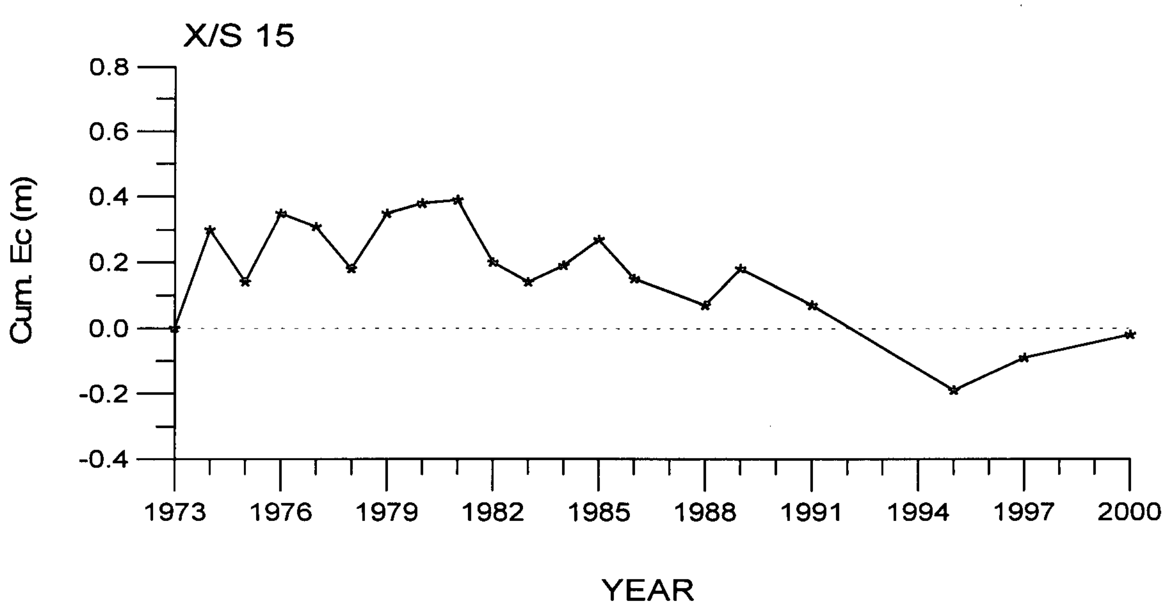
X/S 6
Cum. Ec (m)
Year



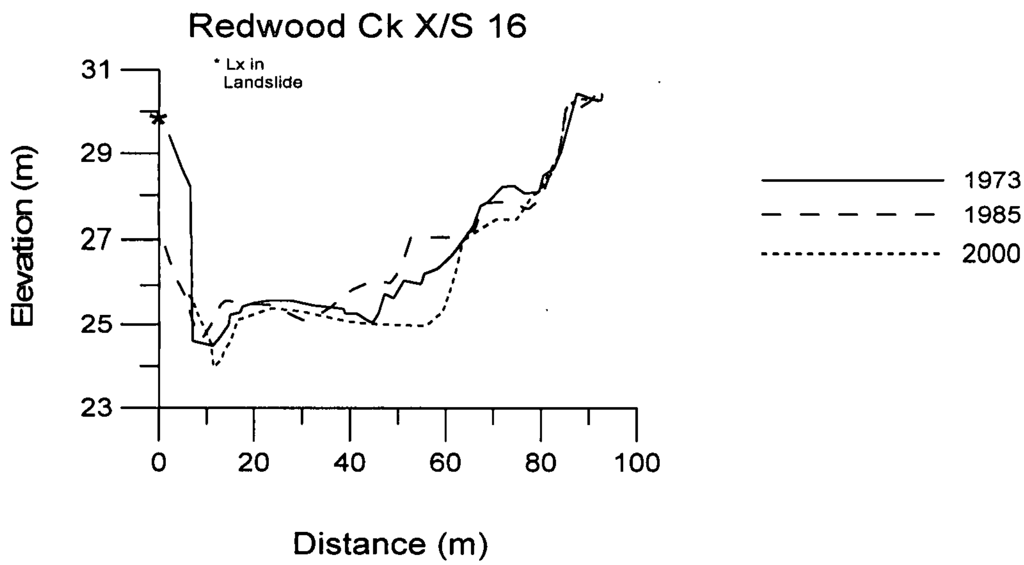
Redwood Ck X/S 15
Elevation (m)
31
29
27
25
23
0
20
40
60
80
100
Distance (m)
1973
1985
2000



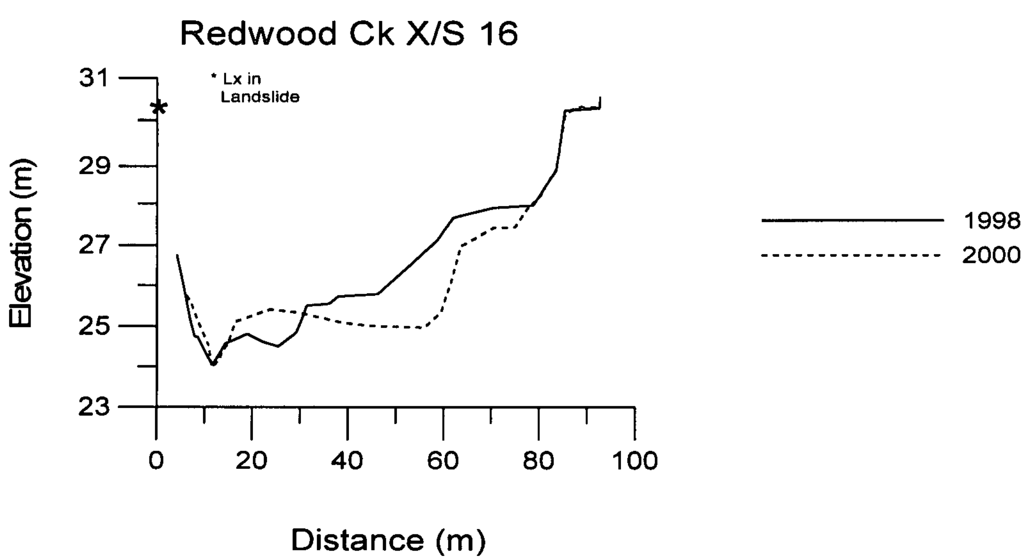
Redwood Ck X/S 15
Elevation (m)
31
29
27
25
23
0
20
40
60
80
100
Distance (m)
1997
2000



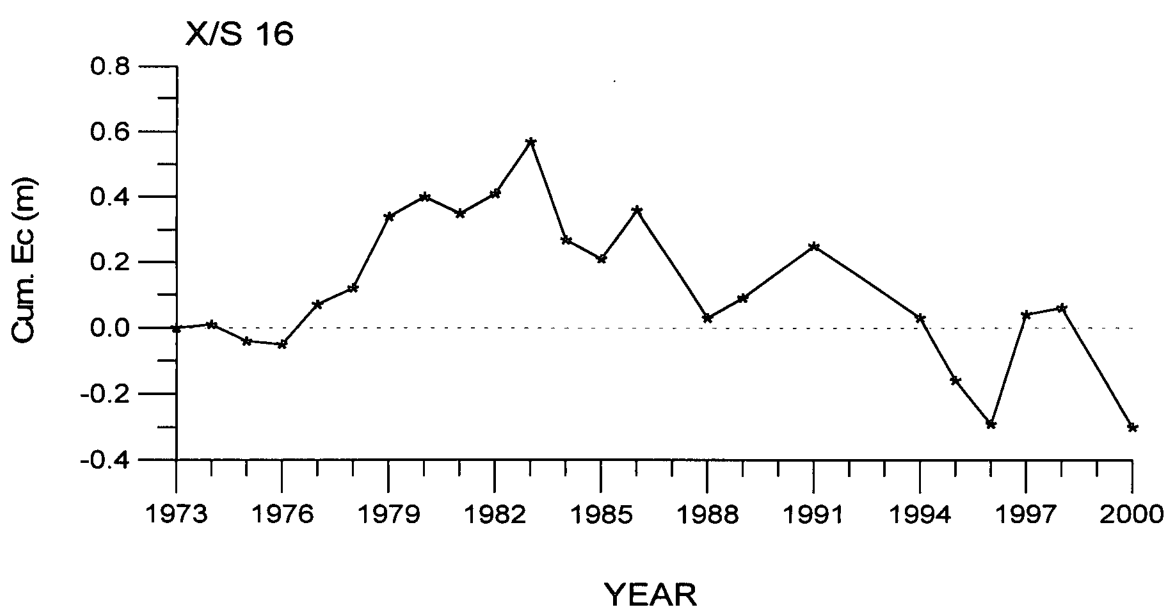
X/S 15
Cum. Ec (m)
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
1973
1976
1979
1982
1985
1988
1991
1994
1997
2000
YEAR



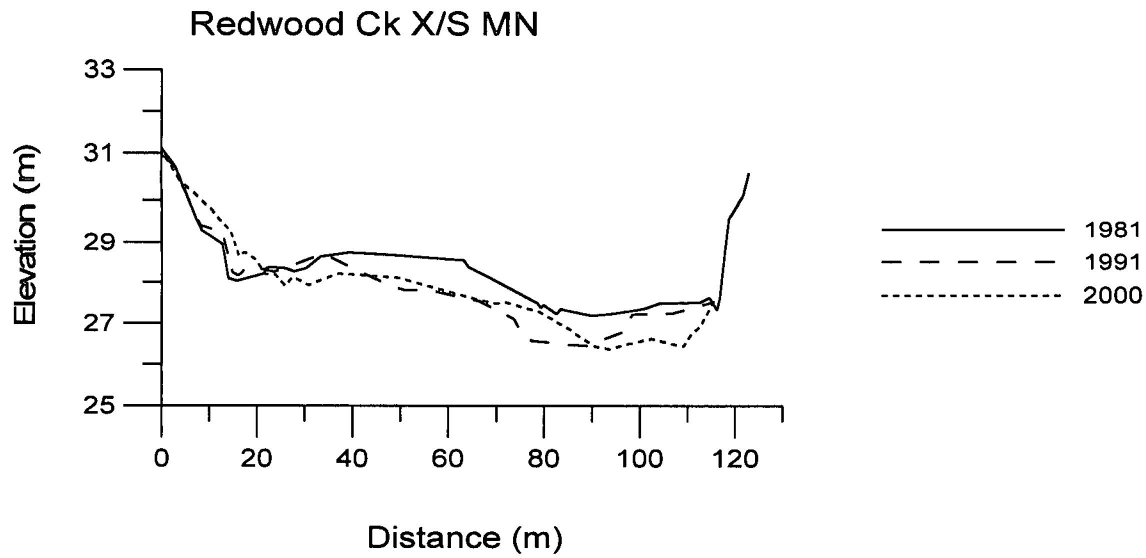
Redwood Ck X/S 16
* Lx in Landslide
Elevation (m)
Distance (m)
1973
1985
2000

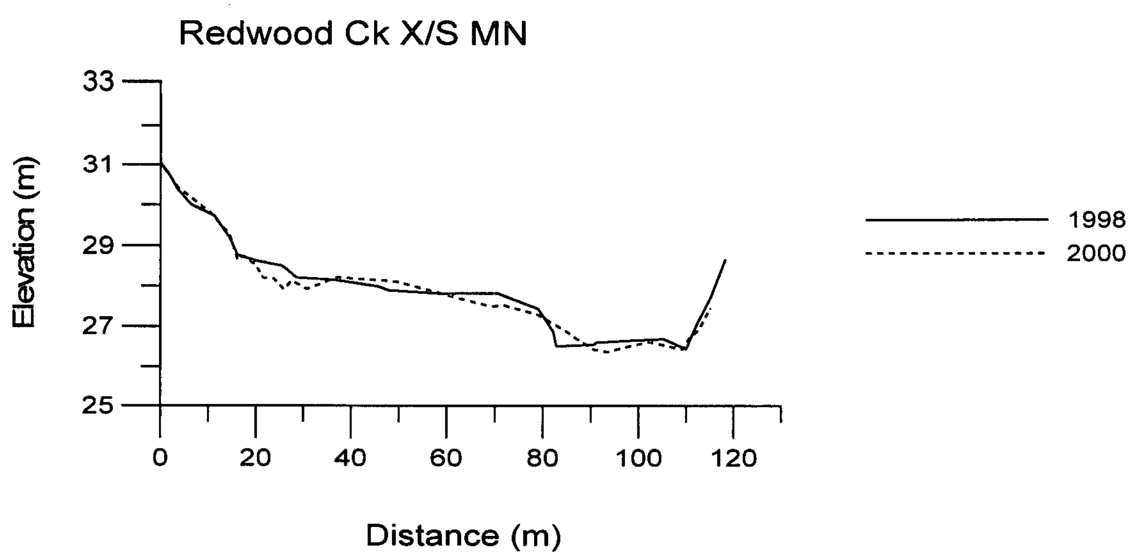


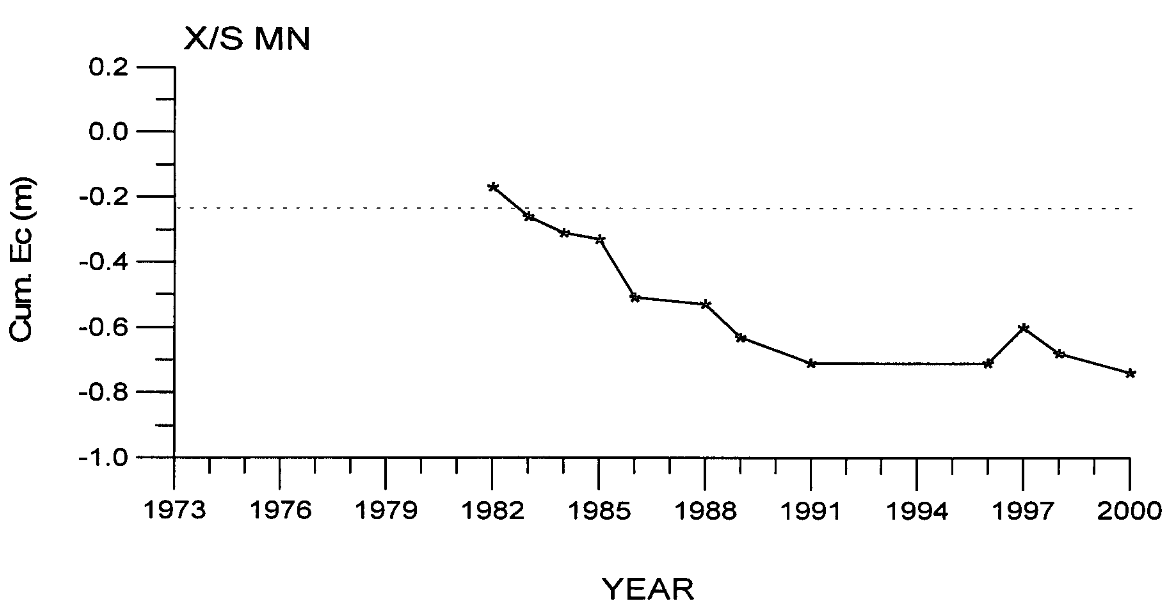
Redwood Ck X/S 16
* Lx in Landslide
Elevation (m)
Distance (m)
1998
2000

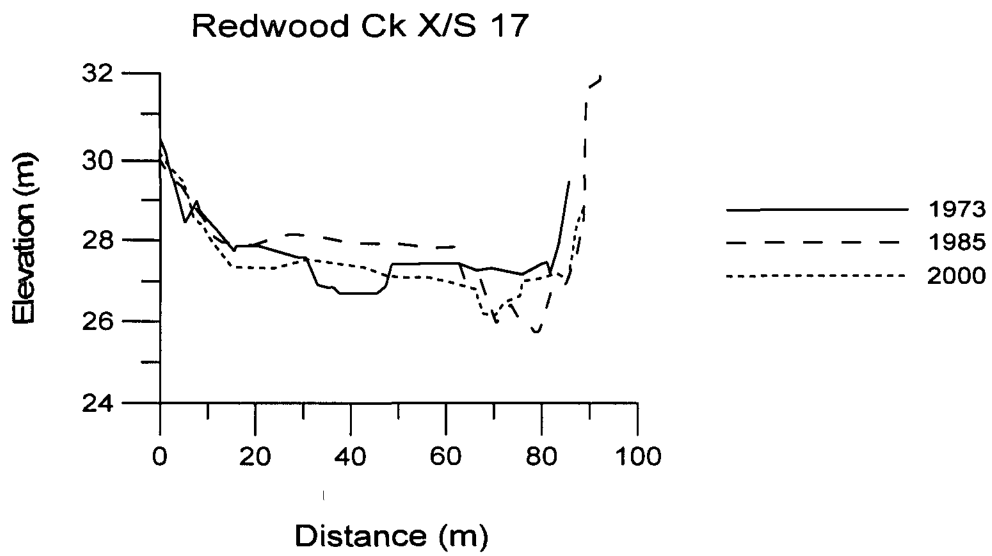


X/S 16
Cum. Ec (m)
YEAR

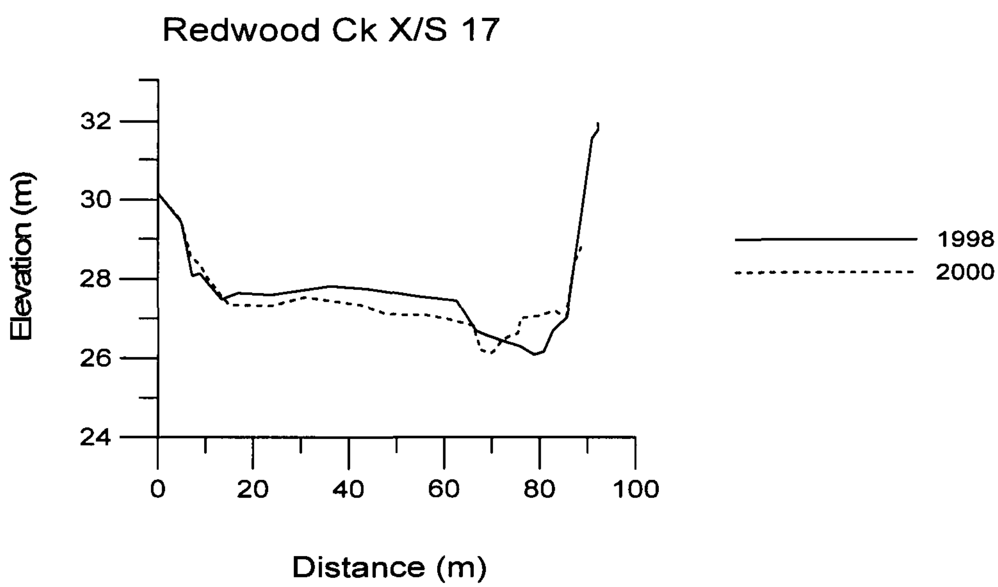

Redwood Ck X/S MN
Elevation (m)
Distance (m)
1981
1991
2000


Redwood Ck X/S MN
Elevation (m)
Distance (m)
1998
2000

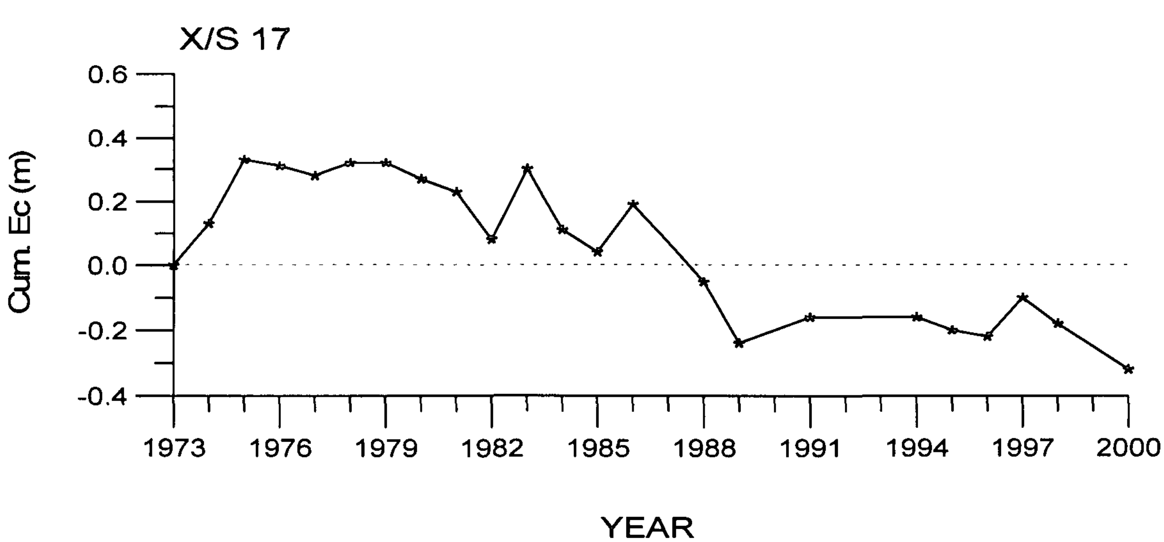

X/S MN
Cum. Ec (m)
YEAR



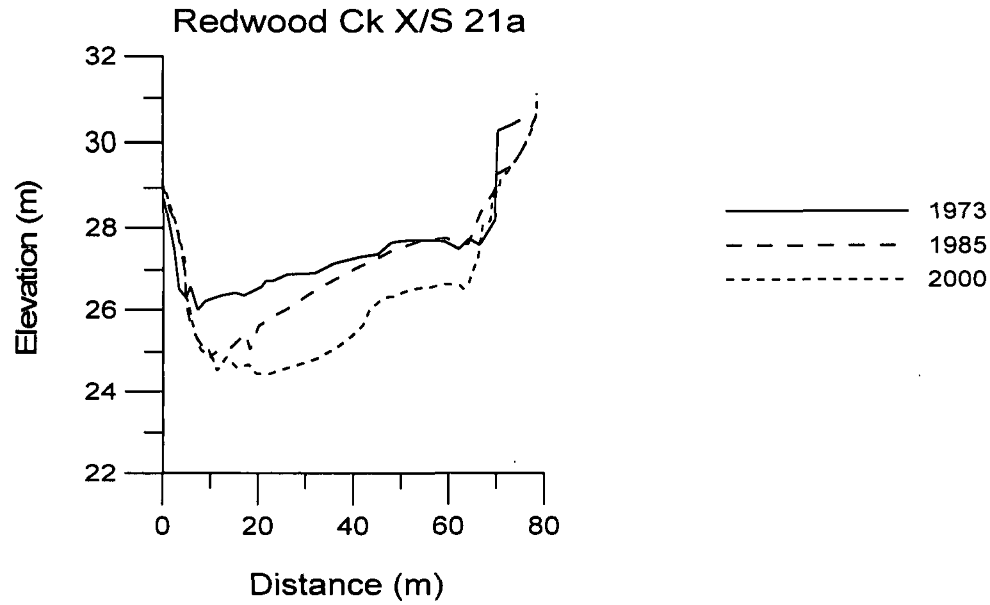
Redwood Ck X/S 17
Elevation (m)
Distance (m)
1973
1985
2000



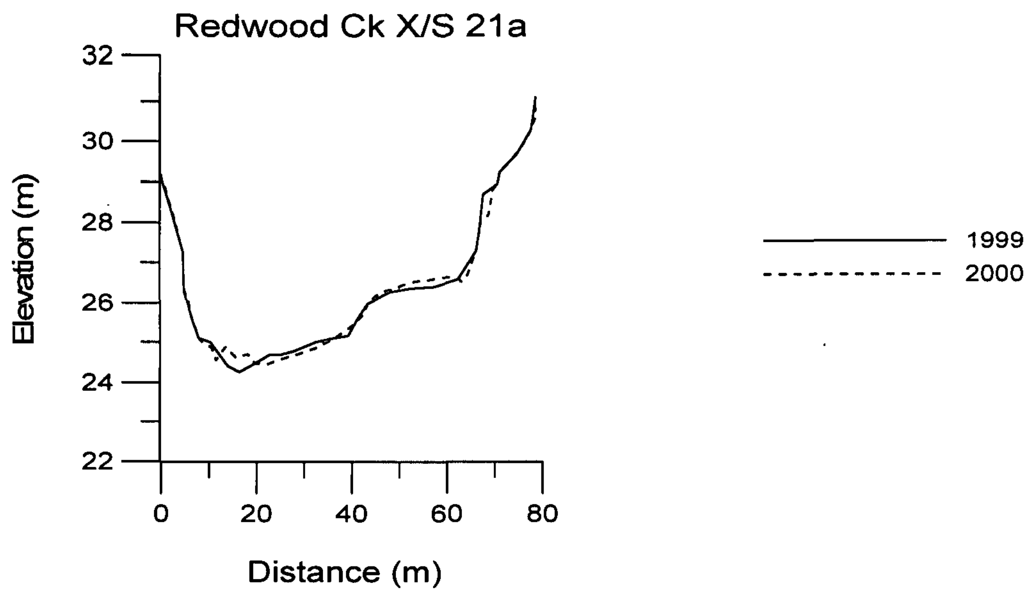
Redwood Ck X/S 17
Elevation (m)
Distance (m)
1998
2000



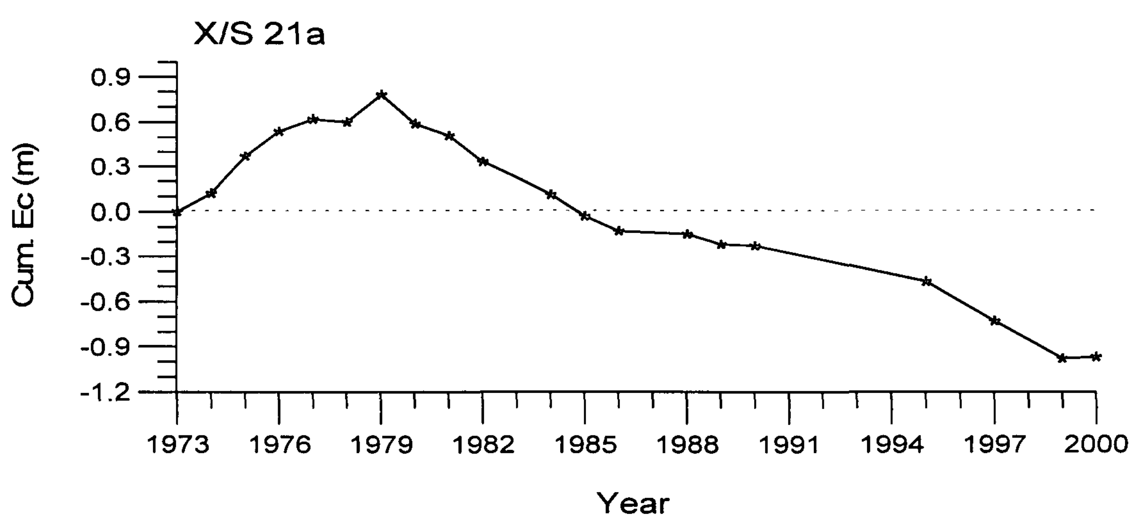
X/S 17
Cum. Ec (m)
YEAR



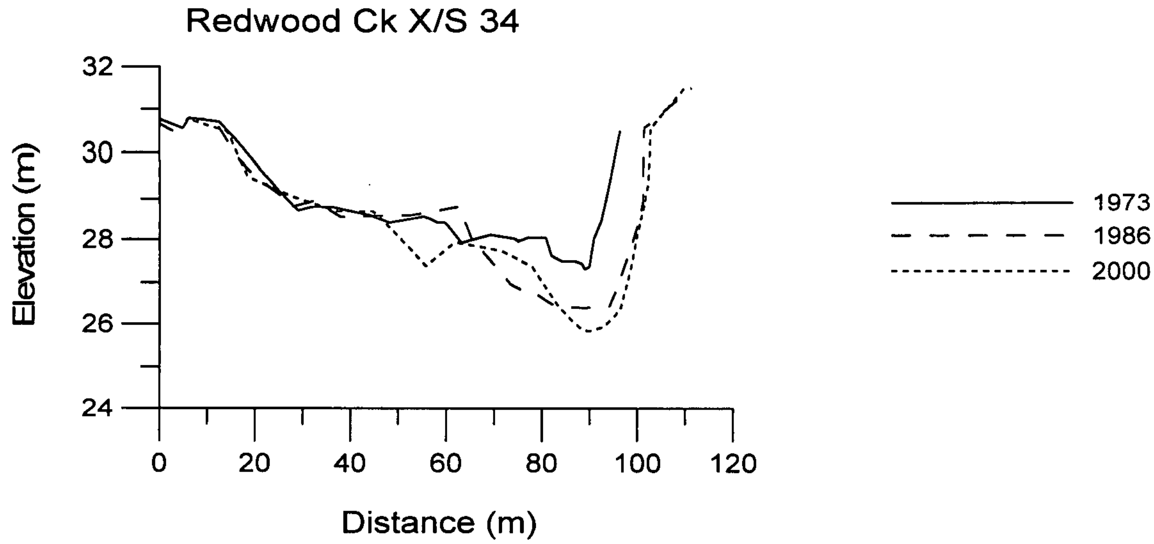
Redwood Ck X/S 21a
Elevation (m)
Distance (m)
32
30
28
26
24
22
0
20
40
60
80
1973
1985
2000

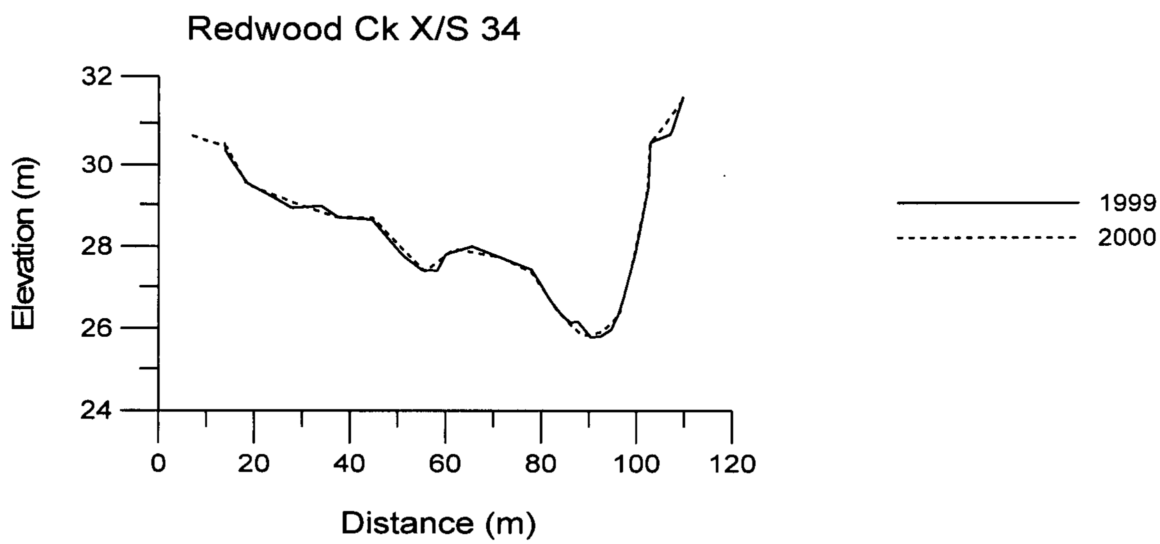


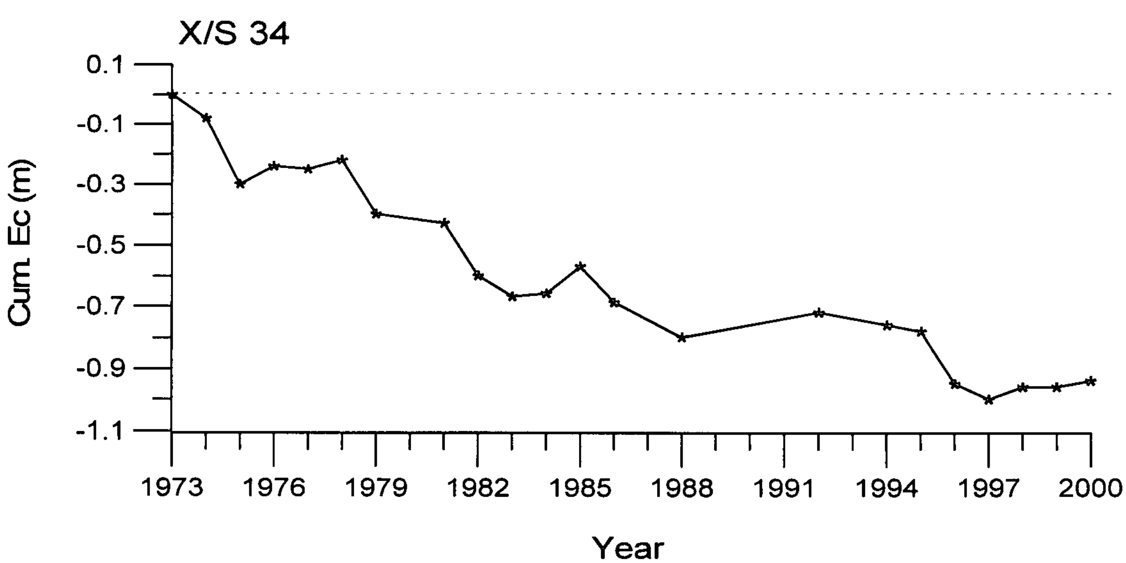
Redwood Ck X/S 21a
Elevation (m)
Distance (m)
32
30
28
26
24
22
0
20
40
60
80
1999
2000

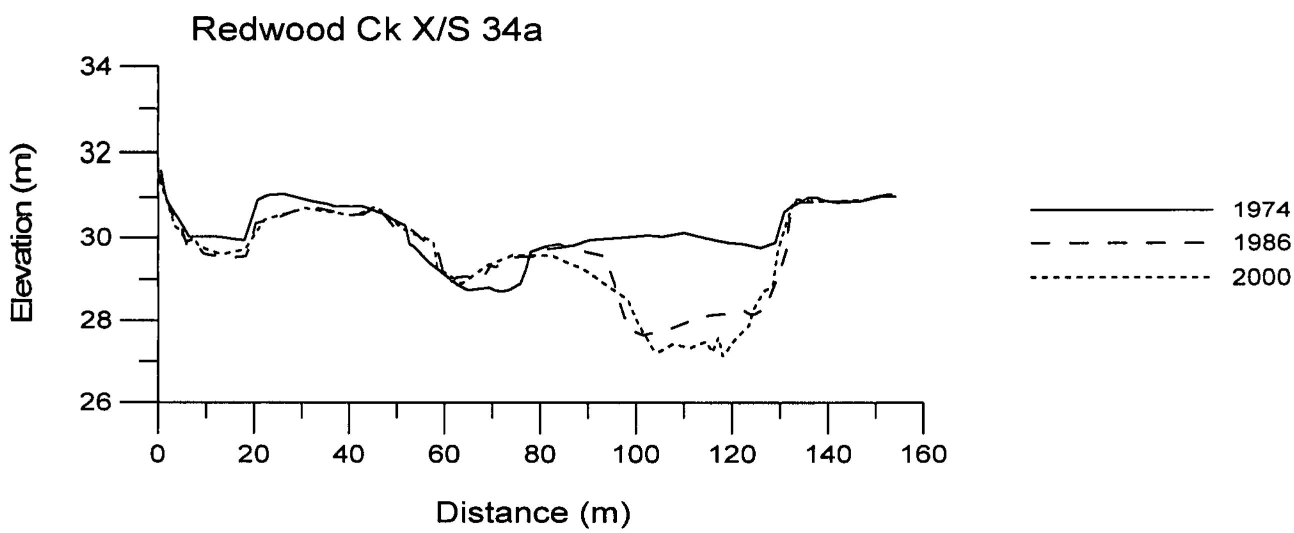


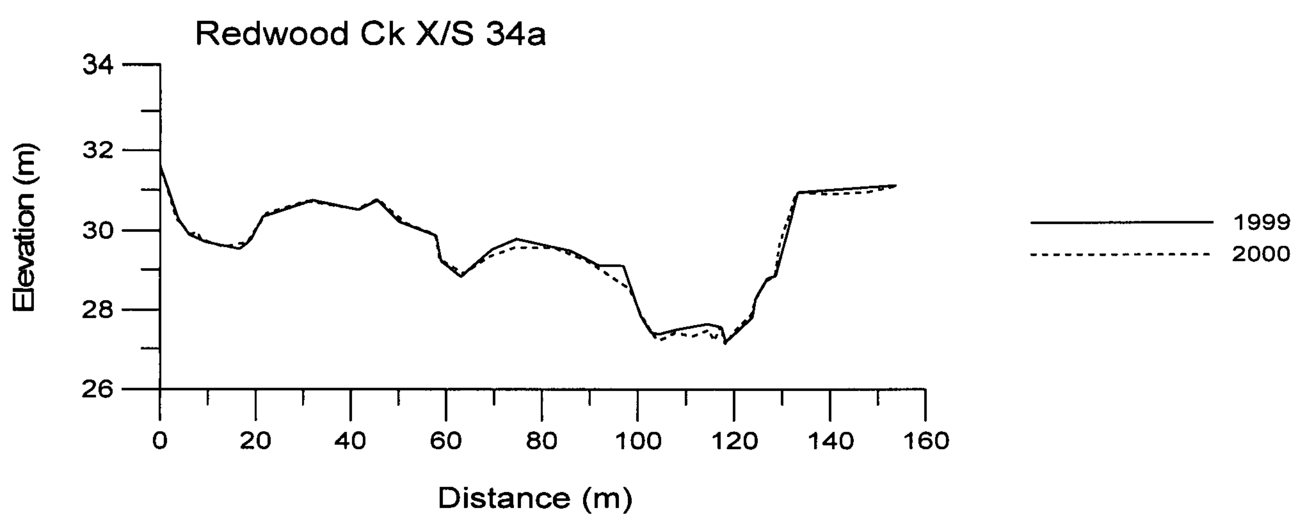
X/S 21a
Cum. Ec (m)
Year
0.9
0.6
0.3
0.0
-0.3
-0.6
-0.9
-1.2
1973
1976
1979
1982
1985
1988
1991
1994
1997
2000

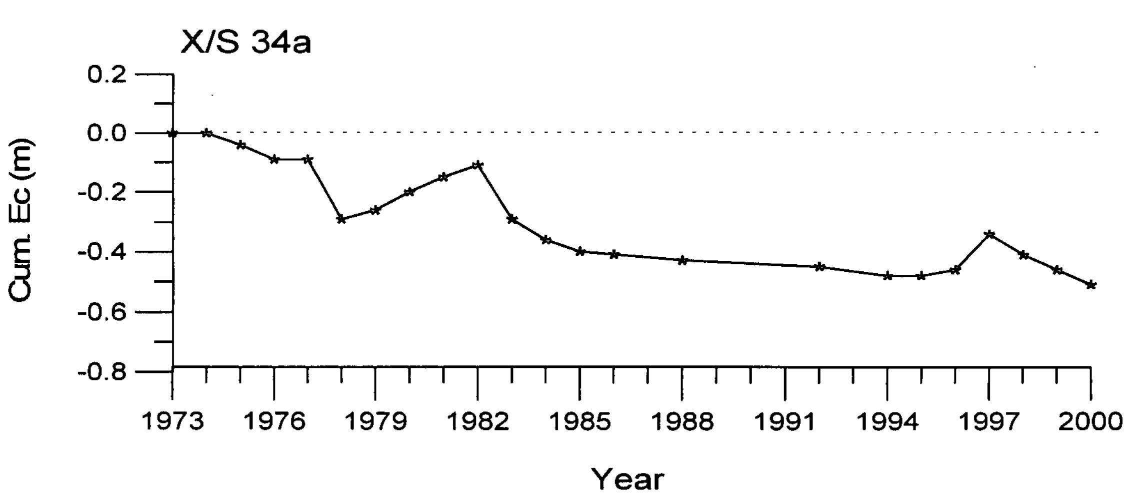

Redwood Ck X/S 34
Elevation (m)
Distance (m)
32
30
28
26
24
0
20
40
60
80
100
120
1973
1986
2000

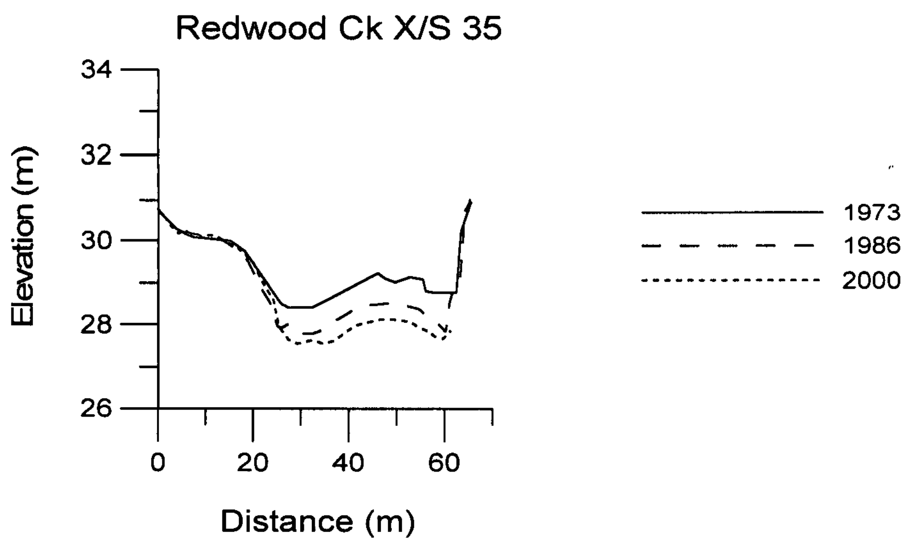

Redwood Ck X/S 34
Elevation (m)
Distance (m)
32
30
28
26
24
0
20
40
60
80
100
120
1999
2000

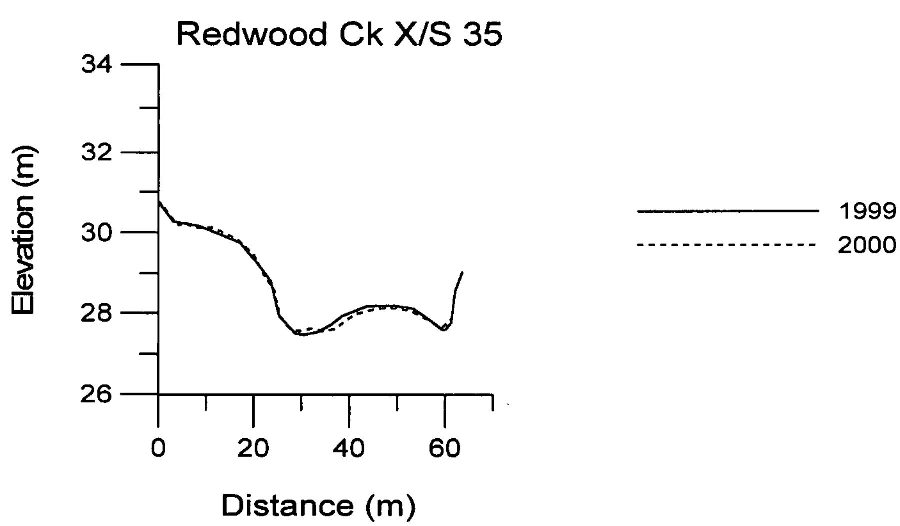

X/S 34
Cum. Ec (m)
Year
0.1
-0.1
-0.3
-0.5
-0.7
-0.9
-1.1
1973
1976
1979
1982
1985
1988
1991
1994
1997
2000

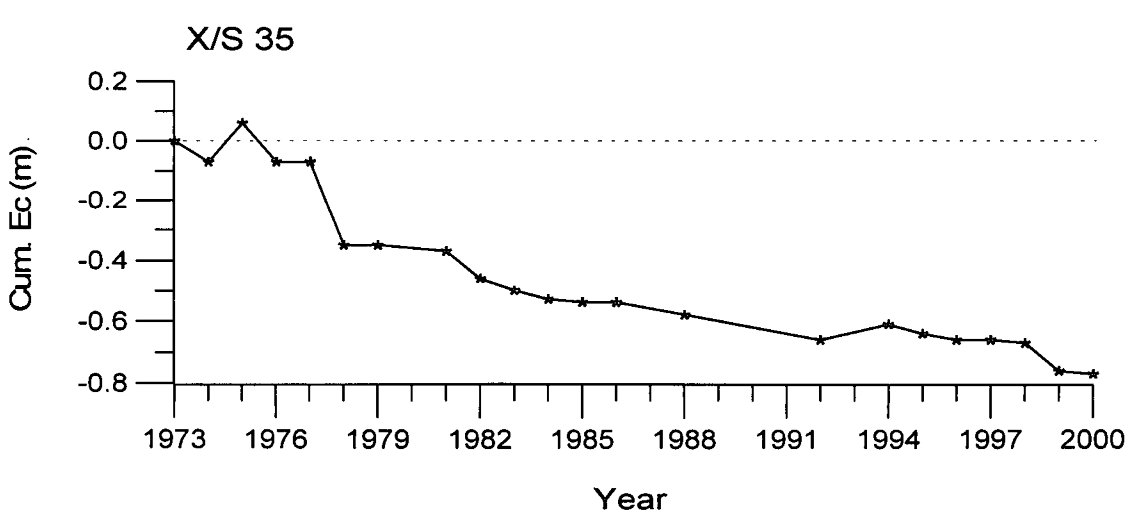

Redwood Ck X/S 34a
Elevation (m)
34
32
30
28
26
0
20
40
60
80
100
120
140
160
Distance (m)
1974
1986
2000

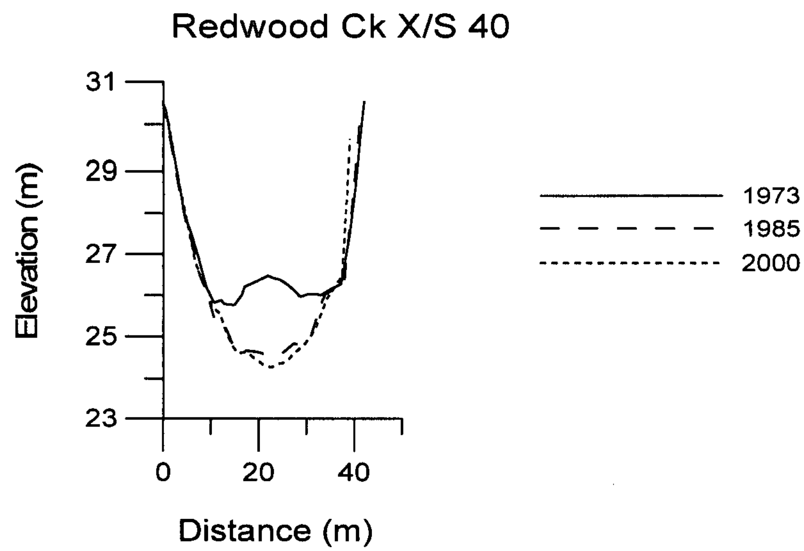

Redwood Ck X/S 34a
Elevation (m)
34
32
30
28
26
0
20
40
60
80
100
120
140
160
Distance (m)
1999
2000

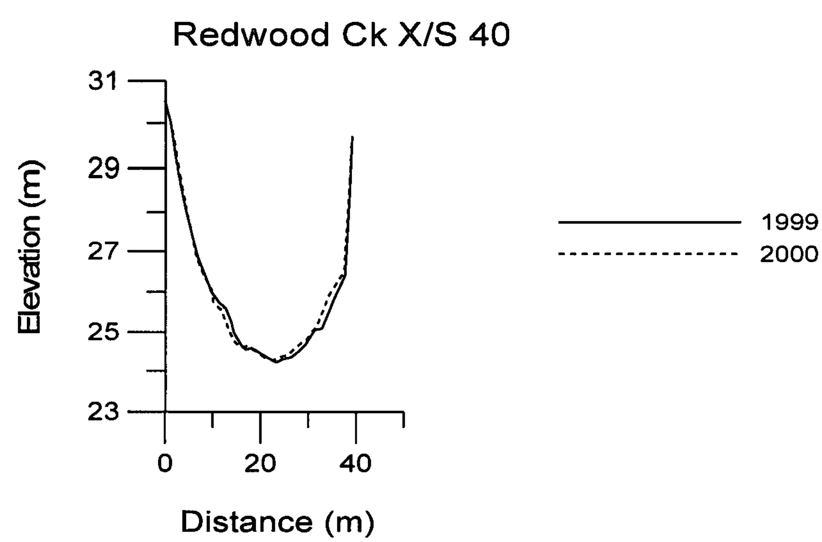

X/S 34a
Cum. Ec (m)
0.2
0.0
-0.2
-0.4
-0.6
-0.8
1973
1976
1979
1982
1985
1988
1991
1994
1997
2000
Year

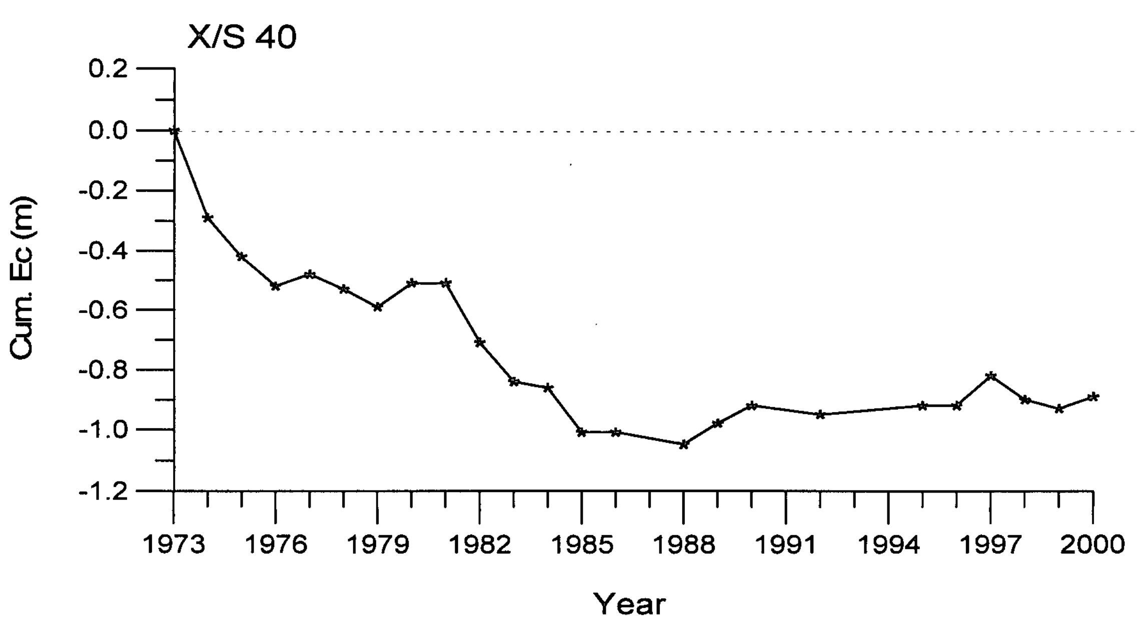

Redwood Ck X/S 35
Elevation (m)
Distance (m)
1973
1986
2000
34
32
30
28
26
0
20
40
60

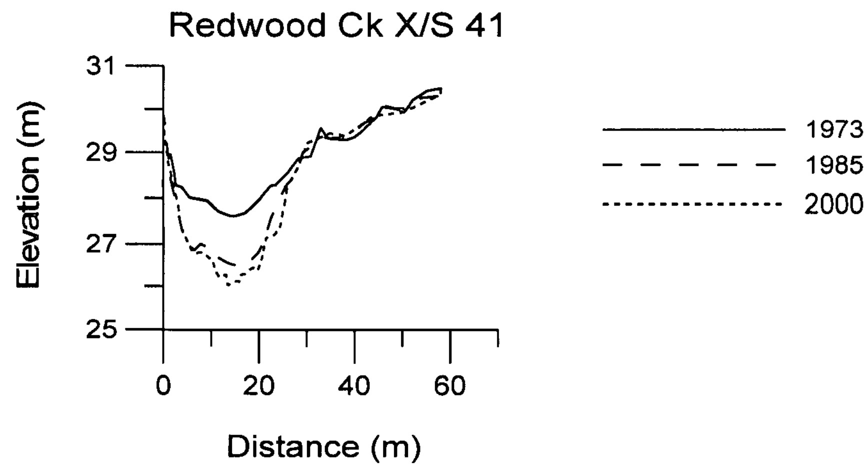

Redwood Ck X/S 35
Elevation (m)
Distance (m)
1999
2000
34
32
30
28
26
0
20
40
60


X/S 35
Cum. Ec (m)
Year
0.2
0.0
-0.2
-0.4
-0.6
-0.8
1973
1976
1979
1982
1985
1988
1991
1994
1997
2000

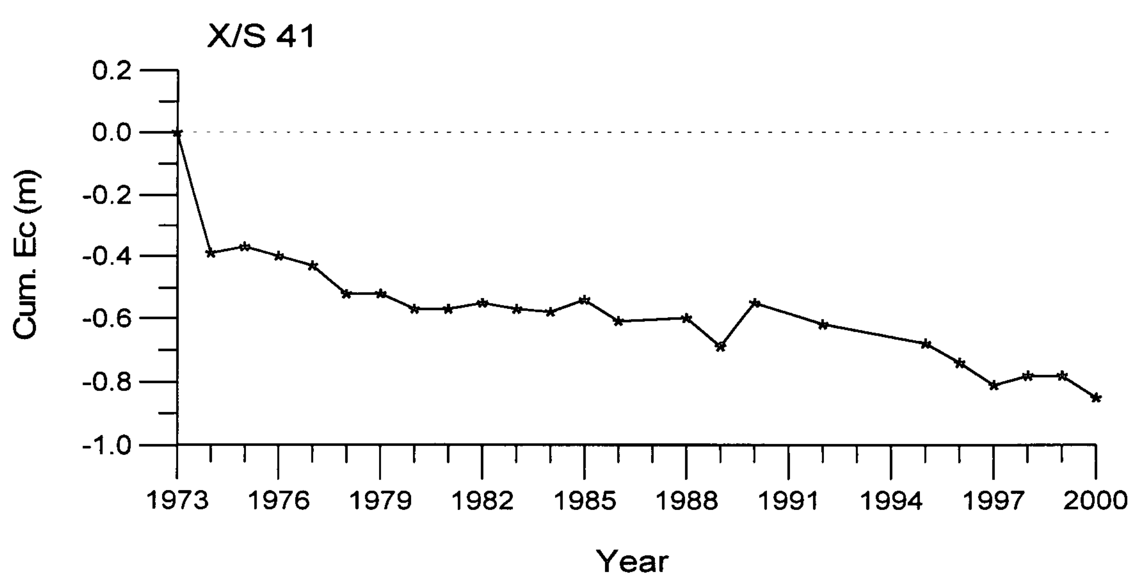

Redwood Ck X/S 40
Elevation (m)
31
29
27
25
23
0
20
40
Distance (m)
1973
1985
2000


Redwood Ck X/S 40
Elevation (m)
31
29
27
25
23
0
20
40
Distance (m)
1999
2000


X/S 40
Cum. Ec (m)
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
1973
1976
1979
1982
1985
1988
1991
1994
1997
2000
Year


Redwood Ck X/S 41
Elevation (m)
Distance (m)
1973
1985
2000


Redwood Ck X/S 41
Elevation (m)
Distance (m)
1999
2000


X/S 41
Cum. Ec (m)
Year

Attachment 4: Redwood Creek Long-Term Channel Stability Monitoring

Summary of Channel Changes at Redwood Creek Cross Sections 1998-2000
Tables 1-3

TABLE 1: Summary of Channel Changes at Redwood Creek Cross Sections, 1998.

	Cross Section Number	Year Estab.	Change in Thalweg Elev. (m)	Scour (-) (m^2)	Fill (+) (m^2)	Net Change in Area (m^2)	Active Channel Width (m)	Ec* (m)	Absolute Change (m)	Comparison Year
LOWER REACH	5	10/73	-0.271	10.3	14.78	4.48	114	0.04	0.22	1997
	6	10/73	0.137	7.54	8.89	1.35	112	0.01	0.15	1997
	10	10/73	0.359	21.54	18.08	-3.46	99	-0.03	0.40	1997
	12	10/73	-0.635	14.51	11.31	-3.20	75	-0.04	0.34	1997
	14	10/73	-0.50	7.22	7.08	-0.14	61	0.00	0.23	1997
	IJ	11/82	1.23	55.47	58.06	2.59	141	0.02	0.81	1997
	16	10/73	-0.44	13.04	14.55	1.51	85	0.02	0.32	1997
	MN	12/82	-0.16	24.21	14.99	-9.22	120	-0.08	0.33	1997
	17	10/73	-0.87	19.45	12.31	-7.14	87	-0.08	0.37	1997
	19	10/73	0.24	12.20	18.03	5.83	128	0.05	0.24	1997
MIDDLE REACH	20	10/73	-0.16	20.52	0.07	-20.45	58	-0.35	0.36	1997
	32	10/73	-0.14	2.11	0.59	-1.52	35	-0.04	0.08	1997
	34	10/73	-0.14	1.30	4.01	2.71	67	0.04	0.24	1997
	34a	10/74	-0.16	12.28	3.04	-9.24	127	-0.07	0.03	1997
	35	10/73	0.00	1.29	0.89	-0.40	51	-0.01	0.08	1997
UPPER REACH	40	10/73	-0.17	3.12	0.48	-2.64	34	-0.08	0.11	1997
	41	10/73	0.15	0.58	1.48	0.90	29	0.03	0.07	1997

* A shaded box indicates that Ec ≤ 0.05 are within measurement error. As a result, changes at these cross sections document no particular trend.

TABLE 2: Summary of Channel Changes at Redwood Creek Cross Sections, 1999.

	Cross Section Number	Year Estab.	Change in Thalweg Elev. (m)	Scour (-) (m^2)	Fill (+) (m^2)	Net Change in Area (m^2)	Active Channel Width (m)	Ec* (m)	Absolute Change (m)	Comparison Year
LOWER REACH	2	10/73	-0.14	56.01	12.36	-43.65	141	-0.31	0.48	1997
	3	9/73	0.18	21.80	20.28	-1.52	127	-0.01	0.33	1997
	5	10/73	-0.19	18.82	15.93	-2.89	114	-0.03	0.30	1998
	6	10/73	-0.003	10.33	3.26	-7.07	112	-0.06	0.12	1998
	10	10/73	-0.348	18.18	13.25	-4.93	99	-0.05	0.32	1998
	11	10/73	-0.665	20.72	9.26	-11.46	71	-0.16	0.42	1997
	12	10/73	0.107	3.11	10.43	7.32	75	0.10	0.18	1998
	14	10/73	0.59	5.26	11.80	6.54	61	0.11	0.28	1998
	21a	10/82	-0.65	22.77	5.12	-17.65	71	-0.25	0.39	1997
	22	10/73	-0.10	30.36	0.00	-30.36	58	-0.52	0.52	1995
MIDDLE REACH	34	10/73	-0.06	2.57	2.24	-0.33	67	0.00	0.15	1998
	34a	10/74	-0.30	7.80	1.15	-6.65	127	-0.05	0.05	1998
	35	10/73	-0.05	5.13	0.31	-4.82	51	-0.09	0.07	1998
UPPER REACH	40	10/73	-0.02	3.06	1.97	-1.09	34	-0.03	0.15	1998
	41	10/73	-0.08	0.72	0.84	0.12	29	0.00	0.05	1998

* A shaded box indicates that $\Delta Ec \leq 0.05$ are within measurement error. As a result, changes at these cross sections document no particular trend.

TABLE 3: Summary of Channel Changes at Redwood Creek Cross Sections, 2000.

	Cross Section Number	Year Estab.	Change in Thalweg Elev. (m)	Scour (-) (m^2)	Fill (+) (m^2)	Net Change in Area (m^2)	Active Channel Width (m)	Ec* (m)	Absolute Change (m)	Comparison Year
LOWER REACH	3	9/73	0.03	7.28	8.19	0.91	127	0.01	0.12	1999
	5	10/73	0.079	10.94	5.33	-5.61	114	-0.05	0.14	1999
	6	10/73	-0.171	10.96	5.23	-5.73	112	-0.05	0.14	1999
	15	10/73	0.345	14.07	18.66	4.59	62	0.07	0.53	1997
	16	10/73	-0.05	41.02	10.64	-30.38	85	-0.36	0.61	1998
	MN	12/82	-0.08	12.00	5.17	-6.83	120	-0.06	0.14	1998
	17	10/73	0.04	20.86	9.05	-11.81	87	-0.14	0.34	1998
	21a	10/82	0.18	4.22	5.03	0.81	71	0.01	0.13	1999
MIDDLE REACH	34	10/73	0.05	2.15	3.22	1.07	67	0.02	0.16	1999
	34a	10/74	-0.05	7.27	1.12	-6.15	127	-0.05	0.03	1999
	35	10/73	0.07	2.27	1.69	-0.58	51	-0.01	0.06	1999
UPPER REACH	40	10/73	0.06	1.36	2.63	1.27	34	0.04	0.12	1999
	41	10/73	-0.07	2.12	0.17	-1.95	29	-0.07	0.08	1999

* A shaded box indicates that $\Delta Ec \leq 0.05$ are within measurement error. As a result, changes at these cross sections document no particular trend.