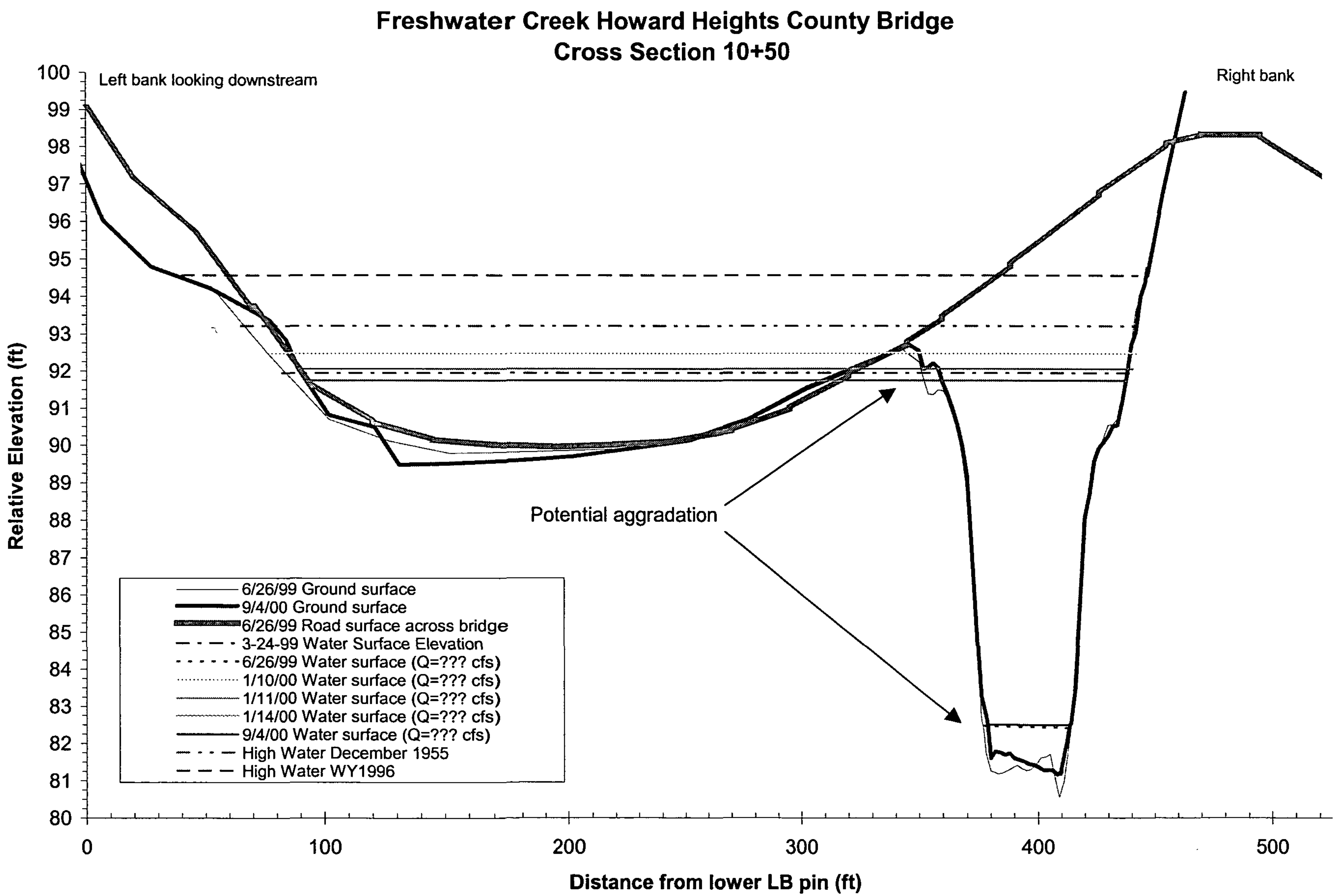
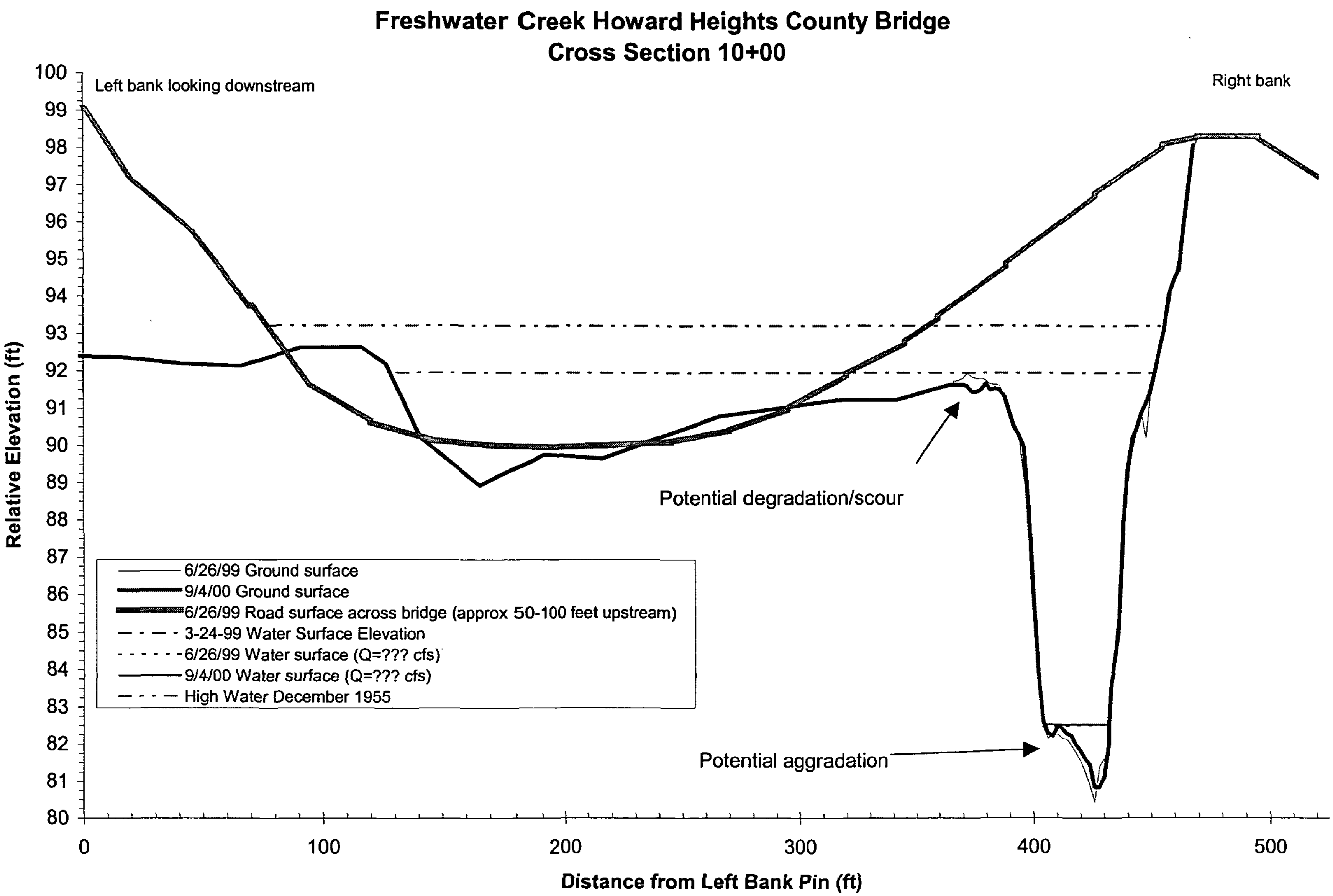
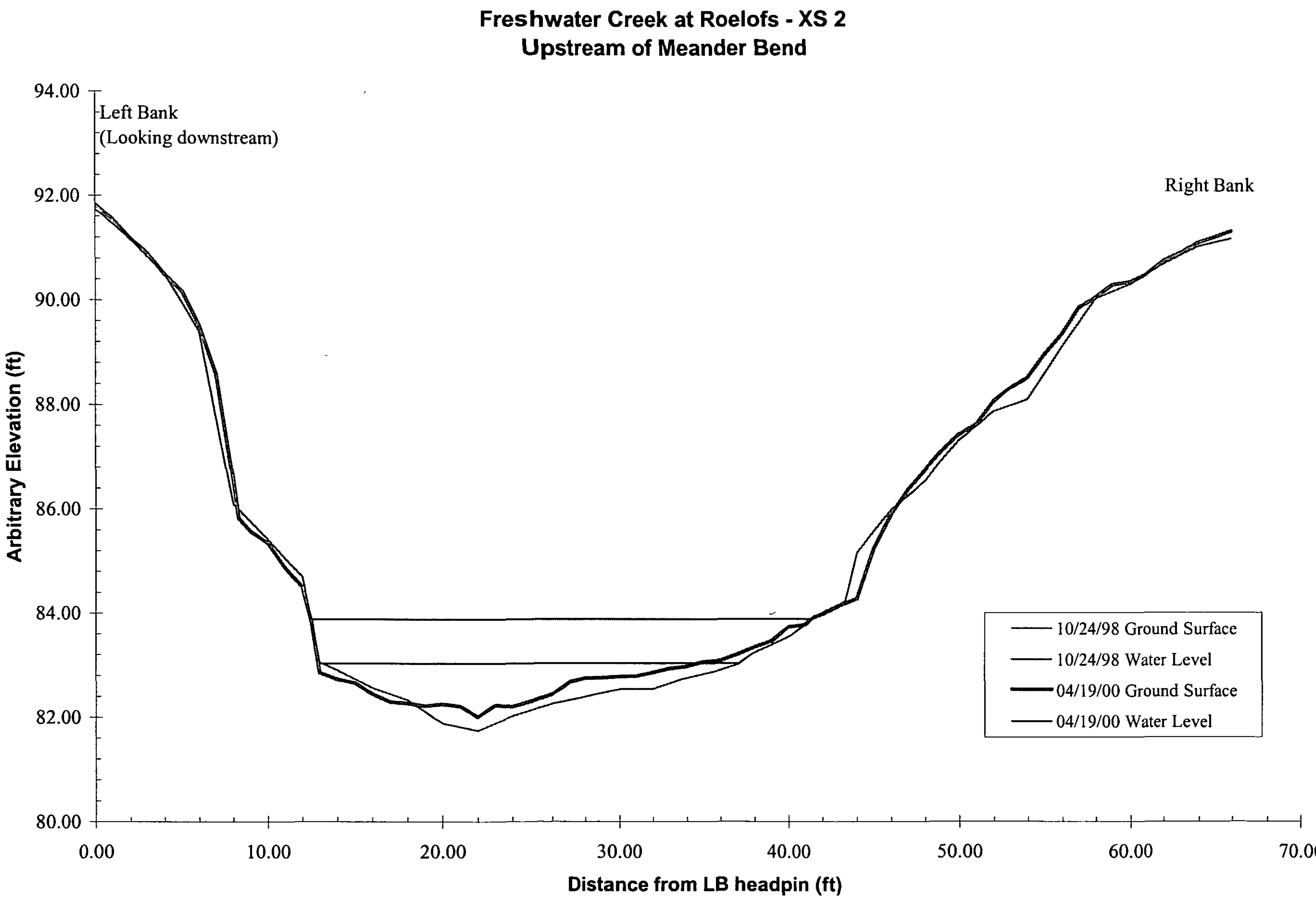
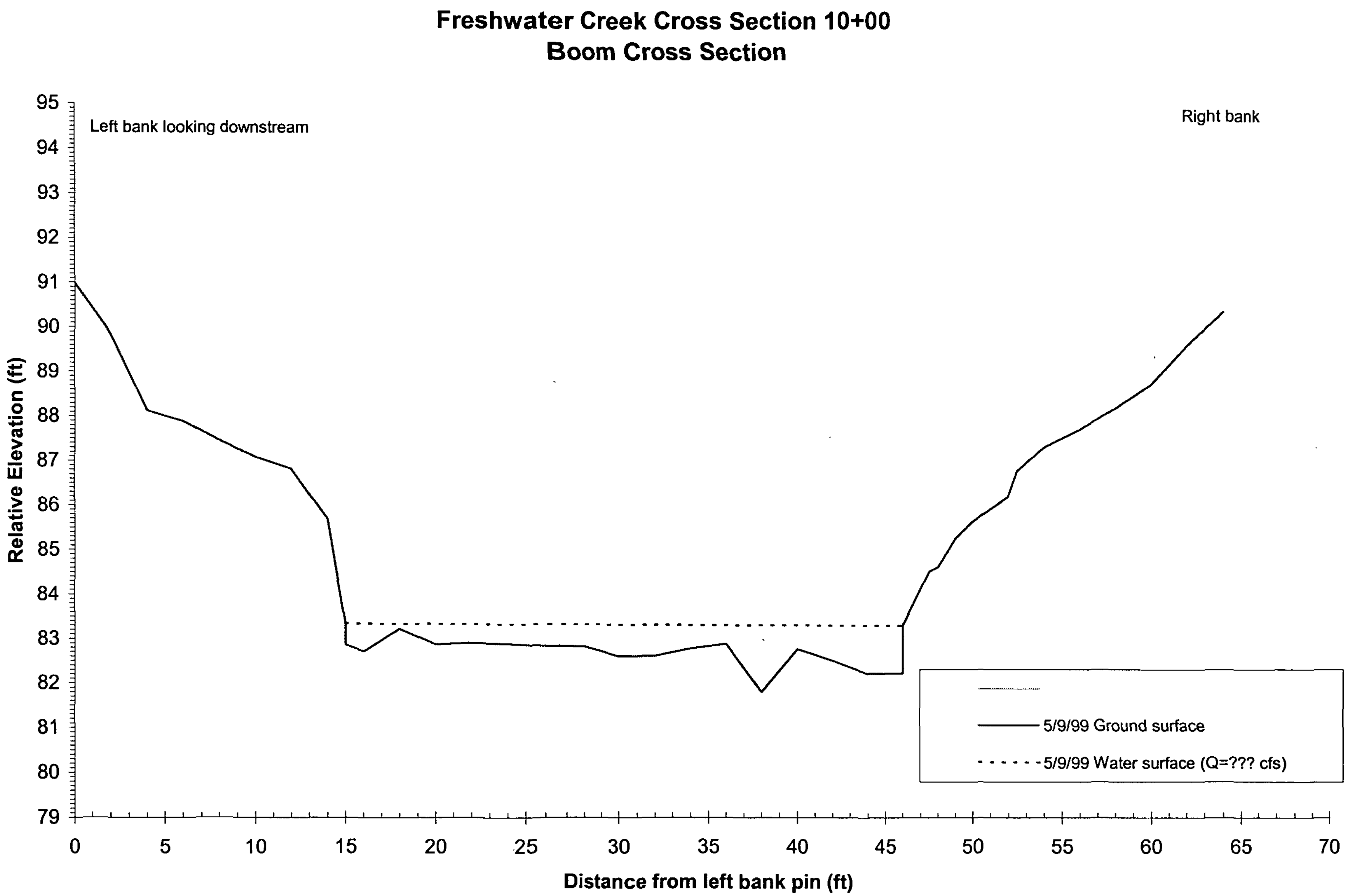

Freshwater Creek Howard Heights County Bridge
Cross Section 10+50
Left bank looking downstream
Right bank
Relative Elevation (ft)
Distance from lower LB pin (ft)
Potential aggradation
6/26/99 Ground surface
9/4/00 Ground surface
6/26/99 Road surface across bridge
3-24-99 Water Surface Elevation
6/26/99 Water surface (Q=??? cfs)
1/10/00 Water surface (Q=??? cfs)
1/11/00 Water surface (Q=??? cfs)
1/14/00 Water surface (Q=??? cfs)
9/4/00 Water surface (Q=??? cfs)
High Water December 1955
High Water WY1996
100
99
98
97
96
95
94
93
92
91
90
89
88
87
86
85
84
83
82
81
80
0
100
200
300
400
500


Freshwater Creek Howard Heights County Bridge
Cross Section 10+00
Left bank looking downstream
Right bank
Relative Elevation (ft)
100
99
98
97
96
95
94
93
92
91
90
89
88
87
86
85
84
83
82
81
80
0
100
200
300
400
500
Distance from Left Bank Pin (ft)
6/26/99 Ground surface
9/4/00 Ground surface
6/26/99 Road surface across bridge (approx 50-100 feet upstream)
3-24-99 Water Surface Elevation
6/26/99 Water surface (Q=??? cfs)
9/4/00 Water surface (Q=??? cfs)
High Water December 1955
Potential degradation/scour
Potential aggradation



Freshwater Creek at Roelofs - XS 2
Upstream of Meander Bend
Left Bank
(Looking downstream)
Right Bank
Arbitrary Elevation (ft)
Distance from LB headpin (ft)
94.00
92.00
90.00
88.00
86.00
84.00
82.00
80.00
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
10/24/98 Ground Surface
10/24/98 Water Level
04/19/00 Ground Surface
04/19/00 Water Level



Freshwater Creek Cross Section 10+00
Boom Cross Section
Left bank looking downstream
Right bank
Relative Elevation (ft)
95
94
93
92
91
90
89
88
87
86
85
84
83
82
81
80
79
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
Distance from left bank pin (ft)
5/9/99 Ground surface
5/9/99 Water surface (Q=??? cfs)

Figure 2. Cotton Cross Section 1 (9/10/00), compared to Freshwater Creek RM 2.74 ACOE Cross Section No. 3

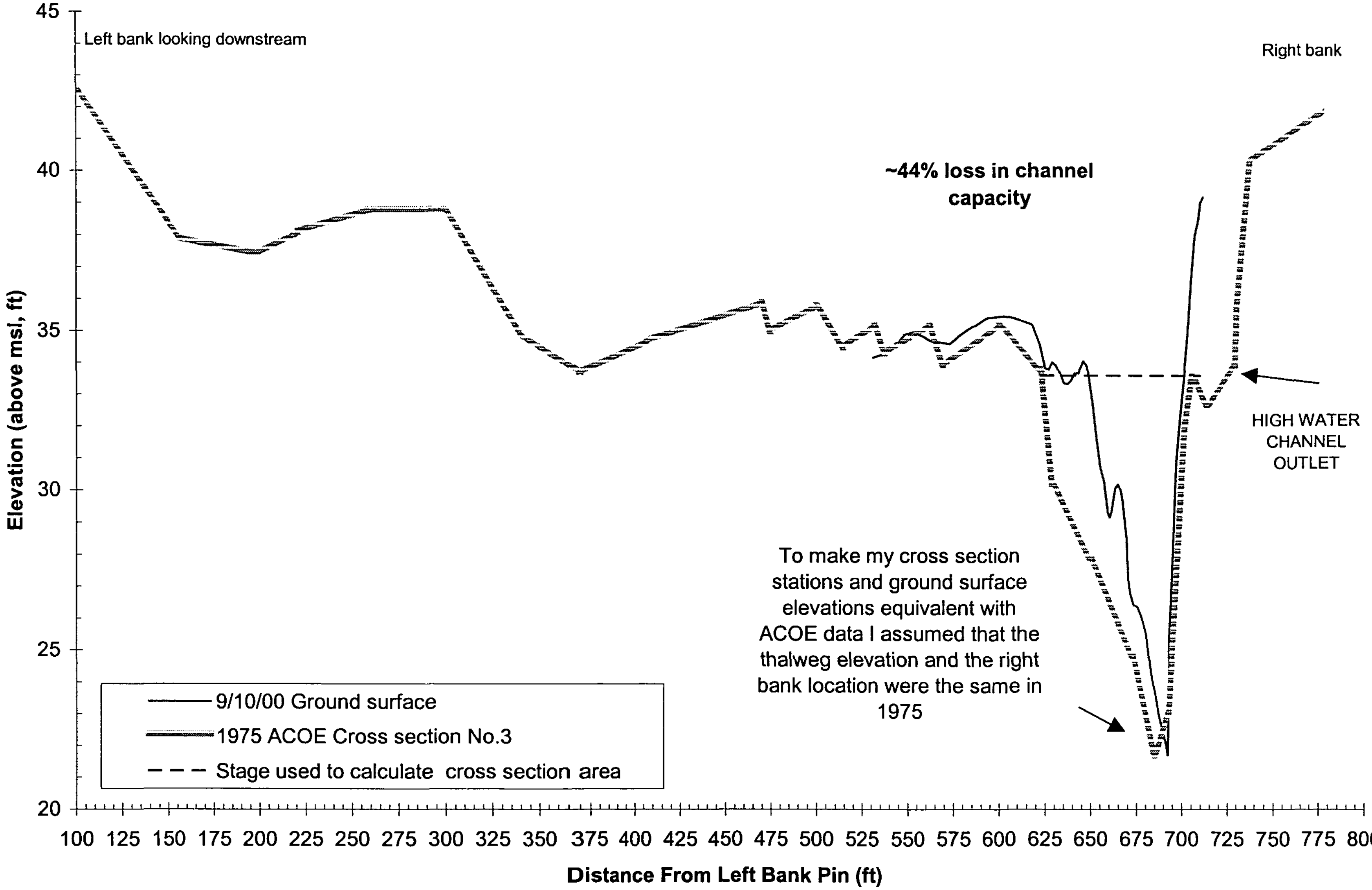
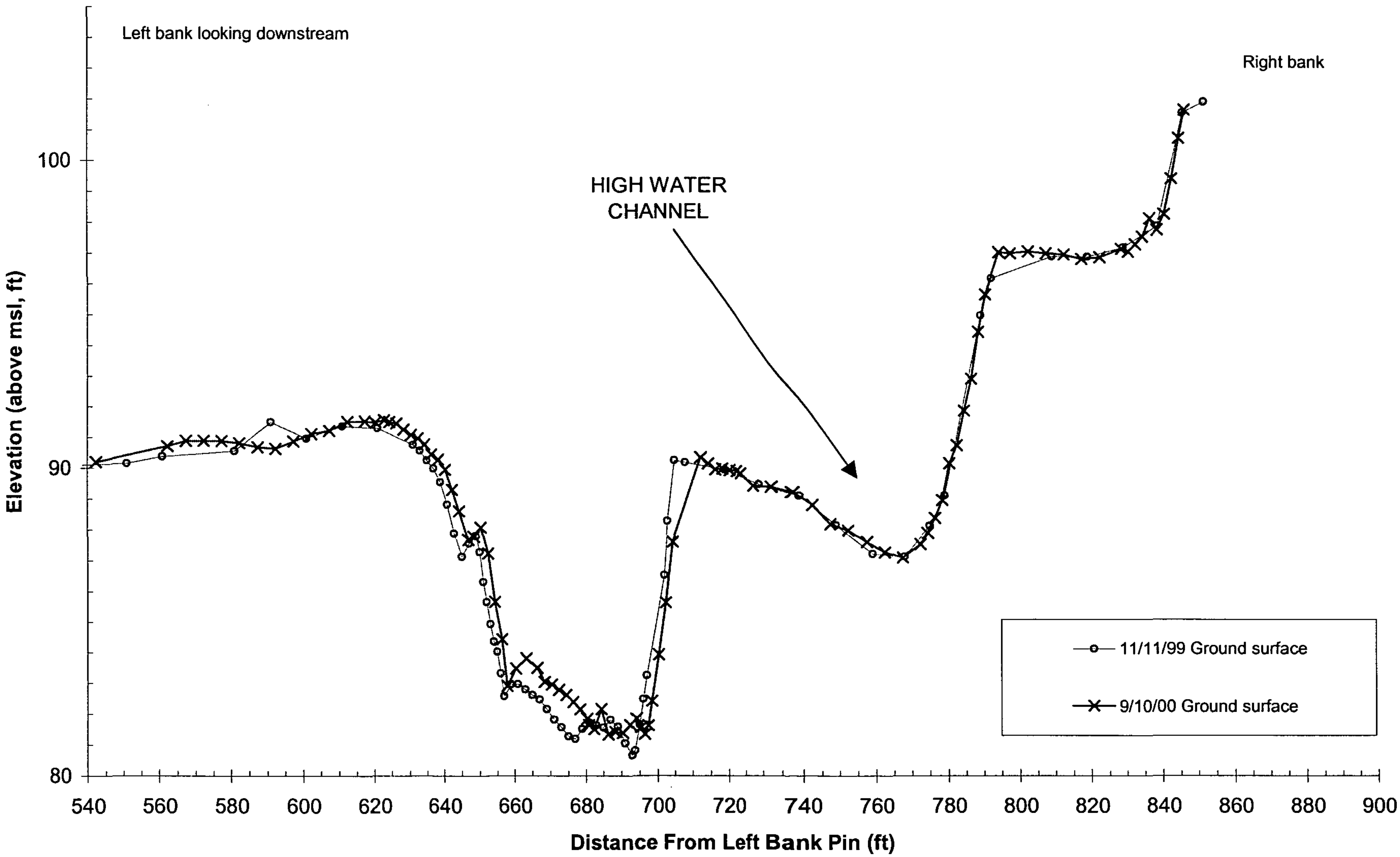
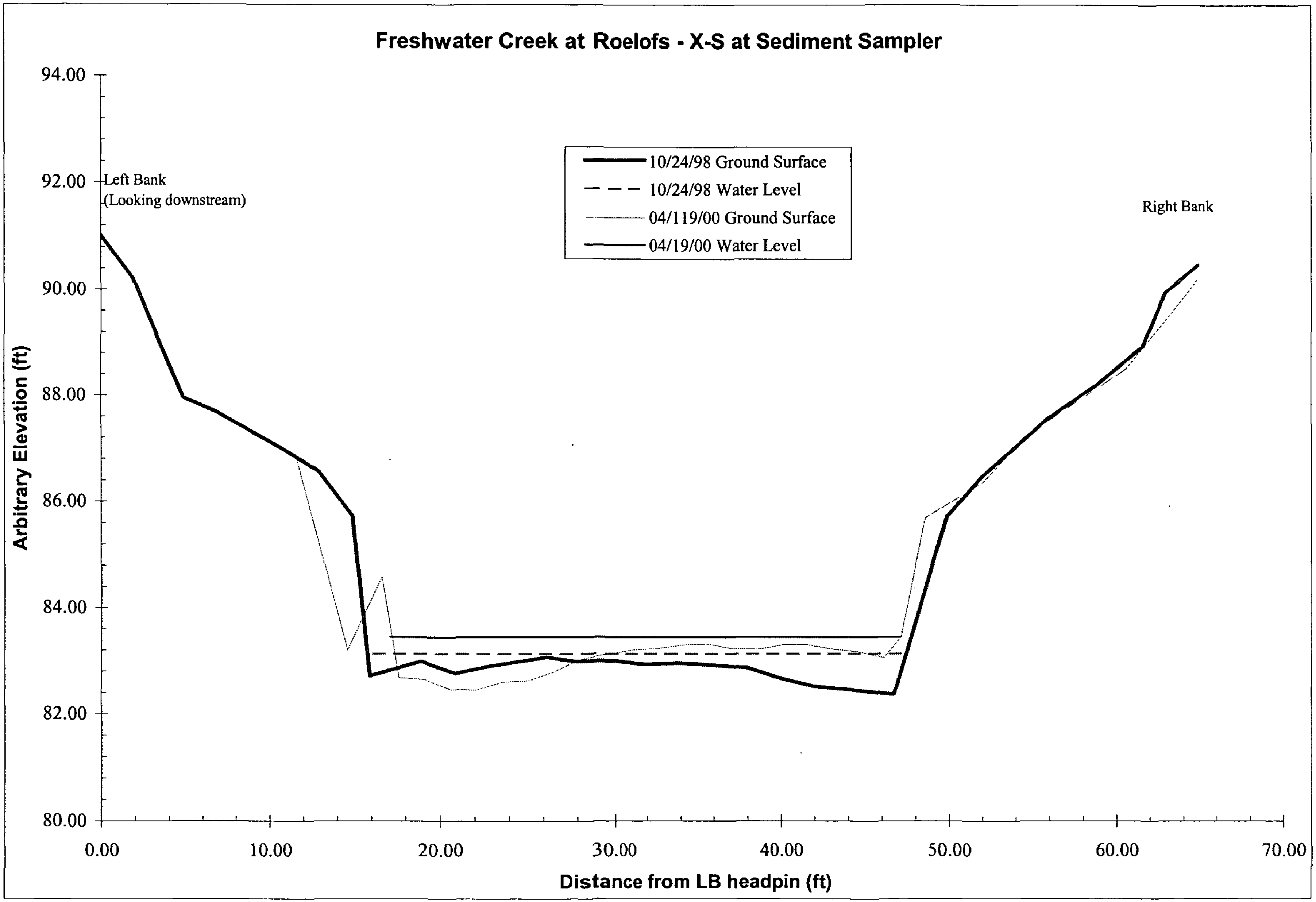
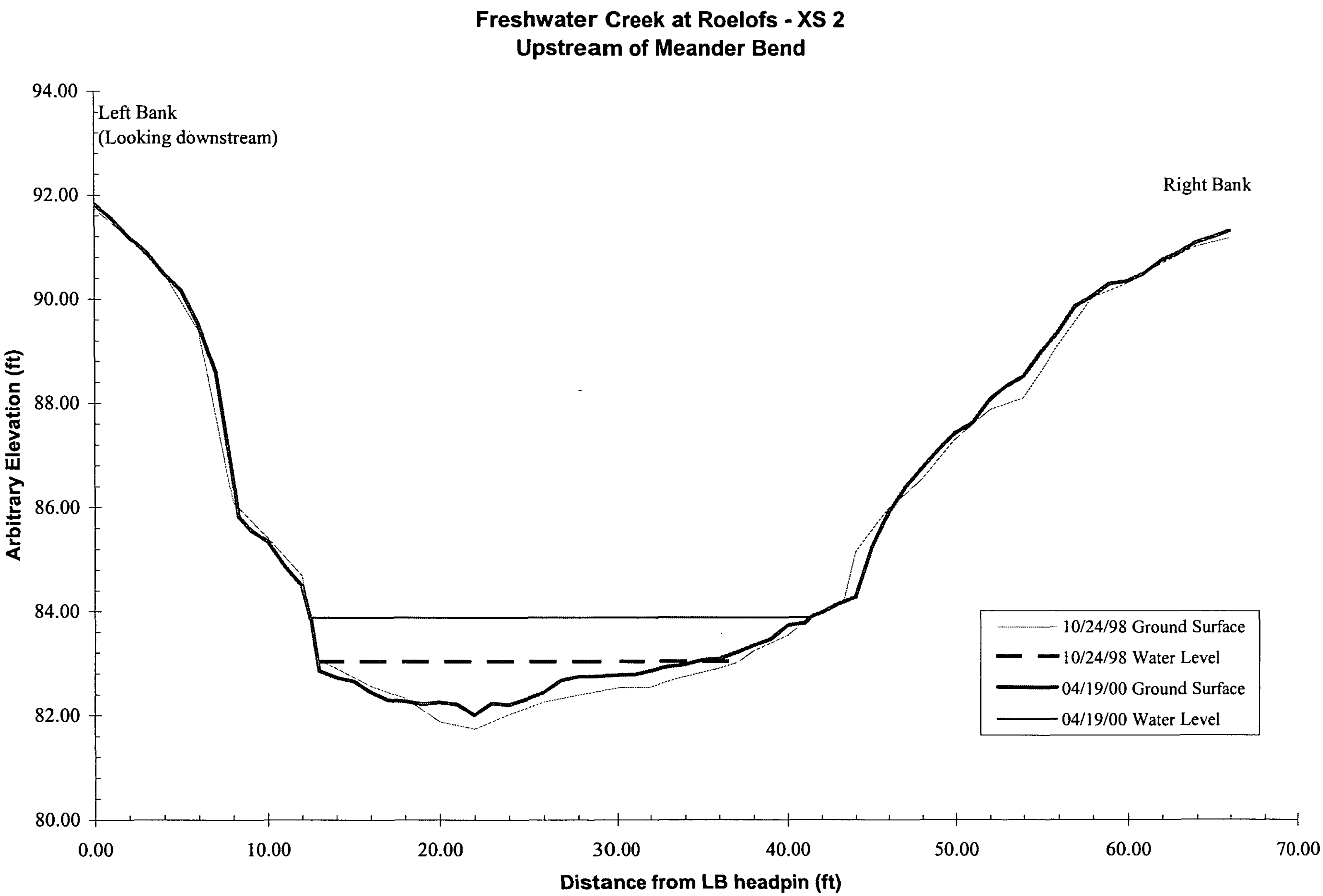


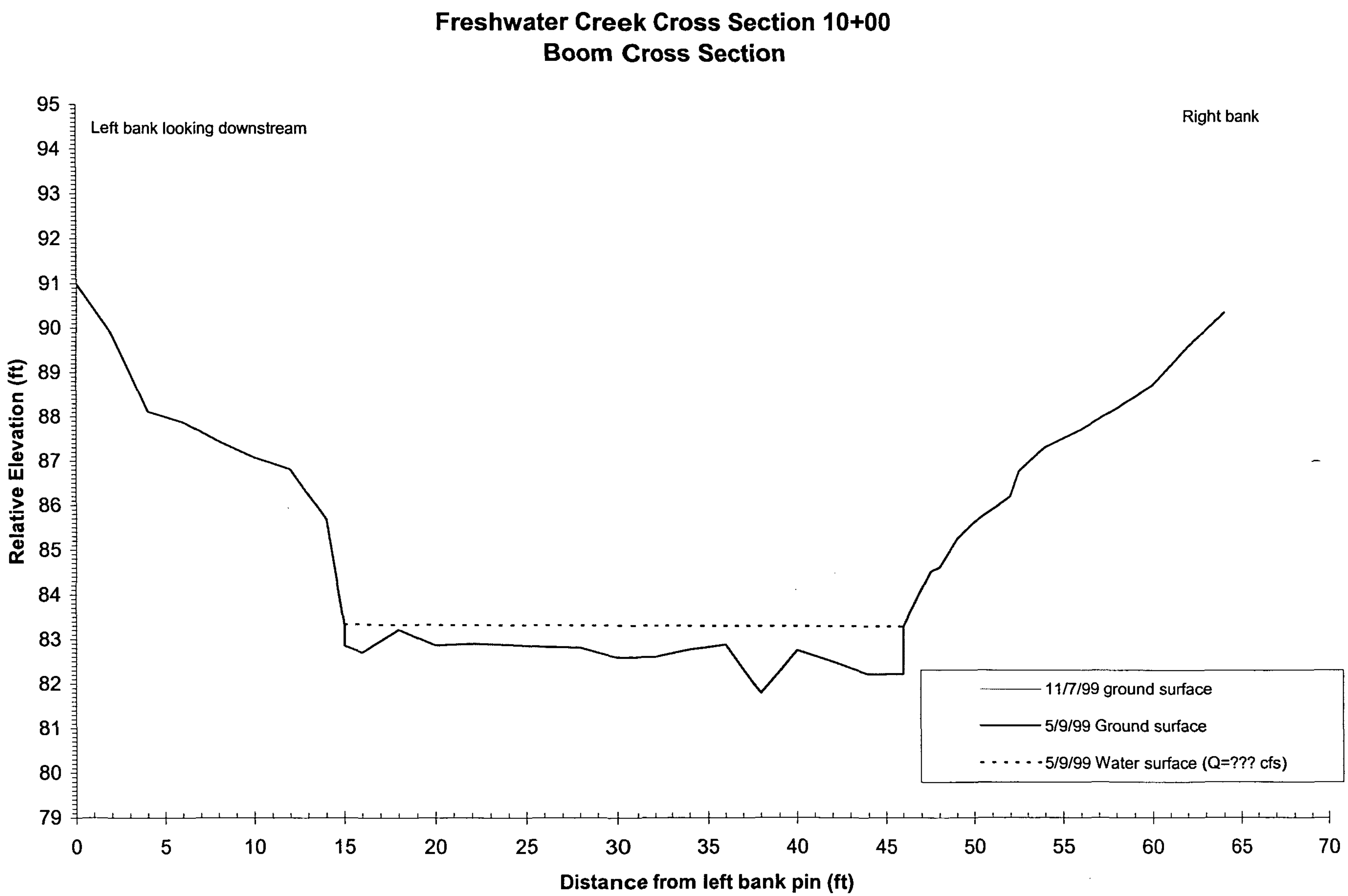
Figure 1. Cotton Cross Section 1



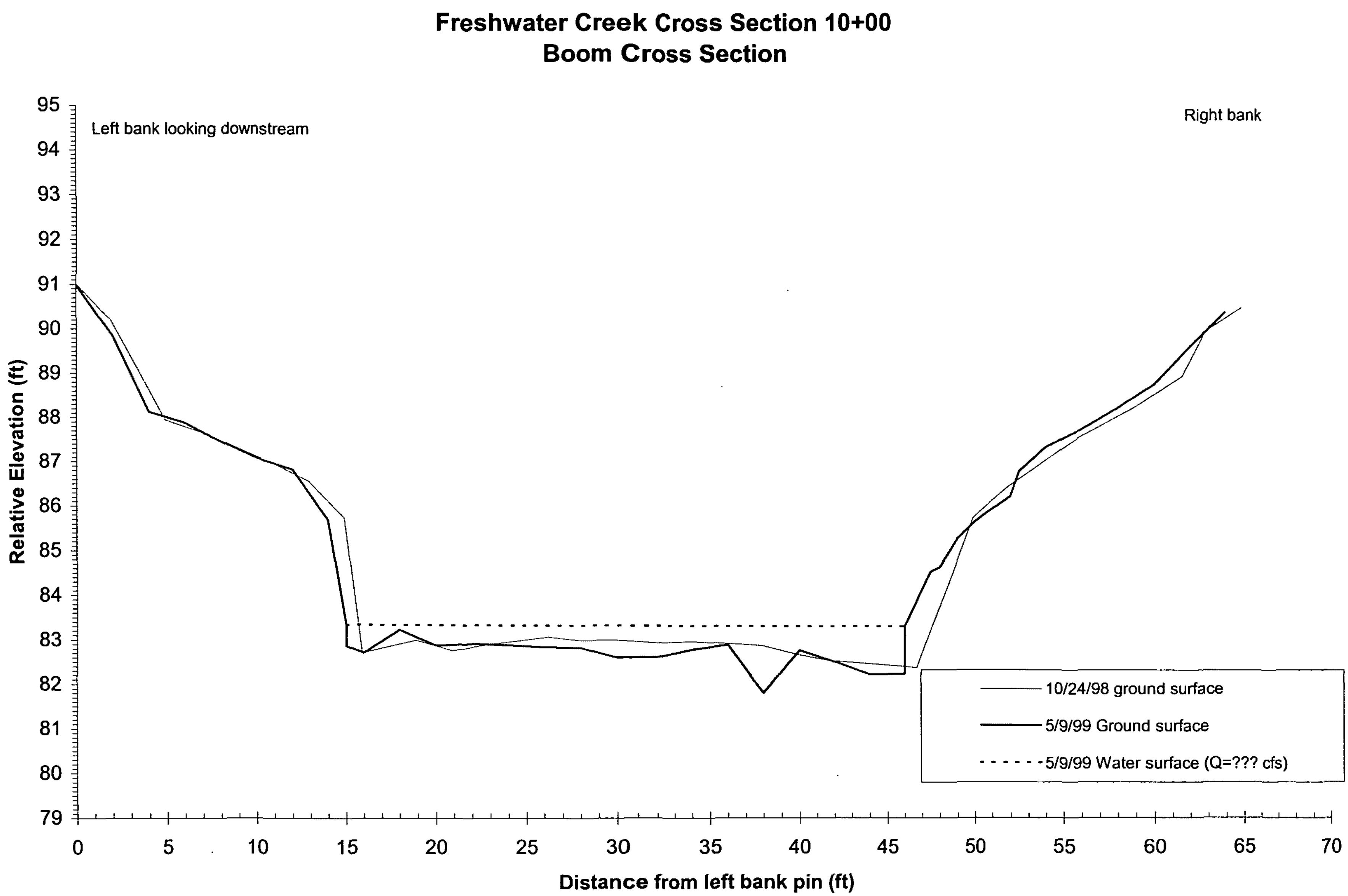


Freshwater Creek at Roelofs - X-S at Sediment Sampler
Arbitrary Elevation (ft)
94.00
92.00
90.00
88.00
86.00
84.00
82.00
80.00
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
Distance from LB headpin (ft)
Left Bank
(Looking downstream)
Right Bank
10/24/98 Ground Surface
10/24/98 Water Level
04/119/00 Ground Surface
04/19/00 Water Level

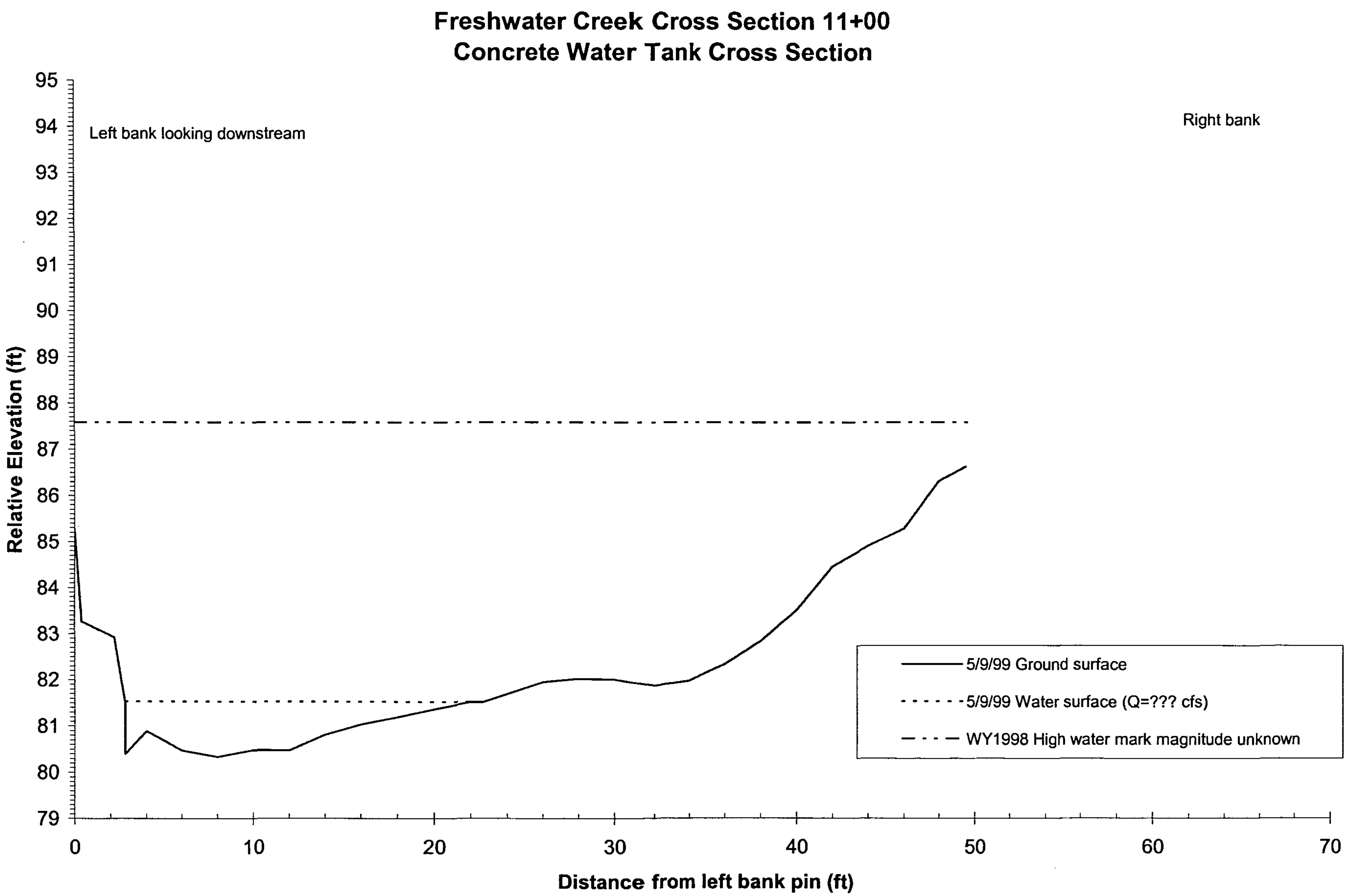

Freshwater Creek at Roelofs - XS 2
Upstream of Meander Bend
Left Bank
(Looking downstream)
Right Bank
Arbitrary Elevation (ft)
94.00
92.00
90.00
88.00
86.00
84.00
82.00
80.00
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
Distance from LB headpin (ft)
10/24/98 Ground Surface
10/24/98 Water Level
04/19/00 Ground Surface
04/19/00 Water Level

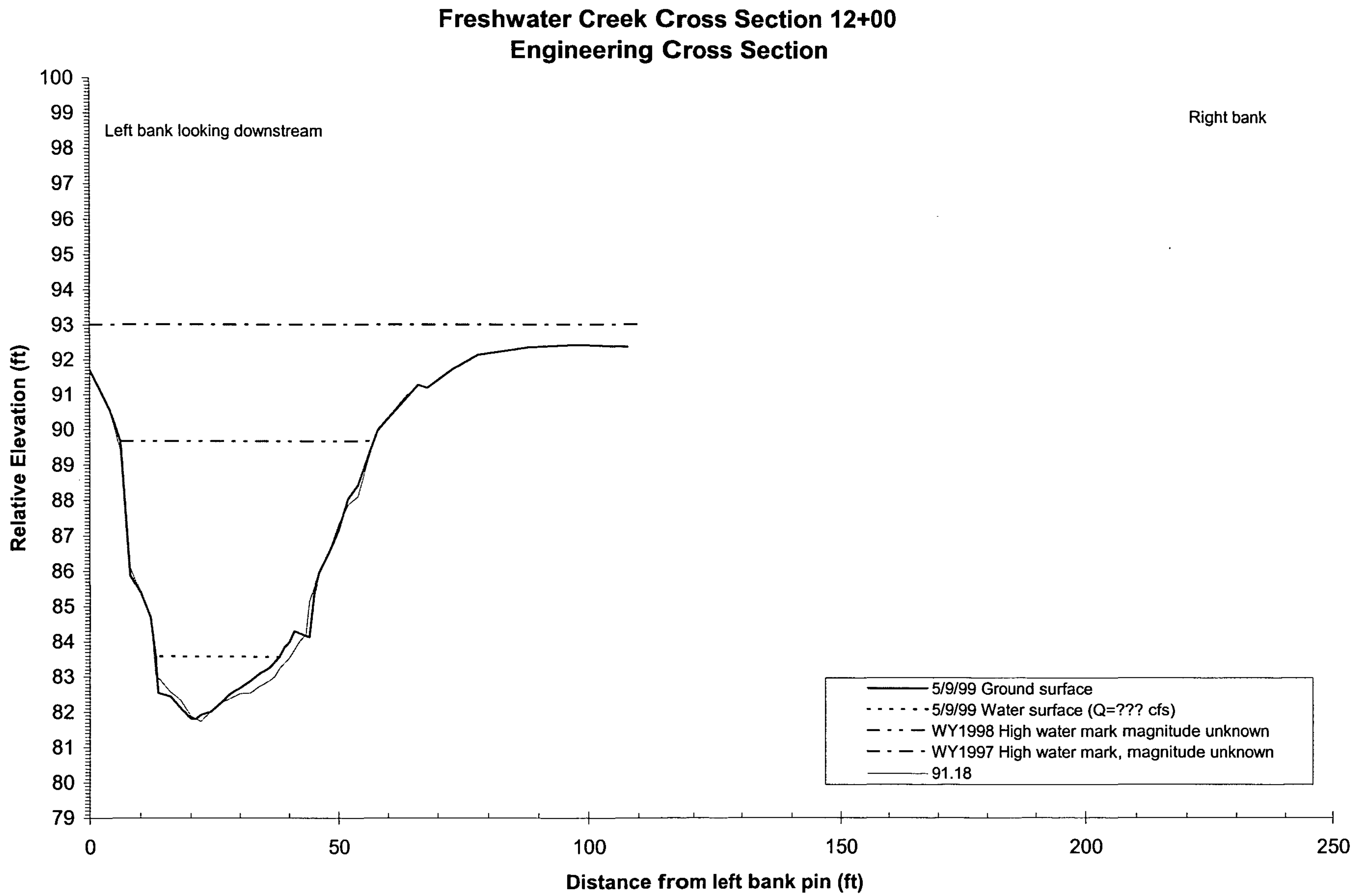


Freshwater Creek Cross Section 10+00
Boom Cross Section
Left bank looking downstream
Right bank
Relative Elevation (ft)
95
94
93
92
91
90
89
88
87
86
85
84
83
82
81
80
79
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
Distance from left bank pin (ft)
11/7/99 ground surface
5/9/99 Ground surface
5/9/99 Water surface (Q=??? cfs)

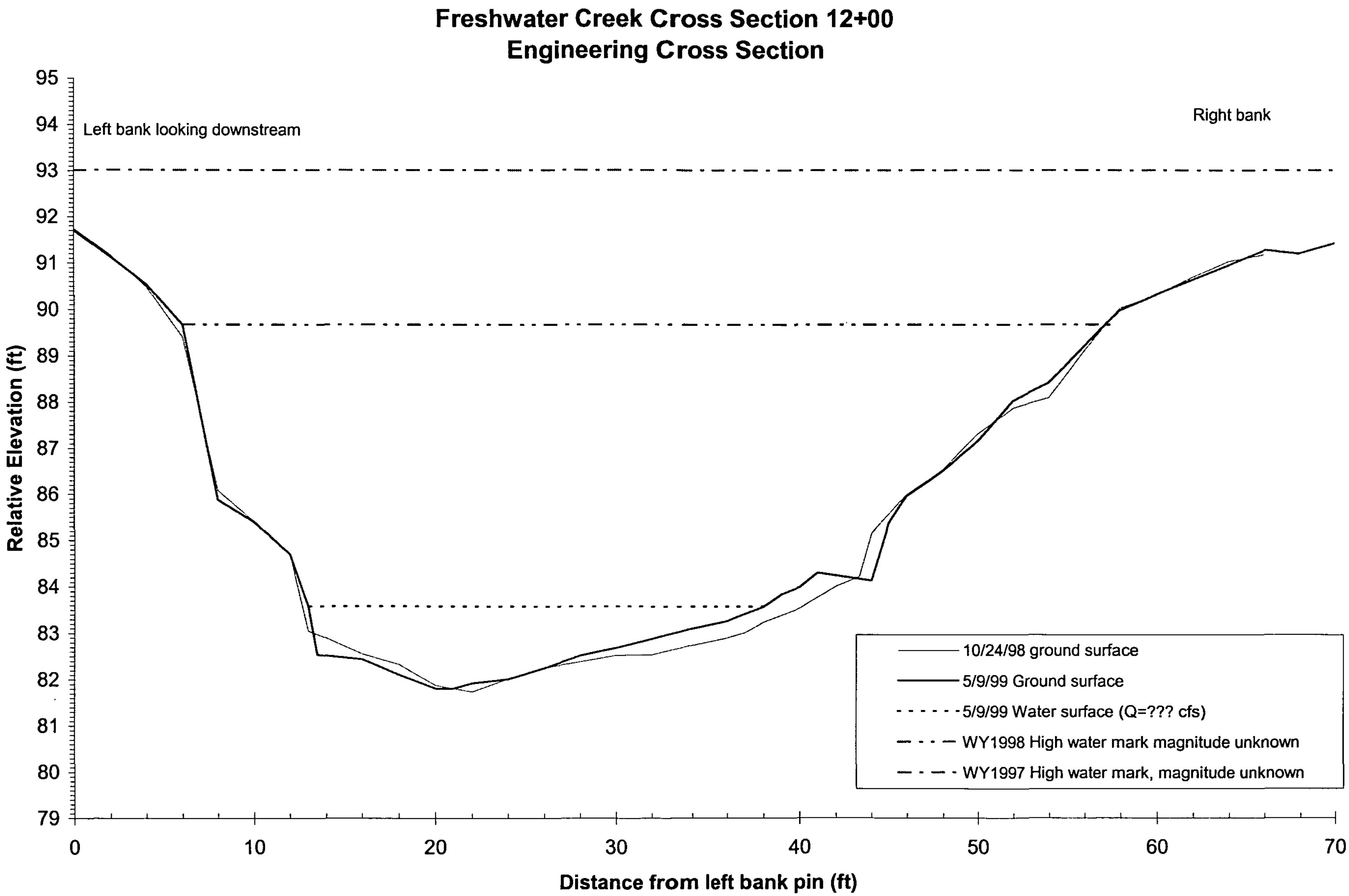


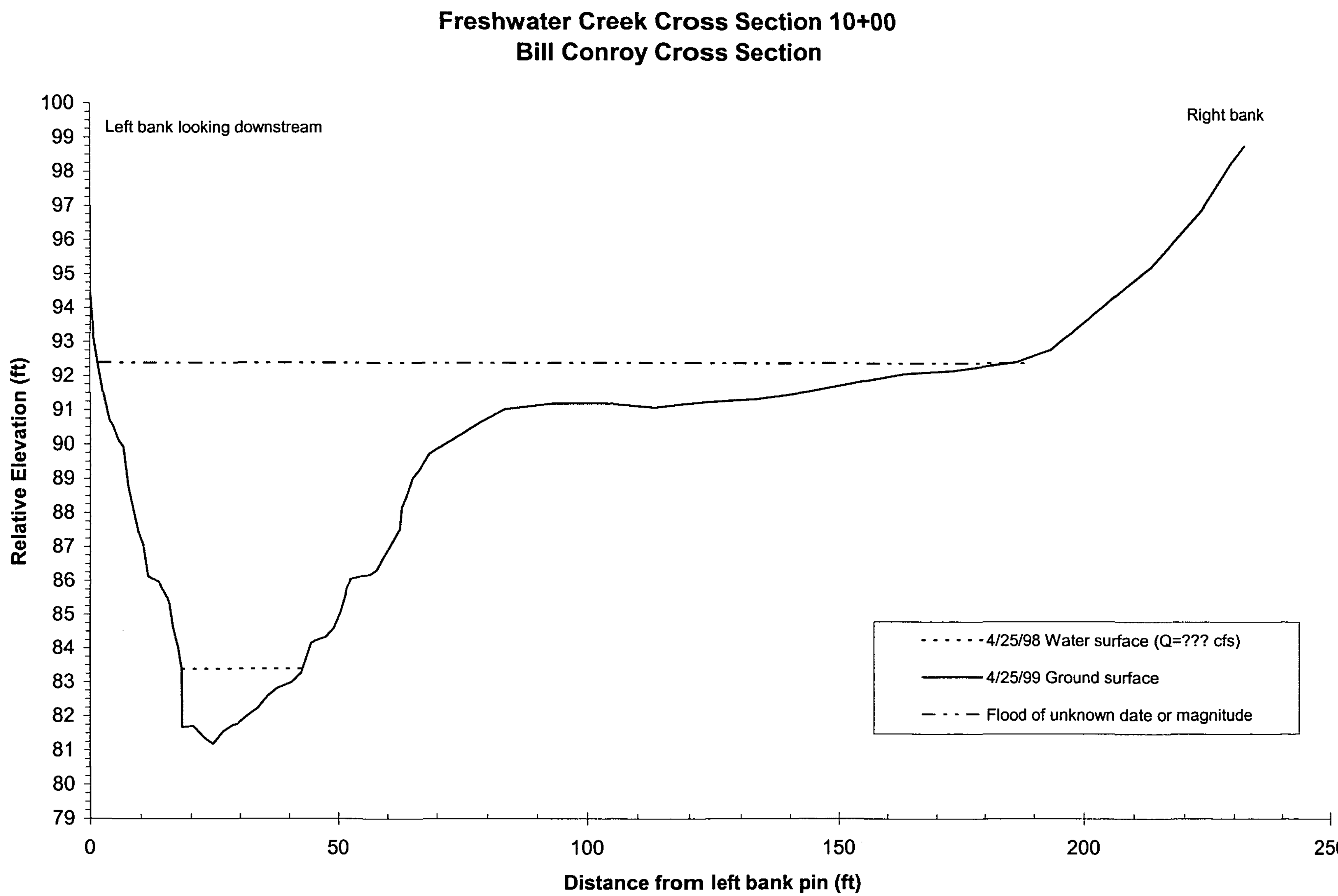
Freshwater Creek Cross Section 10+00
Boom Cross Section
Left bank looking downstream
Right bank
Relative Elevation (ft)
Distance from left bank pin (ft)
95
94
93
92
91
90
89
88
87
86
85
84
83
82
81
80
79
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
10/24/98 ground surface
5/9/99 Ground surface
5/9/99 Water surface (Q=??? cfs)


Freshwater Creek Cross Section 11+00
Concrete Water Tank Cross Section
Left bank looking downstream
Right bank
Relative Elevation (ft)
95
94
93
92
91
90
89
88
87
86
85
84
83
82
81
80
79
0
10
20
30
40
50
60
70
Distance from left bank pin (ft)
5/9/99 Ground surface
5/9/99 Water surface (Q=??? cfs)
WY1998 High water mark magnitude unknown

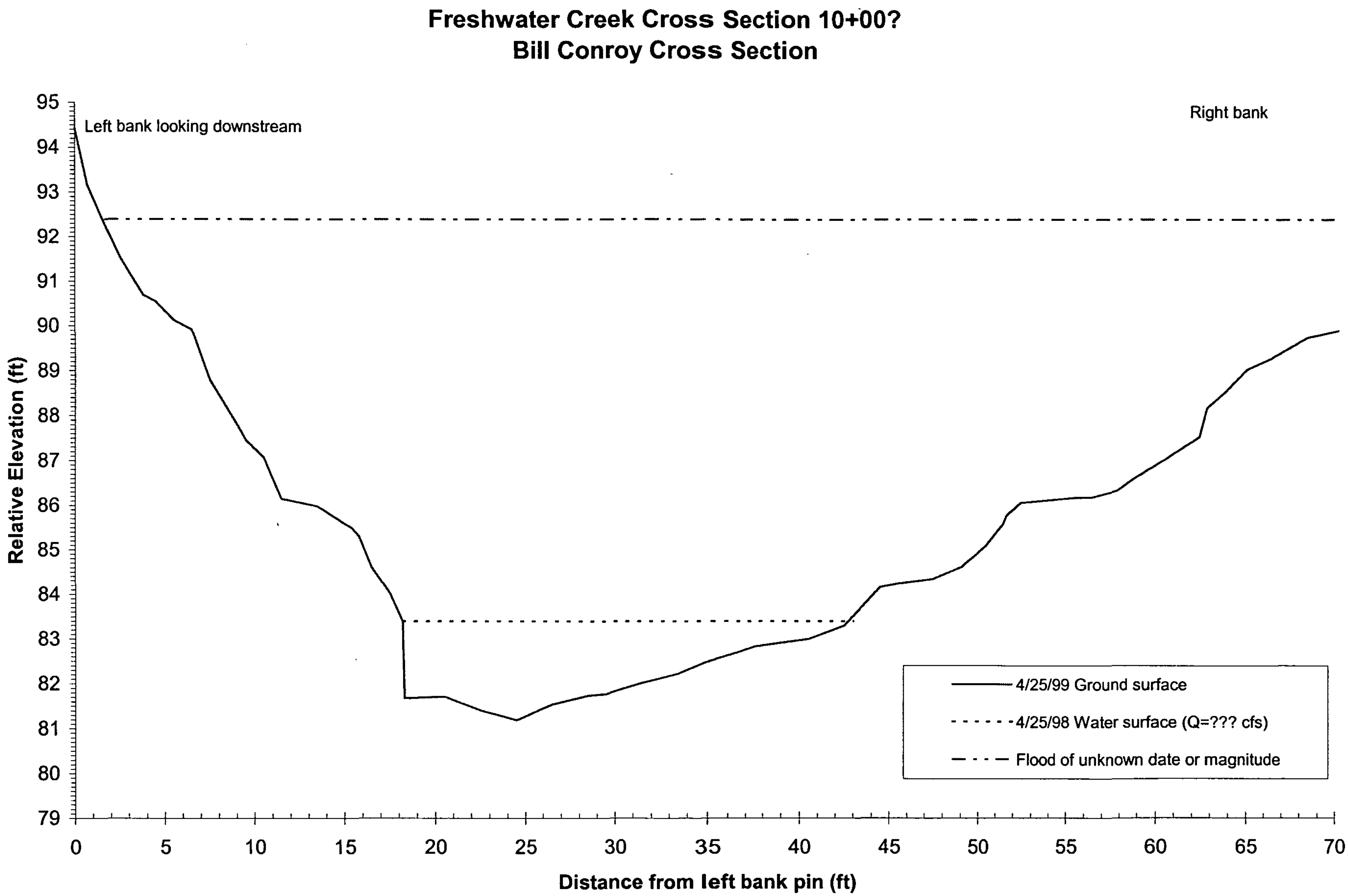


Freshwater Creek Cross Section 12+00
Engineering Cross Section
Left bank looking downstream
Right bank
Relative Elevation (ft)
100
99
98
97
96
95
94
93
92
91
90
89
88
87
86
85
84
83
82
81
80
79
0
50
100
150
200
250
Distance from left bank pin (ft)
5/9/99 Ground surface
5/9/99 Water surface (Q=??? cfs)
WY1998 High water mark magnitude unknown
WY1997 High water mark, magnitude unknown
91.18


Freshwater Creek Cross Section 12+00
Engineering Cross Section
Left bank looking downstream
Right bank
Relative Elevation (ft)
Distance from left bank pin (ft)
95
94
93
92
91
90
89
88
87
86
85
84
83
82
81
80
79
0
10
20
30
40
50
60
70
10/24/98 ground surface
5/9/99 Ground surface
5/9/99 Water surface (Q=??? cfs)
WY1998 High water mark magnitude unknown
WY1997 High water mark, magnitude unknown



Freshwater Creek Cross Section 10+00
Bill Conroy Cross Section
Left bank looking downstream
Right bank
Relative Elevation (ft)
100
99
98
97
96
95
94
93
92
91
90
89
88
87
86
85
84
83
82
81
80
79
0
50
100
150
200
250
Distance from left bank pin (ft)
4/25/98 Water surface (Q=??? cfs)
4/25/99 Ground surface
Flood of unknown date or magnitude



Freshwater Creek Cross Section 10+00?
Bill Conroy Cross Section
Left bank looking downstream
Right bank
Relative Elevation (ft)
Distance from left bank pin (ft)
95
94
93
92
91
90
89
88
87
86
85
84
83
82
81
80
79
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
4/25/99 Ground surface
4/25/98 Water surface (Q=??? cfs)
Flood of unknown date or magnitude

North American Journal of Fisheries Management 13:868–873, 1993

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Newcomb & Jensen

COMMENTS

Canadian Journal of Fisheries and Aquatic Sci

Comment: Utility of the Stress Index for Predicting Suspended Sediment Effects

Newcombe and MacDonald (1991) present a concentration–duration response model intended to be a convenient tool for assessing environmental effects caused by suspended sediment. As a much-needed synthesis of the available literature on the impacts of suspended sediment on salmonid fishes, their work is commendable. However, as an accurate predictive management tool, we find their stress index model is unreliable. These authors conclude that their stress index, $\log_e$ (concentration × duration), will be useful in assessing the severity of suspended sediment effects when there is a lack of either time or resources to complete a detailed environmental assessment. Because such instances are commonplace, the appeal of an effective tool developed for this purpose is obvious. The stress index model is seductively simple.

Our concerns have been prompted by the queries of salmon stock and habitat managers and hatchery operators in British Columbia, alarmed at the effects the model predicts for specific habitats. We have examined the information reviewed by Newcombe and MacDonald (1991) and have found that the data were highly variable, making the predictive power of their stress index low. Applying a general model, such as the stress index, to a stock-specific problem is a speculative prospect. We agree that duration of exposure as well as concentration must be considered in any assessment of the effect of suspended sediment on aquatic life. However, the stress index model is unrealistically simplistic. Without more detailed knowledge of specific stocks and habitats than the authors imply to be necessary, their stress index model has limited usefulness.

We have several concerns about the paper's treatment of data from the literature and the conclusions Newcombe and MacDonald (1991) presented. First, contrary to claims in the paper, the stress index model cannot be used to predict unquantifiable and subjectively ranked effects (Table 1, ranks 1–7, *in* Newcombe and MacDonald 1991). The model also omits concentration and duration thresholds, beyond which impacts will not occur; therefore, many predictions will be exaggerated. Second, although the authors attempted to cover a wide spectrum of aquatic animal and plant taxa, data from relevant fish species were not considered (e.g., nonsalmonid fishes). Considering the abundance of suspended sediment literature on these other fish species, we are surprised none of these studies were included in their analysis. Third, the model ignores the effects of additional variables normally associated with suspended sediment. Fourth, no statistical or practical validation procedure was performed on the model. Effects were substantially over- or underestimated relative to the observed effects in a high proportion of cases. Their stress index model fails to provide sufficiently accurate predictions of the effects of suspended sediment to be reliably used by managers of fish stocks (salmonid stocks in particular). In this paper, we reveal how each of these points affects the usefulness of the stress index model. We also demonstrate, through examples from our own research as well as from the published literature, that reliance on the stress index might lead fish habitat managers to suggest inappropriate policies for the protection of many fish stocks.

Other than quantifiable metabolic, physiological, and lethal stresses (Table 1, ranks 8–14, *in* Newcombe and MacDonald 1991), the relative ranks of the effects of suspended sediment presented by the authors were subjective and often of debatable biological significance. For example, suspended sediment "avoidance response" (rank 2) could simply have represented a short-term reaction to novel stimuli. Berg (1983) reported that initial observations indicating such avoidance behavior passed quickly in young coho salmon *Oncorhynchus kisutch*. Similarly, the "abandonment of cover" (rank 3) may not be a detrimental effect either. Turbidity may act as a form of cover from predators, affecting predator avoidance and feeding behavior of salmonids (Gregory 1990, 1993; Gregory and Northcote 1993). We also see no empirical support for the order of the sublethal and behavioral effects observed (ranks 1–9). Therefore, the variance their model accounted for (64%) was likely to have been overestimated.

The stress index model uses an open-ended time horizon, which will serve to exaggerate predicted impacts. According to the model, suspended sediment loads as low as 5 mg·L⁻¹ over a year ($\log_e$[5

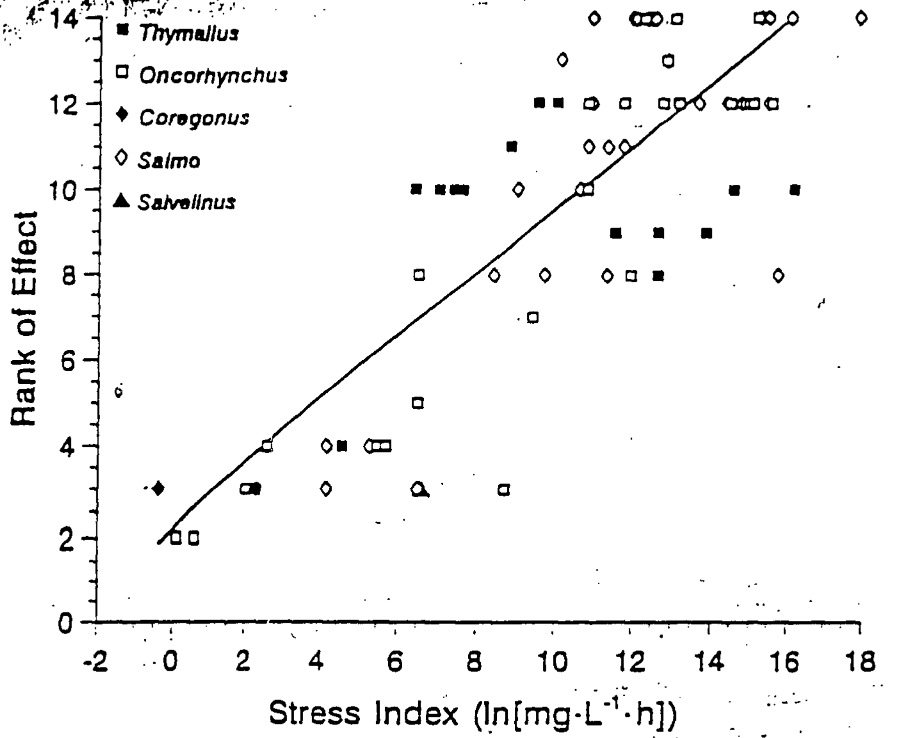

FIGURE 1.—The relationship between stress index (natural logarithm of the product of suspended sediment concentration and duration of exposure) and the observed severity of impact (rank of effect) on salmonids (after Newcombe and MacDonald 1991). Line indicates the prediction of the stress index model (rank effect = 0.738 $\log_e$[concentration × duration] + 2.179). We have removed data on aquatic invertebrates and data on "sediments" with confounding toxic effects (e.g., coal dust—see text) from our reanalysis.

tant topics, we believe their inclusion in Newcombe and MacDonald's (1991) survey was inappropriate. The confounding toxic effects of coal dust and iron hydroxide were likely manifested in the relevant investigations. Although providing valuable information, these studies were not designed to separate the toxicity from the more "inert" particle effects (e.g., angularity, turbidity; etc.). For example, given the abrasive characteristics of silicon particles, the observed effects of diatomaceous earth were (not surprisingly) higher than the model's predictions. Again, the presentation of "generalized" data on particle concentration is not appropriate for inclusion into a model purporting to isolate the effects of suspended sediment.

Effect thresholds receive no treatment in the stress index model, although such threshold values are common in studies on the influence of toxins on fish (e.g., see Sprague 1970). Threshold responses also appear in investigations on suspended sediment effects (Vinyard and O'Brien 1976; Confer et al. 1978; Breitburg 1988). Even when suspended sediment is acutely lethal to juvenile coho salmon, mortality generally occurs within the first few days (J. A. Servizi and D. W. Martens, unpublished data). Such results suggest a duration threshold response. Similar effects were suggested by our reanalysis (Figures 1, 2) of the data compiled by Newcombe and MacDonald (1991). Therefore, the logarithmic response assumed by the model is probably unrealistic.

At both high and low stress index values, predictions of the Newcombe and MacDonald (1991) model were unreliable estimators of observed responses. At low values (≤6), the effects of suspended sediment on salmonids were consistently overestimated (Figure 1). Our analysis of the model residuals (Figure 2) indicated that departures from the predicted effects were significant at these low index values (analysis of variance: $P < 0.001$, $N = 16$). At any given high stress index value (>6), the range of effects reported in the literature surveyed by Newcombe and MacDonald (1991) was excessively large, spanning from five to seven effect categories (Figure 1). Standard deviation of the model residuals was 2.3 rank effect units, indicating that about 40% of predicted impacts would be in error by at least 2.0 rank effect units. Figure

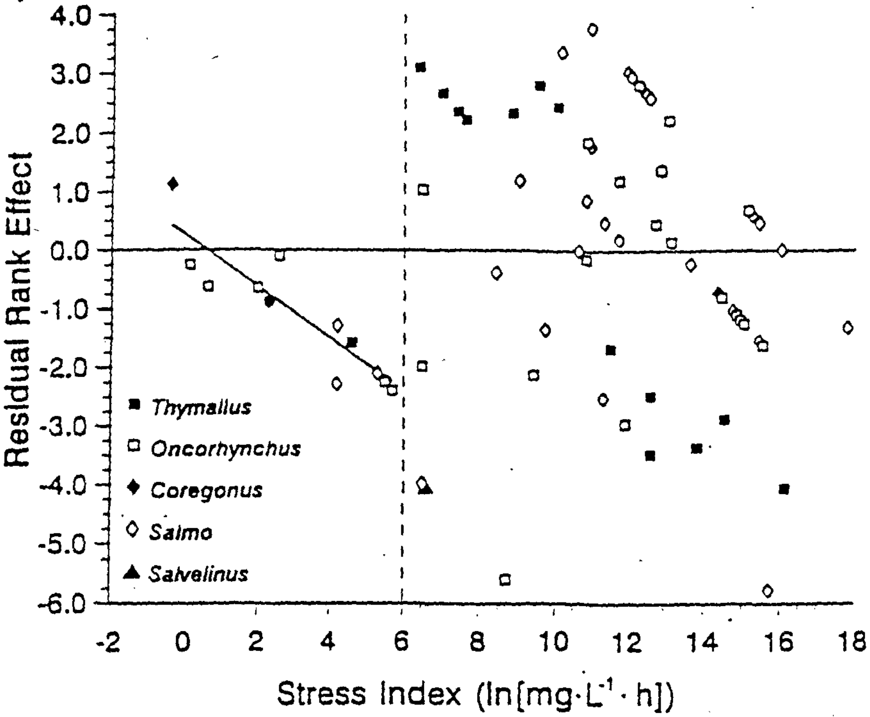

FIGURE 2.—The residuals from the stress index model (Newcombe and MacDonald 1991) calculated from data presented in Figure 1. Solid line indicates the relationship between low stress index values (<6) and the model residuals ($Y = 0.250 - 0.436X$; $r^2 = 0.827$, $N = 16$).

2 also suggests that the degree of error increases with the value of the stress index. We believe that the observed effects depart so frequently from the predictions of the model that the stress index is unreliable for management use.

Suspended sediment loads in the Fraser River can range up to 1,050 mg·L^{-1} (Servizi and Gordon 1989; Servizi and Martens 1992) during the peak of the juvenile salmonid outmigration and turbidity ranges from 30 to more than 100 Jackson turbidity units from May to August (Northcote and Larkin 1989). The stress index model suggests that as few as 2 d of exposure to these concentrations would be sufficient to cause 20% mortality (stress index = 10.8). We have observed suspended sediment concentrations greater than 50 mg·L^{-1} in side channels where underyearling chinook salmon rear for up to 2 months (Levy et al. 1979; Levy and Northcote 1982). Even in these relatively "clear" habitats, the stress index model predicts that mortality could reach 20% during such a residency period (stress index = 11.2). By definition, the survivors would also be subjected to all (or most) of the lower-ranked effects as well (e.g., negative growth, physiological damage, and population decline). However, both growth rate (Levy and Northcote 1982) and feeding rate (Gregory 1990; Gregory and Northcote 1993) of underyearling chinook salmon are high in such "stressful" conditions. Although these fish are exposed to numerous other environmental factors during their estuarine residency, the stress index model is clearly not supported by these latter investigations. On the contrary, the historical evidence for large salmon runs in the Fraser River (Northcote and Larkin 1989) strongly suggests that suspended sediment concentrations in the migratory and rearing portions of the river are nonlethal.

We find Newcombe and MacDonald's (1991) paper a timely addition to the literature because of the value of their synthesis of widely scattered published accounts of suspended sediment impacts on salmonid fishes. However, we maintain that the stress index model of Newcombe and MacDonald (1991) represents an oversimplification of the complex interaction of suspended sediment and the biology of salmonid fishes. At best, the predictions of the model lack the precision to be useful for salmon habitat management. At worst, underestimating potential effects may lead to serious damage of affected salmonid stocks by prompting incorrect habitat management actions (or inaction). Therefore, the use of the stress index model as a convenient predictive management tool would be inappropriate.

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Utility of the Stress Index
Suspended Sediment
Response to Com

Although there is general agre
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Utility of the Stress Index for Predicting Suspended Sediment Effects: Response to Comment

Although there is general agreement that there is a need for a simple method to predict the adverse effects of suspended sediment in aquatic ecosystems, there is still some disagreement on the extent to which the existing information can be used to develop such a tool. It is useful, therefore, to recapitulate the recent history related to our understanding of the environmental toxicology of suspended sediments.

The pollution control strategies used during the 1970s and 1980s were based on the assumption that suspended sediments would cause little or no harm to fish and aquatic life at relatively low concentrations, regardless of the duration of exposure to those levels. In those days, concentrations in the order of 25 $mg \cdot L^{-1}$ were frequently accepted, for pollution control purposes, as the thresholds for adverse biological effects (e.g., USEPA 1973). The concept of exposure duration was not considered in the pollution control paradigm, and thus low-level pollution episodes were officially tolerated for indefinite periods of time.

In the past, the concentration–response model has provided a convenient compromise between administrative (i.e., regulatory) requirements and our relative lack of knowledge of the toxicological effects of suspended sediment as a function of duration of exposure. However, the time-dependent effects of suspended sediments are now better understood and the concentration–response model seems to be somewhat dated. A comparison of the traditional concentration–response model with a dose–response model (dose = concentration × duration) indicates that concentration alone is only weakly correlated with severity of ranked effects, whereas the dose is more strongly correlated with those same effects (Newcombe and MacDonald 1991).

As indicated above, the need for a dose–response model applicable to suspended sediments is not at issue. However, in their Comment, Gregory et al. have raised a number of questions regarding the reliability of the "model" presented in our article (Newcombe and MacDonald 1991). These indicate that they have misinterpreted the intent of the stress index (SI) "model" presented in our original publication. Therefore, the following discussion is offered to clarify the original intent of our paper and to present the stress index model that was developed in the course of our research on the impacts of suspended sediments on aquatic ecosystems (Newcombe 1986, 1993).

Aquatic ecosystems throughout North America are affected by pollution episodes that have the potential to adversely affect fish, invertebrates, and aquatic plants. Although many concerns have been raised in recent years regarding the impacts of toxic chemicals that are released into these systems, the mobilization of fine inorganic particles and their subsequent deposition in sensitive habitats are, arguably, the most pervasive problem facing aquatic environmental managers. However, until recently, researchers in this field have provided these managers with little practical guidance for making regulatory decisions. In the absence of effect-based water quality guidelines for suspended sediments, regulatory decisions have generally been either arbitrary or based on background conditions at the site. In either case, it was assumed that consideration of concentration of suspended sediments alone would provide an adequate basis for protecting the environment.

The effects of an environmental contaminant on aquatic organisms vary substantially depending on diverse factors, including species and life stage, ambient water quality conditions, temperature, and

TABLE 1.—Revised ranking of effects of suspended sediments on fish and aquatic life.

Rank	Description of effect
	Behavioral effects
0	No adverse effects observed
1	Alarm reaction
2	Abandonment of cover
3	Avoidance response; change in swimming behavior
4	Reduction in feeding rate
	Sublethal effects
5	Minor physiological stress; increased rate of coughing or respiration, or both
6	Moderate physiological stress
7	Moderate habitat degradation; impairment of homing
8	Severe physiological stress; poor condition
9	Reduced growth rate; reduced rate of development
	Lethal effects
10	0–20% mortality; increased rate of predation
11	20–40% mortality; reduced size of population
12	40–60% mortality; severe habitat degradation
13	60–80% mortality
14	80–100% mortality

the presence of disease organisms and other contaminants (see CCREM 1987 for comprehensive summaries of the available toxicological data for numerous substances). However, the concentration of the substance and the duration of exposure to that substance are probably two of the most important factors affecting the toxicity of the majority of environmental contaminants. It was surprising to see that much of the published research relating to the effects of suspended sediments has failed to include information on the duration of exposure. Together, the available data led us to believe either that exposure duration was not considered to be a relevant factor for assessing the impacts of suspended sediments or that there were operational difficulties associated with the collection of the required data. Regardless of which factors have precipitated this information deficiency, it is our belief that the concentration–response model implicit throughout the literature on suspended sediments is fundamentally flawed.

The primary objective of our article (Newcombe and MacDonald 1991) was to evaluate the applicability of the concentration–response model described above. As a basis of comparison, a dose–response model, consistent with those developed for other environmental contaminants, was also described. In this context, dose was considered to be a function of both concentration and duration of exposure. To support this evaluation, a listing of the effects that had been reported in the literature in association with pollution episodes with suspended sediments was created. Subsequently, each of these effects was subjectively ranked in increasing order of severity (considering the potential long-term impacts associated with each endpoint measured) to provide a basis for comparing the two models. The results of the regression analyses performed on these data indicated that concentration alone was only poorly correlated with severity of effects, whereas dose (measured as pollution intensity, $mg \cdot h \cdot L^{-1}$) was more strongly correlated with ranked effect. From this information, it was concluded that pollution intensity (which was converted to stress index by taking the natural logarithm) provides a much more reliable tool for assessing the severity of environmental effects of suspended sediment episodes than does concentration alone. However, the regression equation reported in this study was never meant to be used as a predictive model to precisely estimate the nature and severity of effects on aquatic ecosystems. Indeed, we explicitly stated that the considerable variability among the data in the literature was likely to limit the applicability of the stress index for predicting precise responses of aquatic biota to suspended sediment exposures.

Notwithstanding the foregoing discussion, we have developed a stress index model for assessing the potential impacts of suspended sediment pollution episodes in coldwater ecosystems. In contrast to the interpretation provided by Gregory et al., however, this model is not represented by the regression equation reported in Newcombe and MacDonald (1991). Rather, the stress index model (as reported in Newcombe 1986, 1993) was intended to identify ranges of pollution intensities that are generally associated with three broad categories of effects in fish and other aquatic organisms, as follows:

Stress index	General category of effect expected
SI < 6	Behavioral effects
6 ≤ SI ≤ 12	Sublethal effects
SI > 12	Lethal effects

Reliability was one of the central issues addressed by Gregory et al. For this reason, we have attempted to evaluate the predictive capability of our stress index model by using an expanded version of the database described in Newcombe and MacDonald (1991). This expanded database (which now contains 203 records) includes information on a diverse array of fish species and endpoints that are relevant to the assessment of suspended

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TABLE 3.—Summary of rec

Oncorhynchus species	C t (m
Coho salmon *O. kisutch*	
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sediment impacts (Newcombe 1993). A revised ranking system has also been created to more adequately reflect the information that is currently contained in that database (Table 1). As such, a substantial quantity of data is available that relates suspended sediment intensity to severity of effect.

A preliminary evaluation on the reliability of the model was conducted by determining the incidence of each category of effect within the three ranges of pollution intensities identified (Table 2). The results of this evaluation indicate that the stress index model provides a reliable basis for predicting the potential of impacts associated with pollution episodes of various intensities. A very high incidence of behavioral effects (86.7%) was observed within the lowest range of pollution intensities ($SI < 6$); sublethal and lethal effects were observed only rarely within this range. At stress indices of greater than 12, lethal effects were observed with the greatest frequency (74.8%), and the incidences of behavioral (3.2%) and sublethal (22%) effects were relatively low. Therefore, the stress index model provides a reliable tool for estimating the potential impacts of suspended sediments within these two ranges of pollution intensities. However, both sublethal and lethal effects were observed between these two ranges, which indicates that the stress index model tends to underestimate the effects of suspended sediments within the intermediate range of pollution intensities ($6 \leq SI \leq 12$). Therefore, care should be exercised in applying this model when pollution intensities fall within this range. Similarly, care should be exercised in applying the model to situations outside of the range of conditions from which it was developed (i.e., from 7 to 300,000 $mg \cdot L^{-1}$ and from 1 min to 1 year).

TABLE 2.—Incidence of behavioral, sublethal, and lethal effects within the three ranges of pollution intensities identified by the stress index model. $SI = \log_e(\text{concentration} \times \text{duration})$.

Range of pollution intensity	Number of records	Incidence (%) of each type of effect: Behavioral	Sublethal	Lethal
$SI < 6$	30	86.7	13.3	0
$6 \leq SI \leq 12$	150	7.3	42.0	50.7
$SI > 12$	123	3.2	22.0	74.8

The stress index model is intended to provide resource and environmental managers with general guidance for assessing the impacts of suspended sediments in aquatic ecosystems. In this context, the model provides a convenient screening tool for predicting the severity of effects associated with pollution episodes of measured intensity. When pollution intensities fall within the lowest range identified by the model ($SI < 6$), only minor biological effects are likely to be observed. Therefore, generally it would not be necessary to initiate regulatory or remedial actions at the site under investigation. However, moderate and severe impacts on aquatic ecosystems are predicted when pollution intensities fall within the moderate (i.e., $6 \leq SI \leq 12$) and high (i.e., $SI > 12$) ranges, respectively. Under these conditions, it is rec-

TABLE 3.—Summary of recent information on the effects of suspended sediments on underyearling salmon.

Oncorhynchus species	Concentration ($mg \cdot L^{-1}$)	Duration (h)	Stress index ($mg \cdot h \cdot L^{-1}$)[a]	Effect	Rank of effect	Servizi and Martens (year)[b]
Coho salmon *O. kisutch*	20	0.05	0	No increase in coughing frequency	0	1992
	300	0.17	3.91	Avoidance behavior	3	1992
	2,460	0.05	4.81	Coughing frequency increased	5	1992
	240	24	8.66	Coughing frequency increased	5	1992
	530	96	10.84	Blood glucose concentrations increased	6	1992
	2,460	24	10.99	Fatigue of cough reflex	8	1992
	1,000	96	11.47	No mortality	10	1991
Sockeye salmon *O. nerka*	1,261	96	11.7	Body moisture content reduced	8	1987
	2,100	96	12.21	No mortality	10	1987
	3,148	96	12.62	Trauma in gill tissues evident	8	1987
Coho salmon	8,000	96	13.55	1% mortality	10	1991
	8,100	96	13.56	50% mortality	12	1991
Sockeye salmon	9,000	96	13.67	No mortality	10	1987
	13,000	96	14.3	90% mortality	14	1987
	17,560	96	14.34	50% mortality	12	1987
Coho salmon	22,700	96	14.59	50% mortality	12	1991
Sockeye salmon	23,900	96	14.65	90% mortality	14	1987

[a] Stress index = $\log_e(\text{concentration} \times \text{duration})$.

[b] See references.

ommended that further investigations be conducted to evaluate the nature and extent of the impacts that are actually manifested at the site. This preliminary information will provide a relevant basis for determining the need for and developing a remedial action plan to protect aquatic biota.

We concur with Gregory et al. that there may be a need for a more precise model for assessing the impacts of suspended sediment pollution in certain situations (e.g., spawning channel cleaning operations, etc.). However, it is unlikely that the existing data would support the development of a more precise model that could be applied uniformly to fish, invertebrates, and aquatic plants. Moreover, the uncertainty inherent in most of the monitoring data collected on suspended sediment episodes in the field (limited numbers of grab samples are normally collected over short time periods) would restrict the application of a more precise model, even if the available toxicological data supported its development. Therefore, efforts in this area ought to be focused on the establishment of quantitative dose–response relationships for specific species and life stages of aquatic organisms.

To illustrate this process, a preliminary dose–response relationship specific to underyearling salmon has been derived. Regression analysis of the recent data on the effects of suspended sediments on these receptors (data that are independent of the original database: Table 3) results in the following relationship ($r^2 = 0.86$, $N = 17$, $P < 0.01$):

$$\text{severity of effect} = 0.849 \log_e i - 0.591;$$

i is intensity of exposure ($mg \cdot h \cdot L^{-1}$). These data confirm that the natural logarithm of suspended sediment intensity is strongly correlated with ranked effect in underyearling salmon. Although the slope of the quantitative relationship is similar to that reported by Newcombe and MacDonald (1991) for salmonids and aquatic invertebrates, the intercept is different (−0.591 compared to +2.179). These data validate the stress index model, but indicate that juvenile salmon are somewhat more resistant to the effects of suspended sediments than the species represented in the original data set. We believe that similar "models" can be developed for other species and life history stages and challenge researchers in this field to generate the necessary information.

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