Channel Morphology and Habitat for Pacific Salmon in a Headwater Stream Following Timber Harvest, Olympic Peninsula, Washington

by

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to Offer Degree Fisheries

Date June 10, 1994

Master's Thesis

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Abstract

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By Robert P. Jones Jr

Chairman of the Supervisory Committee: Professor S. Mathews
School of Fisheries

Channel morphology, associated aquatic habitats, cover, and substrate in headwater streams are important factors in salmonid production. Logging in riparian and adjacent upland areas can impact these stream features, and thus affect salmonid production. This study compared channel morphology, habitat, instream cover, and spawning substrates of stream sections adjacent to logged riparian areas and stream sections within mature forest in Bear Creek, a fourth-order tributary of the Bogachiel River near Forks, Washington.

Bear Creek adjacent to logged riparian and upland areas exhibited reduced channel complexity and habitat diversity compared to stream sections within mature forest. Shifting channel integrity was pronounced for stream sections adjacent to logged areas. Cover was significantly less abundant in stream sections adjacent to logged areas

compared to stream sections within mature forest. Percent composition of fine materials in substrates judged to be potential spawning gravels was not significantly different in stream sections adjacent to logged areas compared to stream sections within mature forest. Until riparian trees grow large enough to provide a source of stable instream structure, cover abundance will likely decline and channel instability will persist in stream sections adjacent to logged riparian areas.

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Introduction

Riverine environments play a unique role in the life cycle of Pacific salmon and trouts (Oncorhynchus spp.). Headwater streams sustain these species during crucial stages of their life history, from juvenile rearing to adult return and spawning. Multiple life stages and different species also commonly utilize microhabitats of a particular stream concurrently.

Riverine environments function as part of an upland terrestrial, riparian, and aquatic habitat complex. Riparian corridors play a particularly important role in this complex as transition zones between upland and aquatic habitats, and are closely related to riverine environments (Gregory and Ashkenas 1990; Gregory et al. 1991). As a primary source of stream structure (e.g., large wood and rock), riparian areas are crucial in the development and distribution of aquatic habitats and increased habitat complexity, and provide substrates for biological activity (Swanson et al. 1982; Bisson et al. 1987). Riparian vegetation moderates water temperatures and photic regimes (Agee 1988), key factors affecting the behavior, growth and abundance of juvenile salmonids (Lantz 1971; Brett 1979; Martin 1985). Riparian areas also contribute fine vegetation or litter to the food base of riverine

environments (Vannote et al. 1980), and terrestrial invertebrate fauna, an important food source for salmonid fishes (Hunt 1975).

Another important function of riparian areas is their influence on hydrologic, geomorphic, and ecologic processes that shape stream integrity and fish habitats. Habitat and associated fauna characteristic of stream environments have evolved under natural disturbance regimes during extended periods (Pringle et al. 1988). Flood events, high winds and resulting downed trees, and landslides are examples of natural phenomena that affect the delivery and distribution of large wood, rock, sediment, and water, and thus shape stream morphology and characteristic habitat diversity. Natural or undisturbed riparian areas regulate the distribution of materials to streams (Swanson et al. 1982; Gregory et al. 1991), moderate the effect of these natural processes, and thus maintain channel integrity (Sedell and Beschta 1991) and stream productivity, important factors in salmonid production.

The loss and degradation of riverine habitats has been attributed as a primary factor in the decline of both anadromous and resident Pacific Coast salmonid fish stocks,

and the extinction of numerous others (Williams et al. 1989; Nehlsen et al. 1991). Reduced salmonid diversity in some Pacific Northwest streams is another consequence of habitat degradation (Bisson and Sedell 1984, Li et al. 1987, Hicks 1990).

Logging and associated activities can affect the delivery of water and different materials (e.g. sediment) to riverine environments, upset natural processes that maintain stream integrity, and thus result in the loss or degradation of habitats crucial to these fishes (Forest Ecosystem Management Assessment Team 1993). Reduced habitat complexity (variation in stream depth, velocity, etc.) and pool habitat quantity and quality can result following timber harvest in adjacent riparian areas (Bisson and Sedell 1984, Sullivan et al. 1987, Hicks et al. 1991, Bisson et al. 1992, Frissel 1992). Comparing more recent habitat inventories with historical records, Sedell and Everest (1991) described a general deterioration of anadromous salmonid habitat and noted that land use practices, including logging, have reduced large pool habitat between 50% and 75% in the Snake River Basin and other Pacific Northwest river systems. Water temperature regimes, an important factor in the production of anadromous fishes, can also be altered as a result of logging.

(Beschta et al. 1987, Bisson et al. 1987). Accelerated erosion processes often result from timber harvest activities, particularly road construction (Ice 1985, Swanson et al. 1985), leading to changes in sediment transport and storage, upslope stability, channel morphology, and stream substrate composition. Changes in streamflow volume, duration and timing can also result from logging (Keppeler and Ziemer 1990, Wright et al. 1990).

Although riverine habitat degradation and declines in juvenile salmonid production have been established as potential consequences of logging activities, the range and magnitude of these consequences resulting from timber harvest practices remains difficult to predict (Hicks 1990). Complex relationships between upland, riparian and riverine environments, natural variation in riverine habitat (e.g., shifting location of pools and riffles) and fish survival, interspecies interactions, characteristic geology, and variation in weather (e.g., differences in the magnitude and duration of storm events), confound evaluations of timber harvest effects and determination of site specific management practices that afford appropriate habitat protection. Bear Creek studies were designed to discriminate effects from different timber

harvest activities on cutthroat trout (Oncorhynchus clarki) with broader application to other salmonids having similar life histories and habitat requirements.

Study Background

In an effort to assess the effects of timber harvest activities on the stream ecosystem and particularly on indigenous cutthroat trout and their associated habitats, a series of investigations was planned in Bear Creek, a fourth-order tributary of the Bogachiel River on the Olympic Peninsula, near Forks, Washington. The purpose of Bear Creek investigations of which the present study is a part, was to isolate different aspects of logging, and thus better define potential effects to headwater stream habitat and cutthroat trout populations resulting from individual logging activities.

It was determined that the Bear Creek watershed had never been logged and supported a climax forest characteristic of Pacific Northwest coastal areas. Initial studies in 1977 and 1978 (June 1981), provided planimetric maps of the stream (Appendix A), quantified aquatic habitats and instream cover, and described the cutthroat trout population in Bear Creek. This work provided a basis for assessing any effects resulting from subsequent logging

activities, including road building, tree felling, and finally timber removal.

In February 1979, timber was felled adjacent to the lower 1000 meters of the Bear Creek study reach (treatment reach). Logging practices employed at the study site followed United States Forest Service regulations. Except for a limited number of trees (generally red alder) and various shrubs immediately adjacent to the stream channel, the riparian canopy and understory community were eliminated. A reserve within which all riparian vegetation was protected from disturbance or removal was not provided. The watershed upstream remained in its natural state, including the remaining 200 meters of the study reach (control reach), contiguous to but upstream from the treatment study reach.

Subsequent studies investigated cutthroat trout production following timber felling (canopy removal) but prior to any physical disturbance of the stream channel, riparian zone, or upland area that may accompany timber removal. Investigations of food supply, food consumption, and the production of cutthroat trout following canopy removal were conducted in 1979 and 1980 (Martin et al. 1981, White 1981, Martin 1985). Road construction and the removal of felled

timber were delayed until 1981 to isolate any effects resulting from canopy removal.

Study culminating in this thesis planned to evaluate channel morphology and aquatic habitats important to cutthroat trout in treatment and control reaches of Bear Creek, and determine whether cutthroat trout production was affected by logging. Surveys were conducted in 1983, 1984, and 1985 following the removal of previously felled timber and the completion of all timber harvest activities.

Study Objectives

A primary study objective when field work began was to assess whether cutthroat trout production in Bear Creek had been affected by logging. Focus of the study shifted to an assessment of channel morphology and characteristic habitat following logging, after discovery of large numbers of juvenile coho salmon (Oncorhynchus kisutch) in the study reach (approximately 25,000 coho fry were introduced just upstream from the study area in the spring of 1983). Coho salmon did not occur in the study reach during previous assessments of cutthroat trout production, and competitive interactions between cutthroat trout and coho salmon could not be accounted for.

Under these circumstances and considering previous investigations in Bear Creek characterizing channel morphology, aquatic habitats, and instream cover, this study proceeded with the following primary objectives.

1. Determine whether stream morphology in Bear Creek changed as a result of logging,

2. Assess whether the quality, quantity, and dynamic state of fish habitat in Bear Creek changed as a result of logging,

3. Determine whether cover changed as a result of logging, and,

4. Determine whether stream substrates changed as a result of logging.

Chapter 1: Description of the Study Area

This study was conducted in the upper watershed of Bear Creek, a remote fourth-order tributary of the Bogachiel river in the Olympic National Forest near Forks, Washington (Figure 1). Previous to 1981, the watershed was roadless and had never been logged. Following road construction and completion of logging in 1981, vehicular access was limited, and the area experienced little or no use.

Climate and Geology

Climate in this vicinity is oceanic with annual precipitation averaging 300 centimeters, consisting primarily as rain below 600 meters elevation (Phillips 1965). Geology of the study area is characterized by Cretaceous sedimentary rock referred to as the Soleduck formation, the oldest known material in the Olympic Range. This rock consists of coarse textured, thickly bedded graywacke interbedded with fine-textured, thinly bedded mudstone, siltstone, and argillite (Snyder et al. 1972). Surrounding terrain is moderately steep with slopes ranging from 20 to more than 40 percent. Physical characteristics of Bear Creek are provided in Table 1.

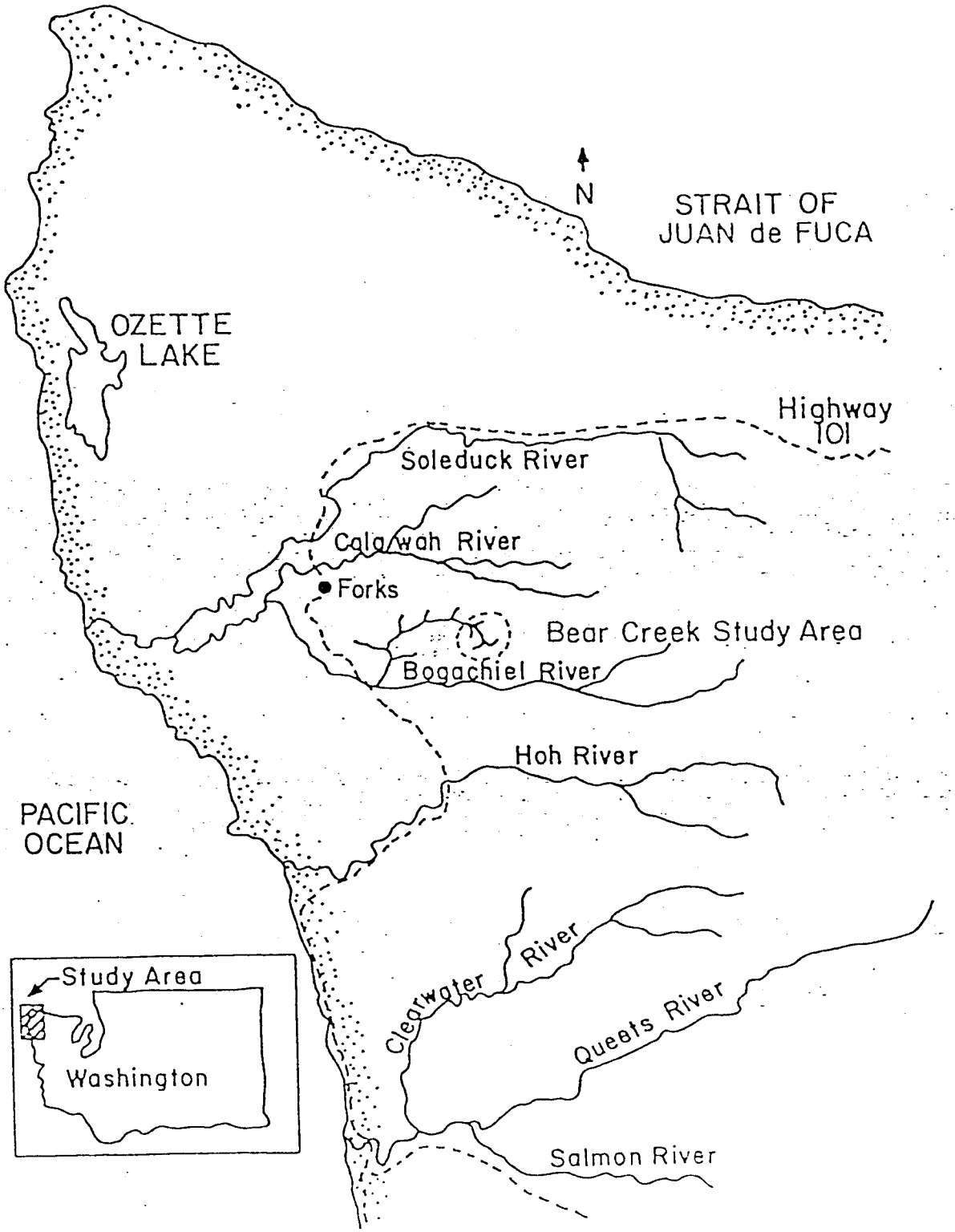

Figure 1. Western Olympic Peninsula with location of the Bear Creek study area.

Table 1. Physical characteristics of the Bear Creek study reach.

Study reach length along the thalweg	0 - 1200 meters
Treatment reach length along the thalweg	0 - 1200 meters
Treatment study sections	75 - 125 meters
	550 - 600 meters
	900 - 950 meters
Control (upstream) reach length along the thalweg	1000 - 1200 meters
Control study sections	1000 - 1050 meters
	1125 - 1175 meters
Elevation at 0 meters (treatment)	184 meters
Elevation at 1200 meters (control)	310 meters
Average gradient	2.1 percent
Sinuosity	1.2 percent
Approximate watershed area of study reach	230 hectares
Stream aspect	Northwest
Approximate minimum discharge	0.02 cubic meters/second
Approximate maximum discharge	5.66 cubic meters/second
Minimum temperature	3.0 degrees C
Maximum temperature	14.8 degrees C
Low-flow water surface area	3477 square meters
Percent pool habitat of total reach surface area	64.8 percent

Ecology

Vegetation in the study area is comprised primarily of mature forest including western hemlock (Tsuga heterophylla), western red cedar (Thuja plicata), and Sitka spruce (Picea sitchensis) (Jones 1936). Other species bordering the control reach, and remnant riparian vegetation of the treatment reach include red alder (Alnus rubra), vine maple (Acer circinatum), salmonberry (Rubus spectabilitis), devils club (Oplopanax horridum), salal (Gaultheria shalion), tall blue huckleberry (Vaccium ovalifolium), and red huckleberry V. parvifolium). Indigenous fishes of the study reach include prickly sculpin (Cottus asper), and both resident and anadromous cutthroat trout (Oncorhynchus clarki). A log-jam waterfall that previously prevented the escapement of larger anadromous salmonids, i.e. coho salmon (Oncorhynchus kisutch) and steelhead trout (Oncorhynchus gairdneri) into the study reach was partially removed in 1982 by a winter storm. Despite modification of this barrier, adult coho salmon and steelhead trout were not observed in the study reach during 1982, 1983, or 1984. Approximately 25,000 coho salmon fry were introduced into Bear Creek at a road crossing a short distance upstream from the study reach by the Washington Department of Fisheries during the spring of 1983.

Chapter 2: Methods and Materials

Experimental Design

The study reach was 1200 kilometers in length, including a 1000 meter treatment reach within a riparian community subject to timber harvest, and an upstream and contiguous 200 meter control reach entirely within mature forest (Figure 2). Five study sections, each section 50 meters in length, were located in the study reach. Three study sections were located in the 1000 meter treatment reach and two sections were located in the 200 meter control reach. Representative study sections were selected in 1977 based on similarities in channel morphology and aquatic habitats. Study sections were established for permanent reference to facilitate later comparison and determination of any resulting effects from different aspects of logging. To ensure that surveys of stream channel morphology were relative from year to year, permanent reference points were established on the left and right banks above the high-water mark at 25 meter intervals for the entire study reach (0 to 1200 meters). Stakes were also positioned in each of the five study sections to monitor stream channel cross-section.

In 1978 prior to any timber harvest activities, surveys were completed and a planimetric view of the entire study

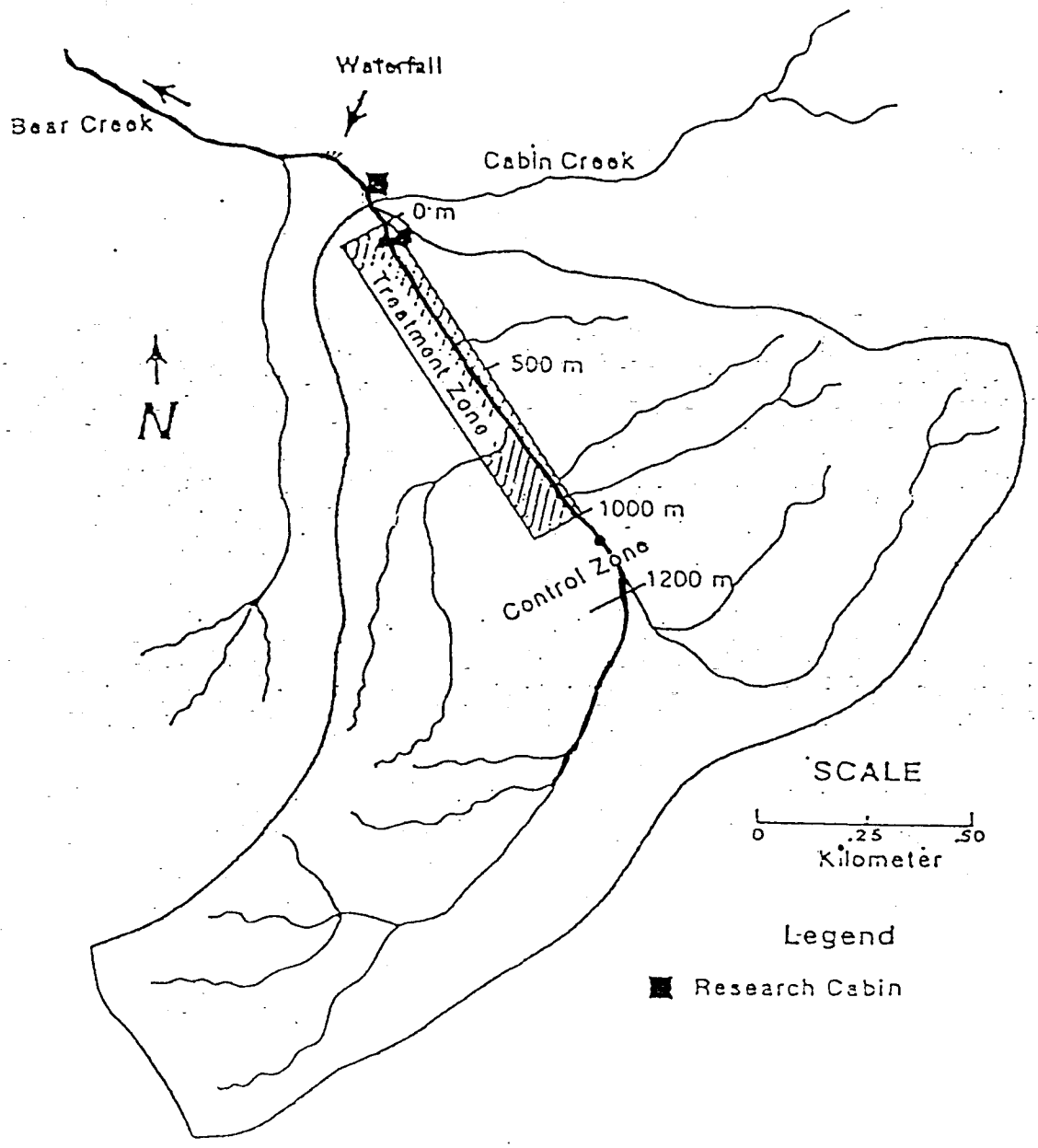

Figure 2. - Upper Bear Creek watershed and study area.

reach was drawn. Before surveys in 1983 and 1984 could proceed, reference points established in 1977 were located and cleared of vegetation to make them clearly visible. Reference points ensured that locations surveyed before and after logging, and resulting ordinate and abscissa scales were identical to facilitate comparison of study section profiles.

Channel Morphology

Channel morphology surveys were conducted in September 1983 and August 1984 with a theodolite and electronic distance meter utilizing laser technology. Polar coordinates were converted to rectangular coordinates and data were plotted to scale using a personal computer and commercial spreadsheet program. Channel morphology for treatment study sections following logging in adjacent riparian and upland areas, and for control study sections within mature forest, was depicted by longitudinal, planimetric, and cross-sectional profiles. Planimetric views of Bear Creek in 1978 previous to logging were digitized and plotted to scale using a personal computer and computer aided drafting program.

Habitat

Previous surveys of Bear Creek in 1978 located pool and riffle habitats on planimetric views of each stream section. Pool and riffle habitats are depicted by longitudinal profiles of stream sections adjacent to logged riparian and upland areas in 1983 and 1984, and of stream sections within mature forest in 1984.

Habitat was inventoried for treatment and control study sections during a low-flow period in January, 1985. Width, depth, and length of pool, riffle, and rapid habitats were recorded, and cover was quantified consistent with 1978 surveys previous to logging. The composition of different habitats was described utilizing a stream habitat definition technique that combines living space requirements with fluvial geomorphology (Bisson et al. 1981). The area and volume of each habitat category (pool, riffle, and rapid) and each habitat sub-category (plunge pool, low gradient riffle, etc. see Appendix B) were recorded and expressed as percentages of the total habitat present in treatment and control study sections. The percentage of total pool habitat in each habitat study section with an average depth greater than 0.4 meters and the percentage of pool habitat less than 0.4 meters in

depth was also reported. Cover structure was identified (e.g. large wood, or boulder substrate) and measured for each habitat category and subcategory. The percentage of each habitat category and sub-category associated with a particular cover structure was also recorded.

Spawning Substrate

Stream substrate was sampled during August 1983 from locations with water velocity and gravel size preferred by spawning cutthroat trout in treatment and control study sections of Bear Creek (typically transition areas between pools and riffles). Samples were collected with a modified McNeil corer and later wet sieved to determine the volumetric displacement and percent composition of different size stream substrates (Cederholm et al. 1978). The percent composition of each sample was reported for substrate greater than 26.9 millimeters (mm), greater than 3.35 mm, greater than 0.85 mm, greater than 0.106 mm, less than 0.10 mm, and less than 0.85 mm. Substrate samples were collected in pairs from each location except where remaining material representative of spawning substrate at that location was disturbed from collection of the first sample. A total of 12 samples were collected from the 1000 meter treatment study reach, and 6 samples from the upstream 200 meter control reach.

Stream Discharge and Surface Area

Stream discharge and surface area measurements were collected on one occasion (discharge measured on October 29, 1983 and surface area on October 9, 1983) under low-flow conditions. Stream discharge, reported in cubic feet per second, was measured near the downstream boundary of the treatment reach (meter 53), the boundary between treatment and control reaches (meter 1000), and at the upstream boundary of the control reach (meter 1200) to determine discharge in the treatment reach and in the control reach. Surface area was measured over the entire 1200 meter study reach.

Salmonid Production

Population census information was collected in treatment and control study sections of Bear Creek, first during late September-early October, 1983, and in April 1984. A high-flow event precluded completion of sampling in July 1983 (recapture of fish previously marked was impossible).

A mark and recapture method was used to estimate the abundance of salmonid species in each study section (treatment and control). Beginning at the origin of the treatment study reach (0 meter stake) and proceeding

upstream, collected fish were marked and then returned to their approximate location of capture. One to three days later, sampling proceeded upstream through the study reach a second time and the number of recaptures (previously marked fish) and others were recorded. For each 25 meter study section, cutthroat trout and coho salmon were measured to the nearest mm and weighed to the nearest 0.1 gram with an Ohaus dial balance scale. A Smith Root Type VII backpack electroshocker was used to collect fish. Cutthroat trout and coho salmon population estimates and 95 percent confidence limits were calculated for individual study sections, for total treatment sections, and for total control sections. Estimates of population abundance were derived by the Chapman modification of the Petersen formula (Chapman 1951):

$$N = \frac{(m + 1)(c + 1)}{(r + 1)}$$

Where N = an estimate of population abundance

m = the number of fish marked on the first pass

c = all fish collected on the recapture pass

r = the number of marked fish recaptured.

Confidence limits (95%) were calculated for cutthroat trout and coho salmon population estimates from Chapman's formula derived from hypergeometric distribution:

$$\text{Var}\ (\hat{N}_c) = \frac{\hat{N}_c^2\ (c-r)}{(c+1)(r+2)}$$

$$\Pr(\hat{N}_c - Z_{\frac{\alpha}{2}} \sqrt{\text{Var}\ \hat{N}_2} \leq N < \hat{N}_c + Z_{\frac{\alpha}{2}} \sqrt{\text{Var}\ \hat{N}_c}) = 1-\alpha$$

Cutthroat trout age structure was determined from previous scale analysis and length frequency distributions of fish in Bear Creek (June 1981), and from a length frequency distribution of fish collected during this study (September and October 1983). Ages are reported as the number of winters survived. The term year class refers to the year a fish emerged from stream substrates following incubation.

Chapter 3: Results

Channel Morphology

Bear Creek featured diverse channel morphology including a sinuous thalweg, numerous pools and riffles, and multiple stream channels in 1978 (from June, 1981) previous to logging (Figures 3 through 7). Planimetric views of Bear Creek previous to logging are provided in Appendix A.

Bear Creek study sections within mature forest surveyed in 1984, again exhibited diverse channel morphology (Figures 8 and 9). Variable channel elevation defining a progression of pool and riffle habitats (Figures 10 and 11) typified these stream sections.

Stream sections adjacent to logged riparian and upland areas in general exhibited little complexity in channel morphology, and limited pool development in 1983 surveys (Figures 12 - 14). This was particularly evident for sections 2 and 3, each section displaying even channel gradient representing continuous riffle habitat interrupted by a single pool. Only section 1 channel morphology was irregular; increasing and decreasing elevation denoting developing pool and riffle habitats. Longitudinal and planimetric views of Bear Creek adjacent

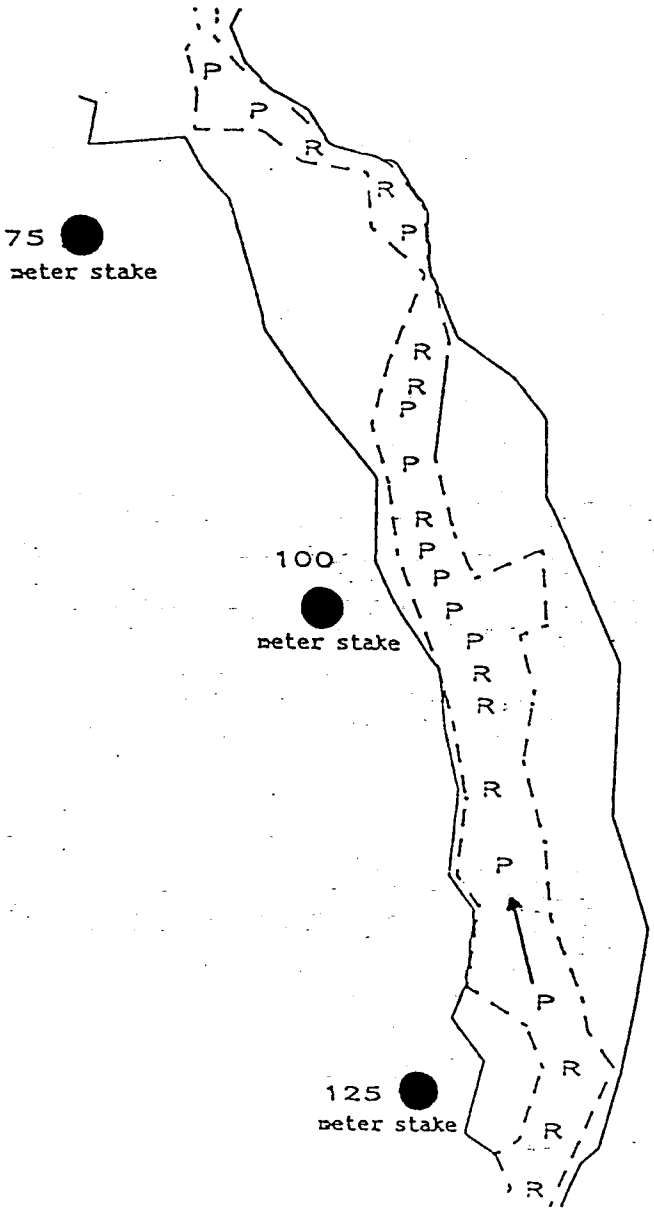

Figure 3. Planimetric view of study section 1, Bear Creek, previous to logging adjacent riparian and upland areas (from June, 1981).

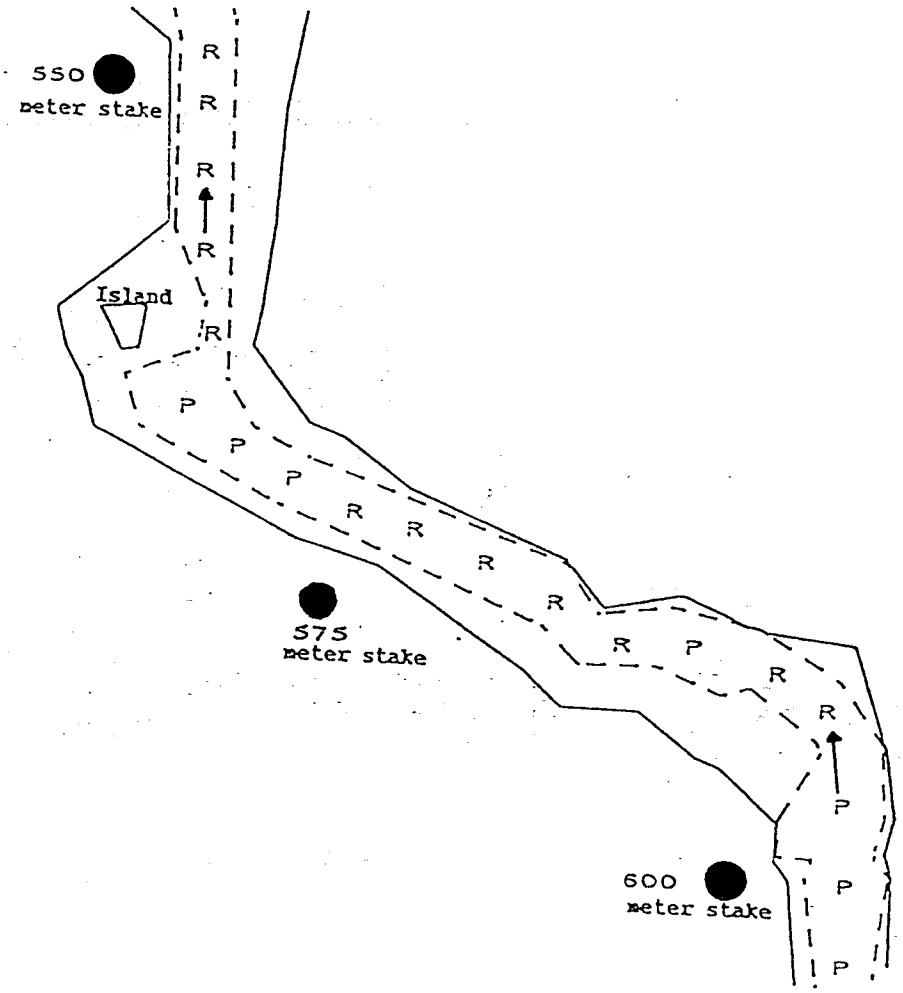

Figure 4. Planimetric view of study section 2, Bear Creek, previous to logging adjacent riparian and upland areas (from June, 1981).

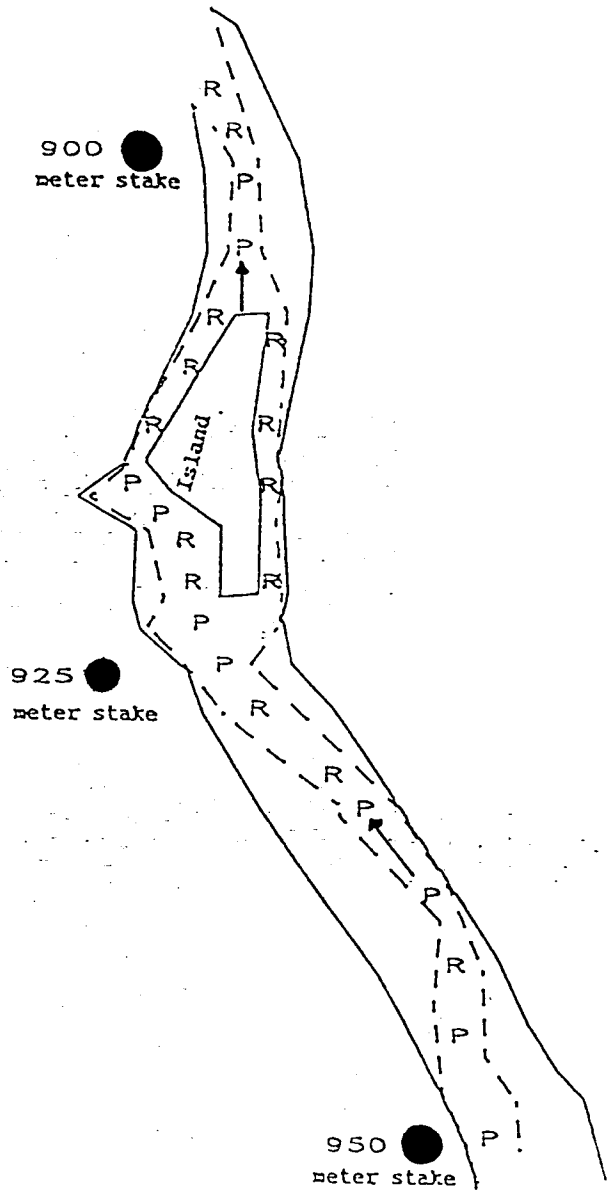

Figure 5. Planimetric view of study section 3, Bear Creek, previous to logging adjacent riparian and upland areas (from June, 1981).

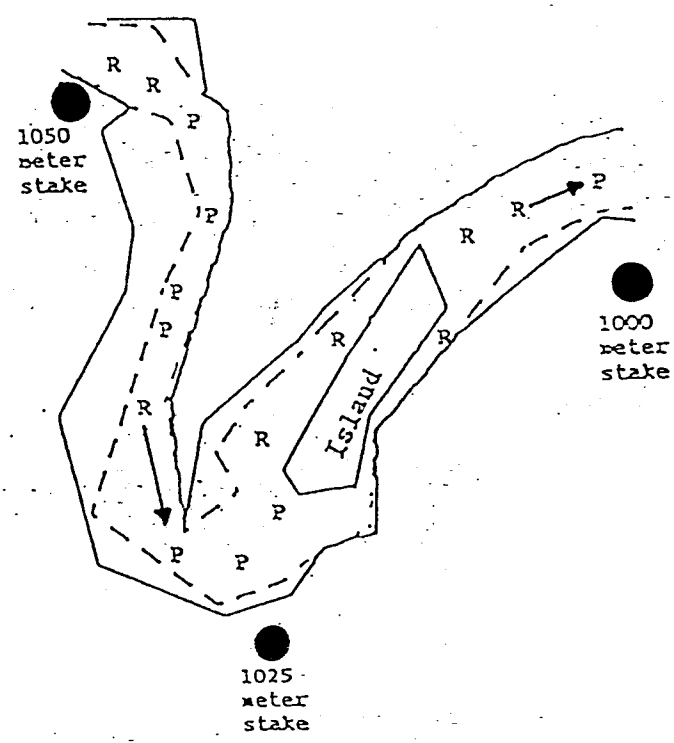

Figure 6. Planimetric view of study section 4, Bear Creek, within mature forest (from June, 1981).

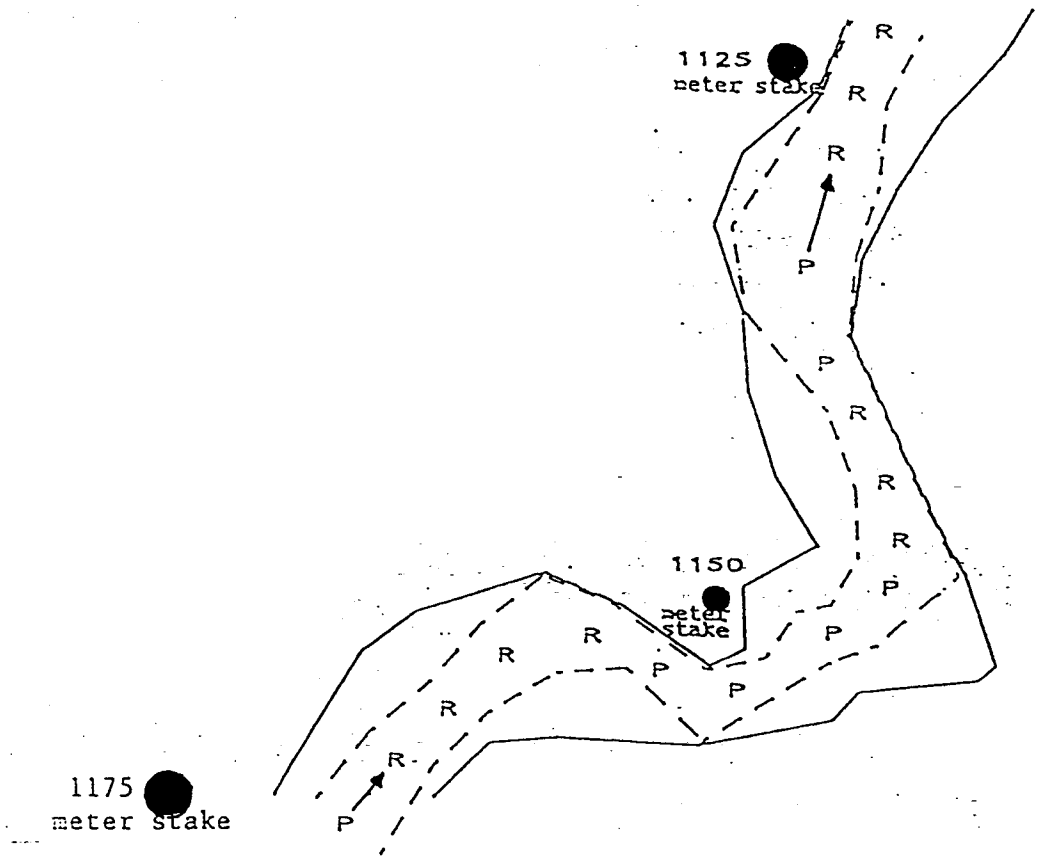

Figure 7. Planimetric view of study section 5, Bear Creek, within mature forest (from June, 1981).

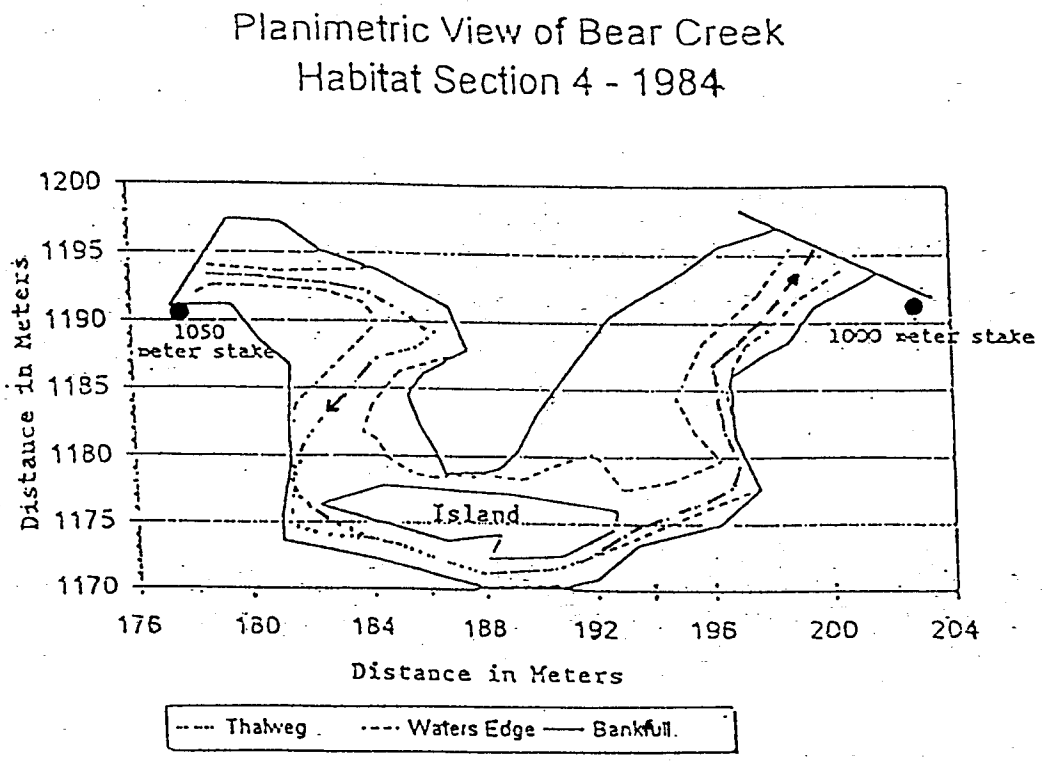

Figure 8. Planimetric view of study section 4, within mature forest, Bear Creek, 1984.

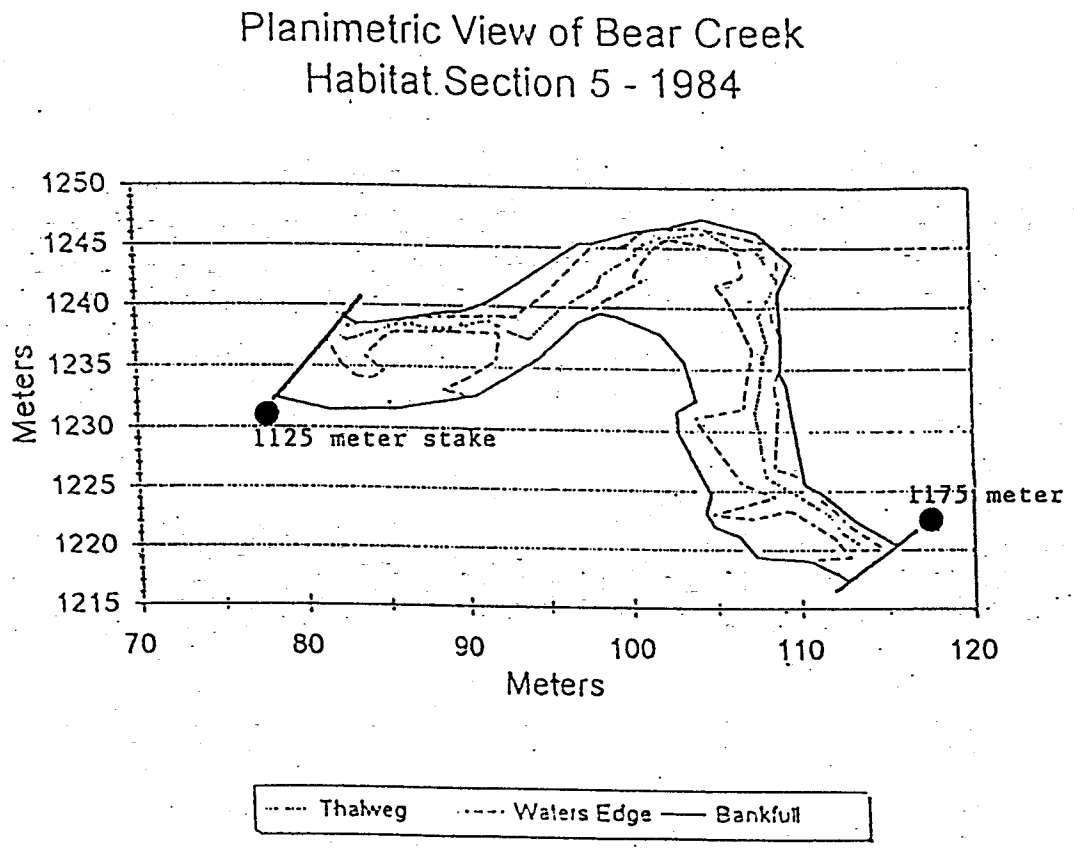

Figure 9. Planimetric view of study section 5 within mature forest, Bear Creek, 1984.

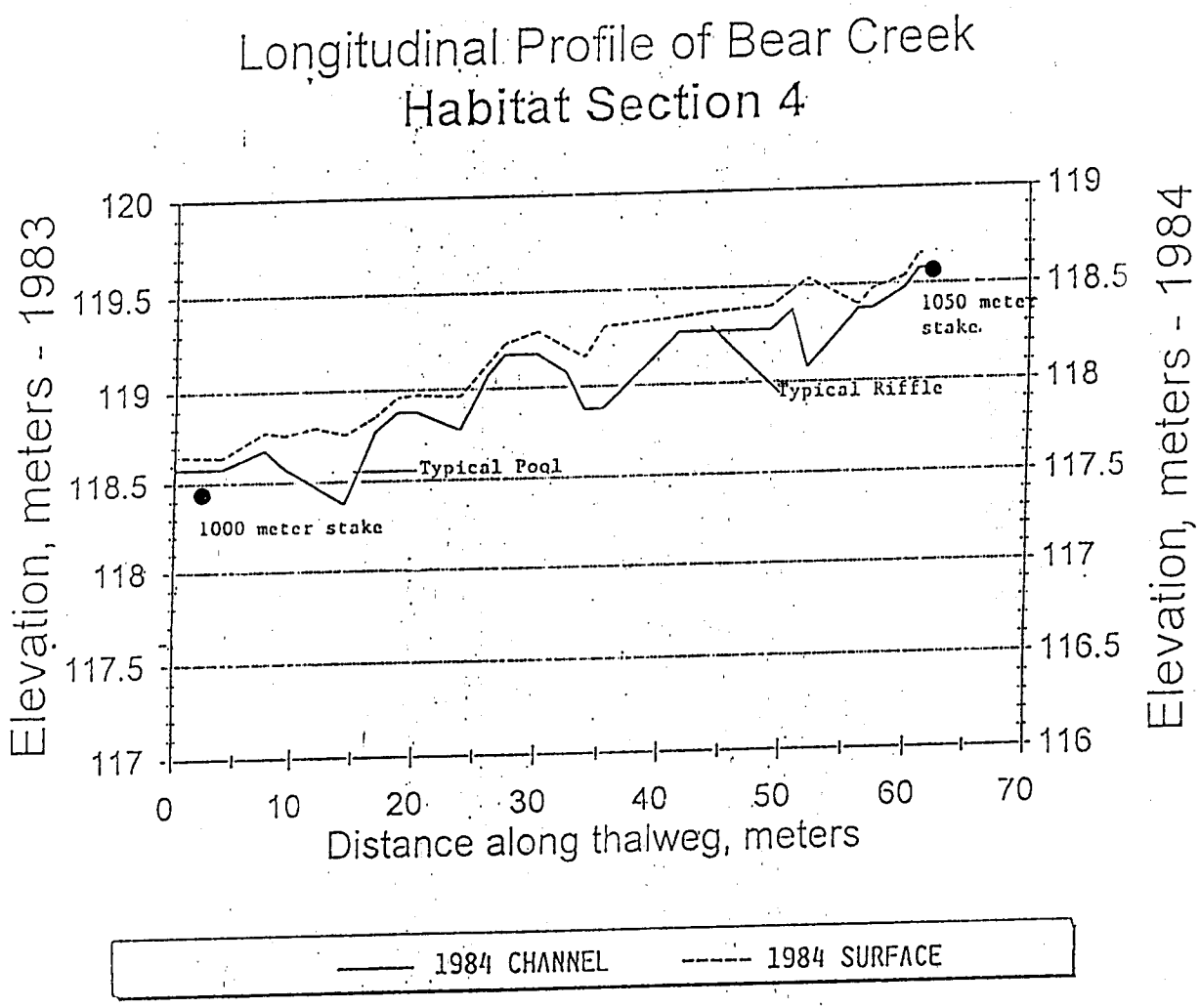

Figure 10. Longitudinal profile of study section 4 within mature forest, Bear Creek, 1984.

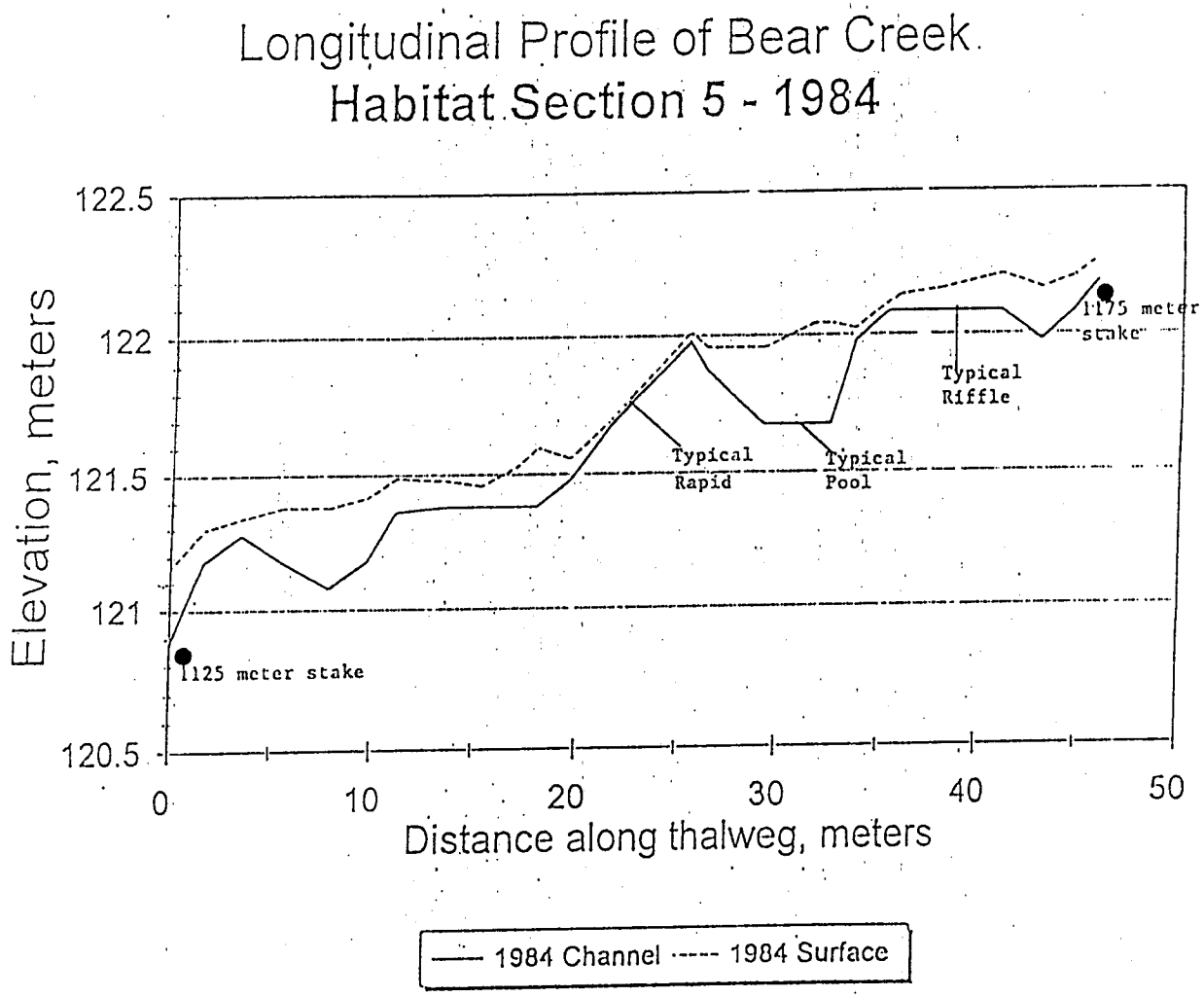

Figure 11. Longitudinal profile of study section 5 within mature forest, Bear Creek, 1984.

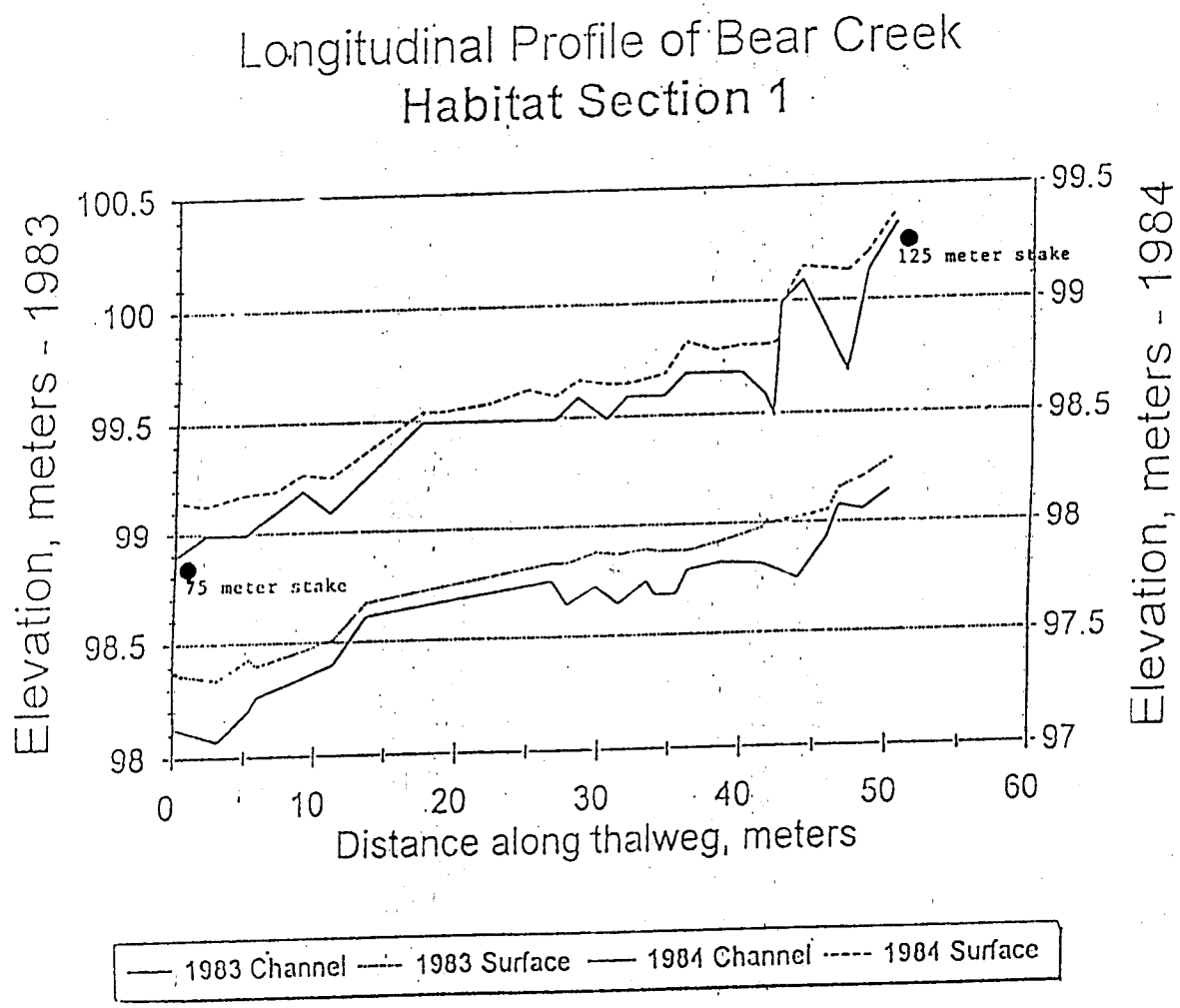

Figure 12. Longitudinal Profiles of study section 1 adjacent to logged riparian and upland areas, Bear Creek 1983 and 1984.

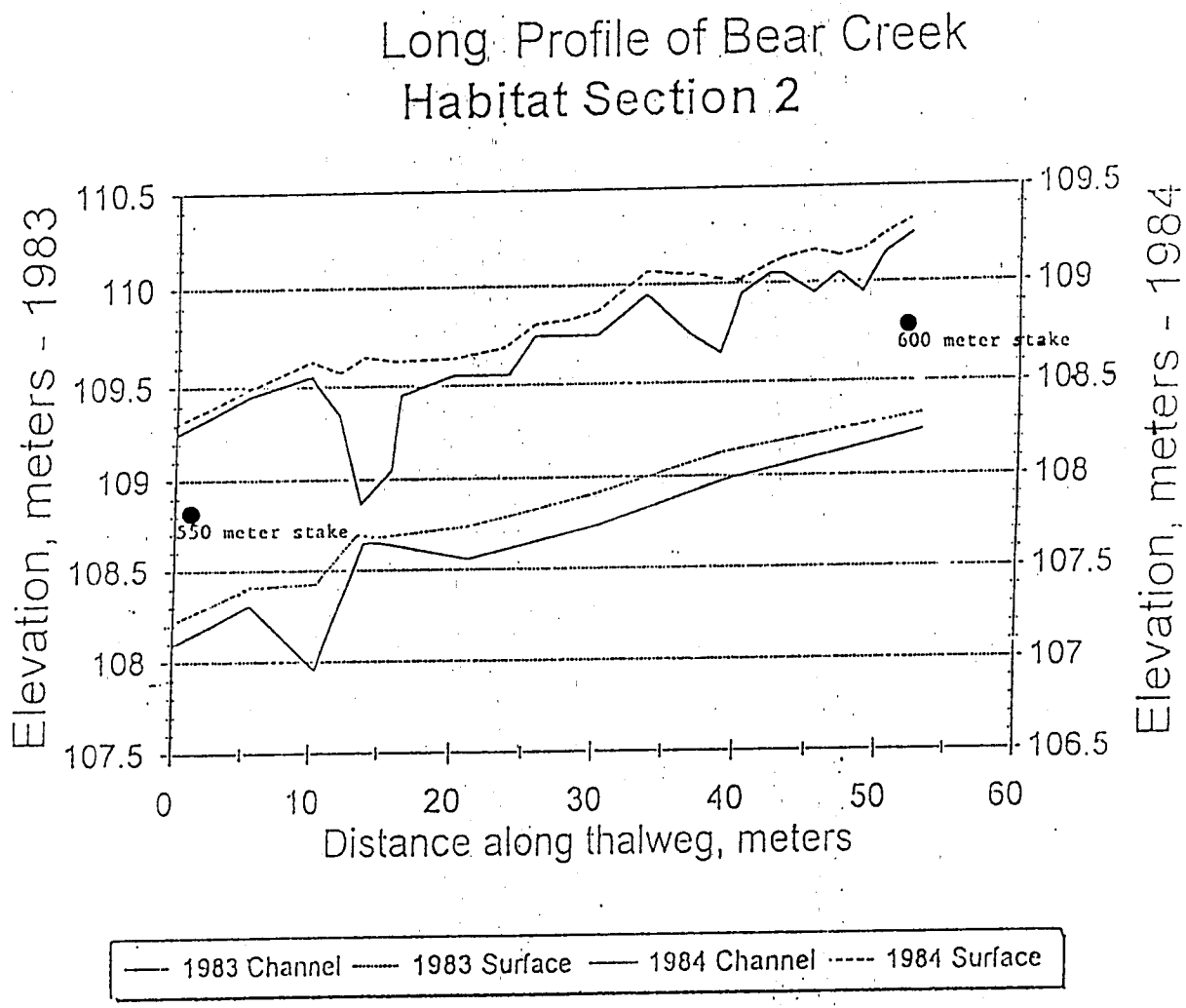

Figure 13. Longitudinal profiles of study section 2 adjacent to logged riparian and upland areas, Bear Creek 1983 and 1984.

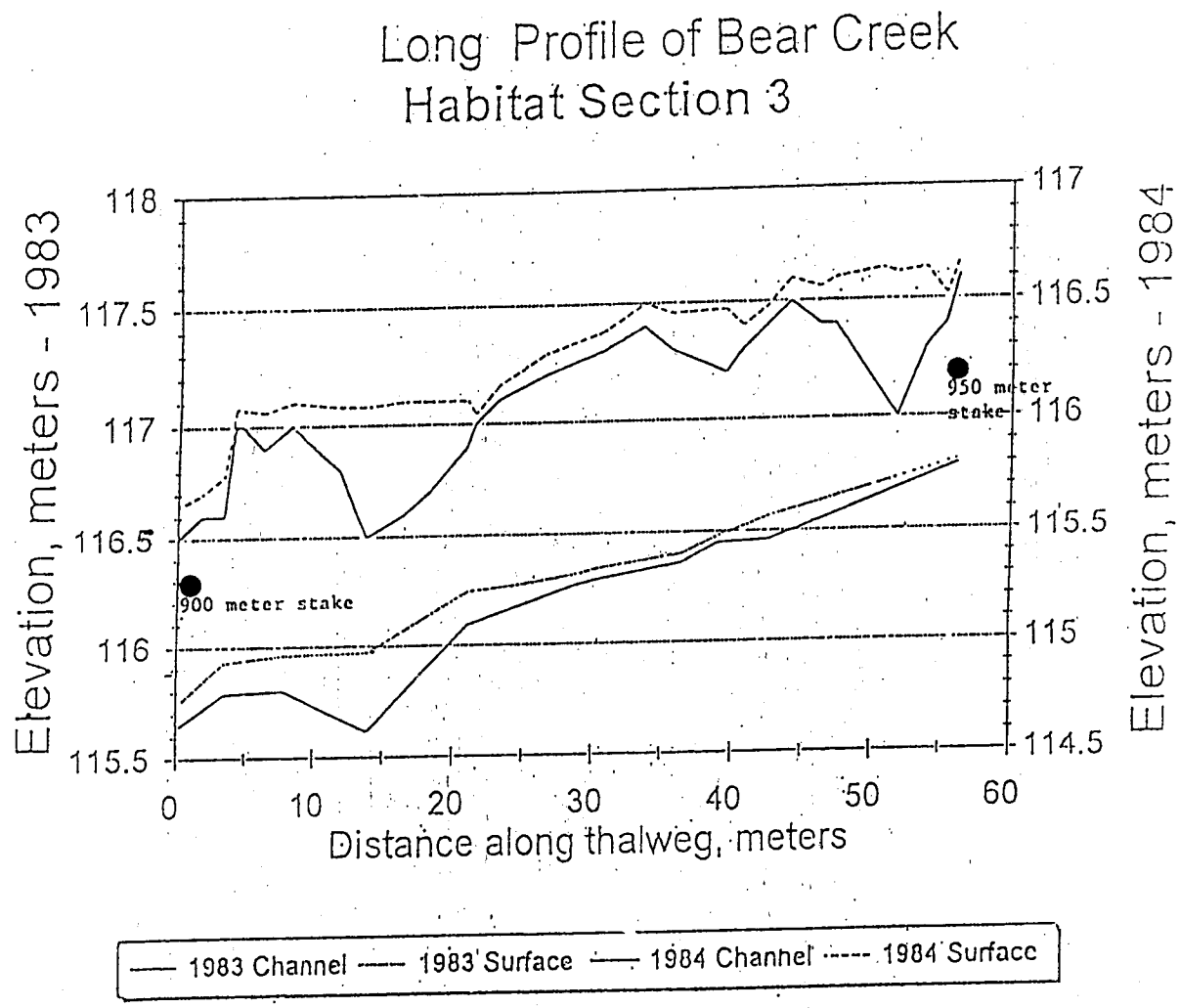

Figure 14. Longitudinal profiles of study section 3 adjacent to logged riparian and upland areas, Bear Creek 1983 and 1984.

to logged areas (treatment sections 1, 2, and 3) and within mature forest (control sections 4 and 5), are provided in Appendix C.

In 1984, irregular channel morphology representing successive pool and riffle habitats was apparent in stream sections adjacent to logged riparian and upland areas. Development of pool habitat, depicted by depressions in channel morphology with associated level or increasing water surface elevations, was prominent in stream sections 1, 2, and 3.

Scour and deposition processes characteristic of dynamic stream environments (evolving channel morphology) were evidenced in stream sections adjacent to logged areas and in sections within mature forest. Cross-sectional profiles of stream sections adjacent to logged areas in 1983 and 1984, and profiles of section 4 within mature forest in 1983 and 1984 and section 5 within mature forest in 1984, are provided in Appendix C.

Habitat

The number of pools per lineal foot of stream was a more dynamic quantity in stream sections adjacent to logging

than in control sections. For treatment sections, pool number decreased sharply until 1984, but then rebounded somewhat in 1985. The number of pools in Bear Creek sections adjacent to logged areas was substantially reduced four years after trees were felled. However, by the fifth year after logging, there was a measured increase in pools. Study section 1 had 5 pools in 1978 (Figure 3), 2 in 1983 and 5 in 1984 (Figure 12). Study section 2 had 3 pools in 1978 (Figure 4), 1 in 1983 and 3 in 1984 (Figure 13). Study section 3 had 5 pools in 1978 (Figure 5), 1 in 1983, and 3 in 1984 (Figure 14). Stream sections within mature forest had the same number of pools in 1984 as in 1978. For study section 4, pools numbered 4 in 1978 (Figure 6), and 4 in 1984 (Figure 10). For study section 5, pools numbered 3 in 1978 (Figure 7), and 3 in 1984 (Figure 11).

Pool habitat as a percentage of total stream surface area increased in all study sections (treatment and control) between 1978 and 1985 (Table 2). Trees downed in treatment and control sections by a storm in October 1981 was the apparent explanation for this increase in pool habitat. Trees falling into treatment sections were

Table 2. Percent pool and riffle area in Bear Creek study sections 1, 2 and 3 before logging (1978) and after logging (1985), and in study sections 4 and 5 within mature forest. 1978 data are from June 1981.

Study Sections	Year	% Riffle/Rapid	% Pool/Run	% Pool > .4 m depth	% Pool/Run .2-.4 m depth
Treatment Sections					
I	1978	63	37	7	30.0
	1985	61	39	0	39.4
II	1978	83	17	1	17.0
	1985	54	46	21.9	32.4
III	1978	93	7	1	7.0
	1985	45	55	0	45.9
Control Sections					
I	1978	76	24	7	17.0
	1985	64	36	3.5	32.8
II	1978	91	9	2	7.0
	1985	46	54	1.3	35.8

relatively small since larger riparian trees were absent after logging. Small to very large trees fell into the control sections. Pools comprised 46.3 percent by area of the total treatment sections adjacent to logged areas in 1985. Mean pool depth was 0.26 meters. Pools comprised 45.3 percent by area of the total control sections within mature forest, with a mean pool depth of 0.27 meters (Table 3).

Cover is any material or condition that provides protection from predators, competitors, or variations in streamflow (Boussu 1954, Lewis 1969). Logs associated with the streambank, woody debris, vegetation near the water surface, rubble, boulders, undercut banks, or water depth may all function as cover (Platts et al. 1983). Comparing mean cover in treatment and control sections (Table 4) each year (groups of two), mean percent stream surface area with instream cover for sections 1, 2, and 3 before logging, and the mean for sections 4 and 5 within mature forest (1978), were not significantly different (t-test, $p \geq .05$). Mean surface area with instream cover for sections 1, 2, and 3 before felled riparian trees were removed, and the mean for sections 4 and 5 within mature forest (1979) were not significantly different (t-test, $p \geq .05$).

Table 3. Percent area and volume (by total stream surface area and total stream volume) of pools, riffles, and rapids, and the mean depth of individual pools at low flow, in total treatment and control study sections of Bear Creek, January, 1985.

Total		% Pool		% Riffle		% Rapid		Mean Depth
Area	Volume	Area	Vol	Area	Vol	Area	Vol	Pool
TREATMENT SECTIONS I, II, AND III AFTER LOGGING TOTAL								
547.6	118.8	46.3	69.8	48.1	27.7	5.6	2.5	.26
STUDY SECTIONS IV AND V WITHIN MATURE FOREST TOTAL								
319.5	66.0	45.3	73.4	36.3	20.1	18.4	6.5	.27

Table 4. Percent stream surface area with cover from woody structure or debris, or from foliage within 1 meter of the water surface in Bear Creek study sections 1, 2, and 3 before logging (1978), before removal of felled timber (1979), and after logging (1985), and in study sections 4 and 5 within mature forest. 1978 data are from June 1981, and 1979 data are from Martin et al. 1981.

No.	Study Section	Percent Cover 1978	1979	1985
	TREATMENT STUDY SECTIONS			
1.	75 - 125 m	20	19	48
2.	550 - 600 m	18	17	68
3.	900 - 950 m	9	19	50
	CONTROL STUDY SECTIONS			
4.	1000 - 1050 m	24	23	83
5.	1125 - 1175 m	21	19	95

Increased instream cover in 1985 for all study sections (treatment and control) is consistent with increased pool habitat found for all study sections, and is attributable to downed trees in the stream channel from a 1981 storm event. Study sections adjacent to logged areas however, had less instream cover compared to study sections within mature forest. Mean percent stream surface area with instream cover for sections 1, 2, and 3 after completion of logging (1985) was significantly different compared to sections 4 and 5 within mature forest (t-test, $p \geq .05$). For sections 1, 2, and 3 four years after completion of logging in adjacent areas, mean surface area with instream cover was only 55.3 percent compared to 89.0 percent for sections within mature forest. Cover was associated with only 48.2 percent of the total pool volume of the treatment sections compared to 65.3 percent of the total pool volume of the control sections (Table 5). For riffle habitat, 10.7 percent of the total riffle volume in the treatment sections had cover compared to 58.3 percent of total riffle volume in the control sections.

Spawning Substrate

Stream substrate was sampled in treatment and control study sections during a low-flow period (August 1983).

Table 5. Habitat composition, and the percentage of each habitat component associated with different cover structures in treatment (subsequent to logging in adjacent riparian and upland areas) and control study sections of Bear Creek during a low-flow period, January, 1985.

Habitat Category	Subcategory	% of stream reach Area	Vol	Total Volume cubic meters	Mean Depth meters	% vol. assoc. with cover structure
TREATMENT SECTIONS I, II AND III TOTAL						
Pool Total		46.1	70.0	82.4	.26	48.2
	lateral scour	27.6	38.8	45.6	.27	30.2
	plunge	10.2	22.0	25.9	.39	100.0
	dammed	6.0	7.5	8.9	.21	0.0
	trench	1.7	1.5	1.8	.18	0.0
	backwater	0.6	0.4	0.5	.15	0.0
CONTROL SECTIONS IV AND V TOTAL						
Pool Total		45.4	73.4	48.4	.29	65.3
	lateral scour	30.3	41.1	27.1	.22	83.7
	dammed	12.8	30.4	20.0	.49	100.0
	backwater	2.3	1.9	1.3	.17	32.4
TREATMENT SECTIONS I, II AND III TOTAL						
Riffle Total		53.9	30.0	35.9	.09	10.7
	low gradient	28.7	16.9	20.1	.12	19.1
	high gradient	19.4	10.8	12.9	.08	0.0
	rapid	5.8	2.5	2.9	.09	0.0
CONTROL SECTIONS IV AND V TOTAL						
Riffle Total		54.6	26.6	17.6	.08	58.3
	low gradient	36.3	20.1	13.3	.10	77.2
	rapid	18.4	6.5	4.3	.06	0.0

Fine materials in spawning substrates provide a measure of sedimentation or siltation that can affect salmonid incubation and emergence from the gravel. Percent fine materials (<0.85 mm) in treatment study sections was not significantly different (t-test, $p \geq .05$) compared to percent fines in control sections. For treatment sections, fine materials comprised 18.22 percent of all substrates sampled compared to 17.78 percent of the substrates from control sections (Table 6).

Stream Discharge and Surface Area

Stream discharge measured during a typical low-flow period (October, 1983) was 5.24 cubic feet per second (cfs) at the downstream boundary (0 meter stake) of the treatment study reach, and 3.84 cfs at the downstream boundary (1000 meter stake) of the control reach (Table 7). Surface areas under low-flow conditions were 517.30 square meters for total treatment sections (the sum of sections 1, 2 and 3), and 307.75 square meters for control sections 4 and 5 (Table 8).

Salmonid Production

Early in the study it became apparent that plans to evaluate whether logging affected cutthroat trout

Table 6. Mean percent composition of stream bottom substrate sampled at potential spawning sites in treatment (stream reaches adjacent to logging) and control (stream reaches within mature forest) study sections of Bear Creek, August, 1983.

No. of Samples	Substrate Percent Composition (mm) >26.9	>3.35	>0.85	>0.106	<0.106	<0.85
			TREATMENT			
12	41.80	30.54	9.44	9.09	9.13	18.22
			CONTROL			
6	46.82	27.14	8.27	10.10	7.58	17.78

Table 7. Bear Creek discharge for treatment and control study sections during a low-flow period, October 22, 1983.

Study Reach	Discharge in Cubic Feet Per Second
Treatment	5.24
Control	3.84

Table 8. Surface areas for Bear Creek during a low-flow period, October 13, 1983.

	Stream Reach	Square Meters
Study Section I	0 - 100	301.85
	75 - 125	179.00
	100 - 200	324.75
	200 - 300	397.90
	300 - 400	351.00
	400 - 500	377.50
	500 - 600	401.10
Study Section II	550 - 600	221.85
	600 - 700	402.50
	700 - 800	392.85
	800 - 900	263.00
Study Section III	900 - 950	116.50
	900 - 1000	240.50
	Treatment Sections Together	517.30
	Total Treatment	3452.95
Study Section IV	1000 - 1050	138.75
	1000 - 1100	266.75
Study Section V	1125 - 1175	169.00
	1100 - 1200	314.00
	Control Sections Together	307.75
	Control Reach Total	888.50
	Study Reach Total	4341.50

production in Bear Creek had been compromised by the introduction of juvenile coho salmon (see ecology section for details).

As was expected, juvenile coho salmon dominated all samples from Bear Creek in 1983, comprising 84.5 percent of all fish collected in July, and 83.0 percent of the fish collected in September (Table 9). Coho salmon densities in 1983 far exceeded cutthroat trout density in Bear Creek. In late September-early October 1983, coho salmon densities were 0.65 fish per square meter (Table 10) for total treatment sections after logging, and 0.31 for total control sections. For April 1984, population estimates were only available for control sections and coho density (total for control sections) declined to 0.12 fish per square meter.

Cutthroat trout abundance, density, and biomass for all age classes, was estimated for stream sections adjacent to logged areas, and for sections within mature forest in 1983 and 1984 (Table 11). Cutthroat trout density averaged over the treatment study sections was not significantly different from the average of the control sections (t-test, $p \geq .05$) in 1983 or 1984.

Table 9. Total cutthroat trout and coho salmon collected in single samples, from stream sections 1, 2 and 3 adjacent to logged riparian and upland areas (designated treatment), and from stream sections 4 and 5 within mature forest (designated control), Bear Creek 1983.

Study Sections	Cutthroat Trout		Coho Salmon	
	July	September	July	September
Treatment	236	253	1370	1216
Control	35	31	108	167

Table 10. Coho salmon population estimates, 95 percent confidence limits for populations, and densities for study sections 1, 2 and 3 after logging in adjacent areas, for sections 4 and 5 within mature forest, and for treatment section totals and for control section totals in Bear Creek, September/October 1983, and April 1984.

Study Section	Population Estimate	Fish/m²
	1983	
I	101.25 ± 45.18	0.33
II	125.18 ± 32.14	0.56
III	122.21 ± 19.60	1.04
IV	45.80 ± 9.19	0.33
V	52.56 ± 10.68	0.31
Total for Treatment Sections	337.28 ± 47.66	0.65
Total for Control Sections	94.57 ± 12.11	0.31
	1984	
I	N/A	N/A
II	N/A	N/A
III	N/A	N/A
IV	17.50 ± 12.93	0.13
V	15.75 ± 10.29	0.09
Total for Treatment Sections	N/A	N/A
Total for Control Sections	36.00 ± 19.82	0.12

Table 11. Cutthroat trout population estimates, 95 percent confidence limits for populations, densities, and biomass for study sections 1, 2, and 3 after logging in adjacent areas, for sections 4 and 5 within mature forest, and for treatment section totals and control section totals in Bear Creek, September/October 1983 and April 1984.

Study Section	Population Estimate	fish/m²	g/m²
		1983	
I	38.33 ± 23.75	0.21	1.06
II	20.57 ± 9.20	0.09	1.69
III	29.25 ± 14.24	0.25	2.46
IV	10.50 ± 4.49	0.07	1.20
V	16.00 ± 9.91	0.09	1.33
Total for Treatment Sections	94.87 ± 32.36	0.18	1.88
Total for Control Sections	24.88 ± 10.19	0.08	1.20
		1984	
I	32.00 ± 31.36	0.17	1.54
II	N/A	N/A	N/A
III	16.66 ± 15.77	0.14	2.08
IV	25.00 ± 30.99	0.18	3.56
V	24.75 ± 17.30	0.14	2.71
Total for Treatment Sections	51.00 ± 39.09	0.17	1.92
Total for Control Sections	48.75 ± 36.59	0.15	3.00

Similarly, average cutthroat trout biomass in treatment sections was not significantly different (t-test, $p \geq .05$) from that of control sections in 1983 or 1984.

Cutthroat trout in Bear Creek were aged based on the length frequency distribution of fish sampled during September and October, 1983 (Figure 15), and previous scale analysis (from June 1981). Mean lengths and weights by age class for cutthroat in the treatment reach after logging and the control reach during fall 1983 and spring 1984 are provided in Tables 12 and 13. Mean length of age 0 cutthroat was significantly less after logging (1983 measurements) (t-test, $p \geq .05$) in the treatment reach (71.71 mm) compared to the control reach (75.33 mm). Greater mean weight of age 0 cutthroat in the control reach (4.43 grams) compared to age 0 cutthroat in the treatment reach (3.92 grams) was not significant (t-test, $p \geq .05$). Age 1 cutthroat mean length and mean weight (1983 measurements) were significantly greater in the treatment reach after logging compared to the control reach (t-test, $p \geq .05$). Mean length and weight for age 2 cutthroat in the treatment reach and the control reach in 1983 were not significantly different (t-test, $p \geq .05$).

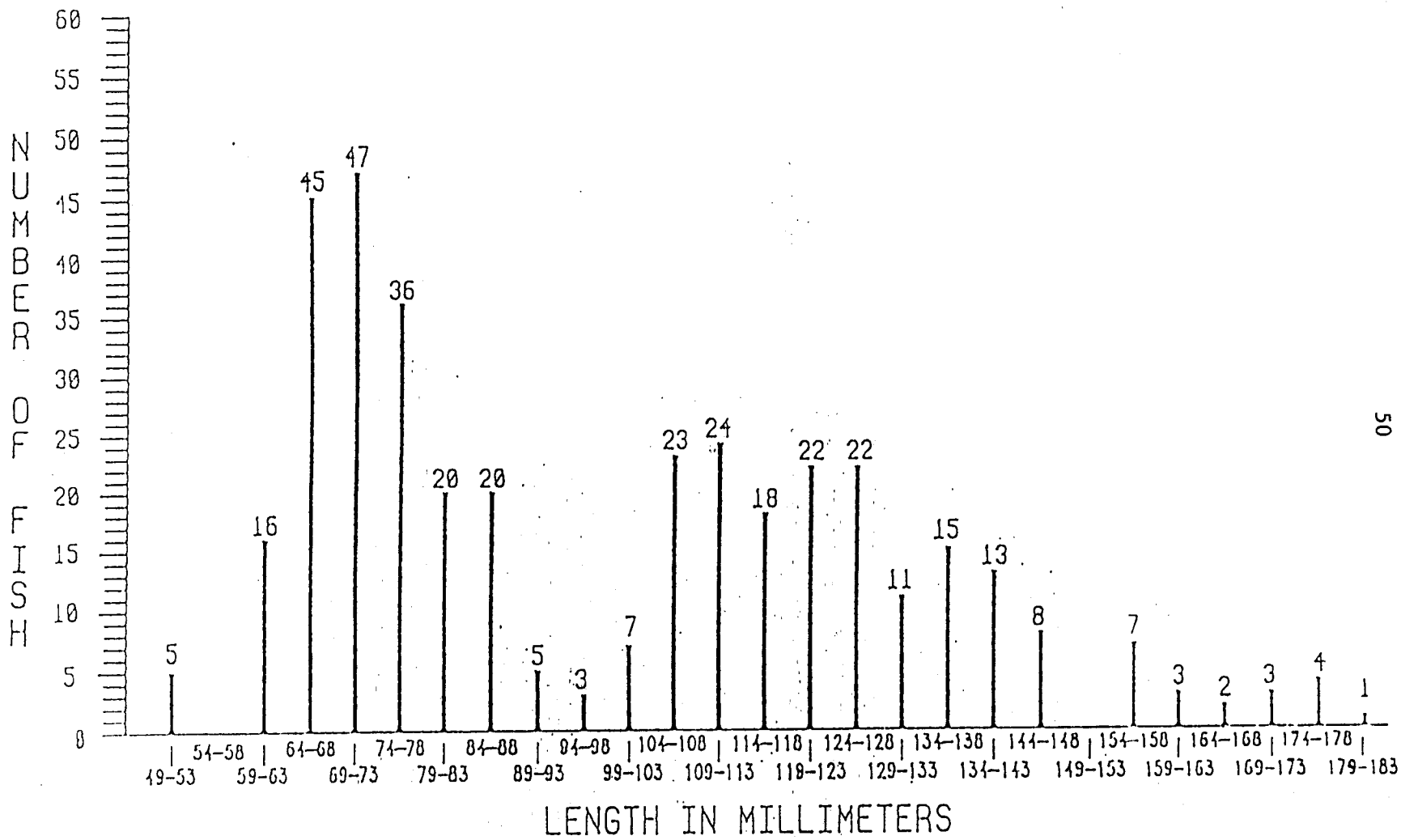

Figure 15. Length frequency distibution of cutthroat trout in Bear Creek, September 27 - October 3, 1983.

Table 12. Mean length (in millimeters) by year class for cutthroat trout in stream sections adjacent to logged areas (designated treatment study reach), and in stream sections within mature forest (designated control study reach), Bear Creek 1983 and 1984. Age class in parentheses, sample size n.

Sample Date	Year Class 1980	1981	1982	1983	1984
		TREATMENT STUDY REACH			
Sept/Oct 1983	III 178.63 n=18	II 140.15 n=47	I 115.03 n=101	0+ 71.71 n=177	
April 1984		III N/A	II 139.00 n=4	I 102.92 n=13	0+ 72.63 n=11
		CONTROL STUDY REACH			
Sept/Oct 1983	III N/A	II 141.50 n=8	I 110.57 n=19	0+ 75.33 n=12	
April 1984		III 182.00 n=2	II 144.50 n=2	I 104.96 n=27	0+ 75.42 n=7

Table 13. Mean weight (in grams) by year class for cutthroat trout in stream sections adjacent to logged areas (designated treatment study reach), and in stream sections within mature forest (designated control study reach), Bear Creek 1983 and 1984. Age class in parentheses, sample size n.

Sample Date	Year Class 1980	1981	1982	1983	1984
	TREATMENT STUDY REACH				
Sept/Oct 1983	III 58.16 n=18	II 25.14 n=47	I 13.95 n=101	0+ 3.92 n=177	
April 1984		III N/A	II 27.17 n=4	I 11.20 n=11	0+ 5.30 n=11
	CONTROL STUDY REACH				
Sept/Oct 1983	III N/A	II 27.35 n=8	I 12.38 n=21	0+ 4.43 n=12	
April 1984		III 63.50 n=2	II 26.70 n=2	I 12.46 n=27	0+ 4.89 n=7

Cutthroat trout mean densities, weights, and biomass in treatment sections previous to logging, in treatment sections after logging, and in control sections are presented in Table 14. The mean density (total for all age classes) of cutthroat trout in treatment stream sections before logging (1977/78), and in treatment sections after logging (1983/84), was not significantly different (t-test, $p \geq .05$).

Table 14. Mean densities, weights, and biomass for cutthroat trout in Bear Creek stream sections 1, 2, and 3 before logging (1977/78), and after logging (1983/84), and in stream sections 4 and 5 within mature forest. Sampling occurred in July and September 1977, April, July, and October 1978, September and October 1983, and April 1984.

		AGE O+			AGE 1			AGE 2 & 3			TOTAL		
STUDY SEC.	YEARS	FISH/ M^2	G/FISH	G/M^2	FISH/ M^2	G/FISH	G/M^2	FISH/ M^2	G/FISH	G/M^2	FISH/ M_2	G/FISH	G/M^2
TREATMENT STUDY SECTION													
1	1977/78	0.107	1.95	0.207	0.067	9.95	0.646	0.017	33.60	0.528	0.192	7.20	1.380
	1983/84	0.127	4.75	0.580	0.025	10.25	0.251	0.321	24.65	0.558	0.199	7.35	1.703
2	1977/78	0.105	2.60	0.260	0.084	9.95	0.808	0.018	25.80	0.484	0.208	8.10	1.556
	1983/84	0.013	5.00	0.067	0.048	13.50	0.657	0.033	32.20	1.01	0.092	18.30	1.707
3	1977/78	0.149	2.05	0.217	0.165	8.75	0.790	0.009	24.80	0.247	0.252	5.45	1.326
	1983/84	0.102	3.70	0.488	0.068	13.20	0.906	0.034	42.40	1.455	0.197	13.27	2.54
CONTROL STUDY SECTIONS													
4	1977/78	0.099	2.15	0.206	0.072	9.60	0.698	0.013	47.05	0.685	0.185	8.45	1.590
	1983/84	0.007	3.70	0.026	0.079	14.25	1.25	0.030	29.45	0.897	0.127	17.80	2.387
5	1977/78	0.110	2.70	0.285	0.127	8.00	1.00	0.019	22.90	0.433	0.255	6.80	1.721
	1983/84	0.021	4.60	0.101	0.082	12.30	0.979	0.023	40.40	1.00	0.112	16.05	1.842

Chapter 4: Discussion

Headwater streams in coastal areas of the Pacific Northwest are important salmonid spawning and nursery areas (Burns 1971, Edie 1975). These streams are generally characterized by diverse channel gradient and water depth representing a succession of pool and riffle habitats (Figure 16). Maintenance of this diversity and habitat order within dynamic environments is another important characteristic of headwater streams. Headwater streams within mature riparian forest typically feature well developed channels and stable banks, fluctuating gradient, and a diversity of complex habitats.

Previous to logging, Bear Creek was representative of a typical headwater stream and supported resident and anadromous cutthroat trout. Habitats utilized by cutthroat trout in Bear Creek were similar to habitats preferred by cutthroat trout elsewhere (Wickham 1967, Everest 1969, Griffith 1972, Bovee 1978). Initial studies (June 1981) quantified habitat in Bear Creek and described cutthroat trout production and habitat preferences previous to logging. Subsequent work evaluated the response of cutthroat trout to elimination of the riparian canopy but before felled trees were removed (Martin 1985).

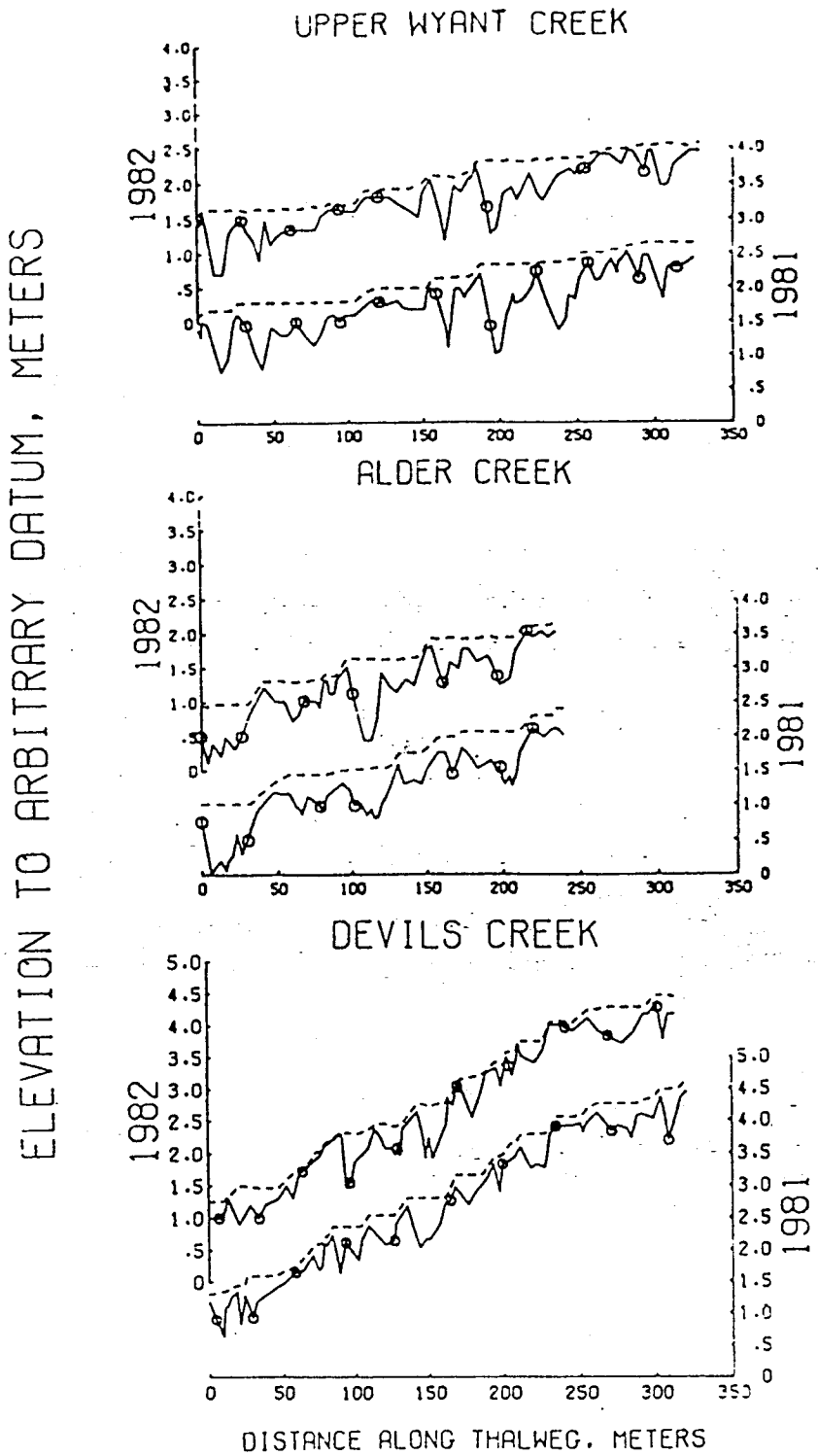

Figure 16. Logitudinal profiles of Lower Columbia River tributary streams within climax riparian communities, (from Jones and Salo, 1986).

Investigating cutthroat trout production in Bear Creek in relation to physical disturbances associated with logging initially was a primary objective of this study. Bear Creek investigations were conceived and systematically undertaken with the intent to isolate any effects on cutthroat trout and their supporting habitats resulting first from felling mature riparian forest, and second from actual removal of those trees. Unfortunately, an unpredicted planting of coho salmon fry occurred during my study, which impeded the ability to evaluate such potential effects on cutthroat trout. Potential competitive interactions between cutthroat and recently introduced juvenile coho salmon could not be accounted for. Under these circumstances, further assessment of cutthroat trout production was minimized and study instead focused on evaluation of stream features and processes important for cutthroat trout.

Stream channel morphology is determined by erosion and deposition processes. Vegetation and instream structure from riparian areas affect the magnitude and duration of these processes, and thus represent an important element in stream channel development and stability. Lestelle (1978) found that habitat stability, bed configuration,

and the degree of deposition and erosion appeared to be related to the abundance and type of debris structure within the stream channel. Mackin (1948) concluded that reduced instream structure resulted in greater bedload movement upsetting any equilibria between pools and riffles. Large organic debris (LOD) recruited from riparian areas thus provides increased aquatic habitat diversity and cover structure, and contributes to streambank and channel stability.

The abundance and distribution of cover structure is also known to be a potential limiting factor in salmonid production (Needham et al. 1945, Hartman 1965, Chapman 1966, Everest 1969, Giger 1973). Juvenile salmonid distribution and survival is closely associated with the presence of woody structure (Bisson and Nielsen 1983). Cover structure in the form of solitary LOD, complex debris matrices, or woody materials imbedded into the streambank provides refuge for fish during low-flow periods and sanctuary from excessive water velocities during high discharge events. Bustard and Narver (1975), June (1981), and Tschaplinski and Hartman (1983) also concluded that cover structure provided important winter habitat for cutthroat trout.

Permanence of instream cover structure depends primarily on its size. Larger materials resist being dislodged by higher flows and persist longer before decomposition results in their failure. Stable cover structure and the development of habitats preferred by salmonid fishes depends on such materials (Lestelle 1978). Habitat recovery and increased cover in streams adjacent to logged areas depends on the regeneration rate of riparian trees. This is especially true where the delivery of LOD from upstream areas is limited.

Logging of riparian trees and removal of other vegetation can reduce stream bank resistance to erosion and recruitment to the stream channel of woody structure, both important factors in stream channel development and configuration. Reduced abundance, stability, and complexity of cover structure in headwater streams can also directly affect the production of cutthroat trout and other salmonid fishes. Murphy and Hall (1981) and Bisson and Sedell (1985) attributed the loss of large woody structure and changes in channel morphology and characteristic habitat, including reductions in pools, to logging. Reductions in instream cover are known to cause declines in the abundance of cutthroat trout (Narver 1972,

Moring and Lantz 1975). Changes in habitat composition and habitat utilization by cutthroat trout have been attributed to reduced LOD from logging (Murphy and Hall 1981) and may contribute to population declines. Instream cover structure has been found to have a significant effect on salmonid population abundance and overwinter mortality. Reduced densities of juvenile salmonids during winter periods was attributed by Murphy et al. (1984) to the absence of LOD in logged streams. Martin et al. (1984) found a positive correlation between the area of cover structure and salmonid spring population abundance, and a negative correlation between area of cover structure and overwinter mortality. Based on these results, Martin et al. (1984) concluded that the rate of recovery of salmonid populations in tributaries of the Toutle River having little cover structure, may have been limited by the rate of recovery of mature riparian vegetation and the rate of recruitment of LOD.

Riverine habitats crucial to the production of cutthroat trout were adversely affected by logging in riparian and upland areas adjacent to Bear Creek. Cover abundance, complex channel morphology, and habitat diversity typical of Bear Creek and other headwater streams within mature

forest were reduced in stream sections adjacent to logged riparian and upland areas.

There was no significant difference in cover abundance between treatment and control study sections before logging. However, cover abundance in treatment sections was significantly less after logging compared to control sections. Logged riparian areas retained few trees of substantial size. Instream cover recruited from these areas is vulnerable to displacement by high flows, and is likely to decompose before larger structure in control sections recruited from adjacent mature forest. Until riparian trees grow large enough to provide a source of stable instream structure, cover abundance will likely decline in stream sections adjacent to logged riparian areas.

Bear Creek study sections adjacent to logged riparian and upland areas exhibited reduced habitat diversity compared to study sections within mature forest. Shifting channel character or unstable channel morphology was also evident in study sections adjacent to logging. In 1983, four years after riparian trees were felled, channel morphology

was very even with little change in elevation denoting pool and riffle habitats. Headwater streams without significant riparian vegetation following the eruption of Mount St. Helens (Martin et al. 1984) exhibited channel morphology and water surface elevations similar to Bear Creek treatment sections in 1983 (Figure 17).

When stream sections adjacent to logged riparian and upland areas were surveyed in 1984, substantial changes in channel morphology were apparent. Increased channel diversity was particularly evident in sections 2 and 3, including notable pool development, an important factor in cutthroat trout production (Griffith 1972, June 1981). These rather impressive changes may be a consequence of the numerous trees downed in the channel by a previous storm event of unusual intensity. Keller and Swanson (1979) concluded that woody debris large enough to resist displacement by high stream flows and rapid deterioration was important in structuring channel morphology. Treatment study section channel development in 1984 may be a temporary condition considering the size of woody structure entering the channel, and the absence of large riparian trees representing a future source of stream structure.

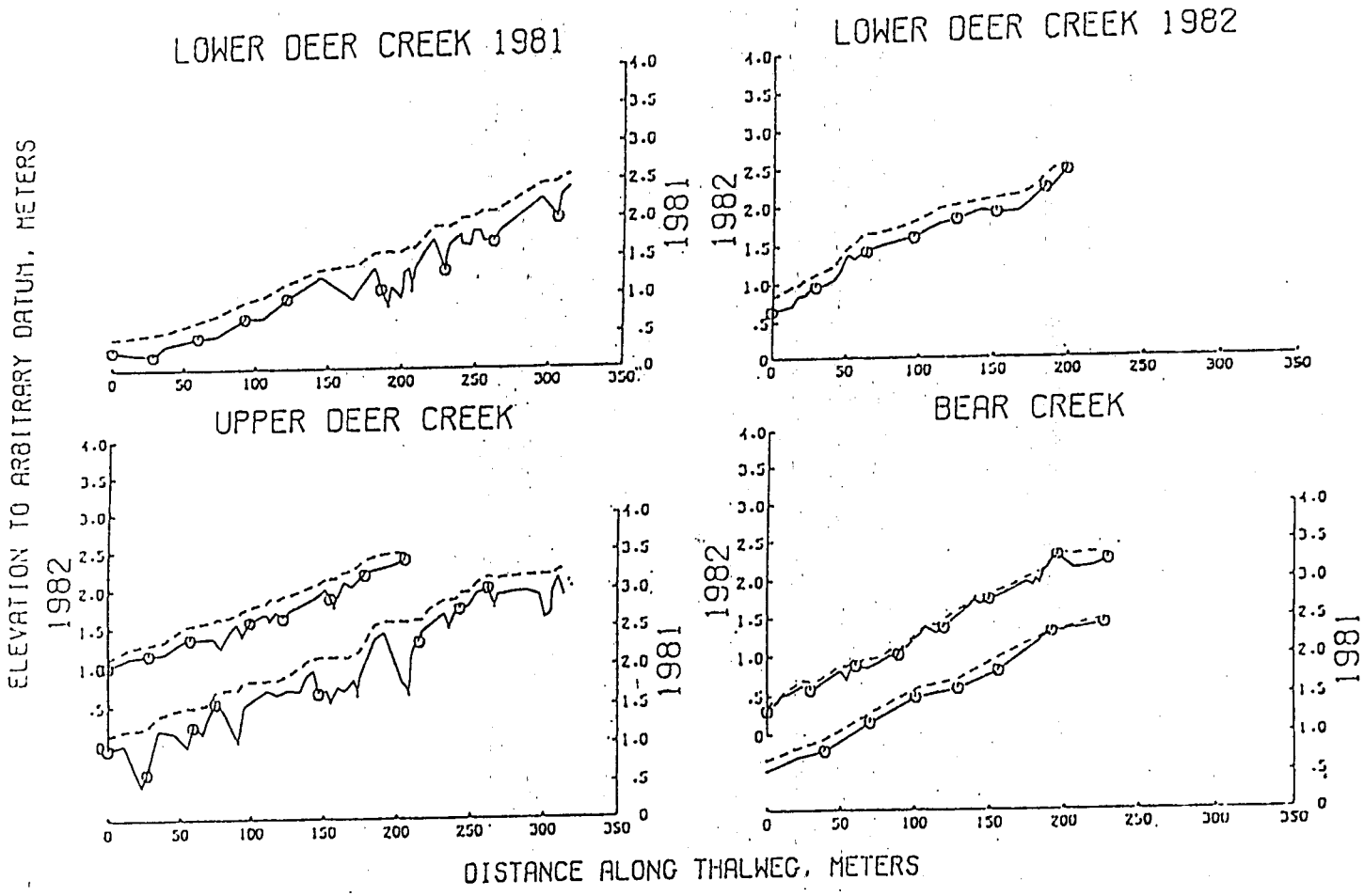

Figure 17. Longitudinal profiles of stream thalweg for Lower Columbia River tributaries without significant riparian vegetation following the eruption of Mount St. Helens. Circles denote approximate location of channel cross-sections. Dashed line is water surface.

The Endangered Species Committee of the American Fisheries Society has identified 214 stocks of anadromous salmon and trouts in Washington, Oregon, Idaho, and California at high or moderate risk of extinction or that have declined to numbers of special concern. All stocks of anadromous coastal cutthroat are recognized as being at some risk of extinction (Trotter et al. 1993). The degradation or loss of freshwater habitats is the most common contributing factor in these declines, and timber harvest and associated activities is identified as a primary action affecting these habitats (Nehlsen et al. 1991).

The threat of further declines and extinctions of many plants and animals has prompted unprecedented efforts to develop land management guidelines that preserve the ecosystems upon which these populations depend, including riverine and associated riparian environments. Careful monitoring and evaluation must accompany implementation of resulting forest practices to determine their effectiveness and whether refinement is required to accomplish the necessary habitat protection.

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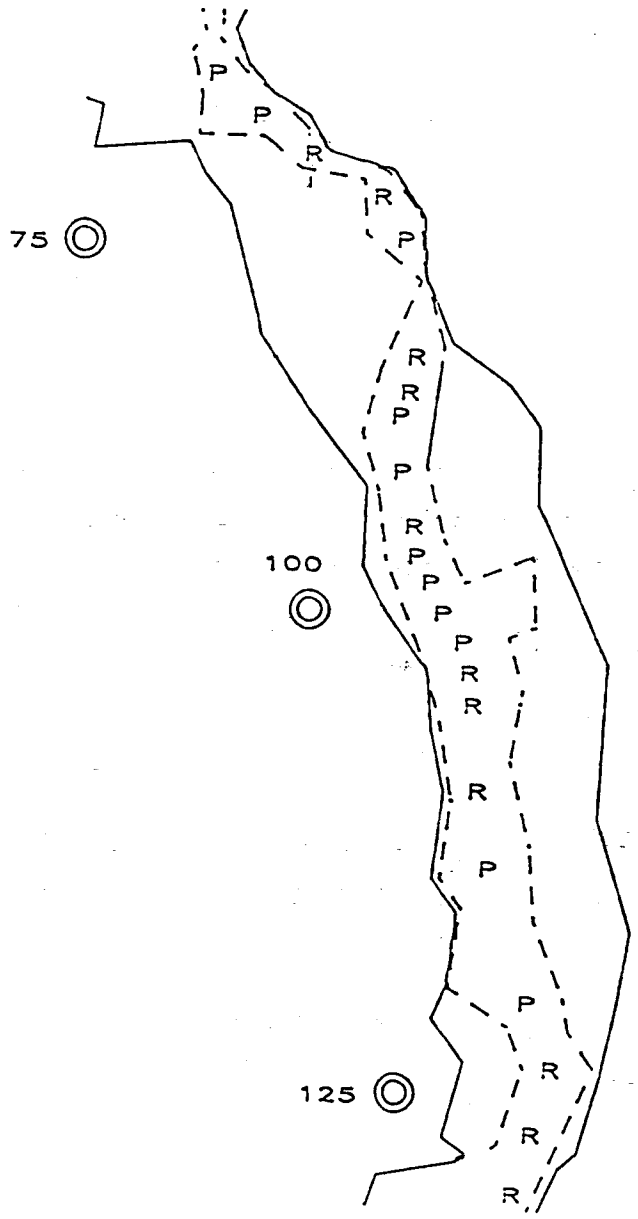
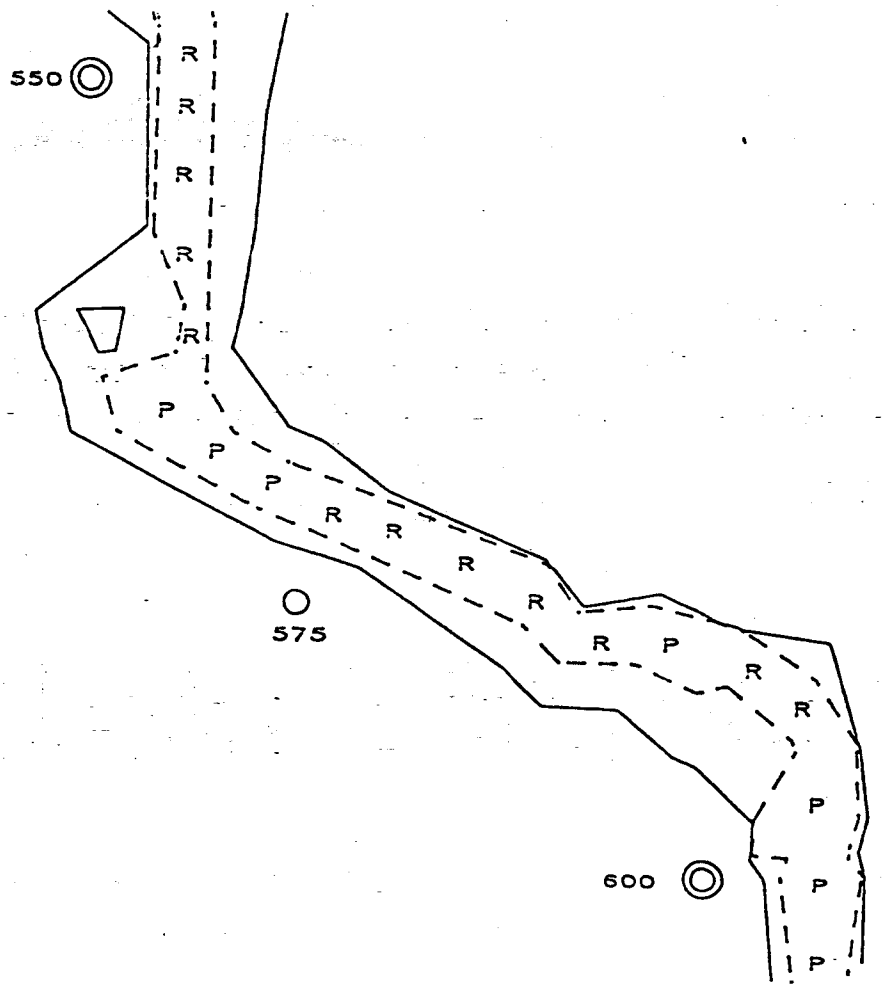


Appendix A. Planimetric view of Bear Creek previous to any logging activities (plotted from June 1981 data).



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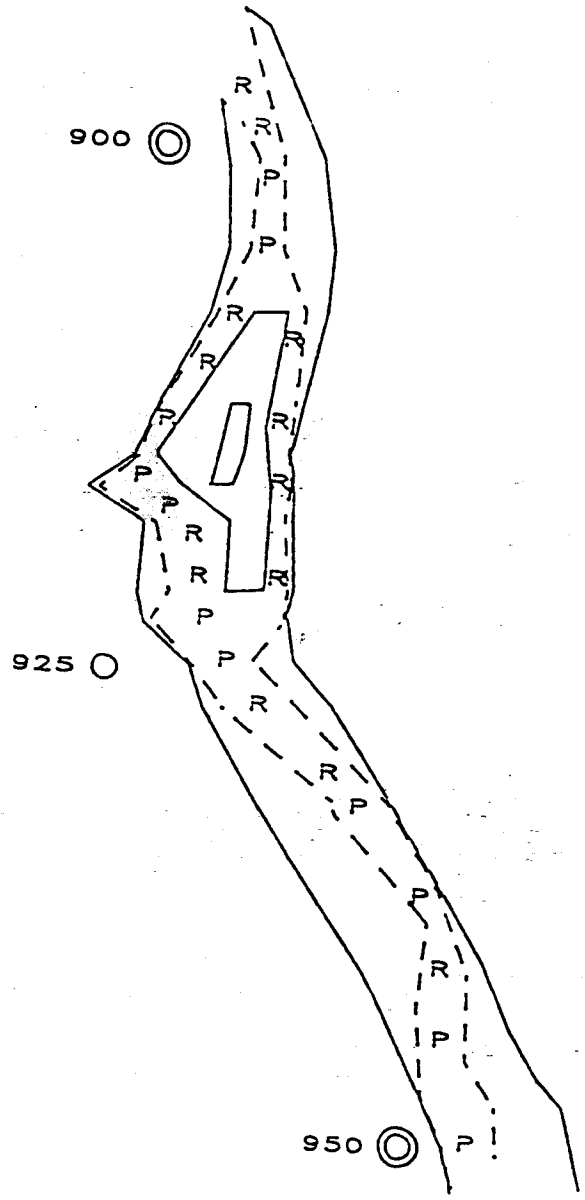

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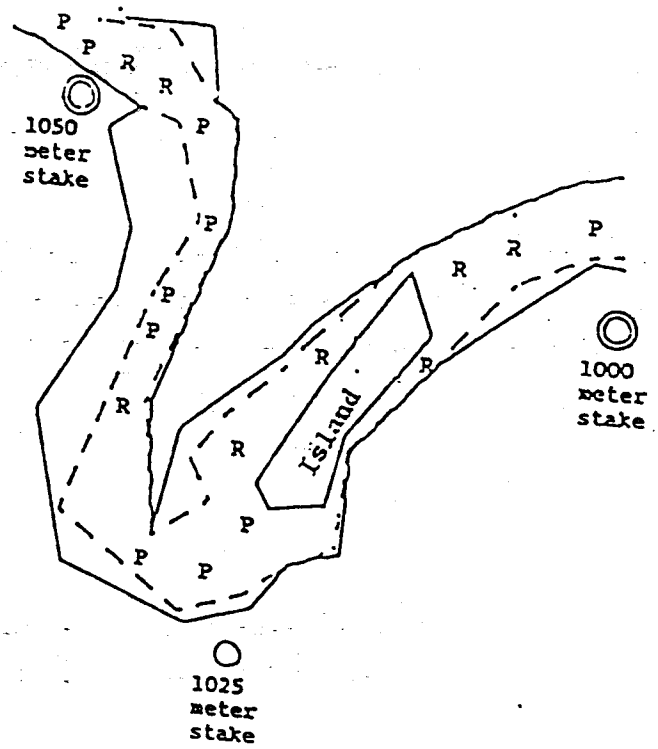

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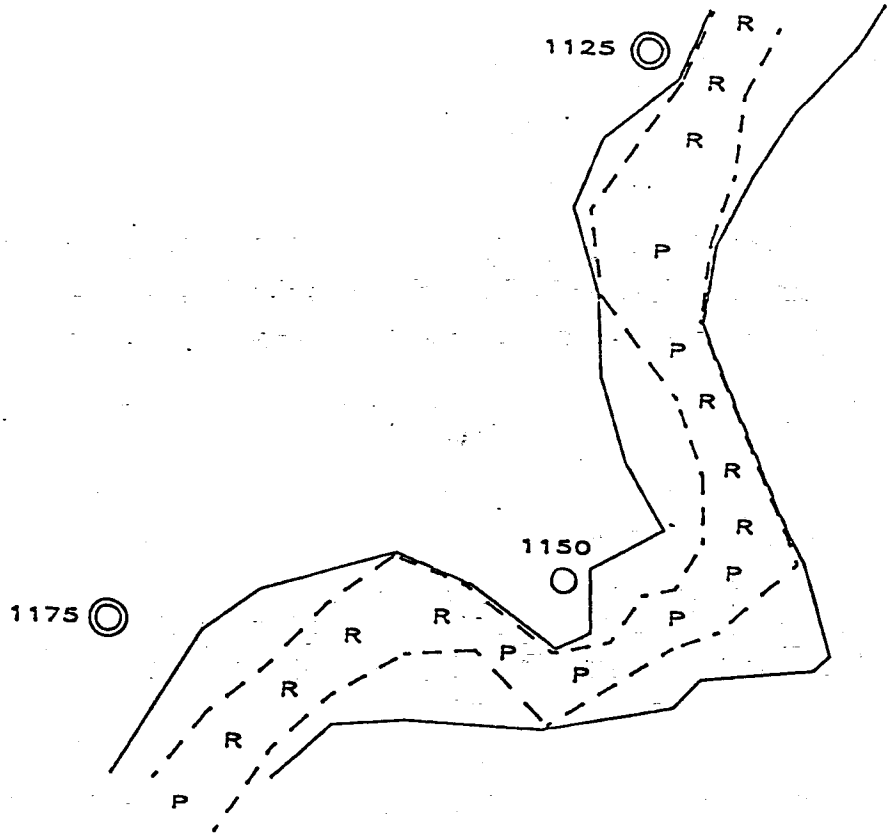
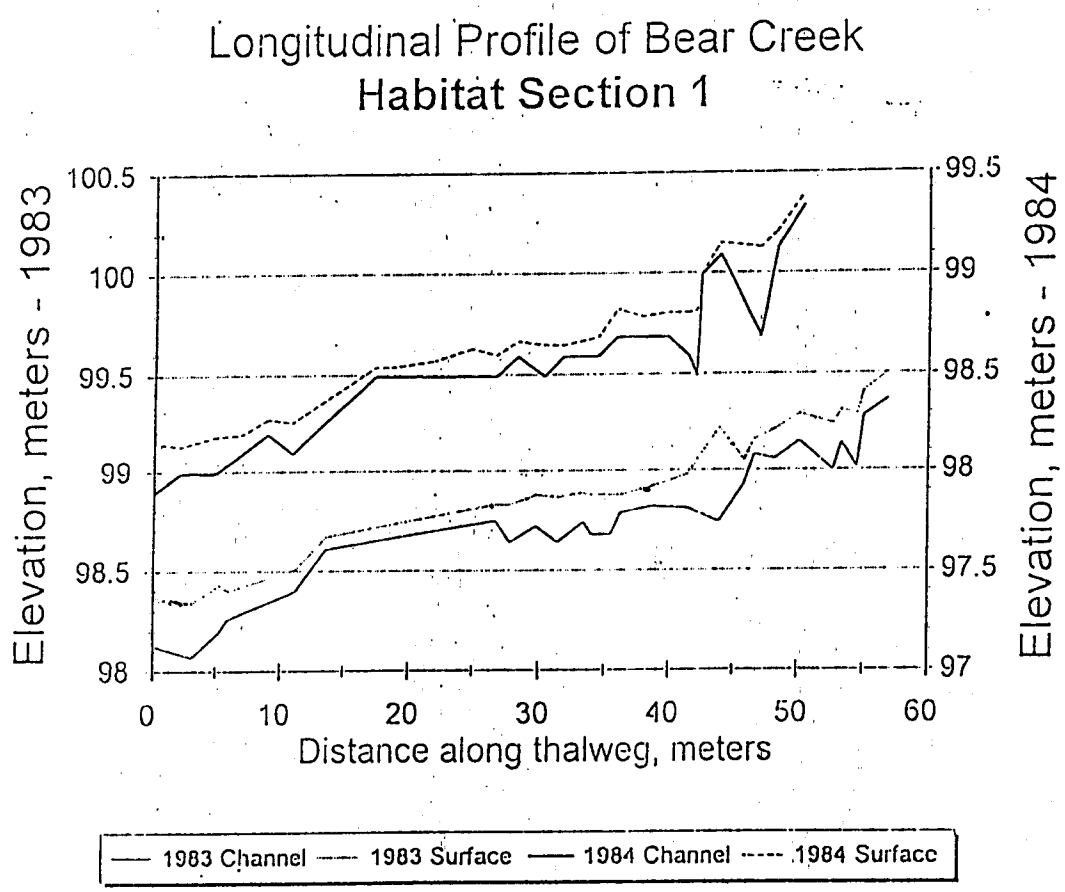


Appendix A. (Continued)

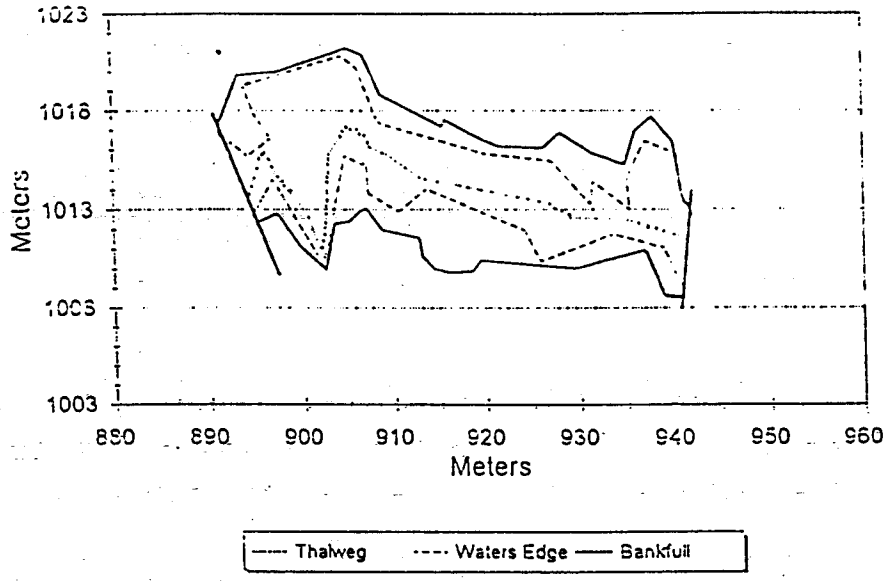
Appendix B. Definition of habitat components utilized to assess the geomorphology, flow characteristics and existing cover and substrate in second to fifth order streams in the Pacific Northwest (Bisson et al. 1981)

Habitat component	Description
POOLS	Characterized by deeper low velocity waters. Velocity is the decisive parameter.
1. Lateral scour	Lateral scour results from current deflection by instream structures. Often associated with large organic debris, undercut banks and channel curvature.
2. Plunge pools	Flow passes over a single obstruction which may span the entire channel. Water drops vertically creating a depression.
3. Trench pools	Slots formed in stable channel. Often associated with bedrock and quite long.
4. Dammed pools	Impounded water upstream from channel blockages. Often associated with debris jams and considerable depth.
5. Backwater pools	Also known as eddies, occurring behind large obstructions such as rootwads or boulders. Usually found along channel margins.
6. Secondary channel pools	During low flow periods such pools exist only in braided channels. Generally possess only a small portion of available instream flow.
RIFFLES	Characterized by shallow, medium to high velocity waters.
1. Low gradient riffles	Include shallow waters of moderate velocity with some surface turbulence. Gradient does not exceed four percent.
2. Rapids	Gradient exceeds four percent resulting in high velocities. Rocks or boulders often protrude above the water surface producing considerable turbulence.
3. Cascades	Consist of a series of stepped rapids punctuated by small pools formed by large rocks or boulders.
GLIDES	Characterized by moderate current velocity and uniform depth lacking any pronounced turbulence over a gravel or cobble substrate.

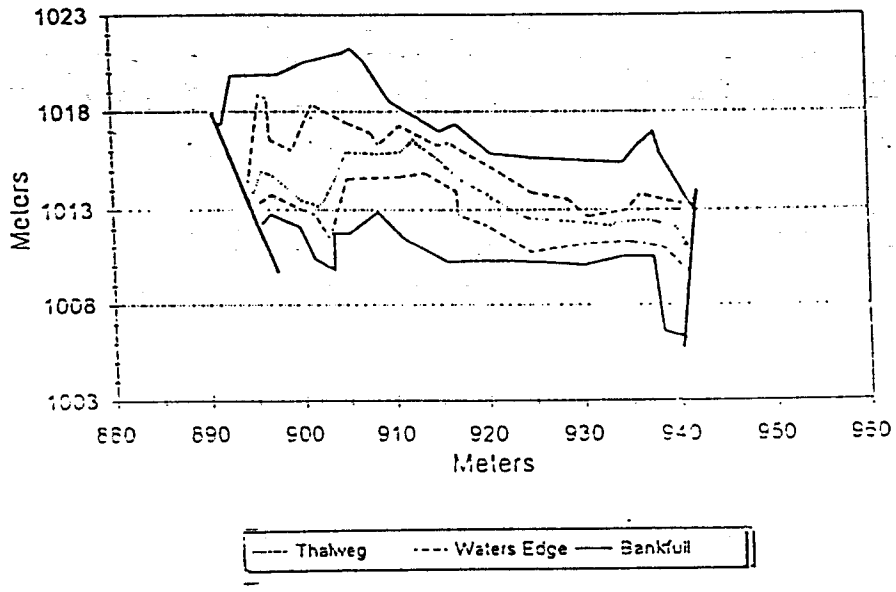


Appendix C. Longitudinal, planimetric, and cross-sectional profiles of stream reaches adjacent to logged areas (treatment study sections 1, 2, and 3), and stream reaches within mature riparian forests (control study sections 4 and 5), Bear Creek, Washington 1983 and 1984.

Planimetric View of Bear Creek
Habitat Section 1 - 1983



Planimetric View of Bear Creek
Habitat Section 1 - 1984



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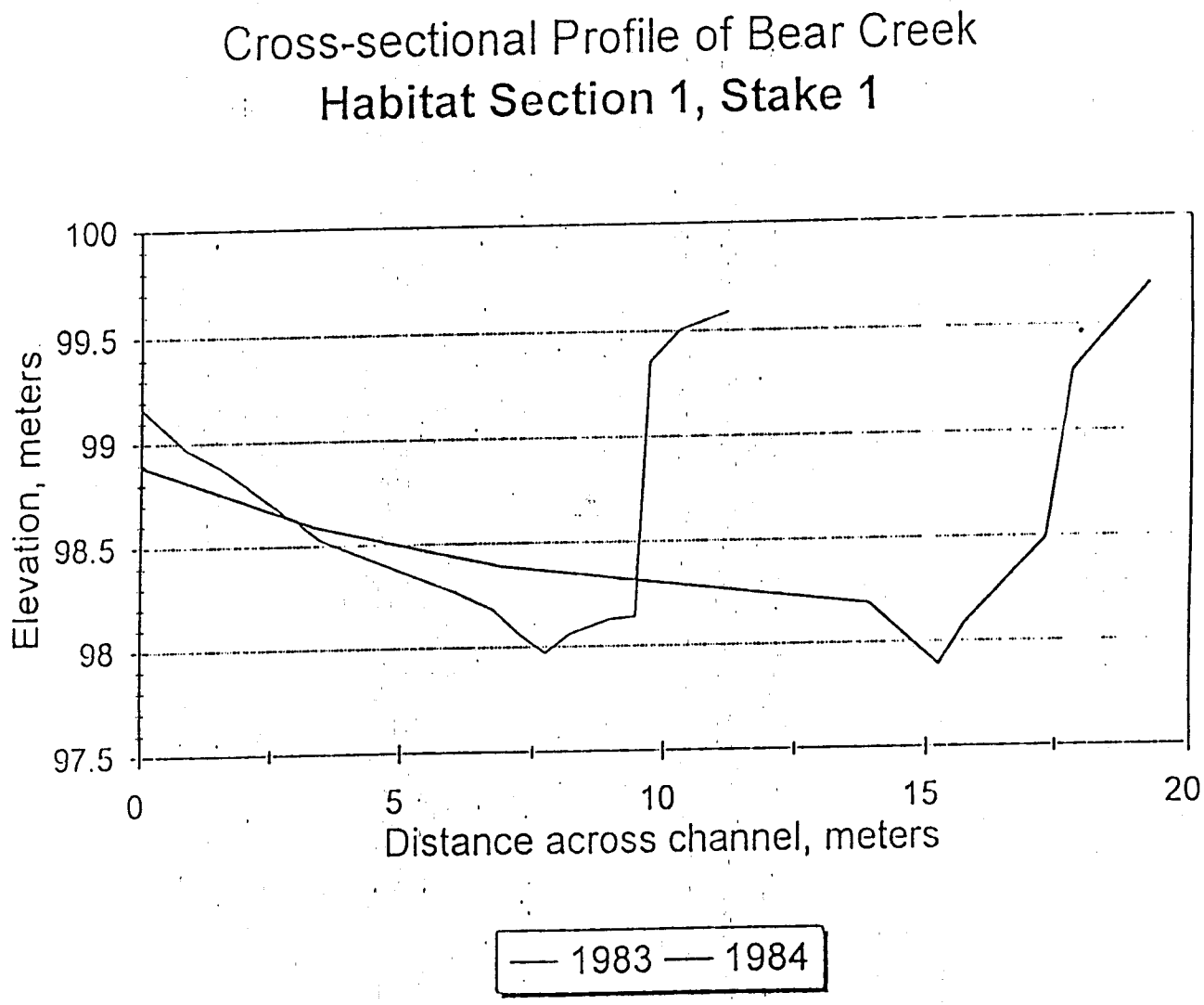

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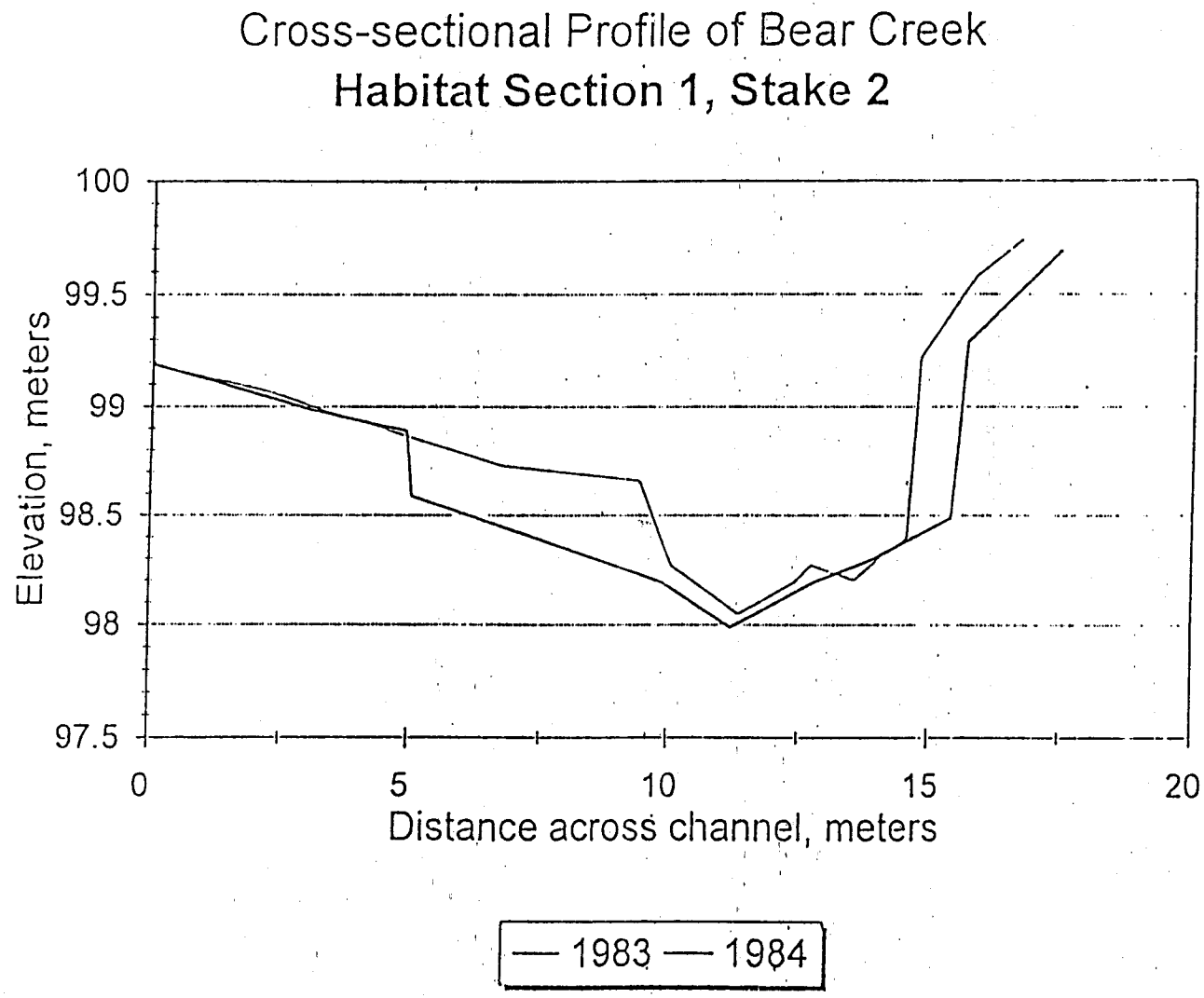

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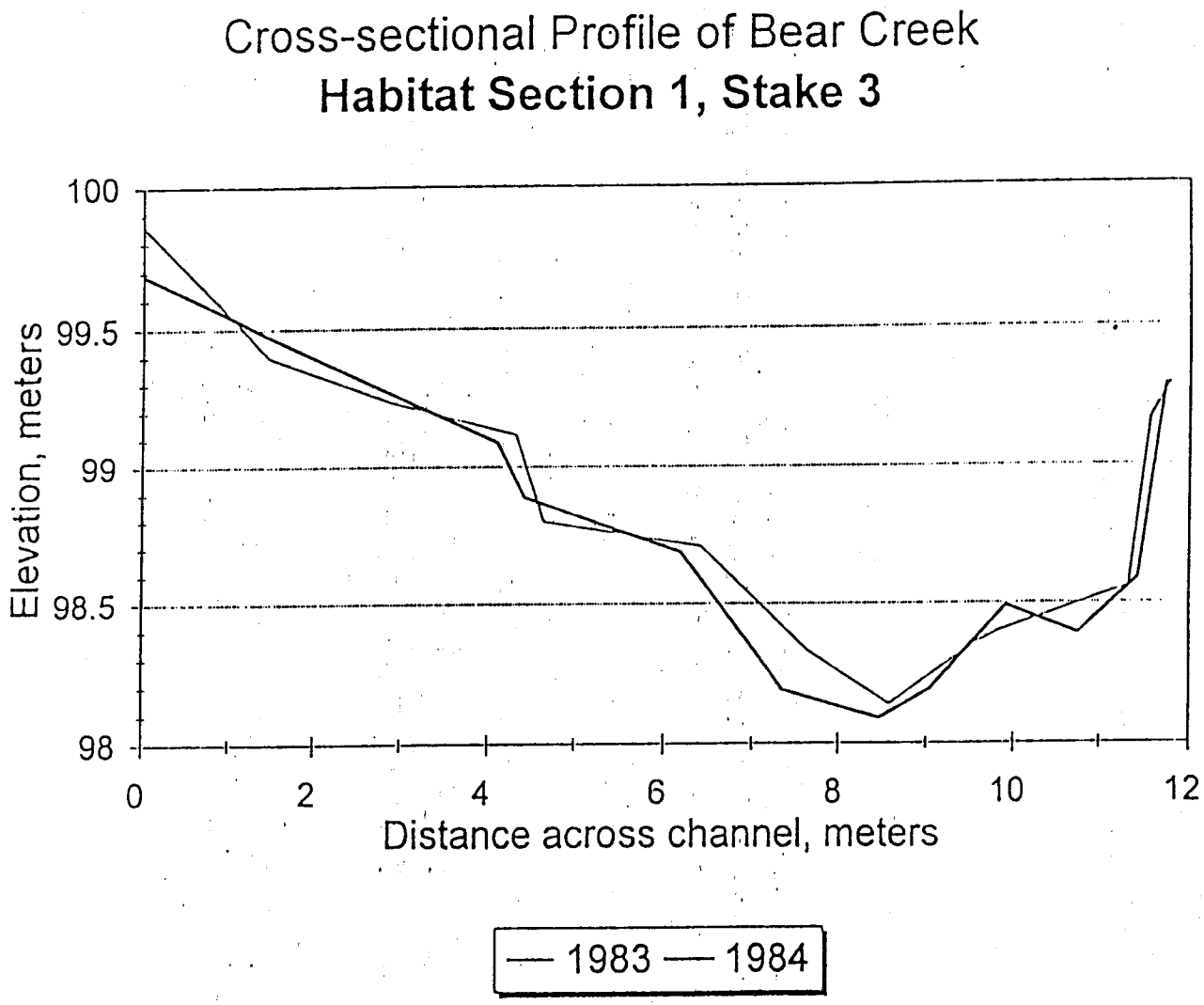

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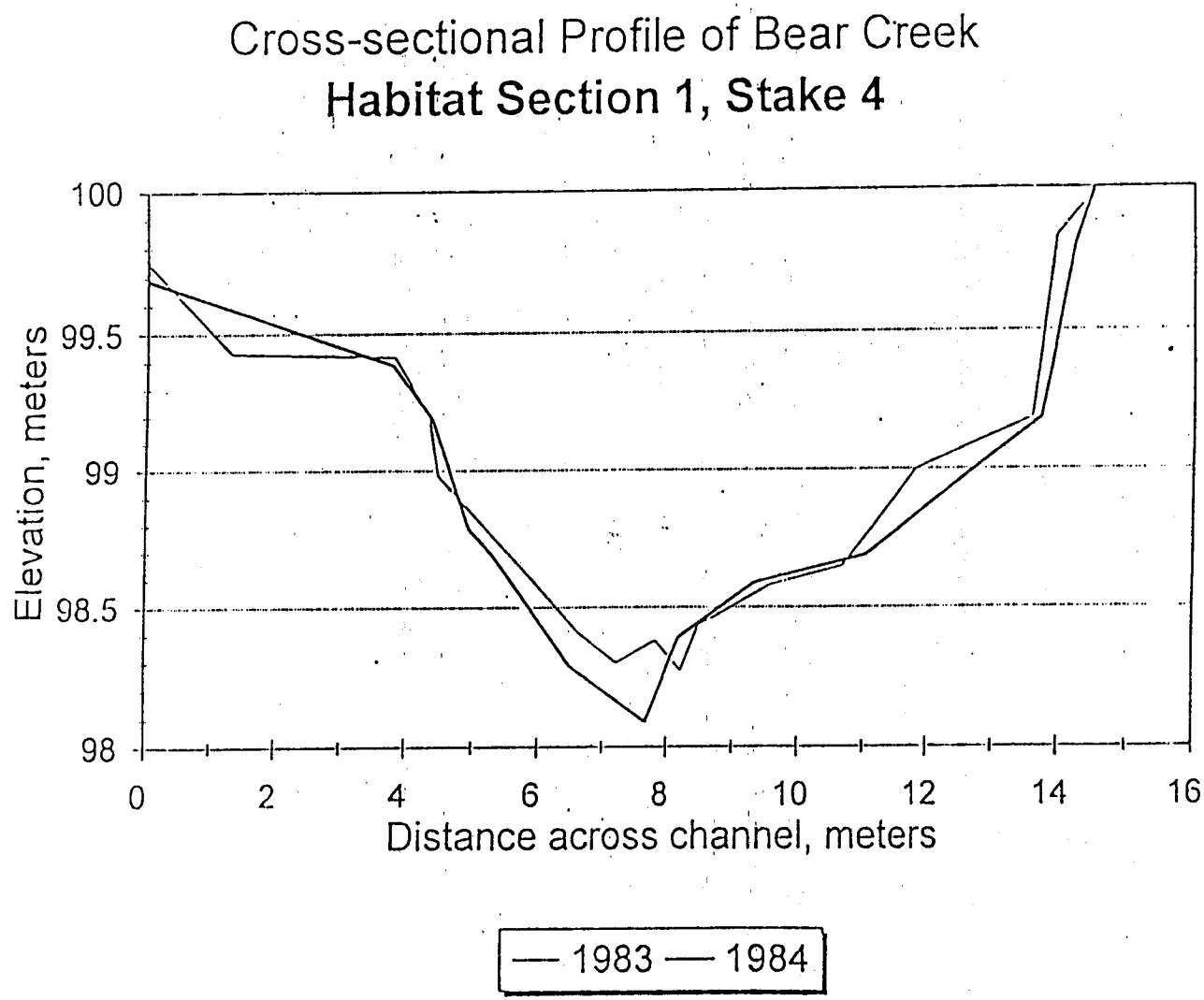

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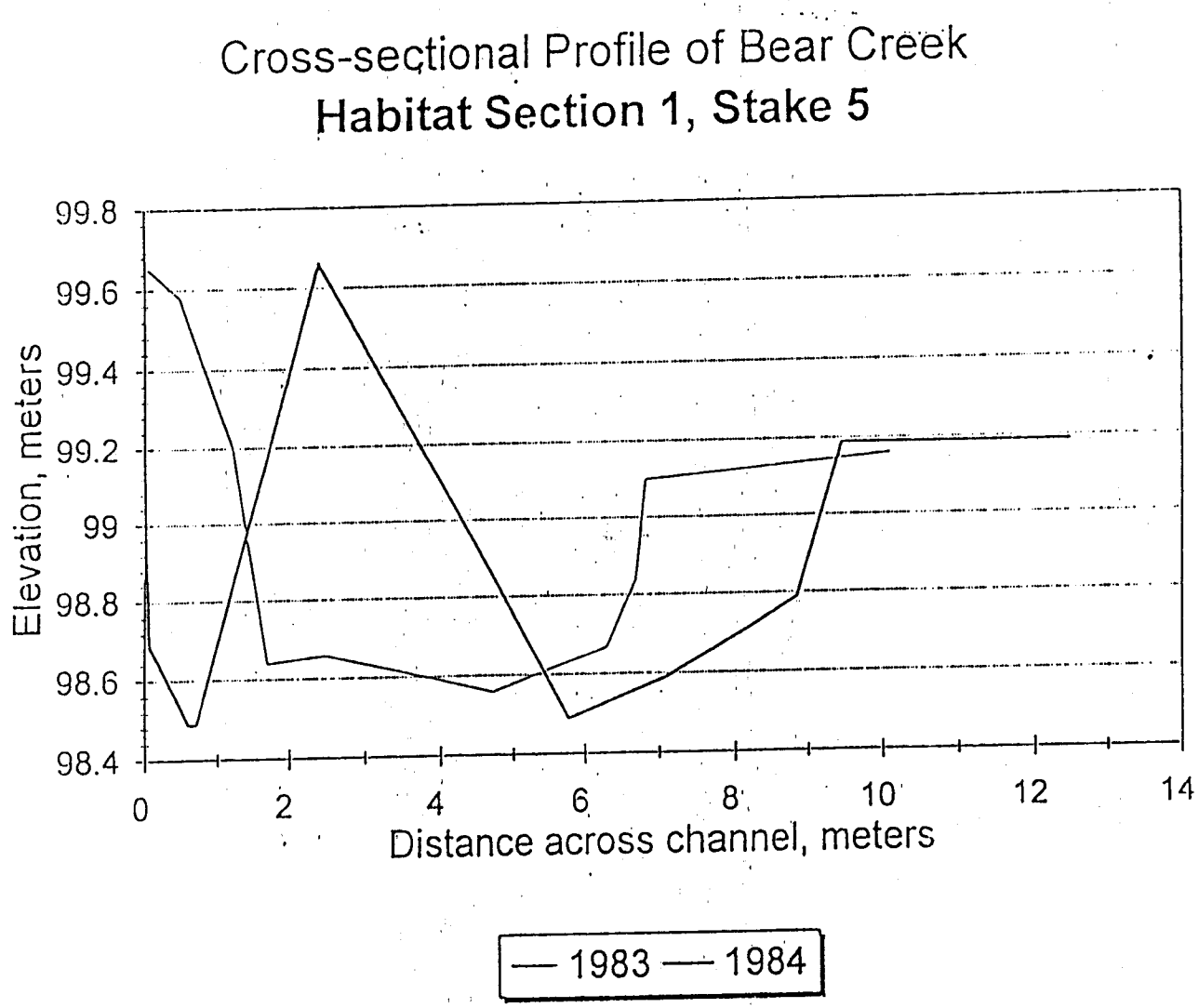

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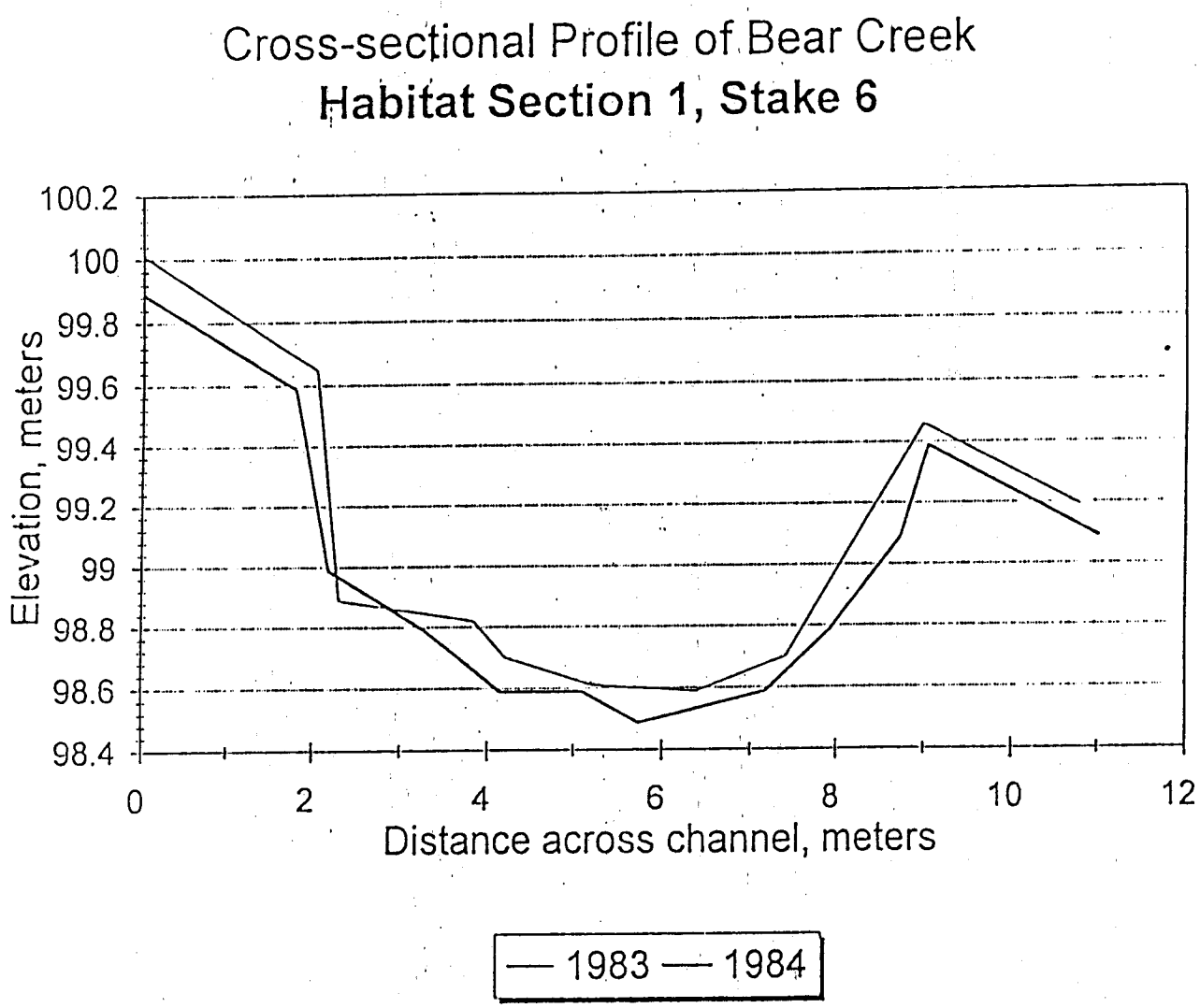

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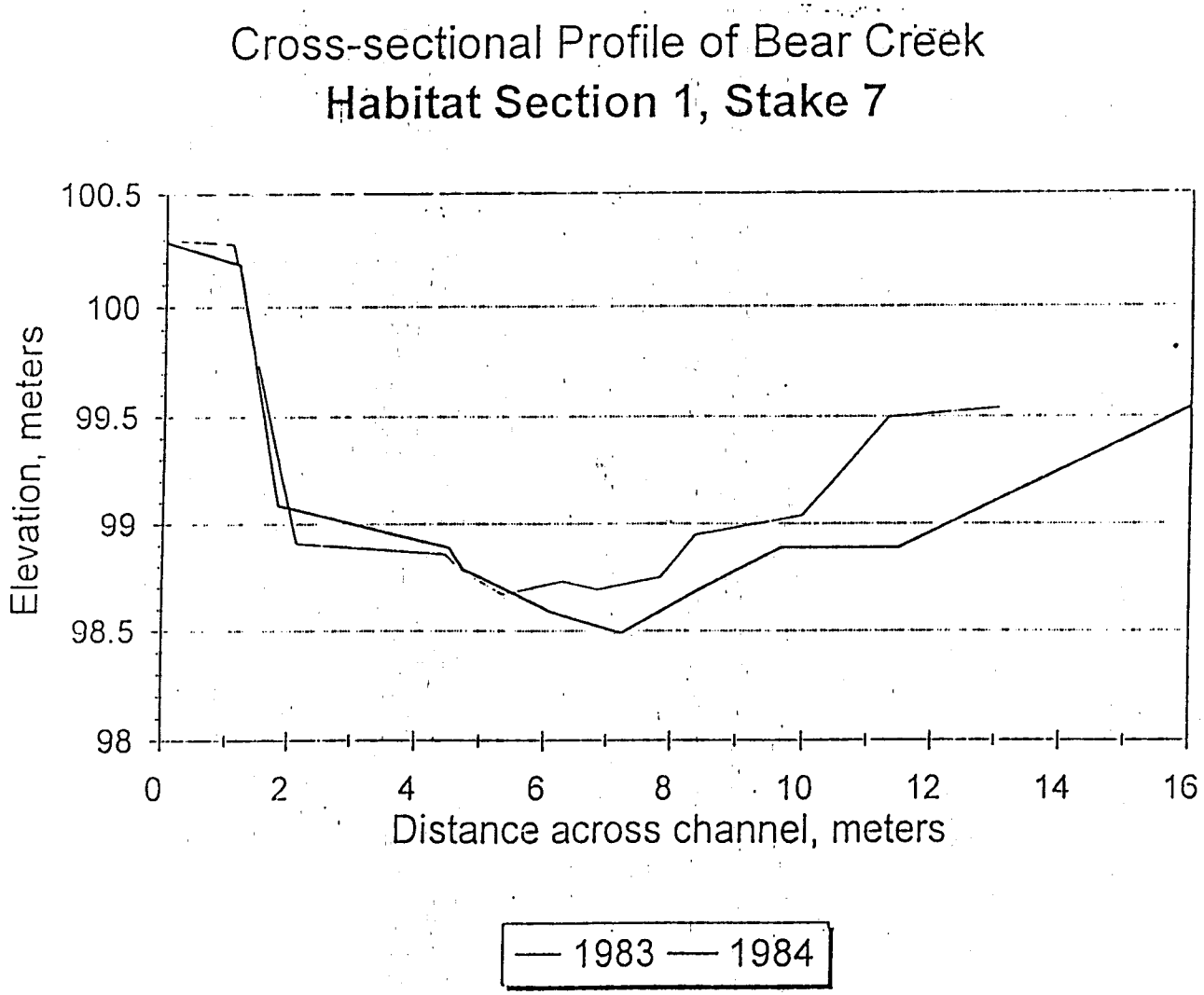

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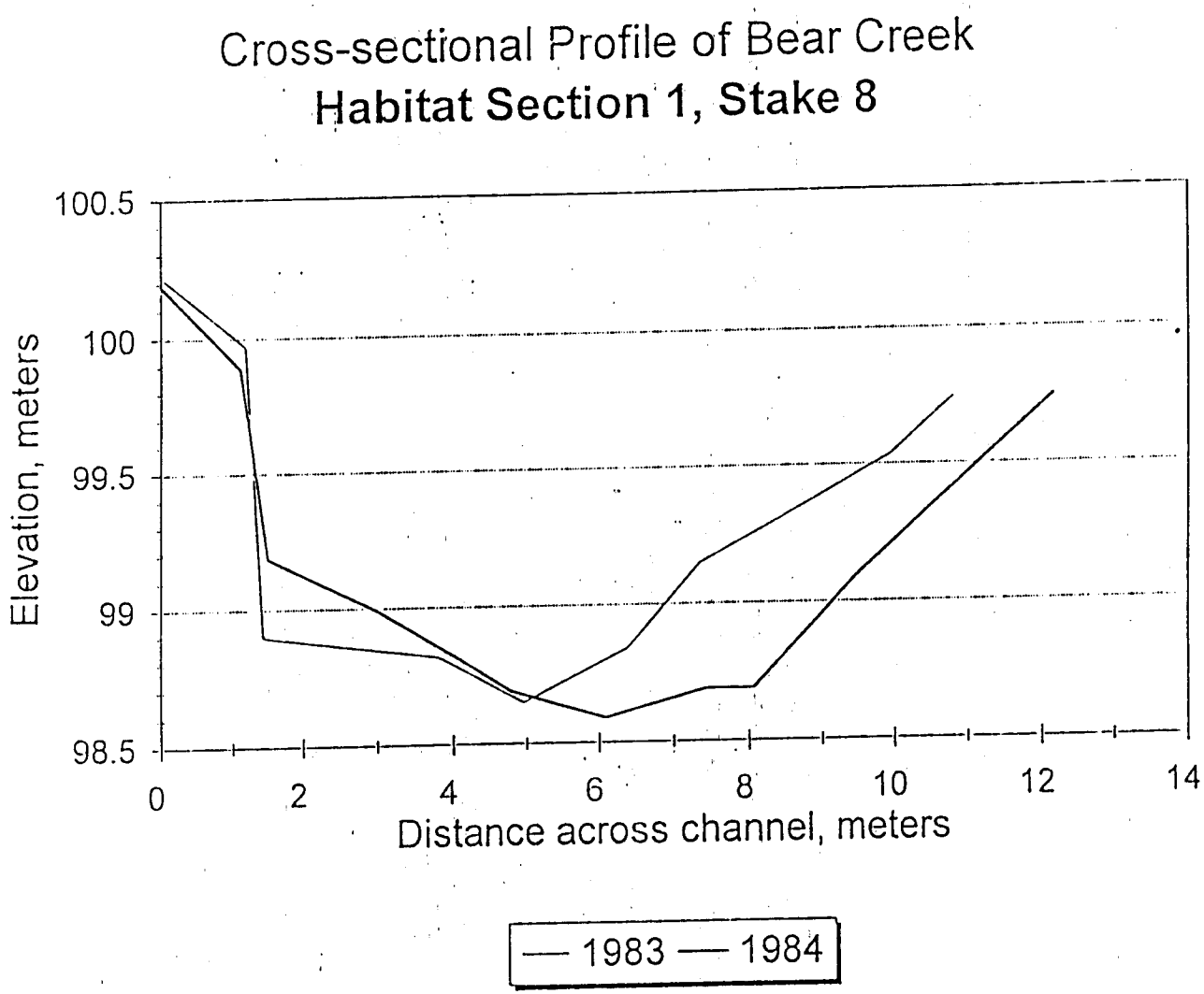

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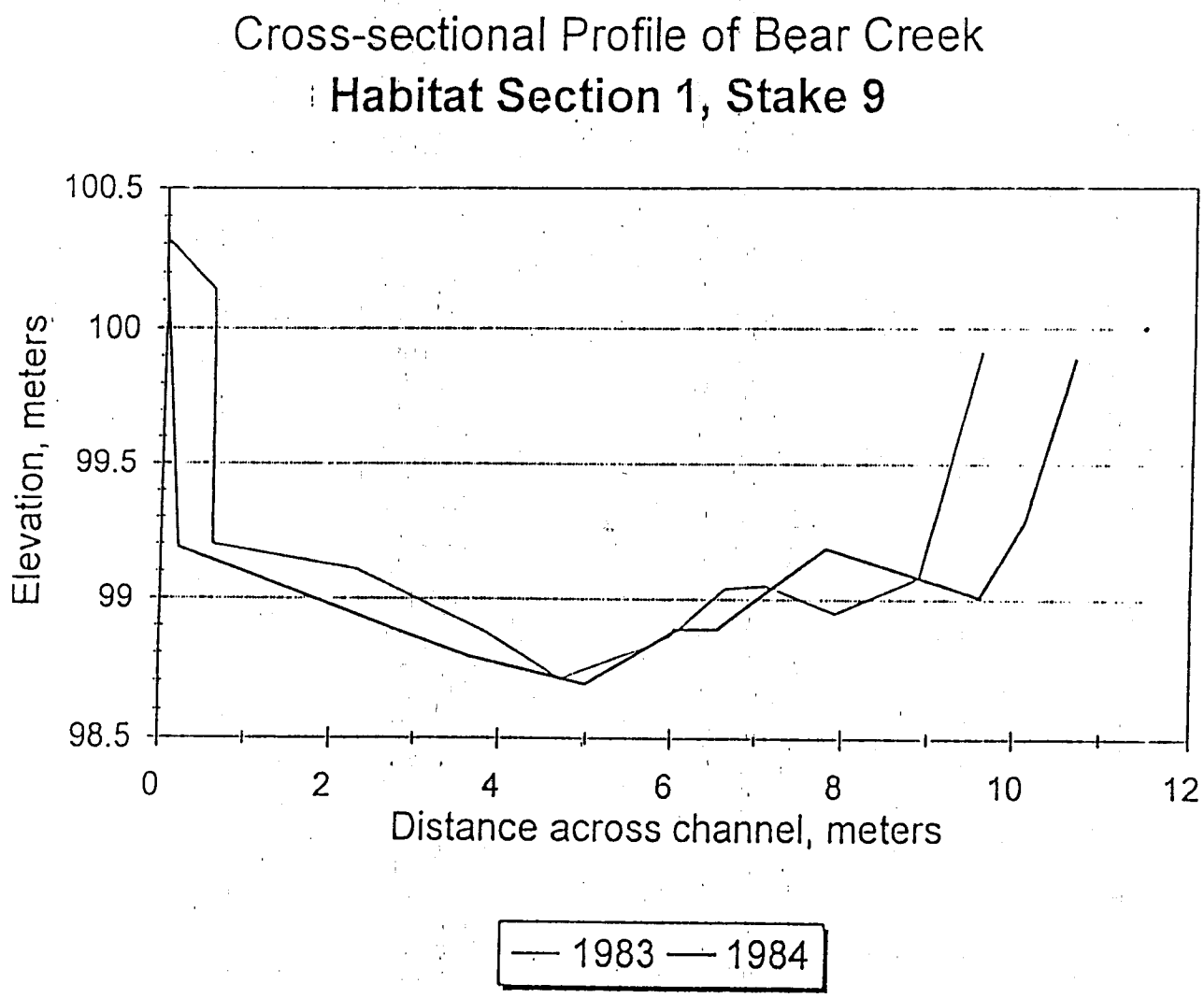

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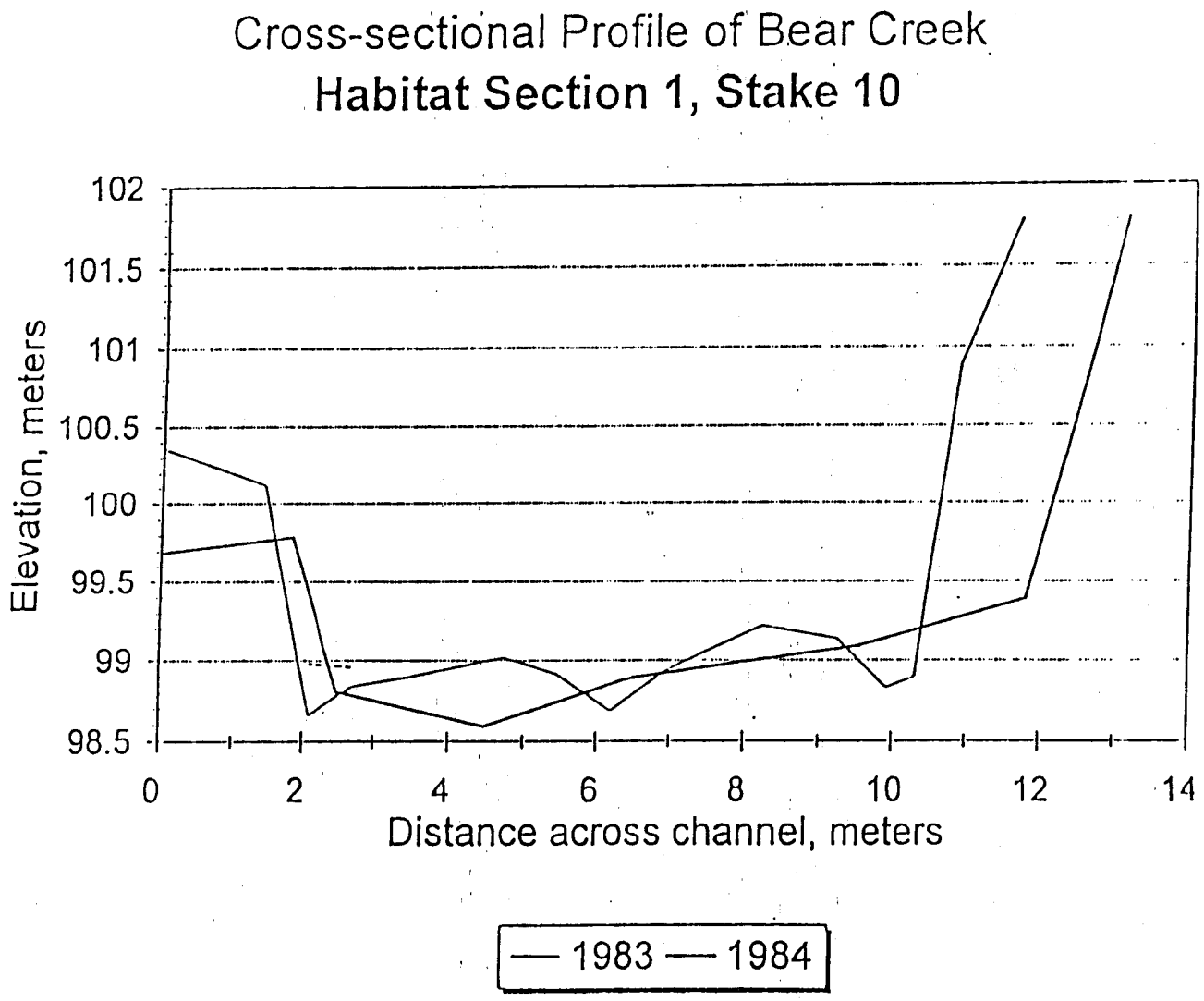

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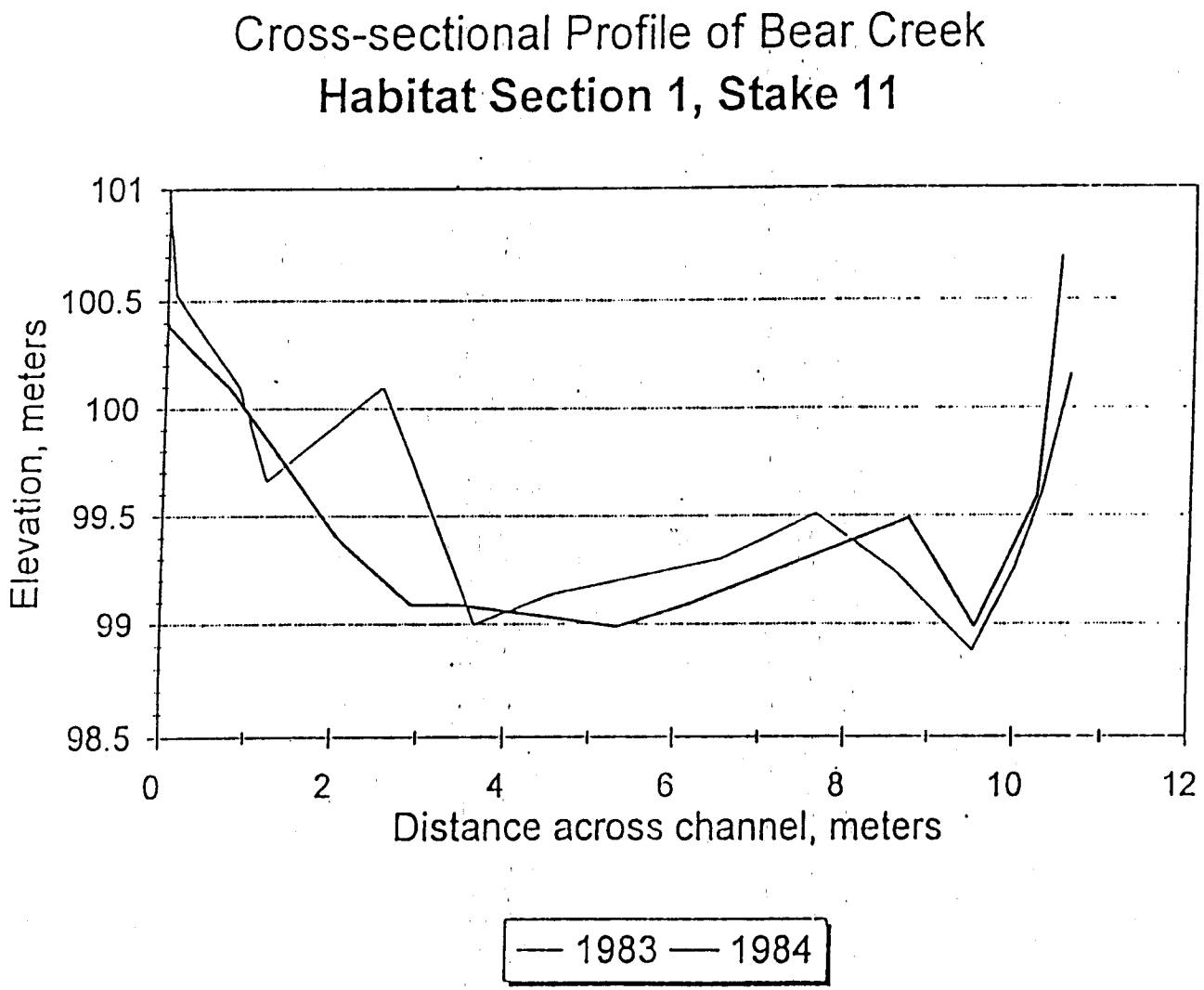

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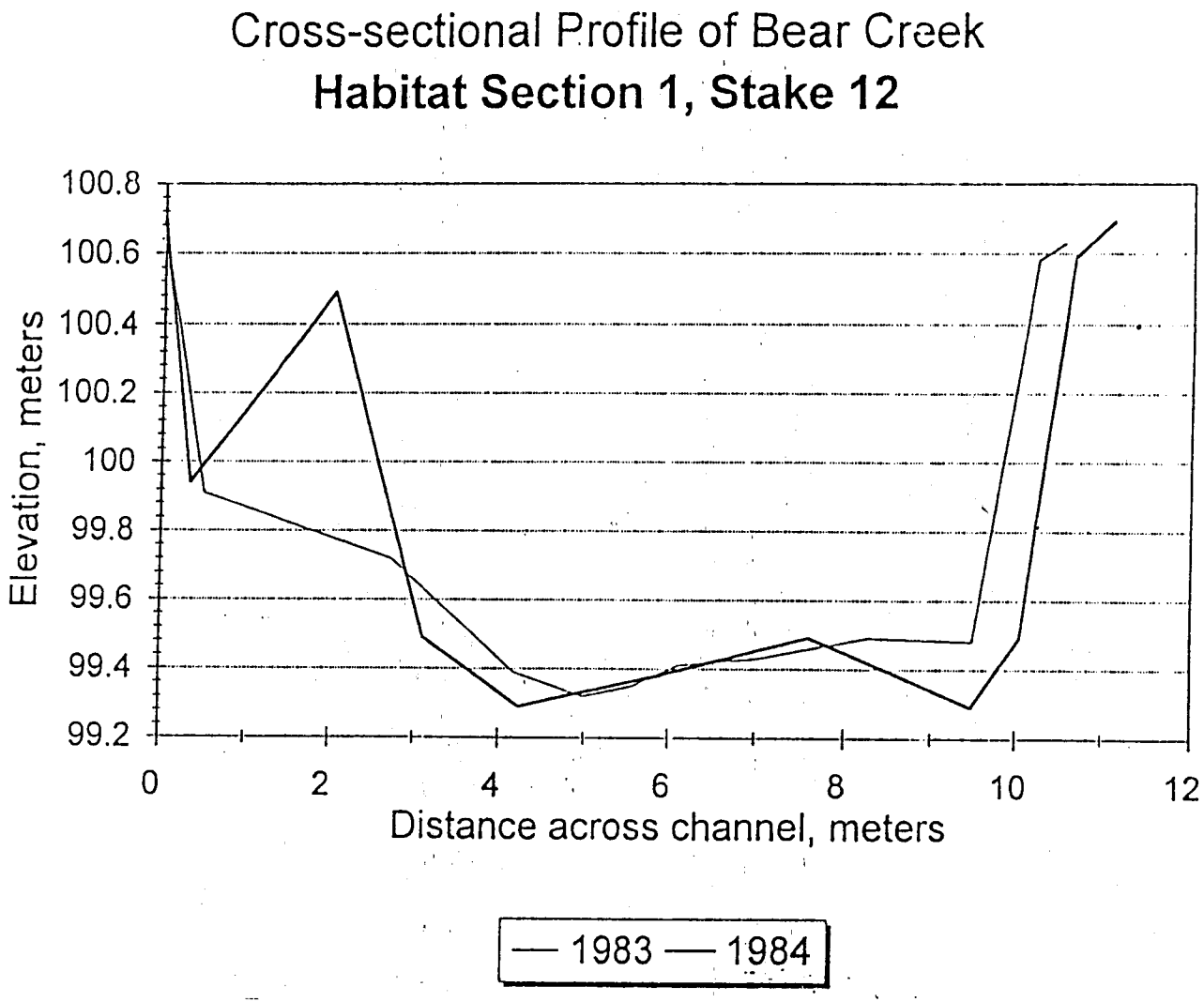

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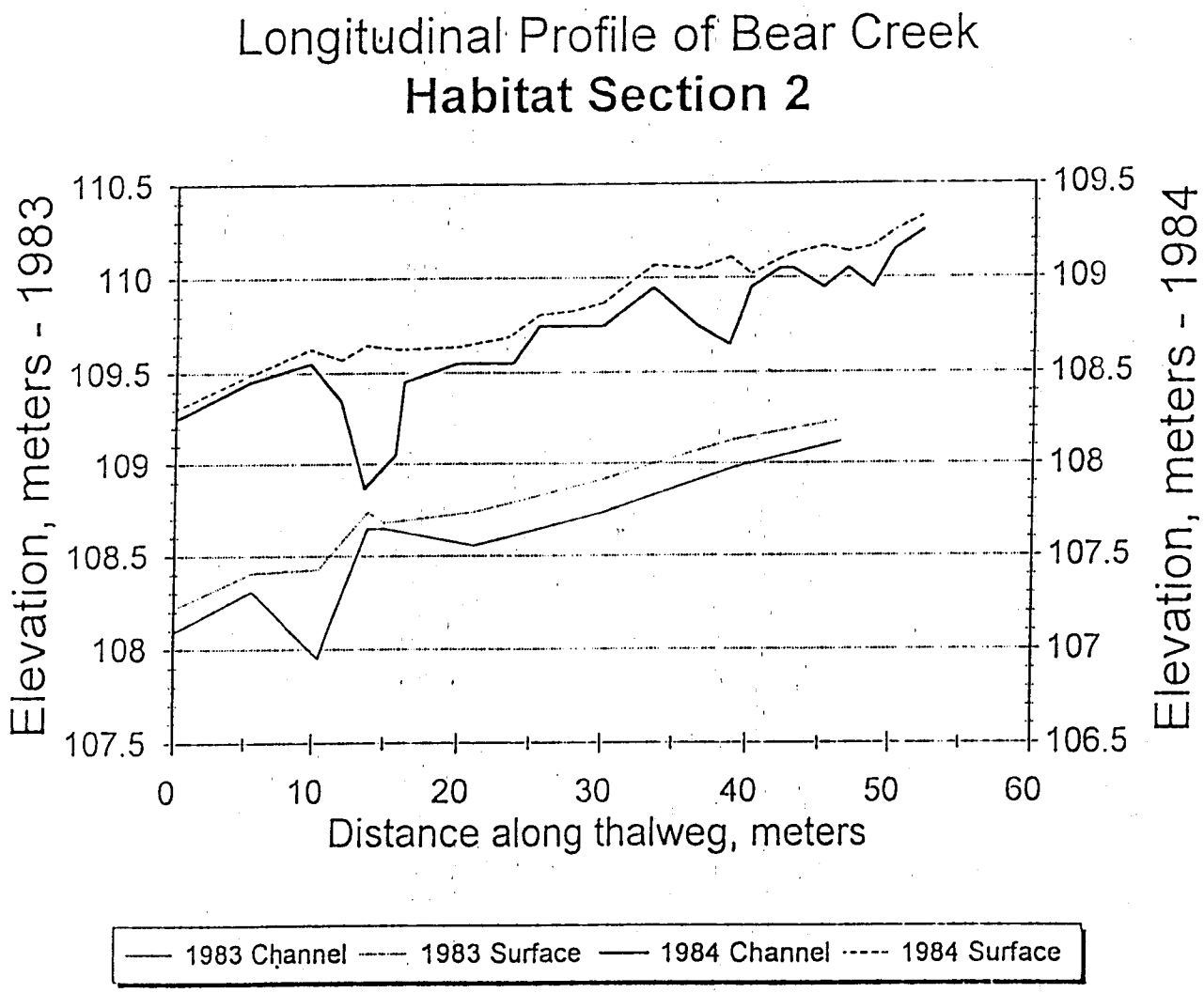
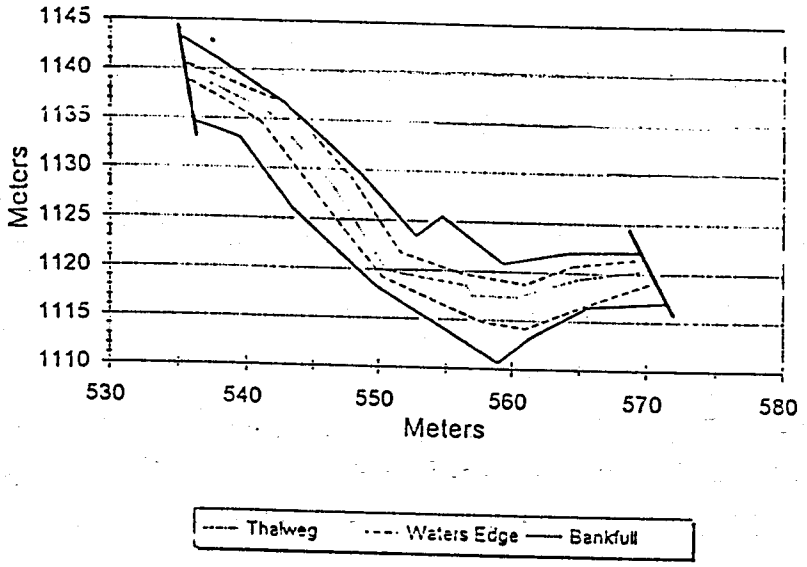
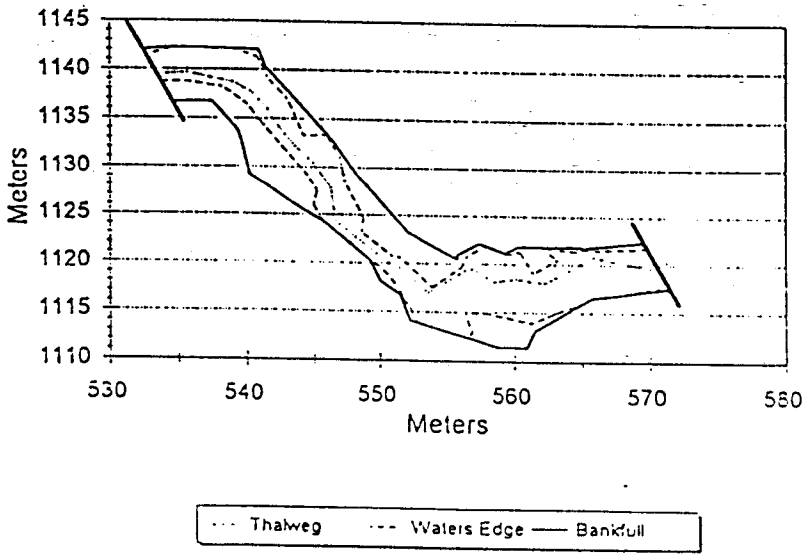


Appendix C. (Continued)

Planimetric View of Bear Creek
Habitat Section 2 - 1983



Planimetric View of Bear Creek
Habitat Section 2 - 1984



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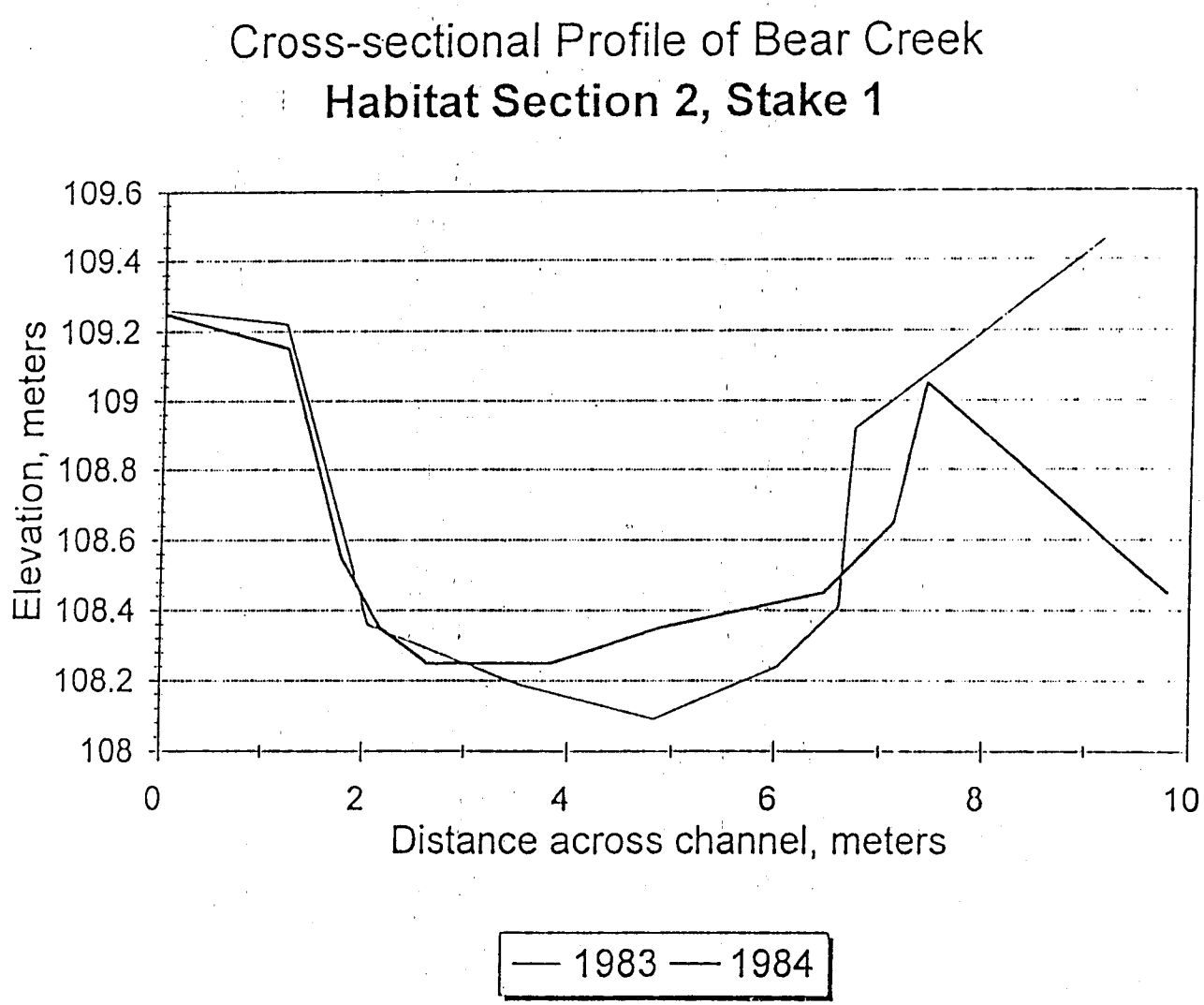

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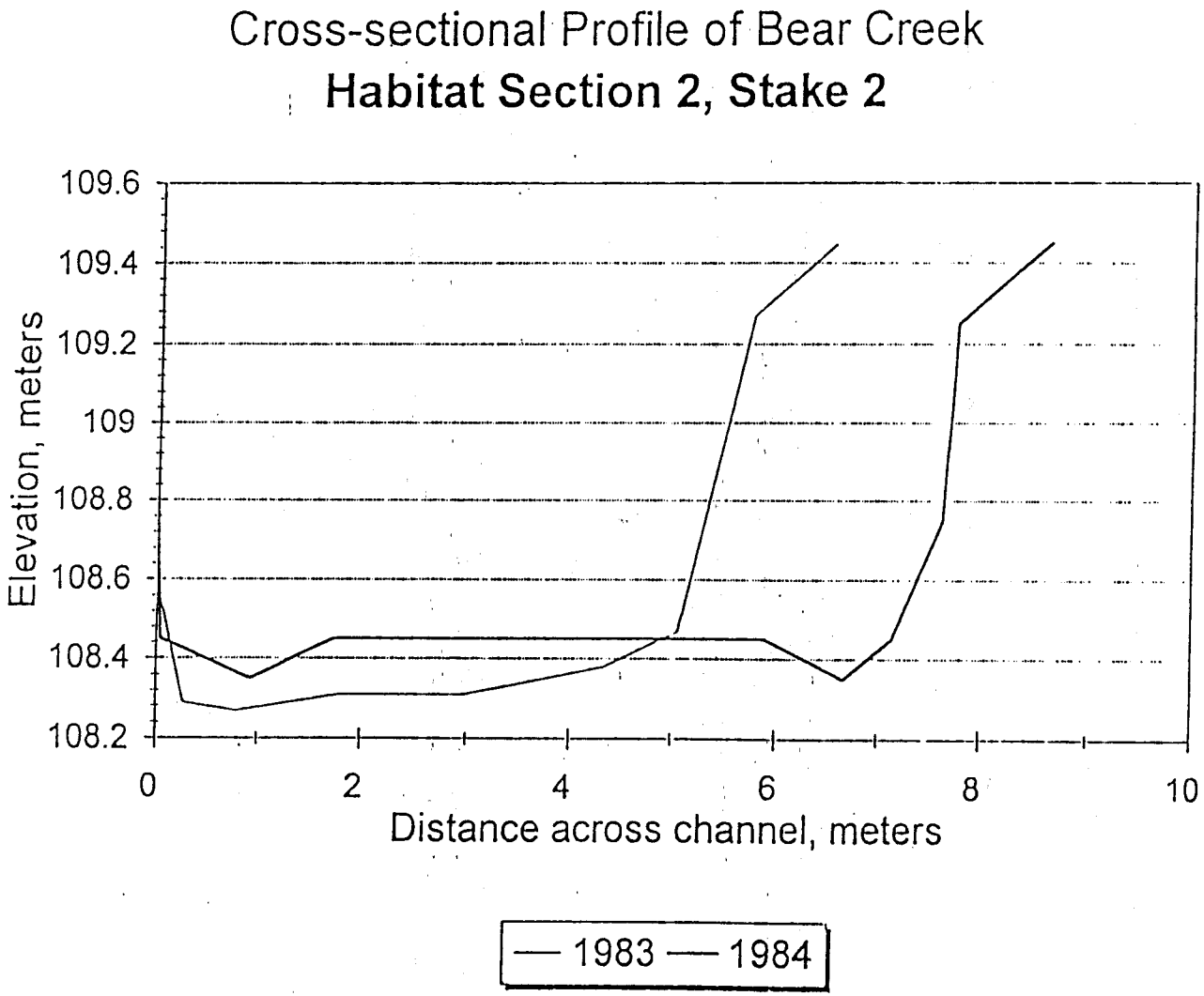

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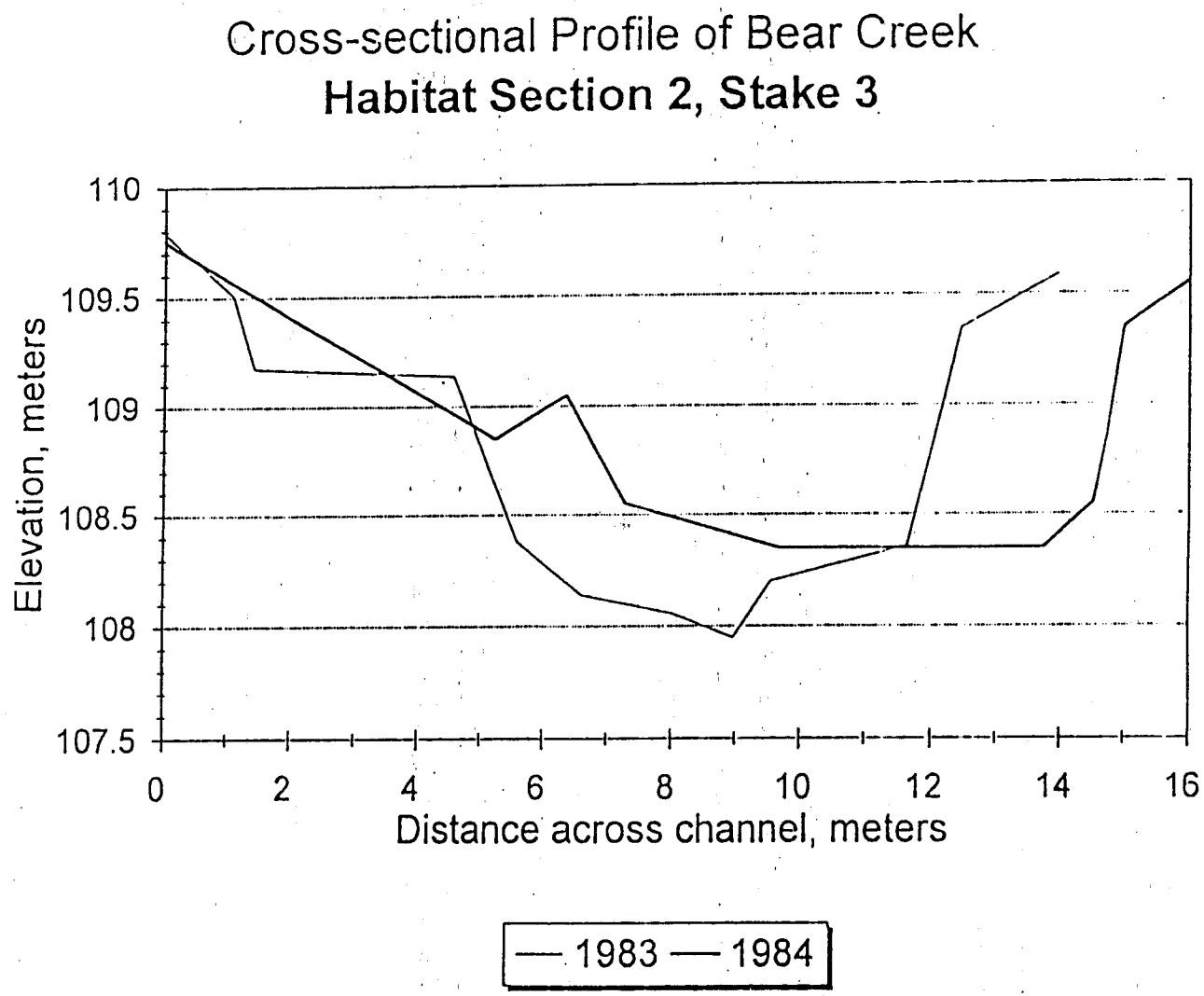

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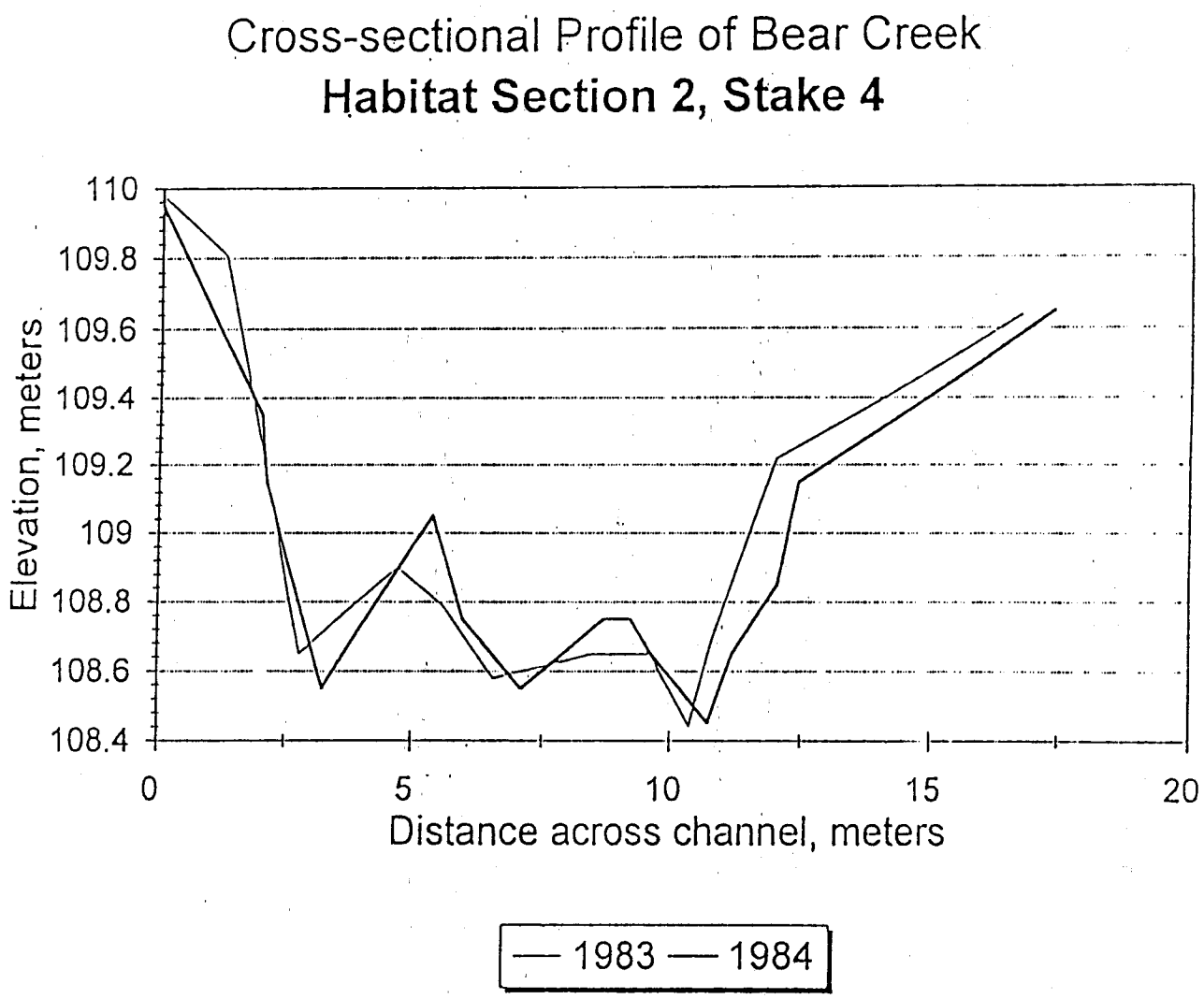

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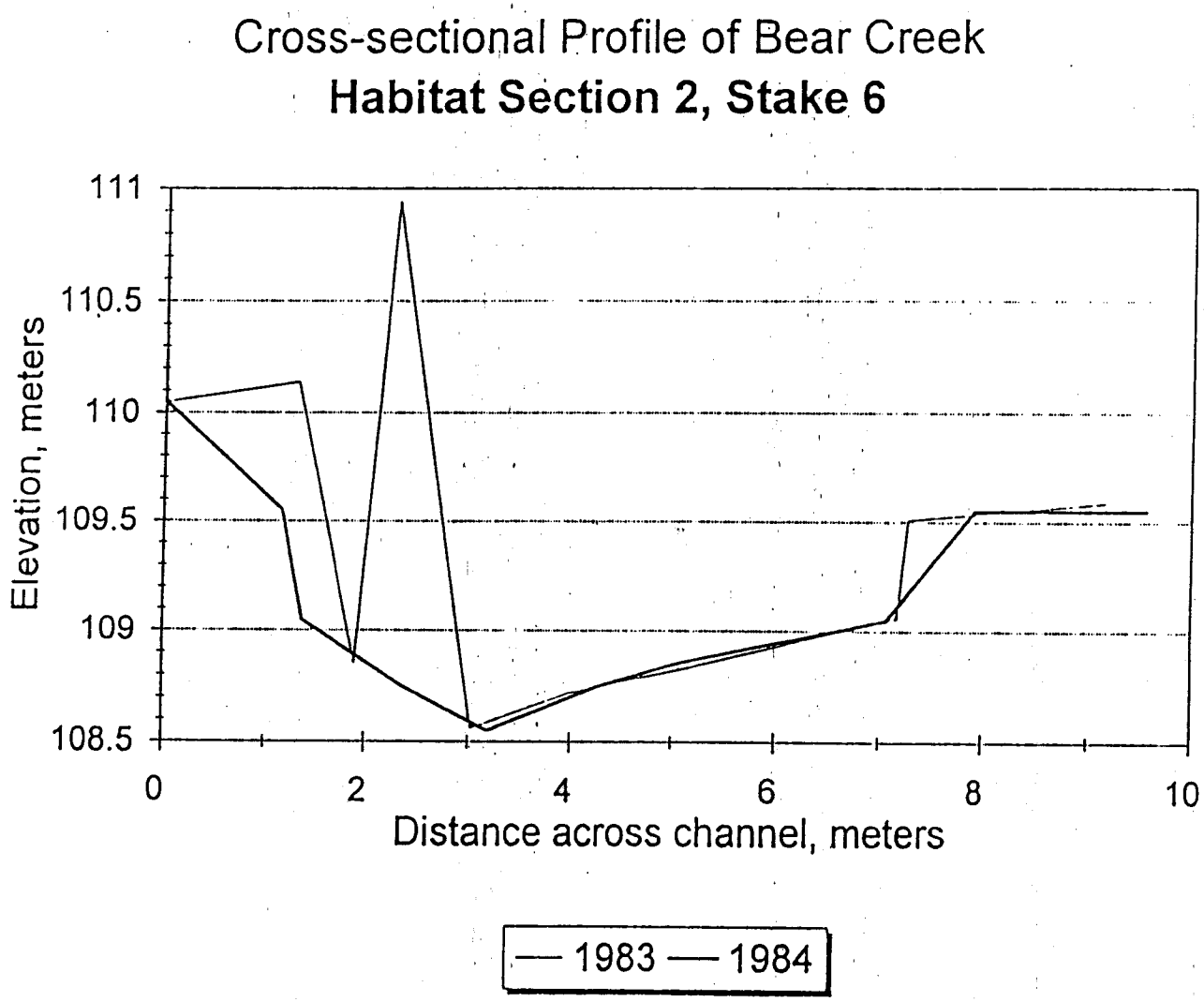

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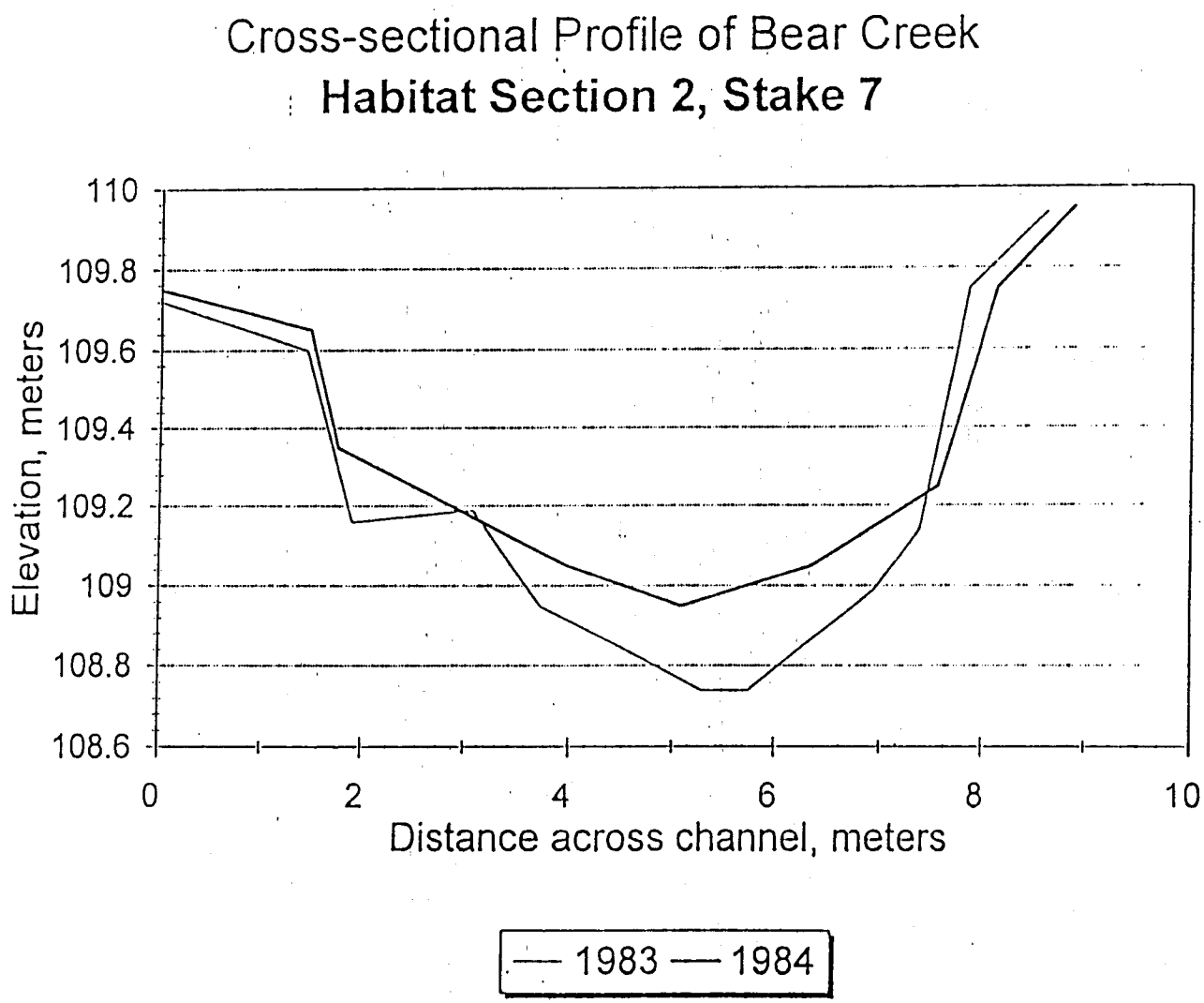

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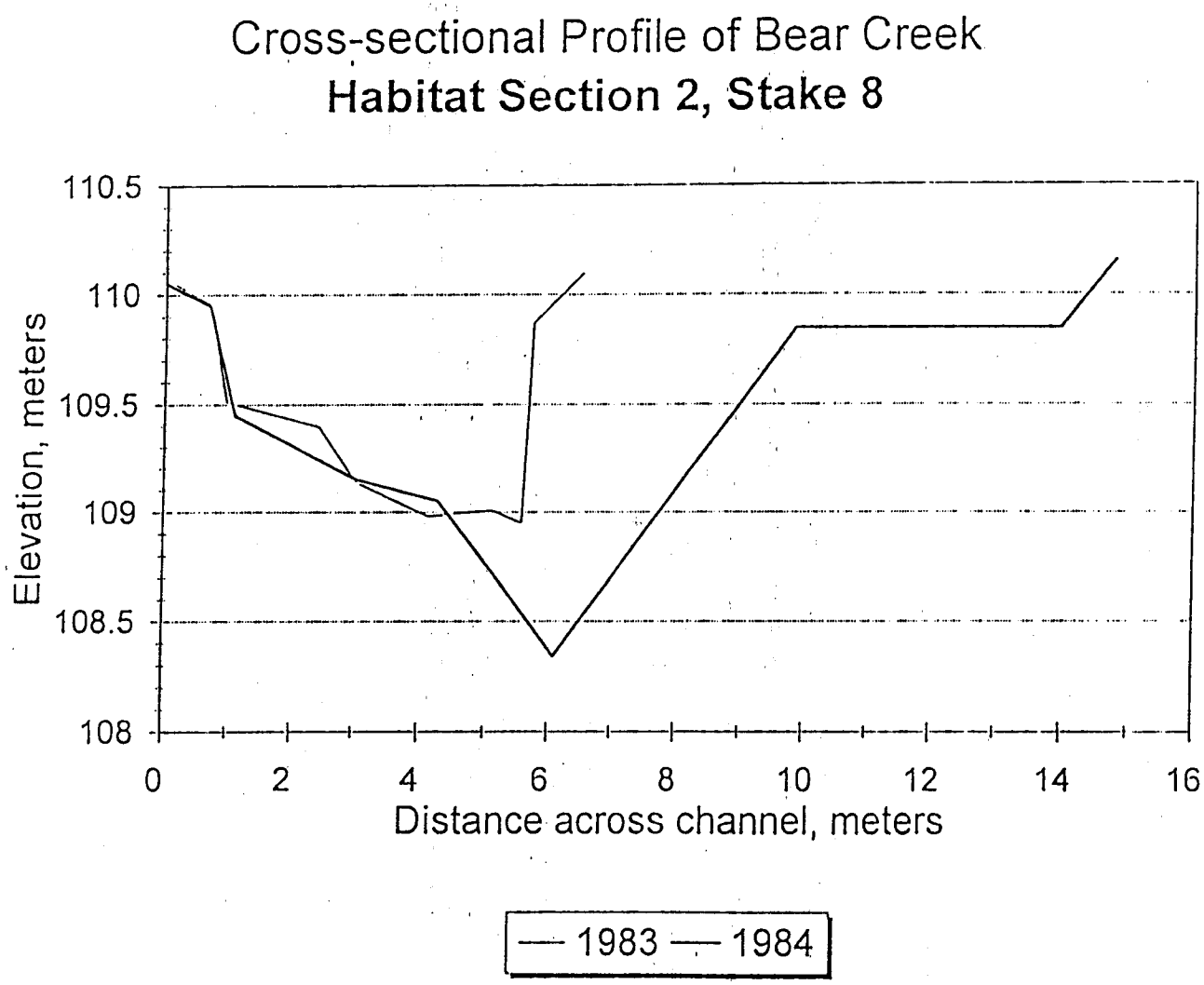

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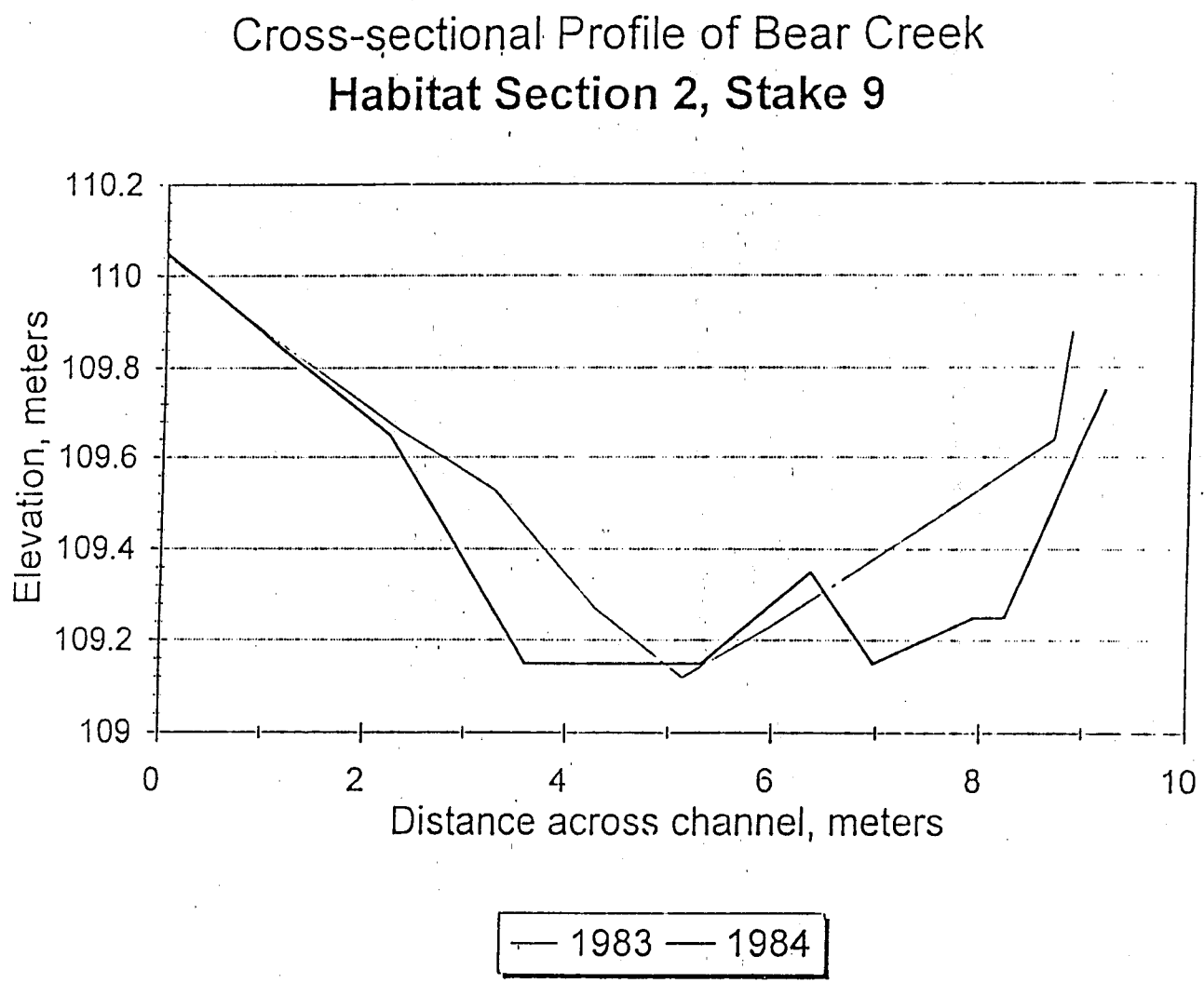

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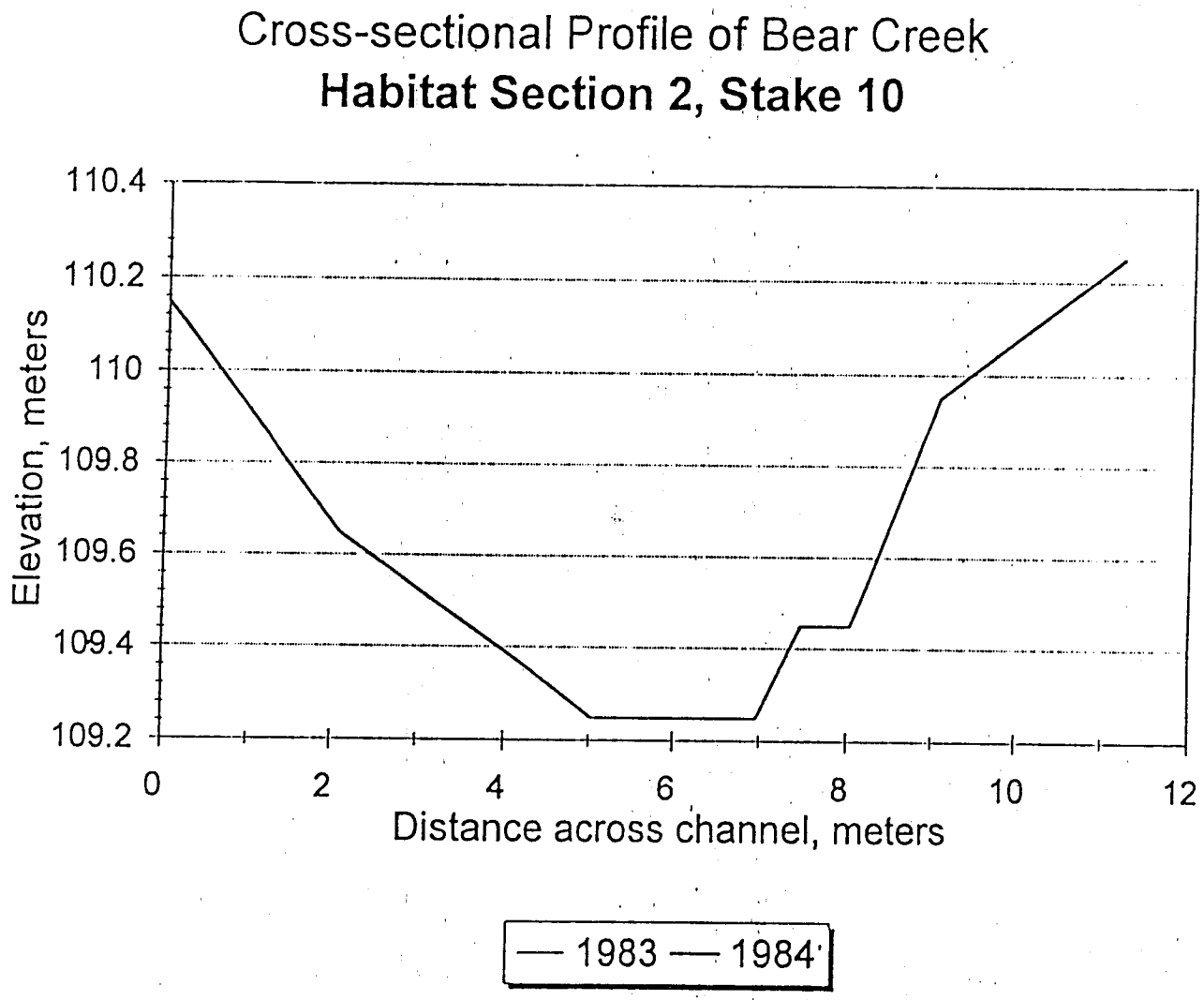

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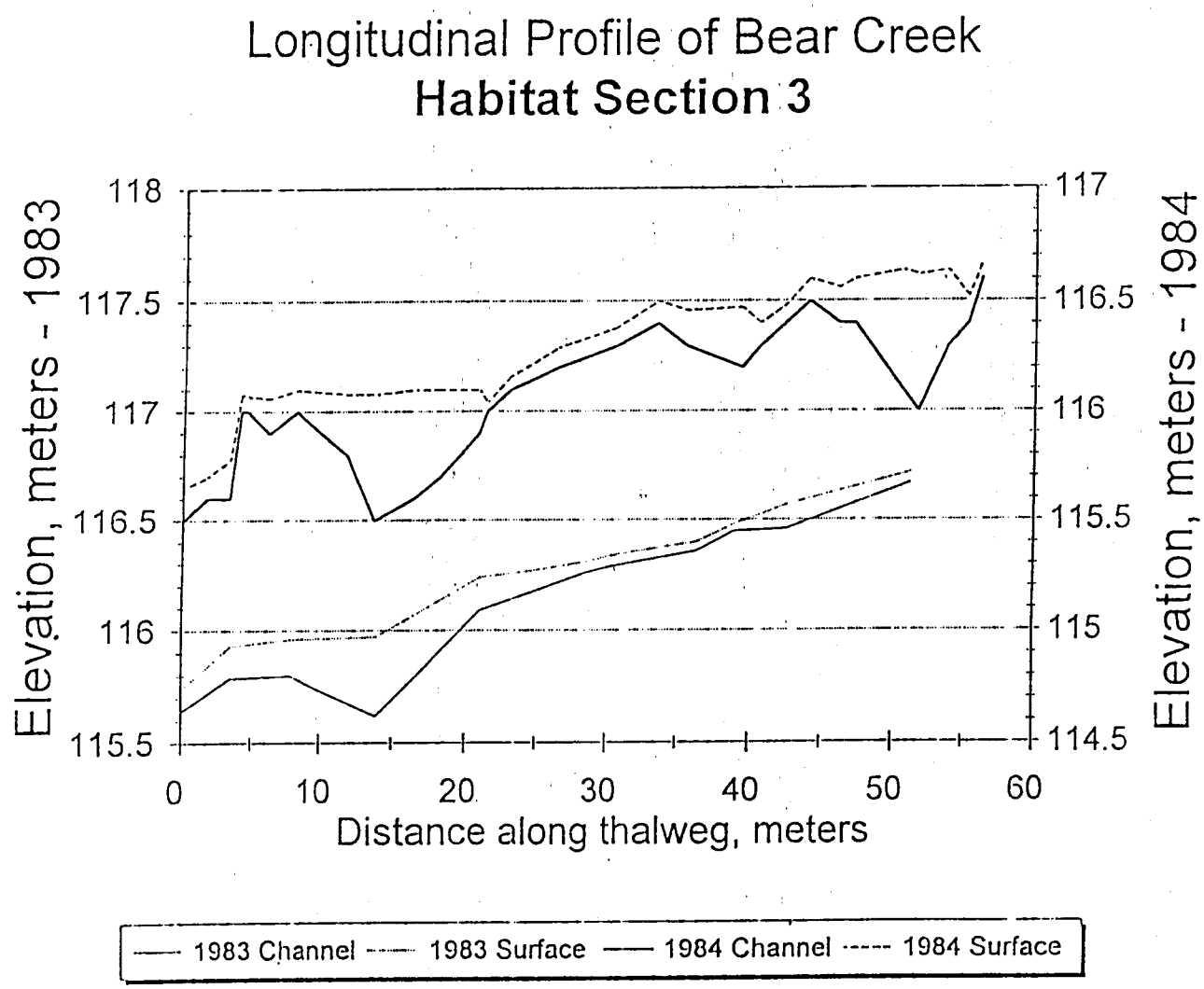
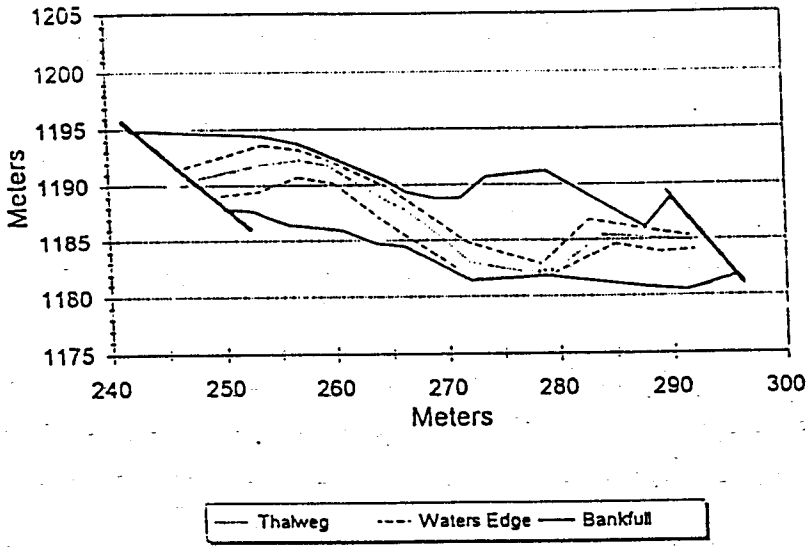
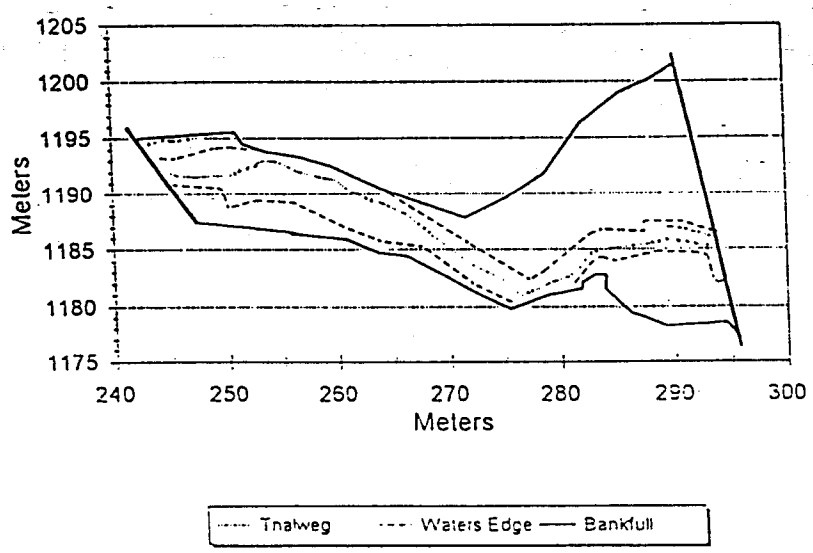


Appendix C. (Continued)

Planimetric View of Bear Creek
Habitat Section 3 - 1983



Planimetric View of Bear Creek
Habitat Section 3 - 1984



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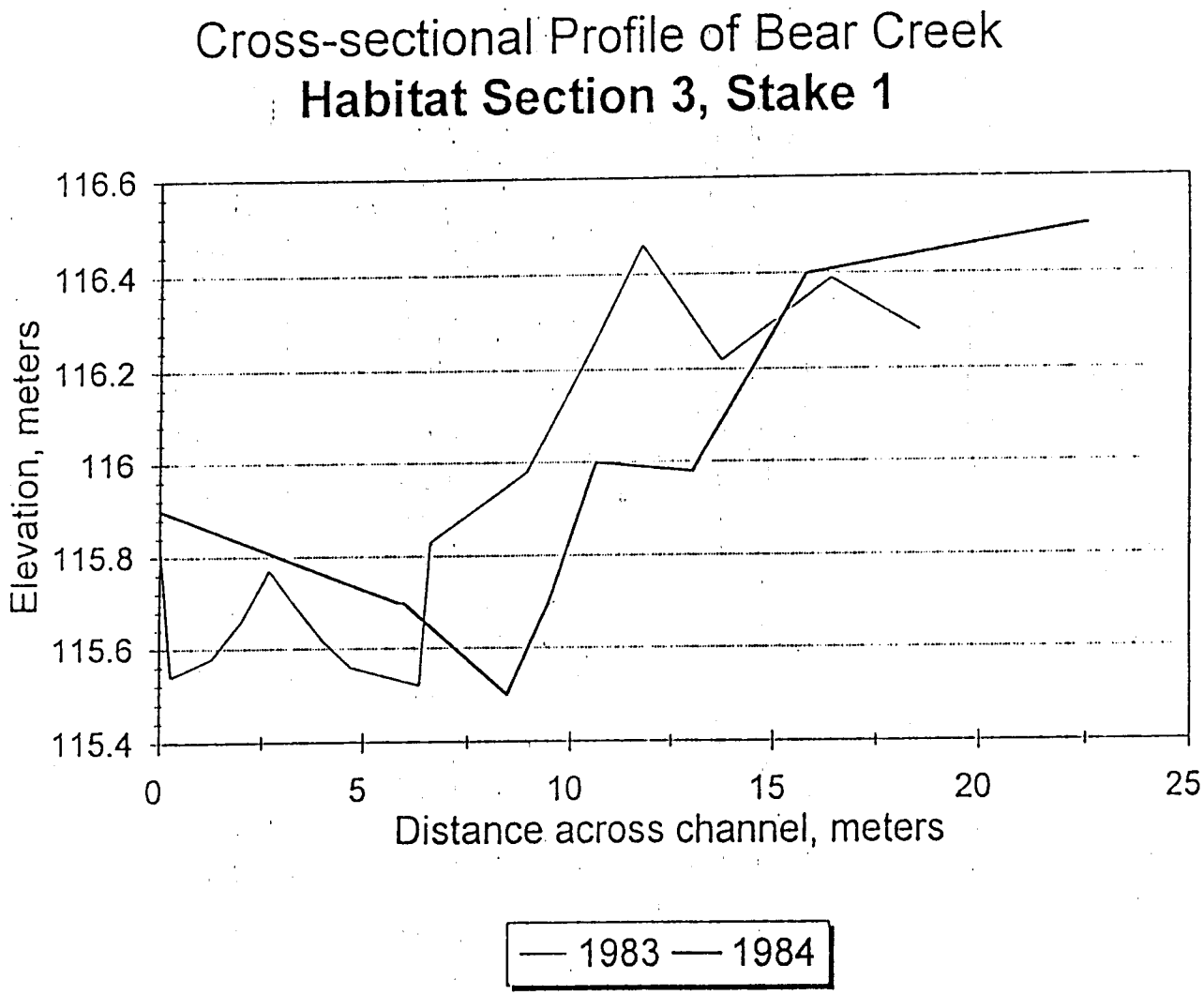

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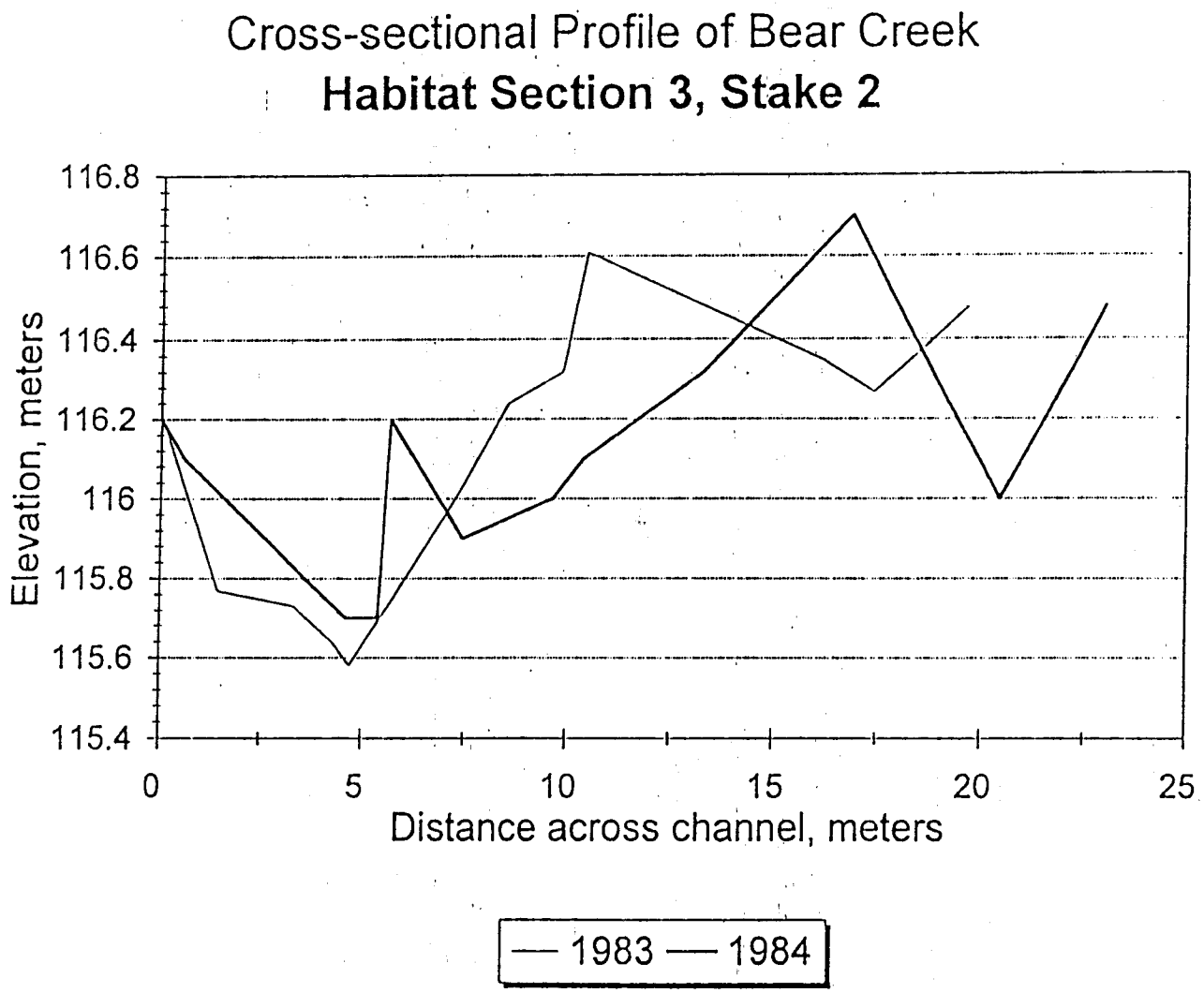

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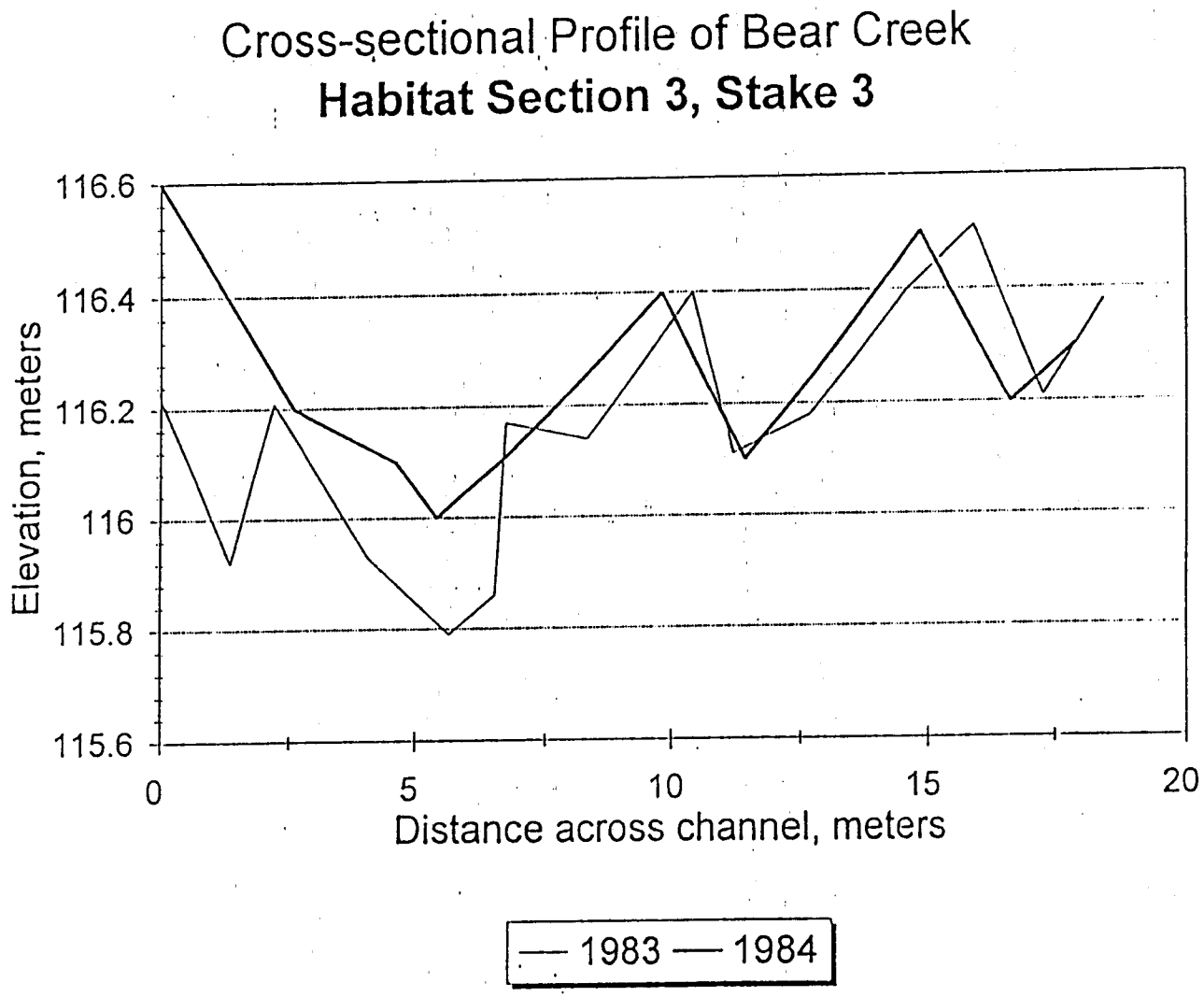

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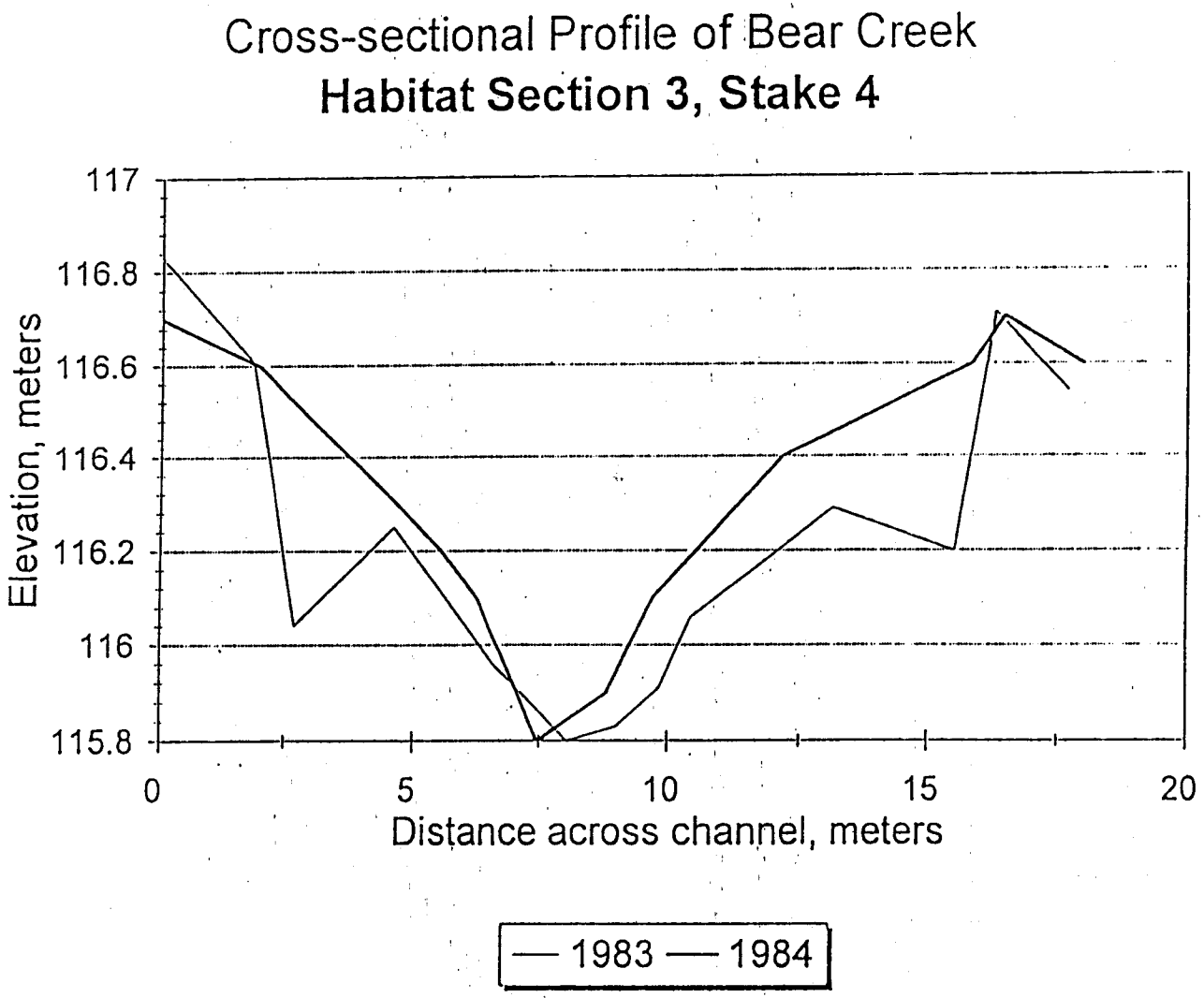

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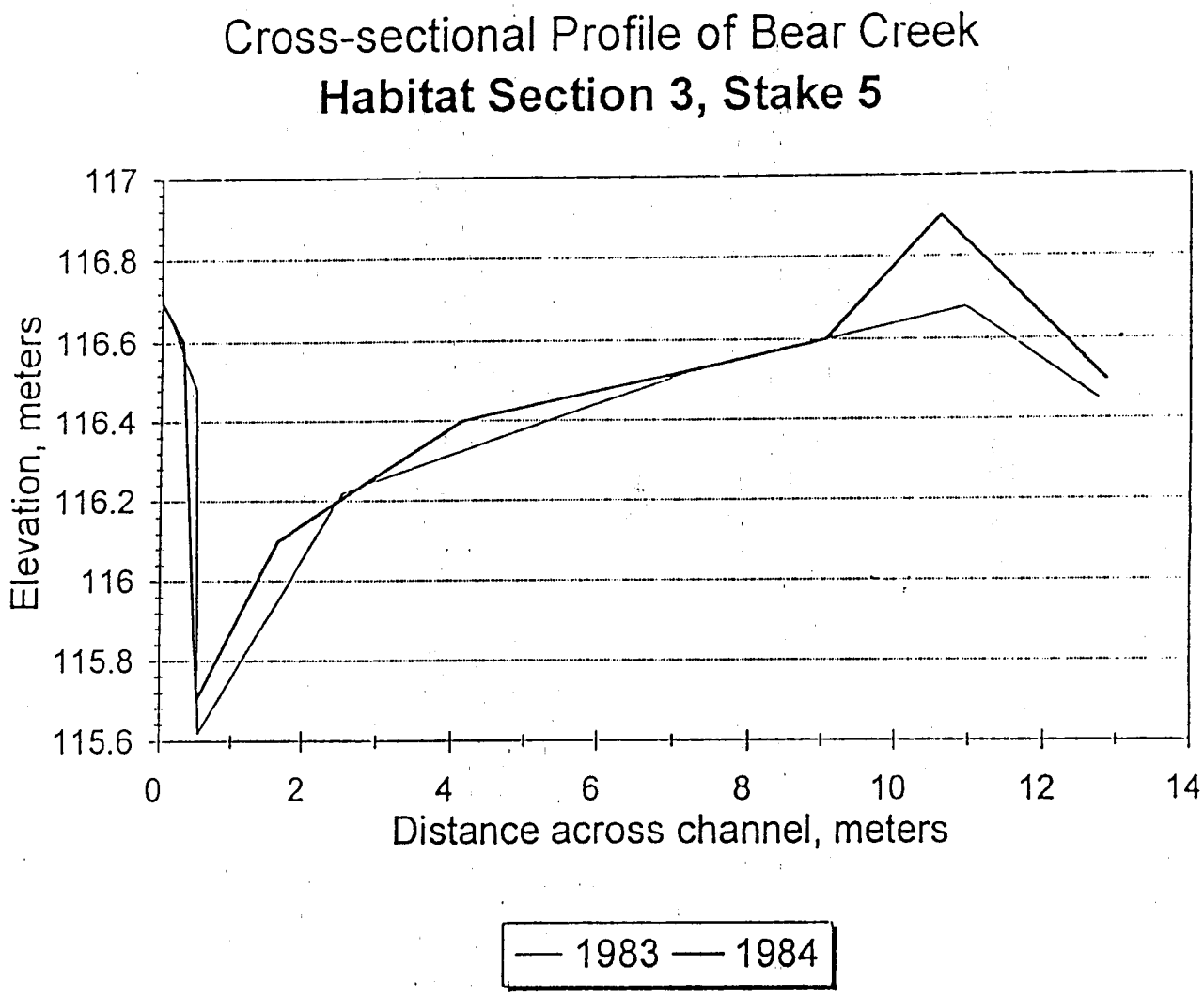

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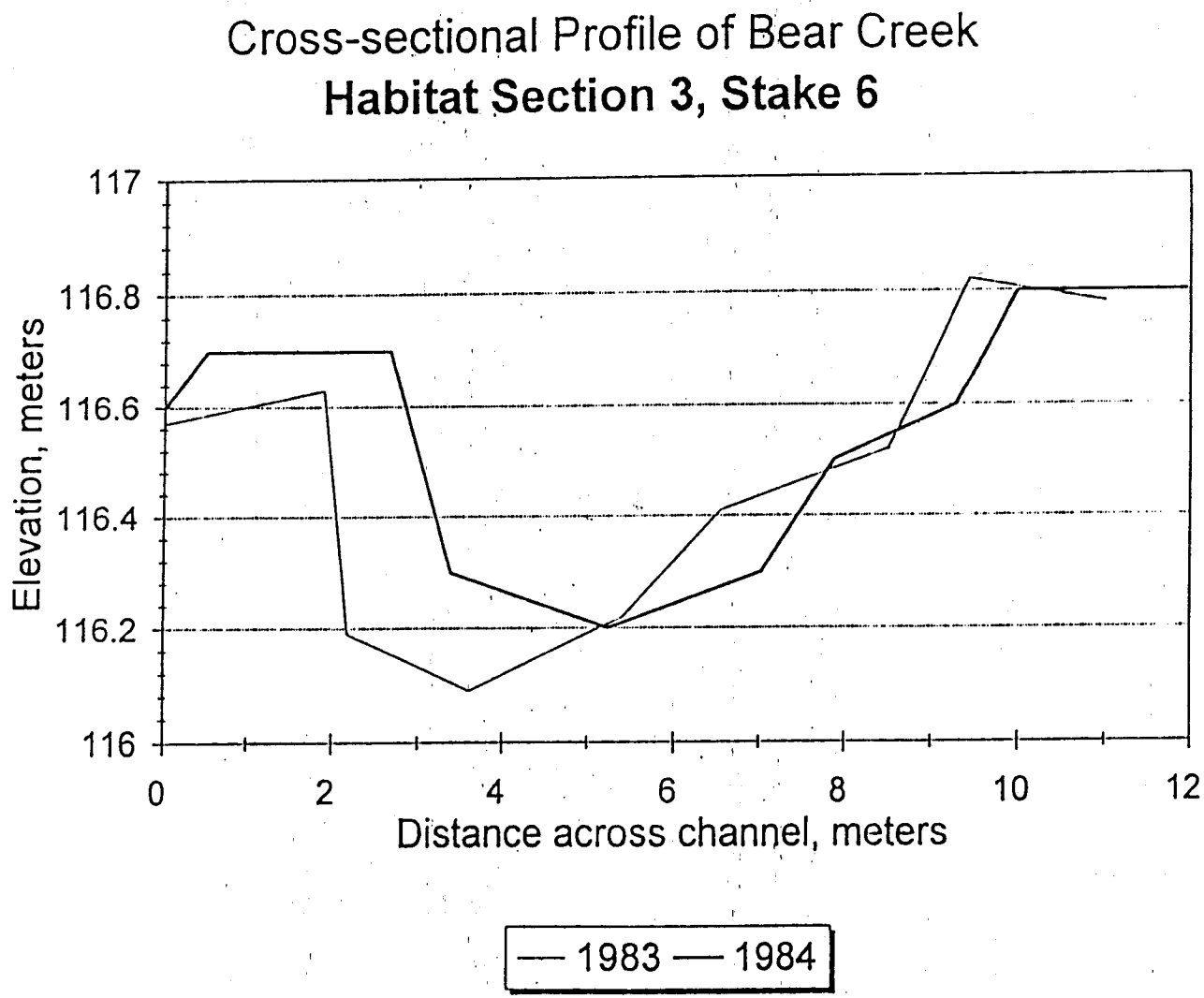

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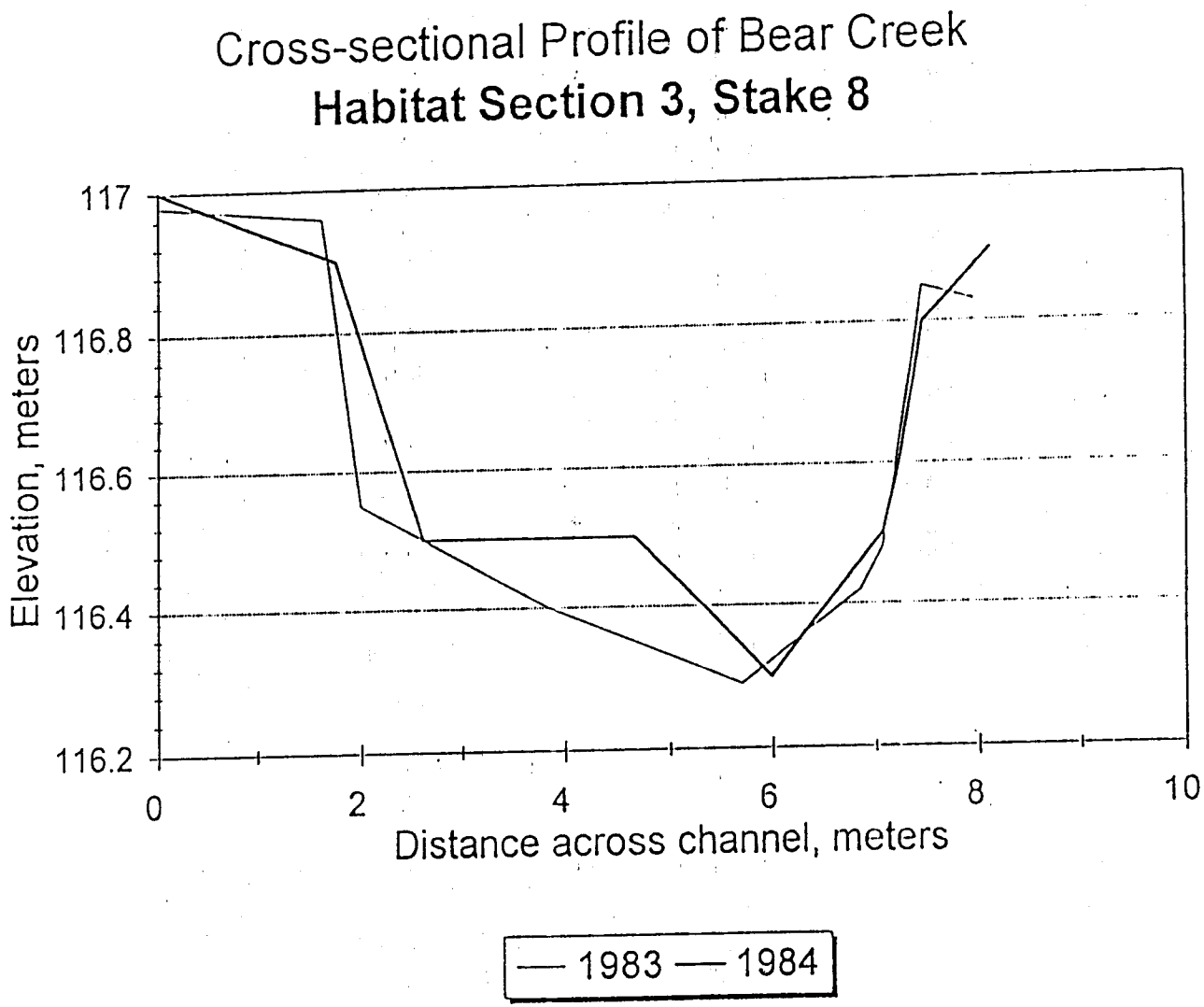

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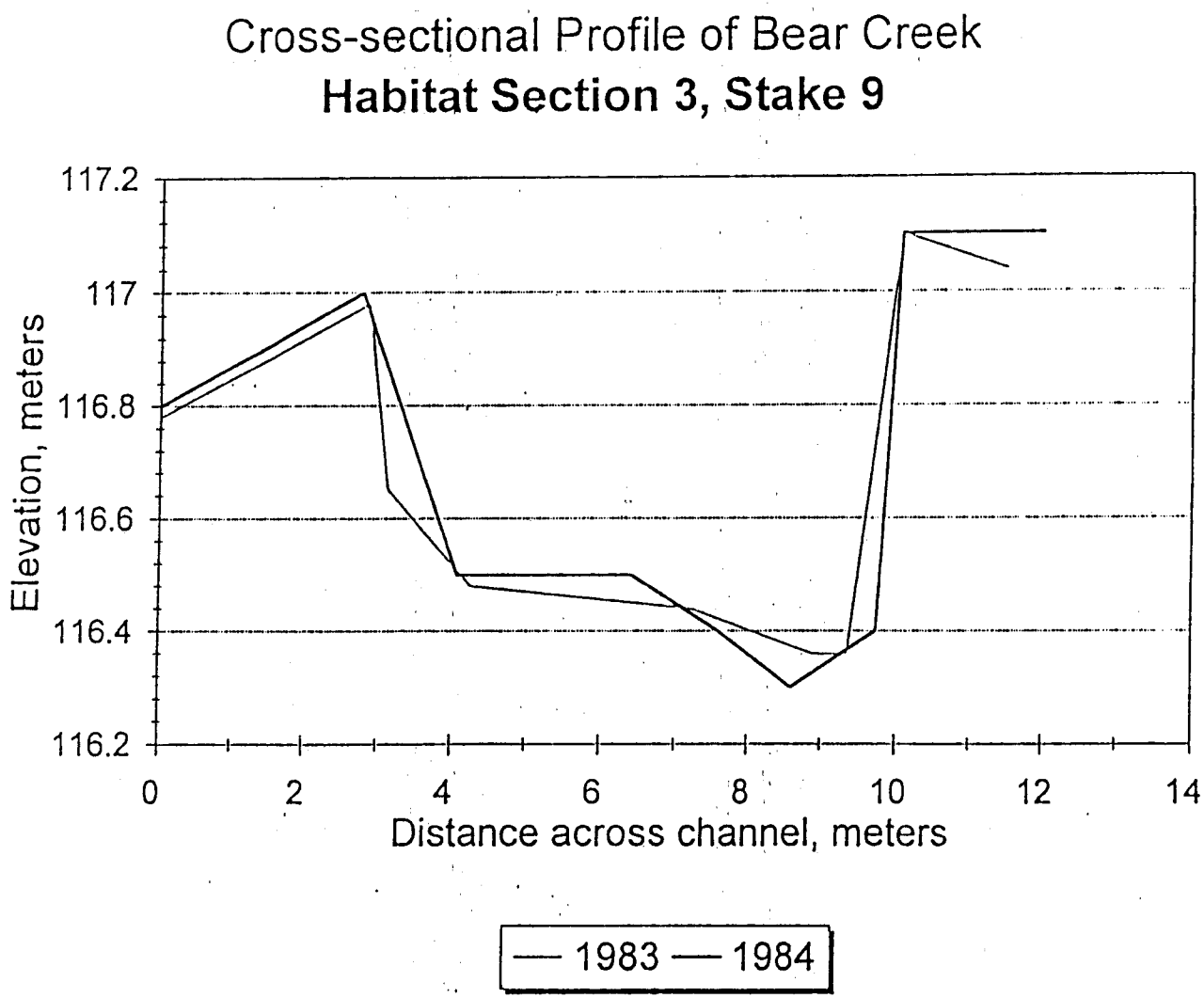

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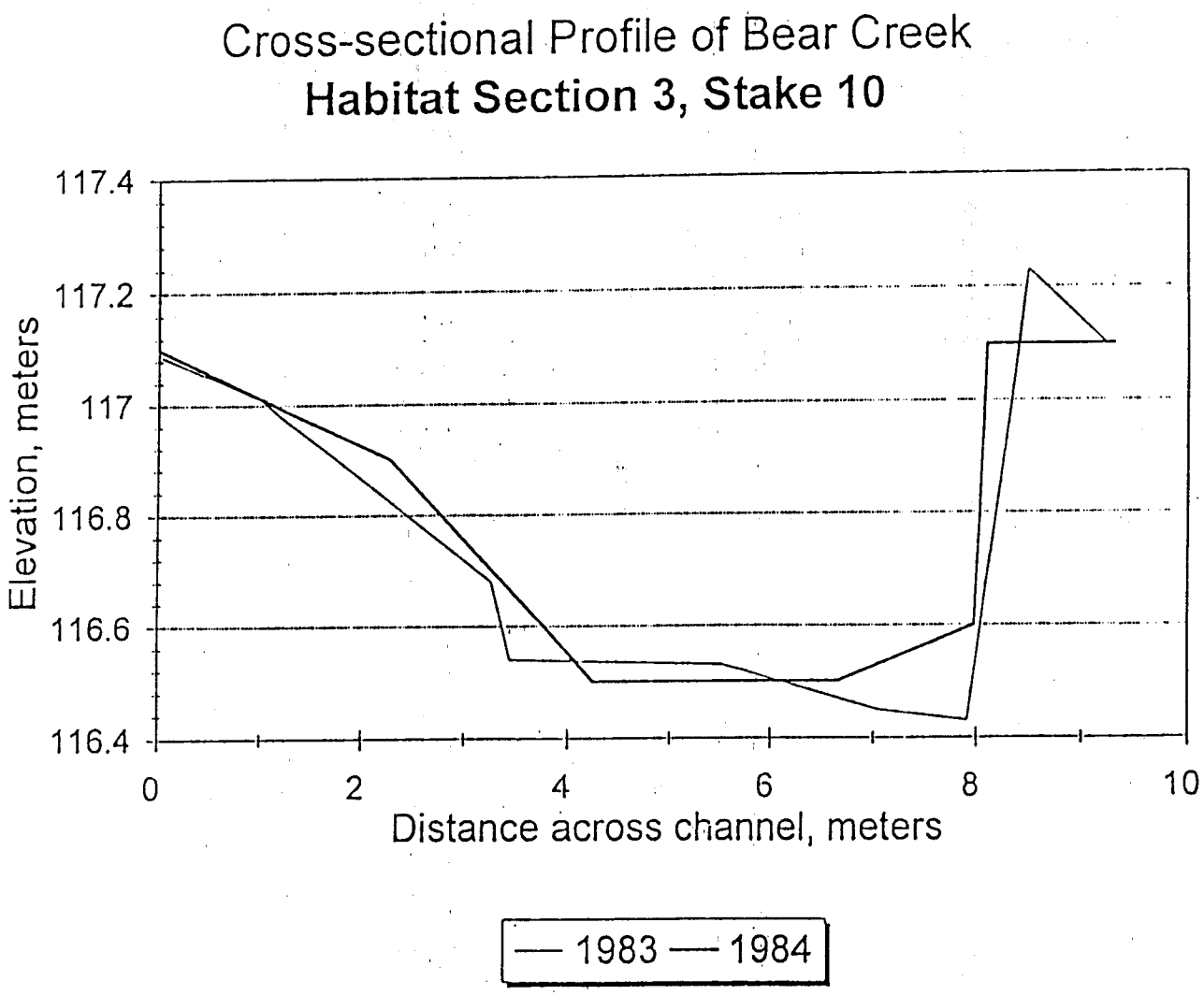

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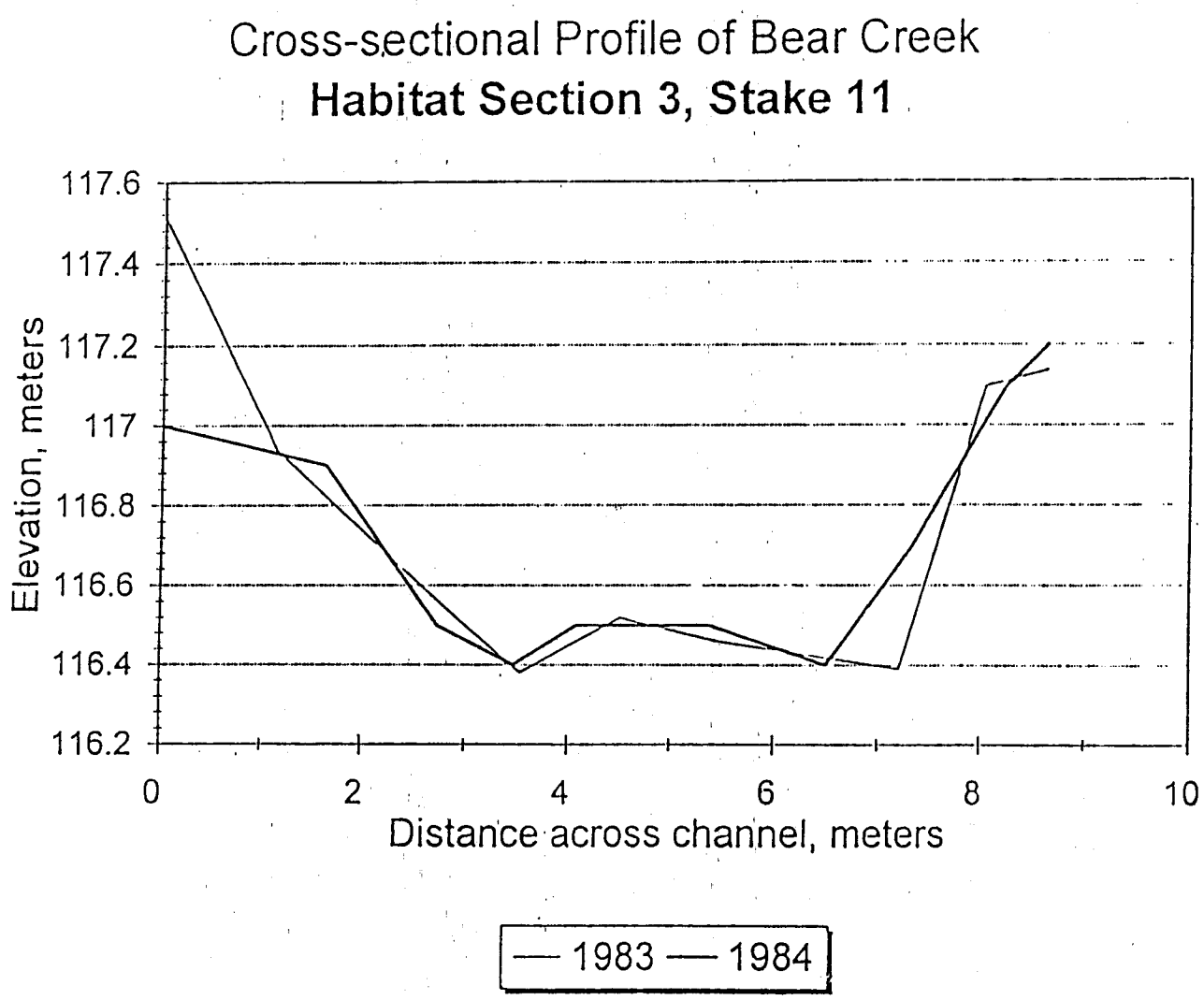

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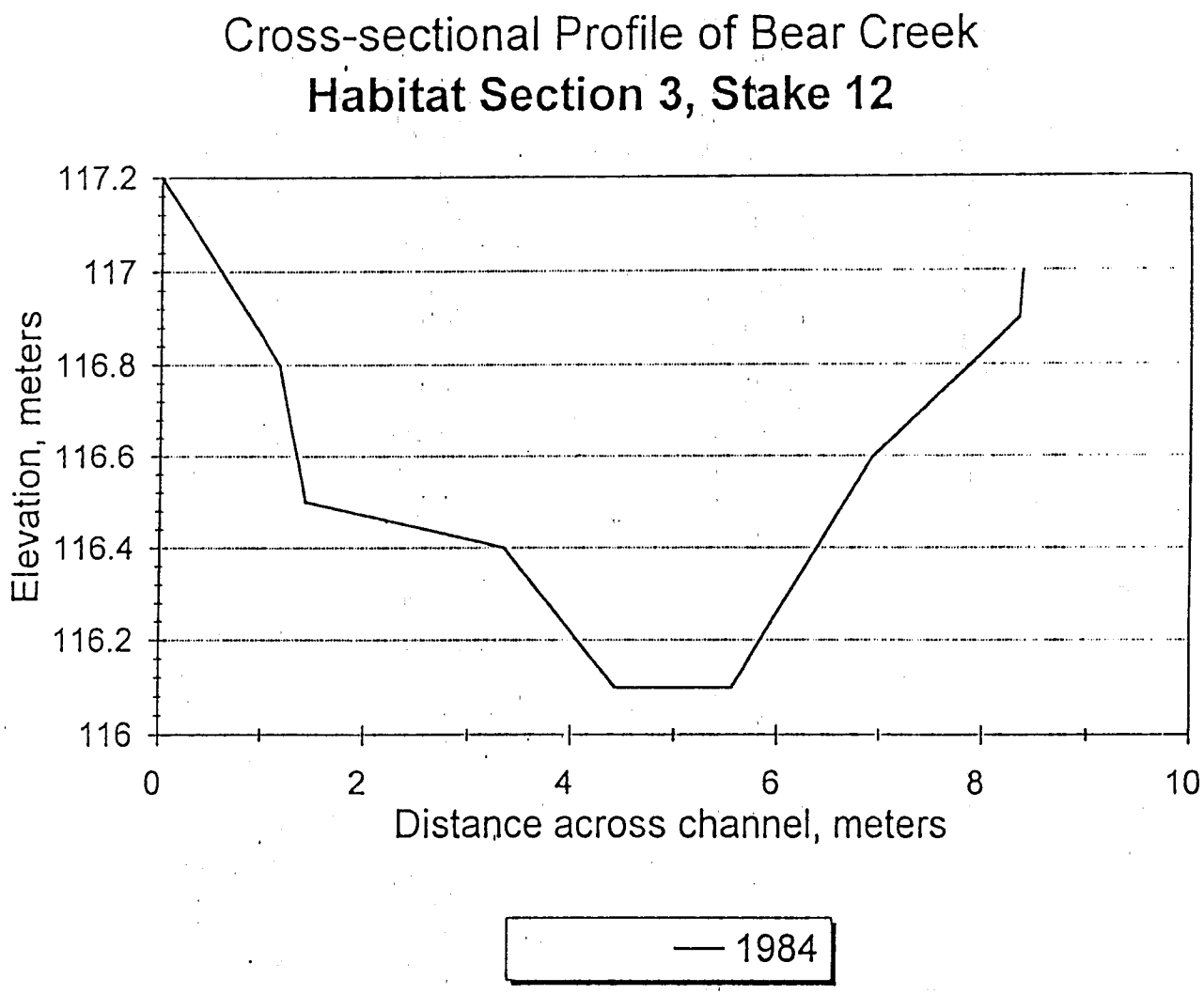

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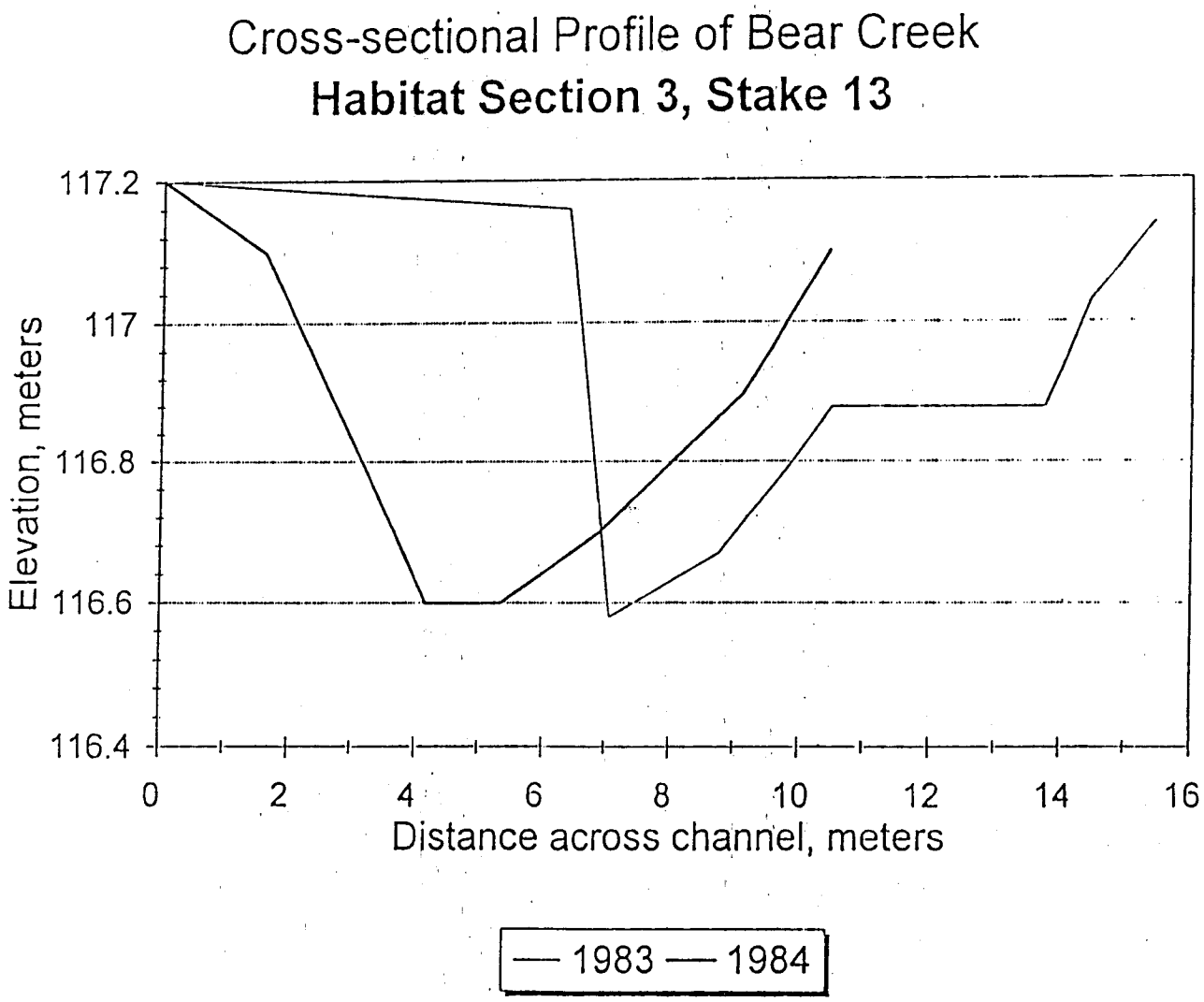

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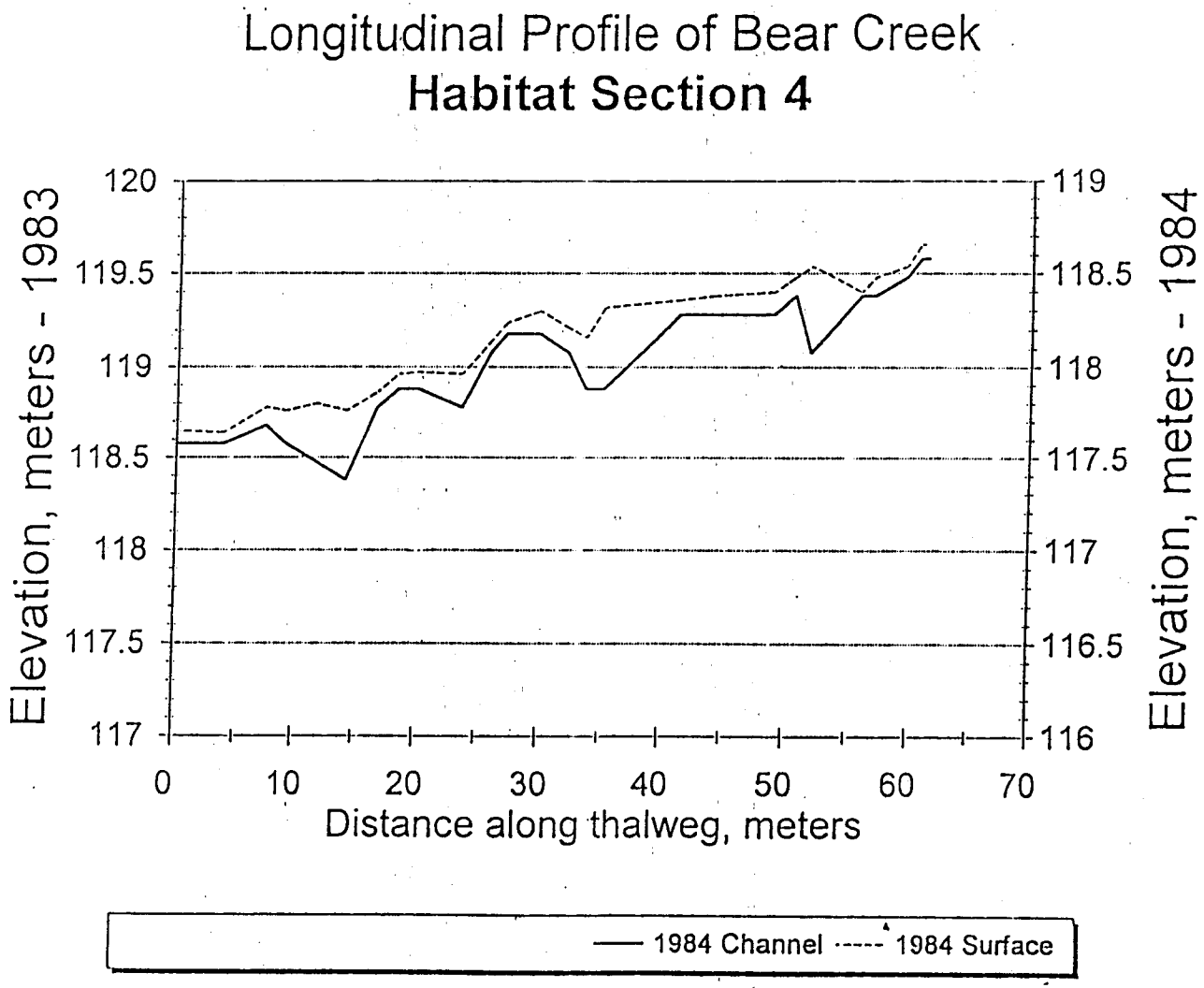

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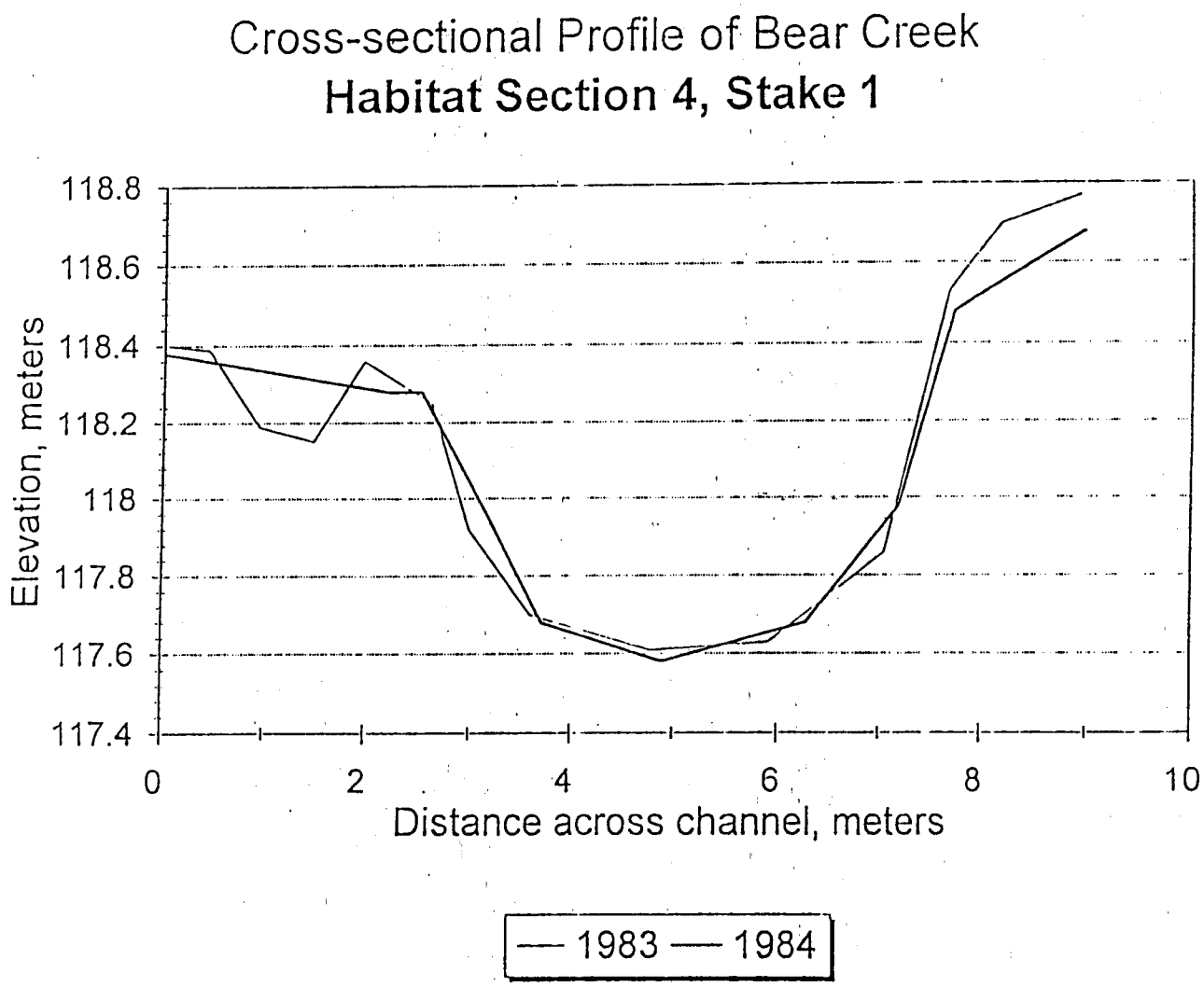

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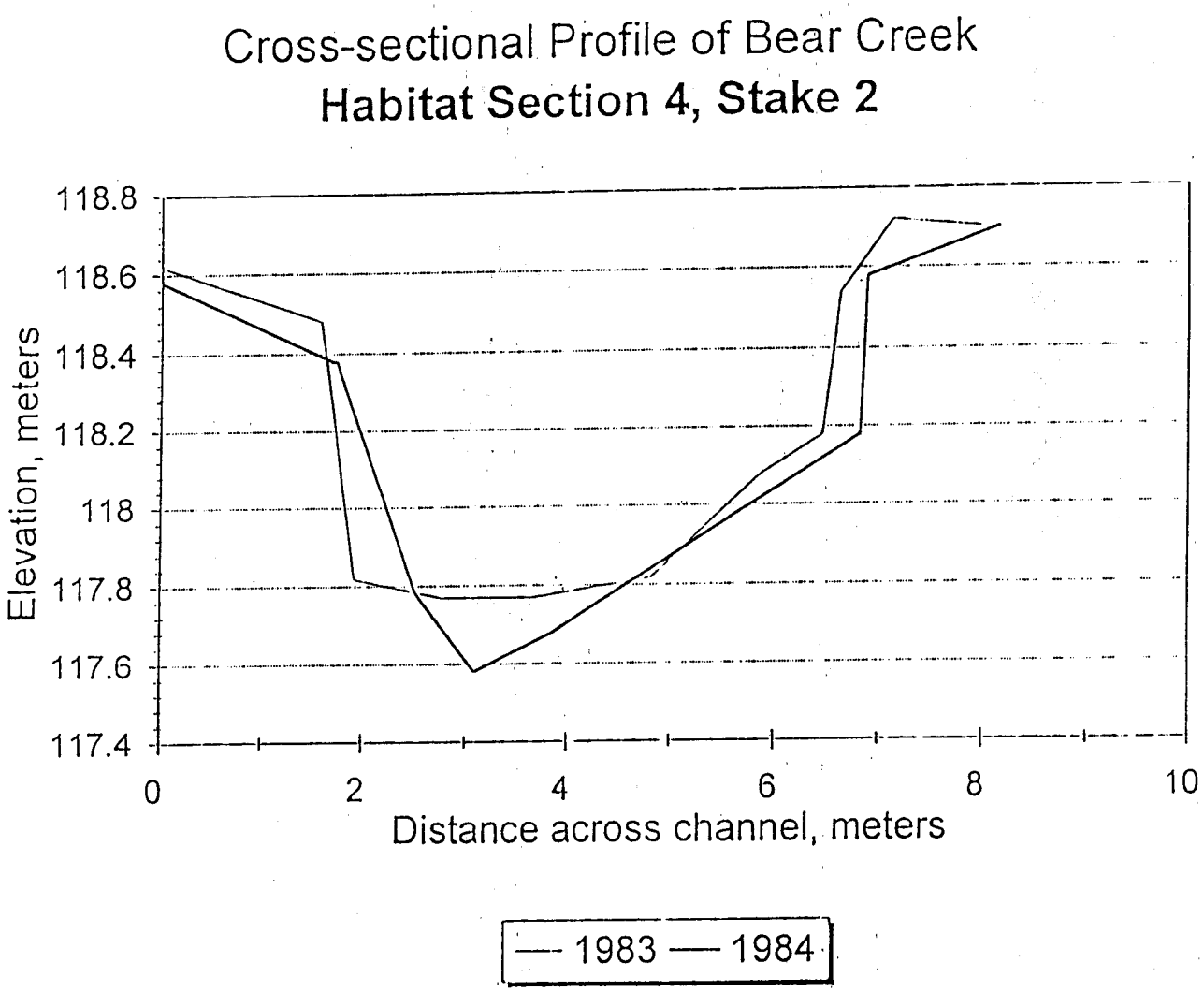

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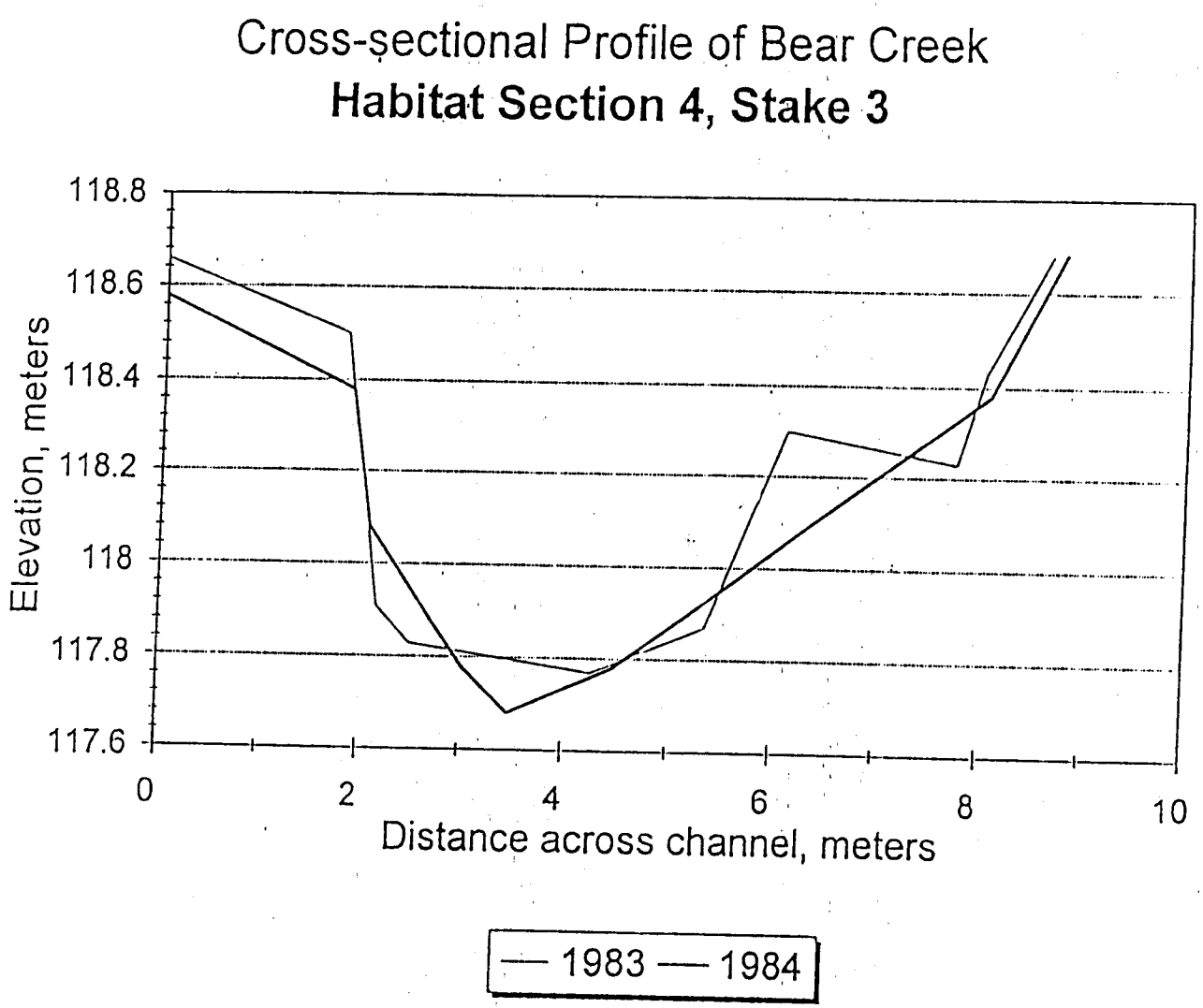

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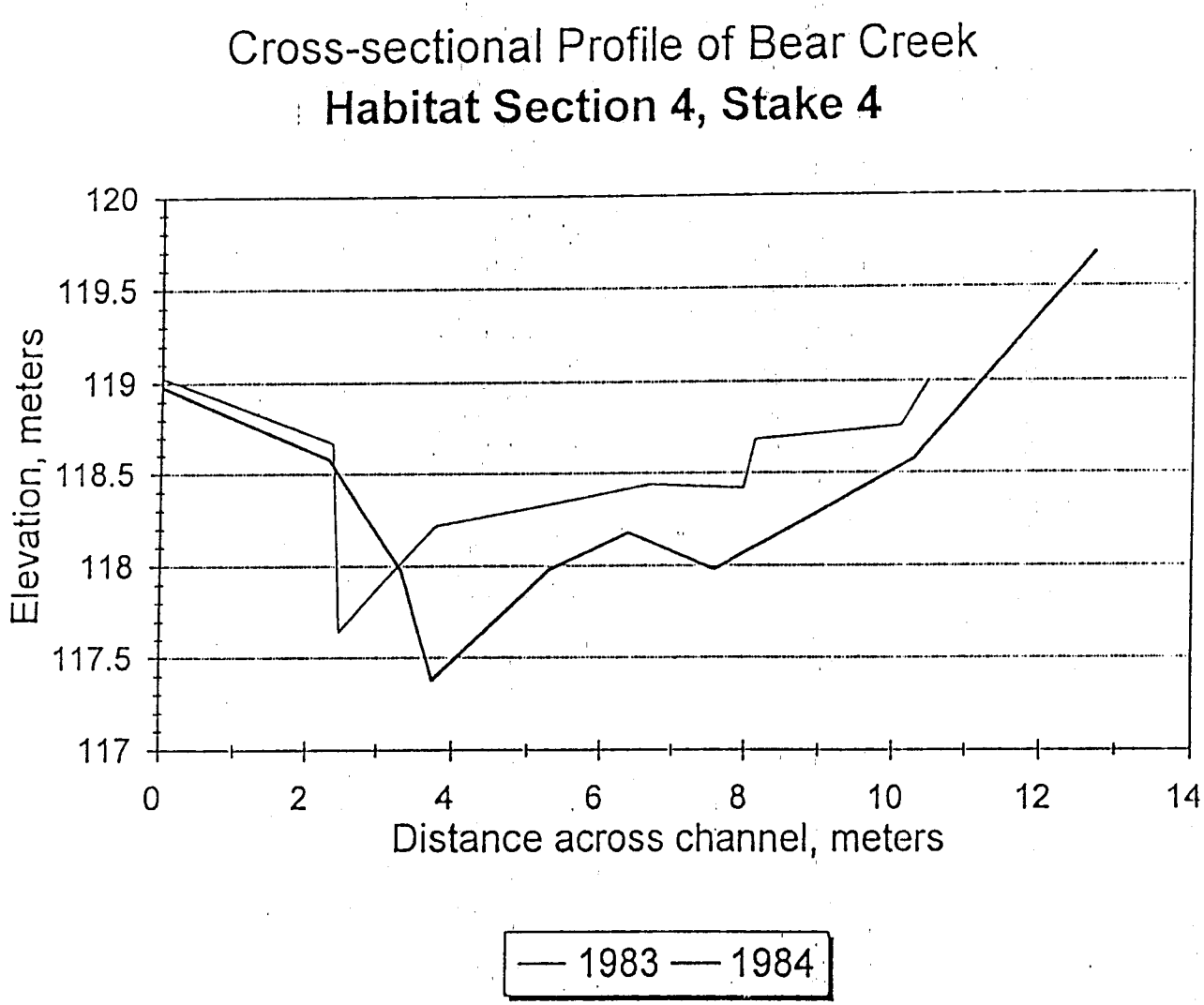

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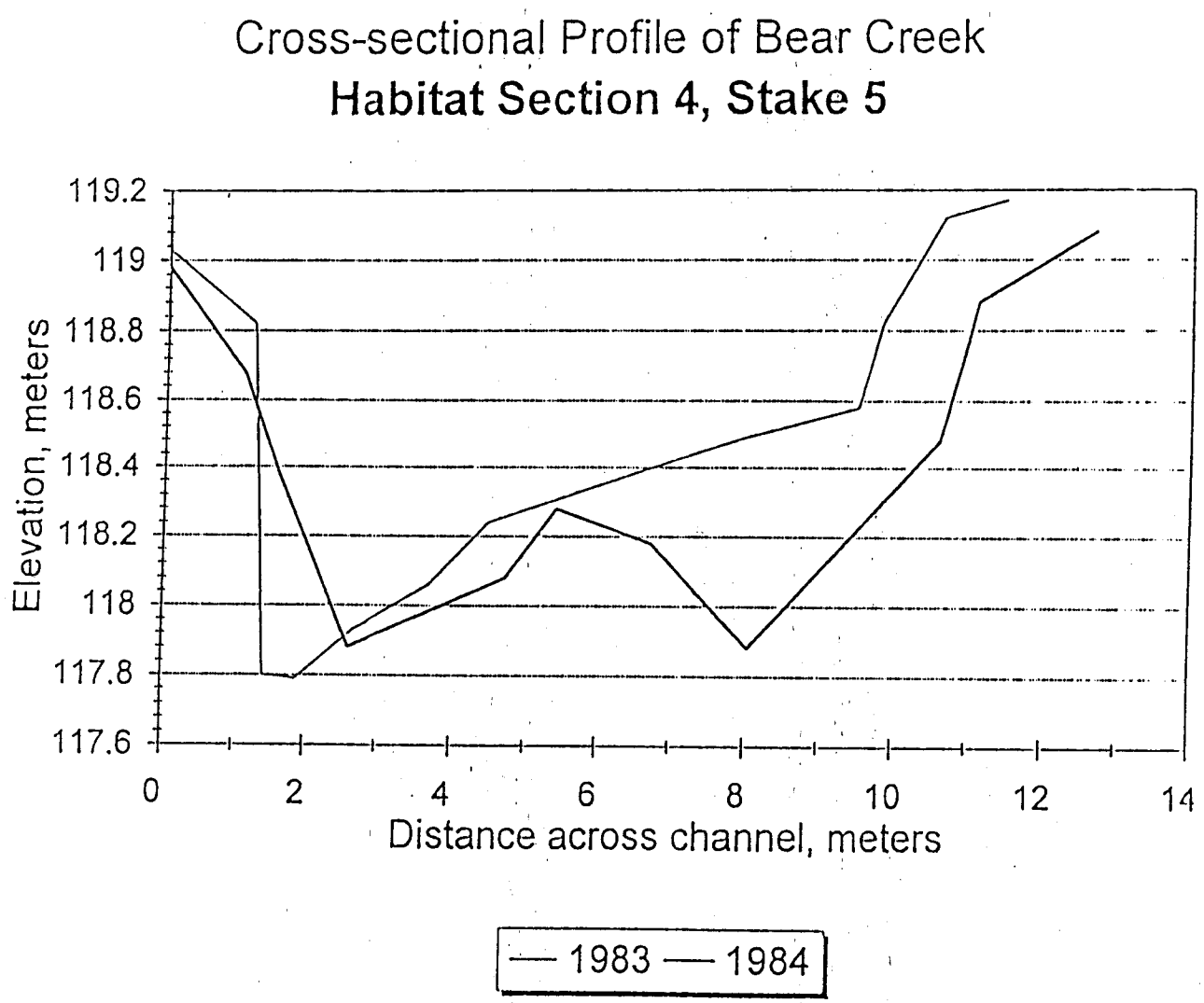

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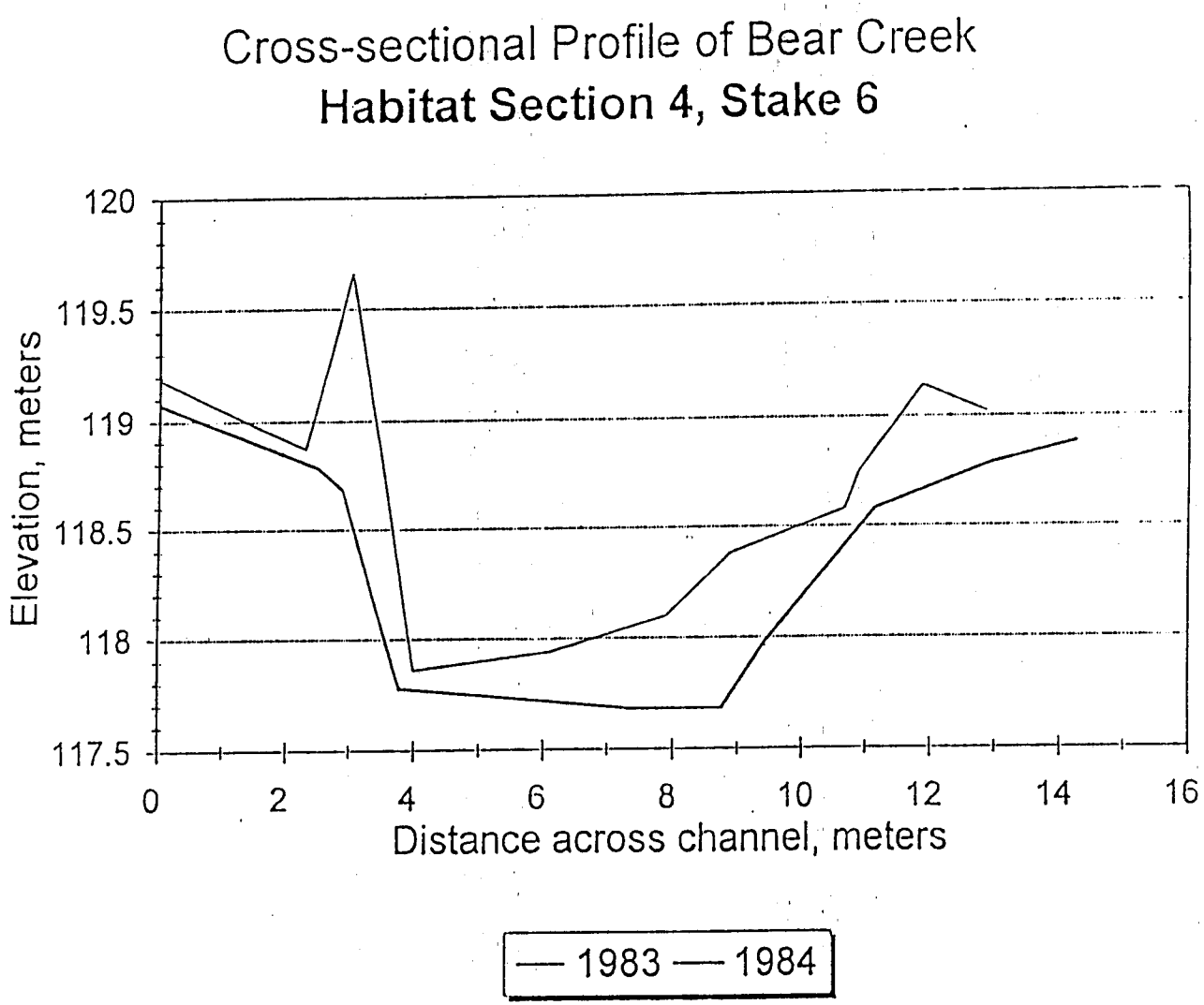

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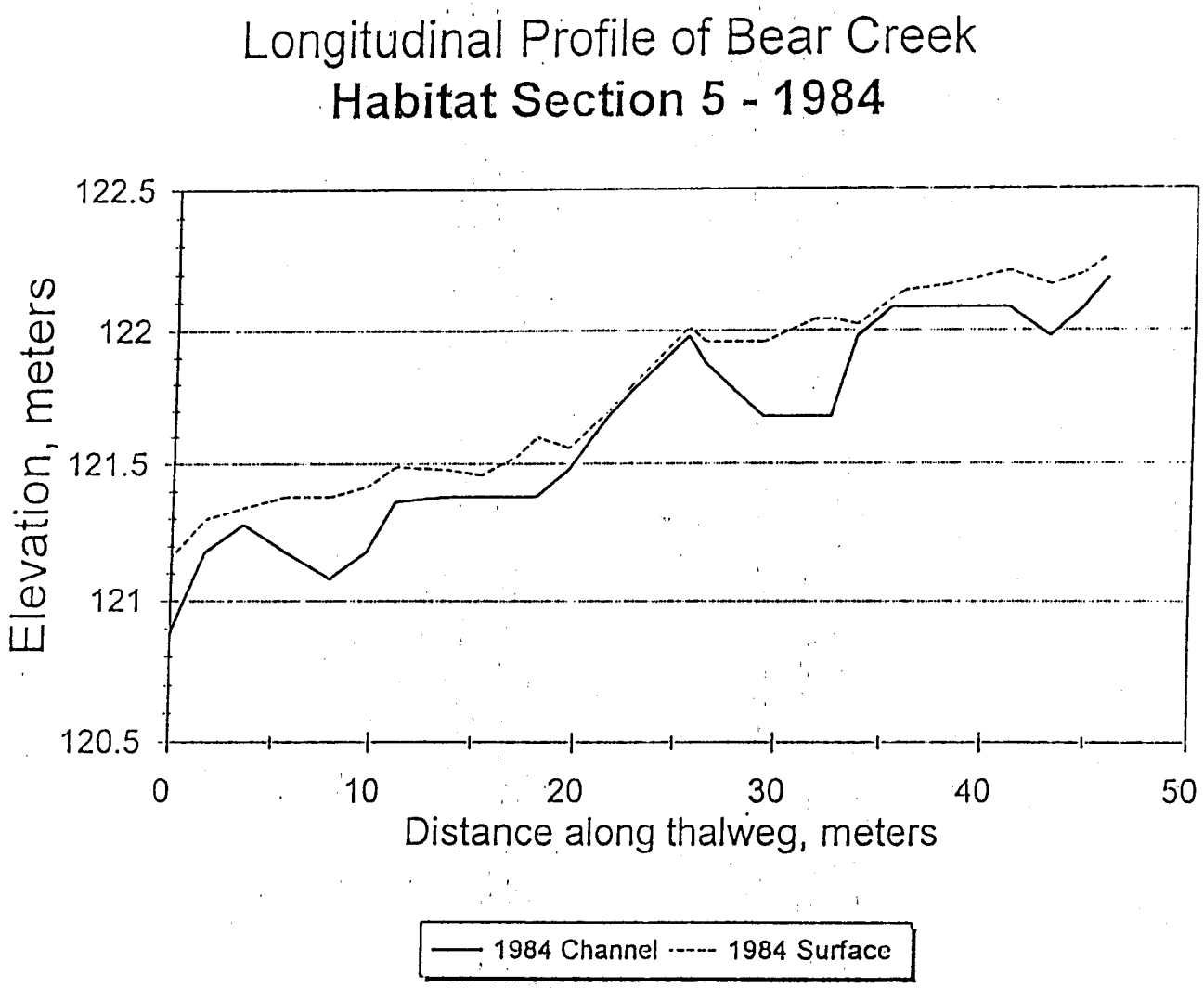

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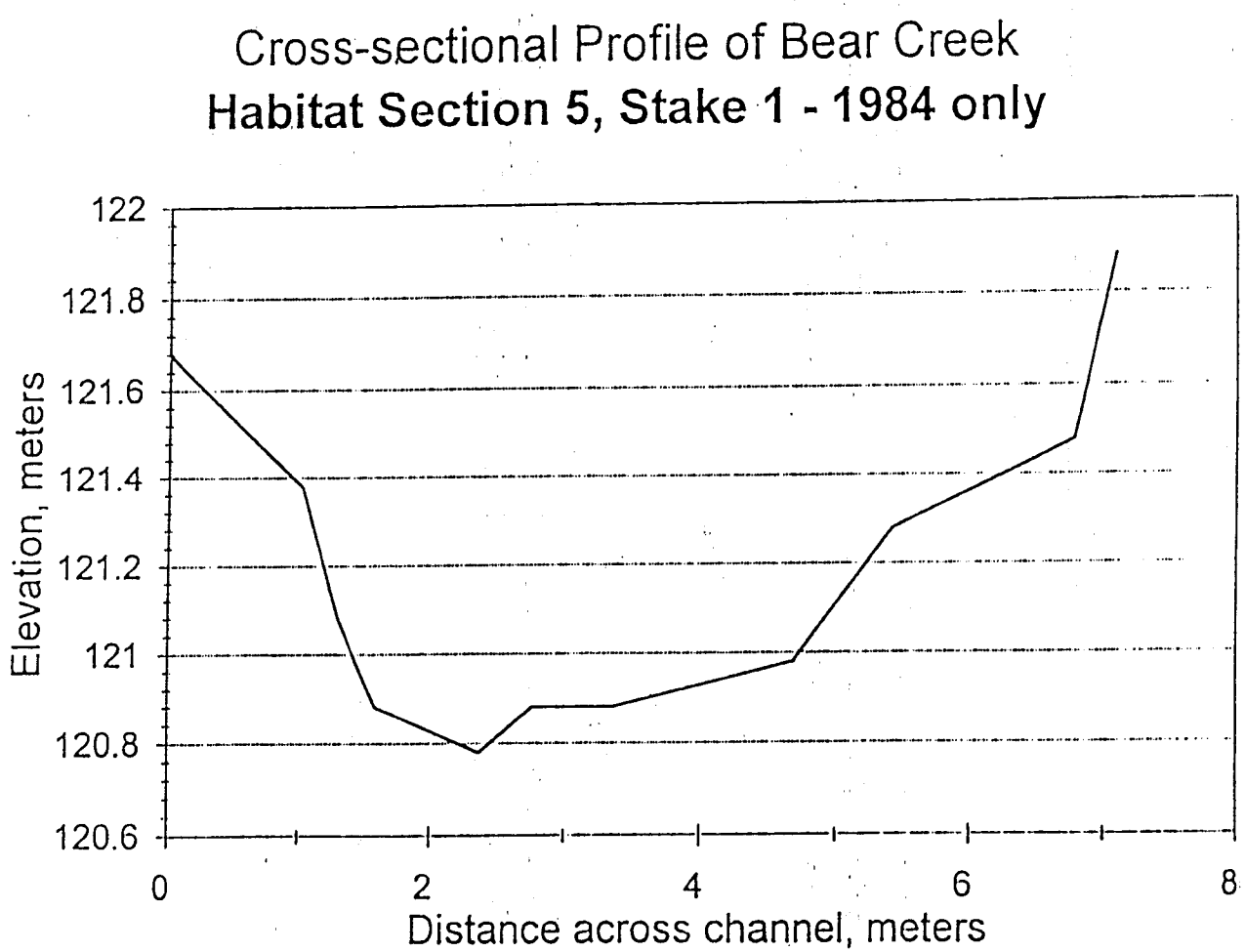

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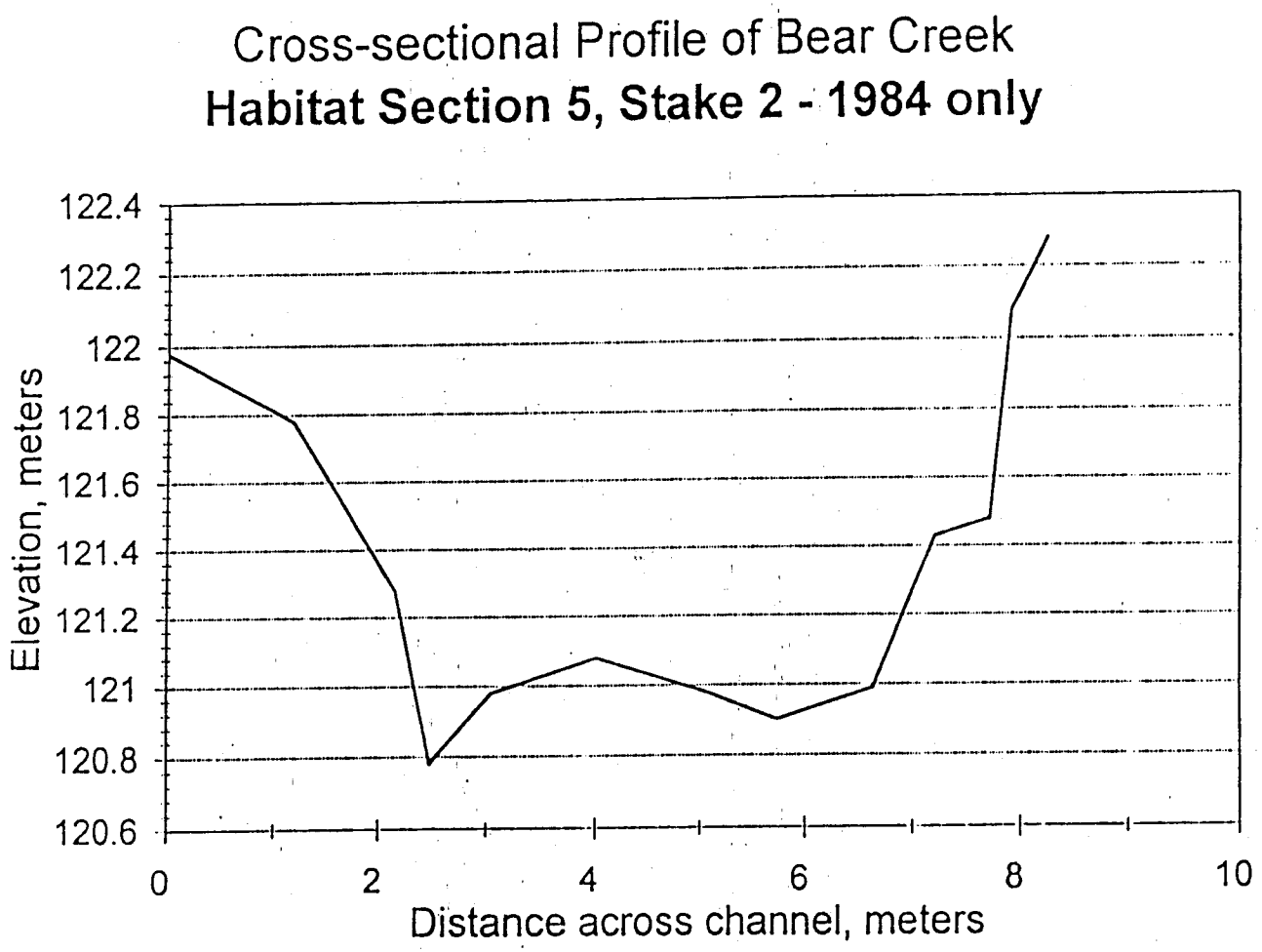

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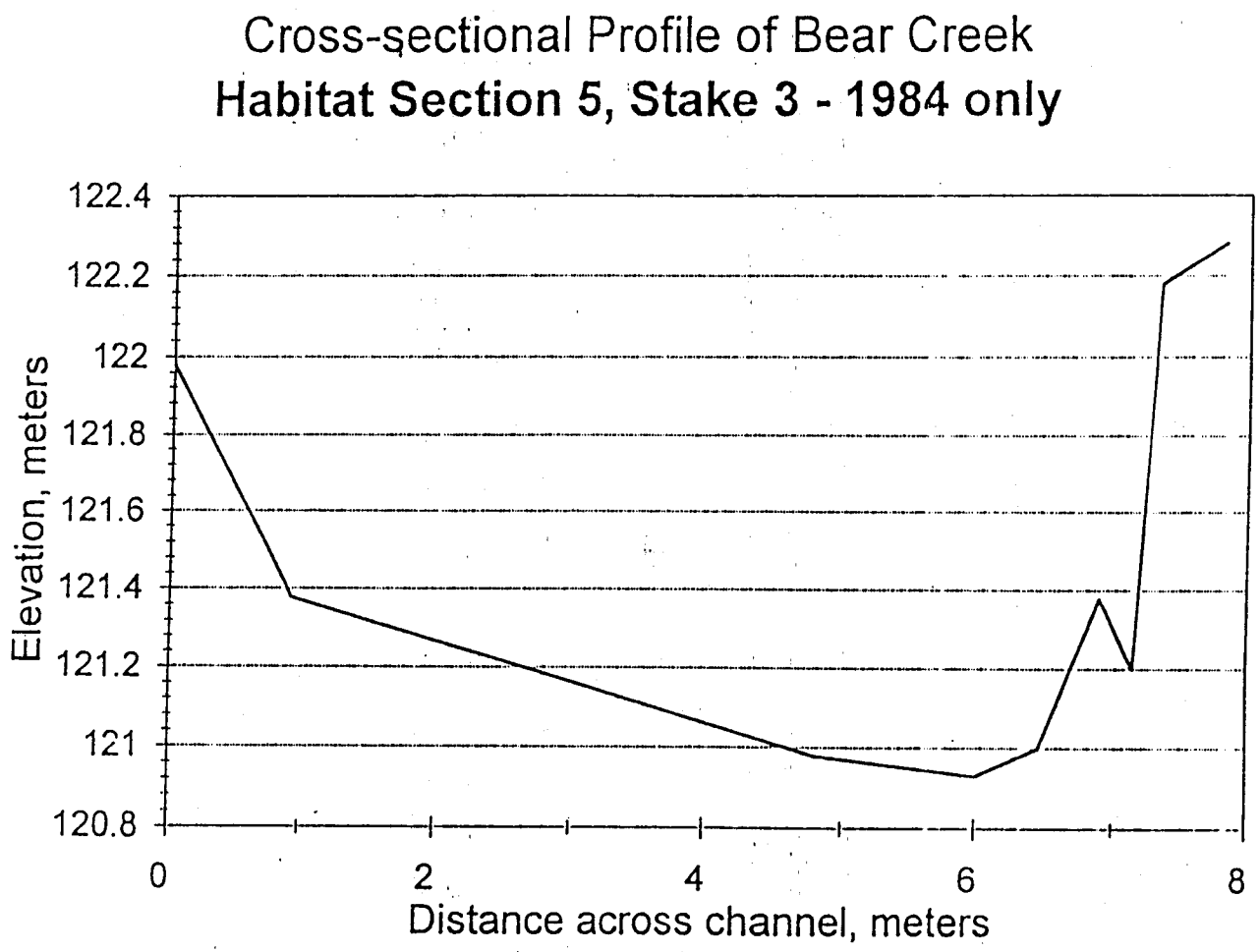

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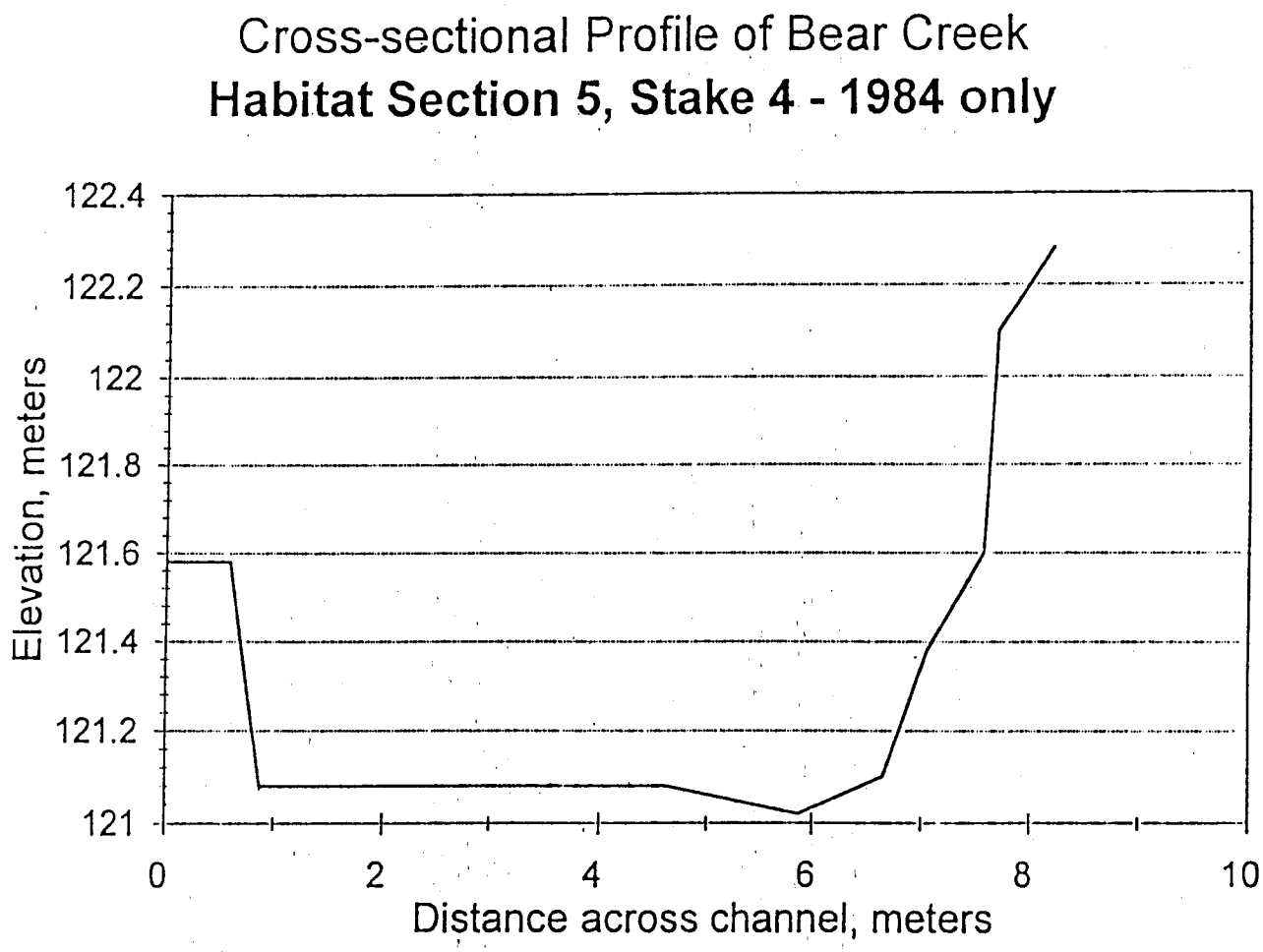

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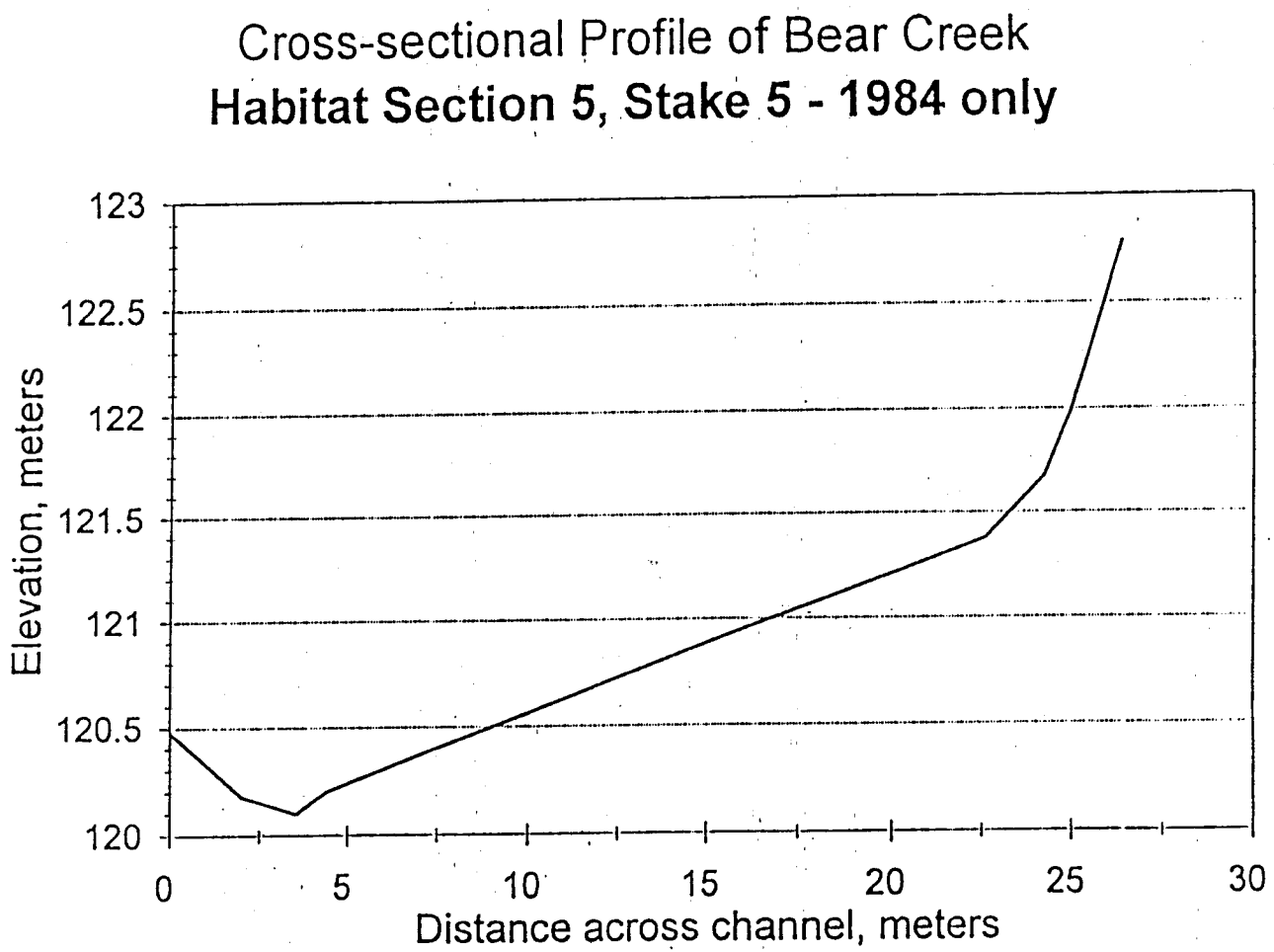

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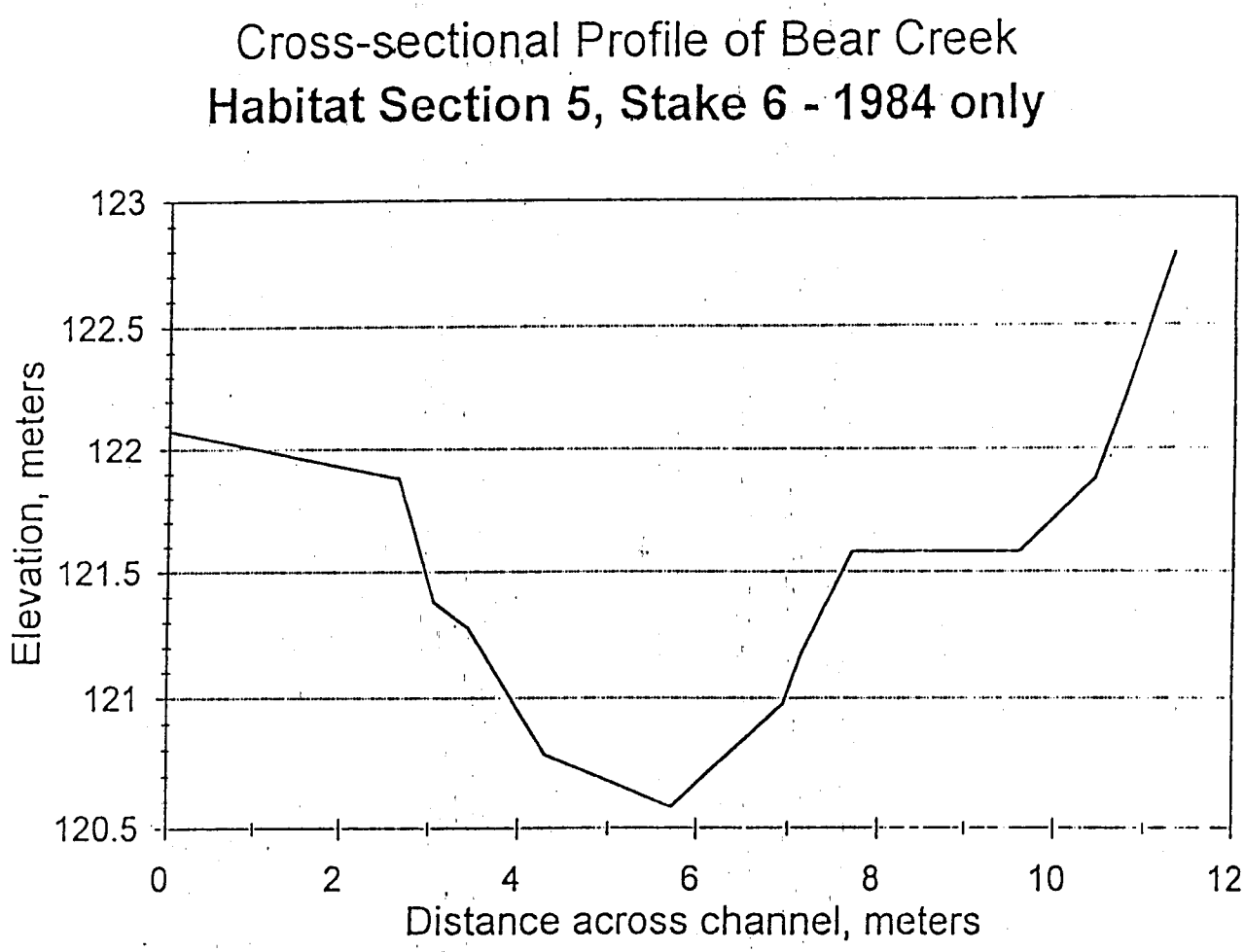

Appendix C. (Continued)