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THE STATUS OF ANADROMOUS FISH HABITAT IN THE NORTH AND SOUTH FORK TOUTLE RIVER WATERSHEDS, MOUNT ST. HELENS, WASHINGTON, 1984

by

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

ABSTRACT

The May 18, 1980 eruption of Mount St. Helens destroyed 218 km (77%) of the 280 km of the fish habitat formerly utilized by anadromous salmonids in the Toutle River drainage. Fishes inhabiting tributaries affected by landslide and mudflow impacts were eliminated. During the summer of 1984, channel morphology, instream cover, riparian vegetation and juvenile salmonid distribution were studied in impacted and unaffected tributaries of the North and South Forks of the Toutle River. These investigations reported: 1) the status of stream channel recovery; 2) the condition of existing salmonid habitat; 3) the condition of instream cover; 4) the status of riparian zone revegetation; and 5) the distribution of juvenile salmonids.

Tributaries of the North Fork Toutle River, downstream from the landslide debris flow, and reaches of the South Fork, inundated by mud flows, have created new channels or re-developed old stream beds to approximately pre-eruption levels. Pre-existing woody debris and riparian timber exposed during this process contributed to rapid channel development and to the formation of preferred fish habitat. Tributaries that had the large woody debris removed exhibited a slower rate of development as evidenced by channel instability, the absence of well-defined pools and a greater incidence of riffles.

The regeneration of riparian trees which promotes channel stability, moderate water temperature and provides large organic debris will ultimately determine the time frame of habitat recovery. The input of large organic debris resulting from riparian trees will occur in less than 50 years in tributaries throughout the lower and middle portions of the Toutle River watershed. The absence of riparian trees on the landslide debris flow and in the upper portions of the South Fork Toutle watershed will substantially retard the recovery of salmonid habitat in these areas.

Juvenile salmonids occur in tributaries throughout the South Fork Toutle River watershed. Tributaries of the North Fork of the Toutle River, except those draining the landslide debris-flow areas, also support wild juvenile salmonids.

KEYWORDS

Habitat category: The basic habitat units which comprise flowing waters including pools, riffles and glides.

Habitat component: Habitat subunits which comprise a habitat category (see below).

Terms and associations used in this report are:

Habitat category	Associated habitat components
Pool	Lateral scour pool, plunge pool, trench pool, dammed pool, backwater pool, and secondary pool.
Riffle	Low gradient riffle, rapids, and cascades.
Glide	Individual subunits were not identified for this category.

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DISCLAIMER

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INTRODUCTION

The Toutle River watershed historically supported large populations of anadromous salmonids, including the steelhead trout *Salmo gairdneri*, coho salmon *Oncorhynchus kisutch* and chinook salmon *O. tschawytscha*, which were of considerable value to the economy of the Pacific Northwest. Wild salmonids also contributed an intrinsic quality to the ecosystem enjoyed by the people in the region.

During the 1940's, salmon and steelhead stocks in the Toutle River system were reported to have been large (Bryant 1951). Waters draining the northern slope of Mount St. Helens and adjacent basins of the Upper North Fork Toutle River valley were among the most productive in the entire Toutle River system. Surveys conducted during this period in tributaries of Spirit Lake and the upper North Fork of the Toutle River revealed that spawning coho salmon were abundant relative to escapements in other lower Columbia River tributaries (Allen et al. 1982). Densities of juvenile salmonids rearing in these streams were high. In the following years, the number of spawners, particularly coho salmon, steadily declined, establishing a record low escapement in 1979.

Wild-stock Toutle River salmon and steelhead populations, unable to sustain the exploitation rates exerted by commercial and recreational fisheries, have been augmented by artificial propagation for the past 30 years. The Toutle River hatchery operated by the Washington Department of Fisheries produced an annual average of 1.4 million coho salmon and 3.2 million fall chinook salmon. Prior to 1969, many Columbia River hatcheries reared and released a strain of coho salmon originating from the Toutle River. Hatchery production of coho salmon, chinook salmon, and steelhead trout produced an annual estimated catch of 251,000 fish valued at more than 12 million dollars. The Washington Department of Game annually released approximately 240,000 winter and summer run steelhead smolts into the Toutle River system (Cowlitz County Dept. of Community Development 1983). Adult returns from these plants and those derived from natural production in the Toutle River watershed sustained a sport fishery which consistently ranked among the best in Washington (Schuck and Kurose 1982). Anglers throughout the Pacific Northwest generally considered the Toutle to be one of the premier salmon and steelhead rivers in the region.

The eruption of Mount St. Helens on May 18, 1980 devastated fisheries resources in the North and South Fork Toutle River watersheds. Tributaries in the upper portions of the North Fork Toutle River basin, including those entering Spirit Lake, were completely destroyed. A massive landslide-debris-flow resulting from the largest slope failure known during the earth's recorded history, traveled 21.7 km (13.5 miles) down the North Fork Toutle Valley. Deposition of debris flow buried 59 km^2 (23 square miles) of terrain to an average depth of 46 meters (150 ft.), including more than 43.4 km (27 miles) of river and tributary streams previously accessible to anadromous salmonids. Ground-hugging flows of gas and rocks approaching 360^oC (680^oF) and traveling at speeds as high as 354-402 km (220-250 miles) per hour leveled everything within a 180^o sector north, east, and west of the mountain 556 km^2 (215 square miles). This area included the upper 14.5 km (9 mi) of the North Fork Toutle River watershed. As hot pyroclastic debris melted snow and glacial ice on the upper slopes of Mount St. Helens, lithic avalanches raced down the upper reaches of the North and South Toutle River valleys, locally reaching velocities up to 160 km/h (100 mi/h). As the speed of these masses decreased away from their sources, avalanches changed into mudflows which abraded and inundated approximately 56 km (34.9 miles) of river and tributary accessible to anadromous salmonids in the South Fork Toutle River system and

43 km (26.6 miles) in the North Fork Toutle drainage.

Following the eruption of Mount St. Helens, several studies evaluated the status of anadromous salmonid populations and habitat in the North and South Forks of the Toutle River watershed. Bisson et al. (1984) assessed existing habitat and coho salmon rearing capability for an affected stream. Based on their results, the investigators concluded that poor habitat conditions, specifically a low proportion of pool area and scarce instream cover, existed as a consequence of mudflow impact. Furthermore, the absence of suitable overwinter habitat may have accounted for the low number of coho smolts produced in the spring. Martin et al. (1984) determined that the overwinter mortality of juvenile coho, in mudflow and landslide debris flow affected streams, was associated with poor channel stability and incidental instream cover provided by large organic debris. Martin et al. (1984) concluded that the time of regeneration of riparian trees, which provide instream cover in the form of large organic debris for tributary streams and mainstem rivers, will be the limiting factor for complete habitat recovery in the Toutle River watershed.

Comprehensive studies conducted in the North and South forks of the Toutle River watershed following the eruption identified the environmental components limiting natural production of anadromous salmonids. These studies determined the most probable course of natural restoration, and estimated the time frame for recovery. Considering the potential value of fisheries resources and the unprecedented nature of this event during recorded time, substantiation of the recovery process was considered necessary.

STUDY DESIGN AND OBJECTIVES

Following the May 18, 1980 eruption, the Fisheries Research Institute conducted an extensive study examining the status of anadromous salmonid populations and their habitat in representative locations throughout the Toutle River watershed (Martin et al. 1984). The results of this investigation included: 1) a post-eruption evaluation of stream morphology, including channel configuration, stability and developmental characteristics for tributary streams which experienced various types and intensities of adverse impacts; and 2) the quantification of parameters comprising anadromous salmonid habitat including water depth, velocity and the presence of instream and streamside cover in tributary streams selected for study. The condition of anadromous salmonid populations and their habitat in the Toutle River watershed was studied for two years following the eruption. These investigations served as a baseline for ensuing studies, including this one.

The present study started in June of 1984 and was completed in June, 1985. Field studies began with a survey examining affected tributary streams of the North and South forks of the Toutle River previously utilized by anadromous salmonids, including some formerly studied (Martin et al. 1984). Each stream was inspected to assure that its present condition and any post-eruption recovery were the results of natural processes. Inspections involved the location of previously established study reaches delineated by survey stakes (Martin et al. 1984). Representative reaches of affected and unaffected (control) streams reflecting existing conditions in the North and South forks of the Toutle River were selected (Tables 1 and 2; Figure 1). Study objectives were to: 1) determine the status of stream channel recovery as it relates to anadromous salmonid habitat, including an examination of

Table 1. Investigations conducted in selected affected and unaffected tributaries of the North and South Forks of the Toutle River (1984).

Stream	Distance from mouth of Toutle River (km)	Impact	INVESTIGATIONS PERFORMED				
			Channel morphology	Habitat assessment	Cover evaluation	Riparian zone revegetation evaluation	Juvenile salmonid distribution
North Fork Toutle							
Lower Wyant Cr.	26.5	Mudflow	X	X	X	X	X
Upper Wyant Cr.	26.5	None		X	X		
Alder Cr.	46.0	None		X	X		
Upper Deer Cr.	52.0	Scorch/mudflow					X
Hoffstadt Cr.		Mudflow		X			
Bear Cr.	54.0	Landslide debris flow					X
Maratta Cr.	66.5	Landslide debris flow	X	X	X	X	X
Castle Cr.	66.0	Landslide debris flow				X	X
Coldwater Cr.	67.0	Landslide debris flow					X
South Fork Toutle							
Herrington Cr.	53.0	Mudflow	X	X		X	X
Unnamed Cr.	58.0	Mudflow					X
Unnamed Cr.	57.5	Mudflow					X
Goat Cr.	61.3	Mudflow	X	X	X	X	X

Table 2. Physical descriptions of affected and unaffected study streams in the North and South Fork Toutle Rivers 1981, 1982 and 1984.

Stream	Impact	Gradient percent	Stream order	Elevation (m)	Low flow area (m^2) 1981	'82	'84	Area of drainage basin above study reach (Km^2)	Distance from mouth of Toutle R. (Km)	Length of study reach (m)
North Fork Toutle										
Maratta Cr.	Landslide debris flow	2.13	4	650	NA	NA	976	9.8	66.5	300
Alder Cr.	None	.57	4	274	1356	1397	1972[1]	30.9	46.0	240[2]
Lower Wyant Cr.	Mudflow	.46	4	143	1456	1266	1355	31.3	26.5	300
Upper Wyant Cr.	None	.33	4	149	1616	1707	1725	30.3	26.5	310
South Fork Toutle										
Goat Cr.	Mudflow	3.68	4	600	NA	NA	2514	28.7	61.3	300
Herrington Cr.	Mudflow	1.24	3	375	1277	1767	NA	8.8	53.0	300

1. Representative study reach was relocated approximately 125 meters downstream and was approximately 300 meters in length.

2. Length of study reach in 1981 and 1982.

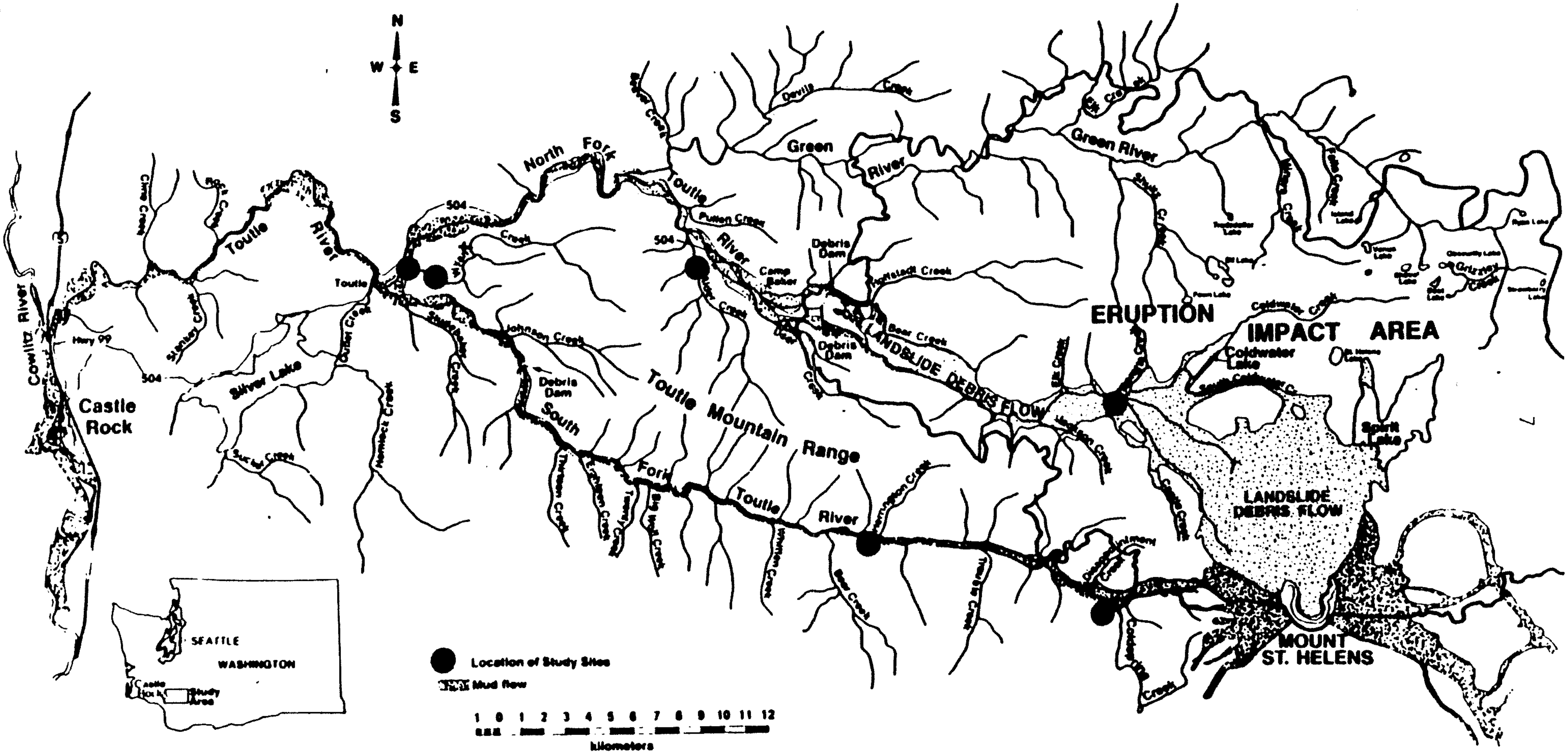

Figure 1. Post-eruption map of Toutle River drainage showing location of study sites and areas of impact.

channel configuration, stability and development; 2) assess the condition of existing anadromous salmonid habitat including quantification of specific habitat types; 3) evaluate existing instream cover; 4) establish the condition of riparian zone revegetation; and 5) document the distribution of wild juvenile salmonids.

METHODS AND MATERIALS

Channel Morphology

Channel morphology was described by longitudinal and planimetric profiles of stream thalweg for two tributaries of the North Fork Toutle River and two tributaries of the South Fork Toutle River. Ground survey measurements were conducted during the summer low-flow period in 1984. A theodolite and electronic distance meter possessing an accuracy of +1 cm were used. Polar coordinates converted to rectangular coordinates allowed data to be plotted to scale by a graphics plotter at the University of Washington, Academic Computer Center.

Reference stakes placed at each study site in 1981 by the Fisheries Research Institute facilitated the collection of replicate measurements in 1982 and were again utilized in 1984 in Lower Wyant and Herrington creeks. New sections were established in Goat Creek and Maratta Creek. All study sections were approximately 300 meters in length.

Habitat

Anadromous salmonid habitat preferences, demonstrated by different age groups of each species, include selected water depth and velocity.

An assessment of existing habitat was completed, utilizing a stream habitat definition technique which combines living space requirements with fluvial geomorphology (Bisson et al. 1981).

Habitat components were inventoried during the low-flow period in four affected and two unaffected reaches selected from three tributary streams of the North Fork Toutle and two tributary streams of the South Fork Toutle River. Habitat measurements for Hoffstadt Creek, a tributary of the North Fork Toutle, and Herrington Creek, a tributary of the South Fork Toutle, were provided by the Weyerhaeuser Company (Appendices 1 and 2). All study reaches were approximately 300 meters long. Individual study reaches were surveyed on foot and data recorded based on the criteria provided in Appendix 3. Width, depth and length measurements were collected for each specific habitat component. Habitat evaluations expressed the length, area and volume of each habitat component as a percentage of the total habitat present for each representative tributary reach. Habitat evaluations also expressed the percentage of each habitat component and habitat category (pool, riffle and glide) associated with a particular substrate or cover structure (e.g., rootwads, boulders, etc.). Computations were produced, at the Weyerhaeuser Company's Research and Technology Center, Federal Way, Washington.

Cover

Anadromous salmonid cover preferences include selected substrate, water turbulence, bank morphology, wetted riparian vegetation and organic debris. Excluding Herrington Creek, cover studies coincided exactly in time and location with morphological habitat investigations. Individual cover items positioned instream and in channel (within channel boundaries but not wetted during low-flow periods) were identified and evaluated for each tributary reach in accordance with criteria provided in Appendix 4.

Riparian Vegetation

The status of riparian vegetation recolonization along affected tributaries of the North and South forks of the Toutle River was determined during August and September of 1984. Foot surveys were conducted over 300 meter representative reaches of three North Fork Toutle and two South Fork Toutle River tributaries. Riparian vegetation assessments included:

1. estimates of percent habitation by each of four cover categories (over water, grass/forb, shrubs, tree crown) within three meters of channel bankfull; and
2. estimates of percent habitation by each of four vertical cover categories (grass/forb, less than 1 meter, 1 to 4 meters, greater than 4 meters) within 30 meters of channel bankfull.

The revegetation of stream banks and the restoration of riparian trees was examined due to the influence each assemblage exerts on the development and subsequent maintenance of salmonid habitat.

Juvenile Salmonid Distribution

The recolonization of affected tributaries in the North and South Fork Toutle River watersheds by wild salmonids was determined during July, August, and September of 1984. Upper Deer Creek, which experienced ash fallout and scorched riparian vegetation, was also examined. Representative reaches of nine streams from 90 to 1800 meters in length were surveyed visually or sampled with a type VII Smith Root portable electroshocking unit. Captured individuals were identified to species and lengths recorded to the nearest millimeter. Records describing juvenile coho salmon introductions into tributaries of the Toutle River watershed were provided by the Washington Department of Fisheries.

RESULTS

Channel Morphology

Morphometric surveys conducted in 1984 indicated that channel stability and stream bottom topography in Lower Wyant Creek (Figure 2) closely resembled those parameters examined during 1981 and 1982 in Alder Creek, Devils Creek, and Upper Wyant Creek, tributaries unaffected by volcanic activity (Figure 3). There was very little thalweg sinuosity in Lower Wyant Creek (Appendix 5). Stream channel topography in unaffected tributaries is characterized by a constant pool/riffle succession and stable channel banks supported by normal riparian vegetation. During the eruption, Lower Wyant Creek was inundated by mudflow deposits ranging from 3 to 5 meters in depth (Janda et al. 1981). Surveys conducted in November of 1980 characterized Lower Wyant Creek as very shallow (<20 cm deep), without a defined channel, flowing through stands of dead alder and accumulations of woody debris. Observations made in July of 1981 indicated a channel, characterized by an alternating shallow pool and riffle profile, had been cut into the mudflow. Flow modulation structures including large organic debris and standing dead timber were abundant. Continued degradation produced substantial increases in channel width and depth by summer 1982.

Herrington Creek has experienced marked development since 1981, and in 1984 appeared to have a fundamentally stable channel. Extensive mudflows scoured the South Fork Toutle River valley, effectively removing organic debris and riparian vegetation, and altering the courses of many streams, creating new terrace tributaries. Terrace tributaries in this area parallel the mainstem for some distance before their confluence with the South Fork Toutle River.

Diversity in channel topography has clearly appreciated in Herrington

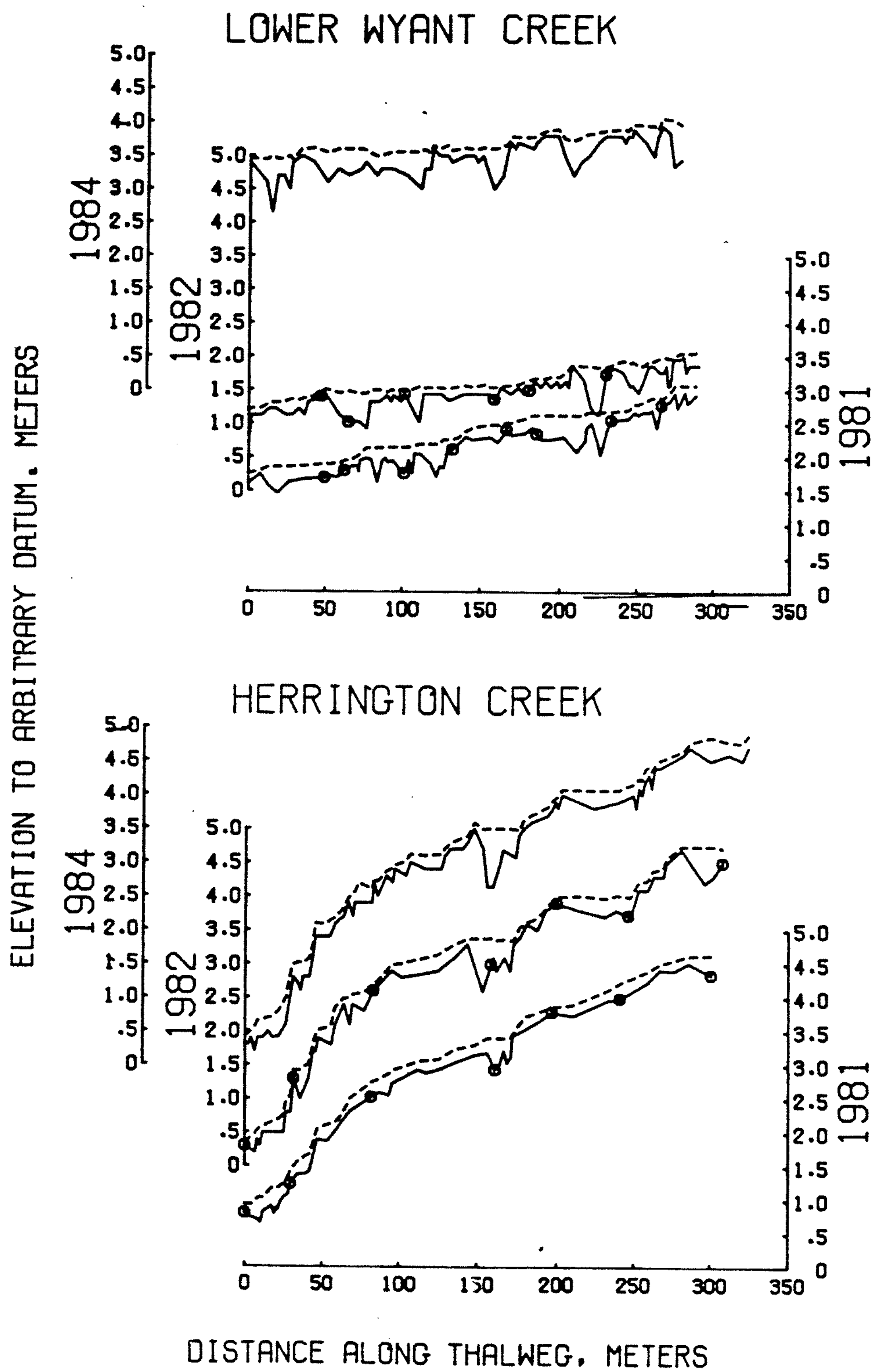

Figure 2. Longitudinal profiles of stream thalweg for Lower Wyant Creek and Herrington Creek during summer low flow periods in 1981, 1982 and 1984. Circles denote the approximate locations of channel cross-sections (Martin et al. 1984). Dashed lines represent water surfaces.

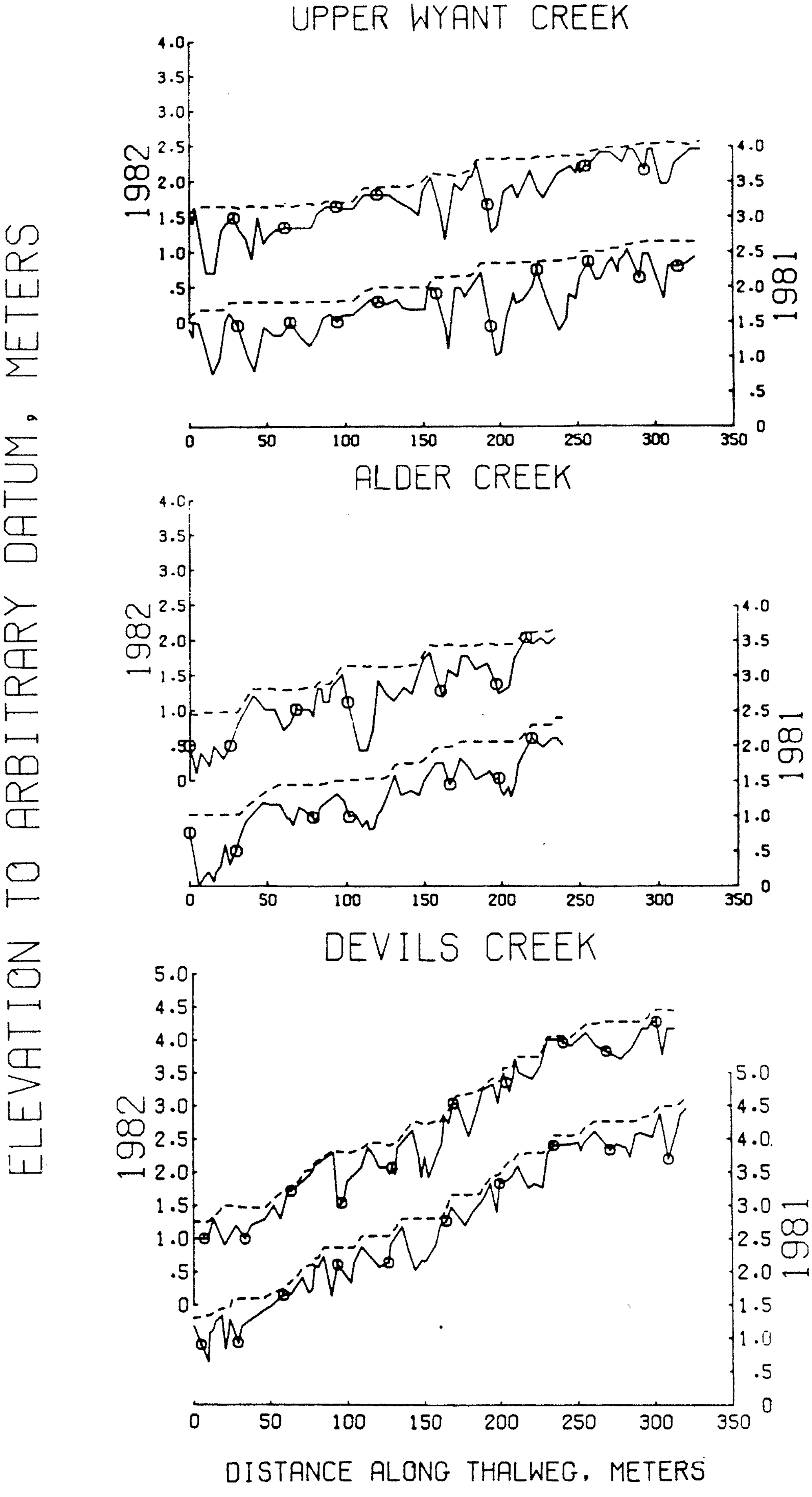

Figure 3. Longitudinal profiles of stream thalweg for unaffected tributaries in the Toutle River watershed during summer low-flow periods in 1981 and 1982. Circles denote the approximate locations of survey cross-sections (Martin et al. 1984). Dashed lines represent water surfaces.

Creek (Figure 2). However, while the number of pools has increased, individual pool size remains quite small. Within the study reach a single pool (160 meters along thalweg) has demonstrated consistent development in size and stability. The only large organic debris exposed within the study section exists at this location. Increased channel gradient is a consequence of headward erosion occurring in the downstream portion (115 meters) of the study section. Stream thalweg measurements indicate sinuosity is very limited (Appendix 6). Channel stabilization has resulted from the armature of stream banks by boulders, a principal constituent in this portion of the mudflow. The recolonization of riparian vegetation has also contributed to channel stability.

Goat Creek, examined during August of 1984, consisted of numerous small pools and limited variation in water depth relative to unaffected tributaries (Figure 4). The portion of Goat Creek upstream approximately 3 kilometers from its confluence with the South Fork of the Toutle River, experienced impacts similar to those sustained by Herrington Creek, resulting in the creation of a new reach of terrace tributary. Vertical channel degradation has deeply incised mudflow substrate from 3 to 10 meters creating small canyons. In some locations, the channel was unstable, migrating horizontally during high flow periods within the confines of the canyon walls. Goat Creek thalweg sinuosity was high relative to other similarly impacted streams (Appendix 7). Large organic debris exposed by channel degradation was comparatively scarce and patchily distributed throughout the study section. Since the majority of this material was not wetted during low discharge periods, its capacity to provide flow modulation was limited. Boulders, which are also flow modulation structures, were abundant throughout the affected portion of Goat Creek. They improve channel stability and promote a cascade-

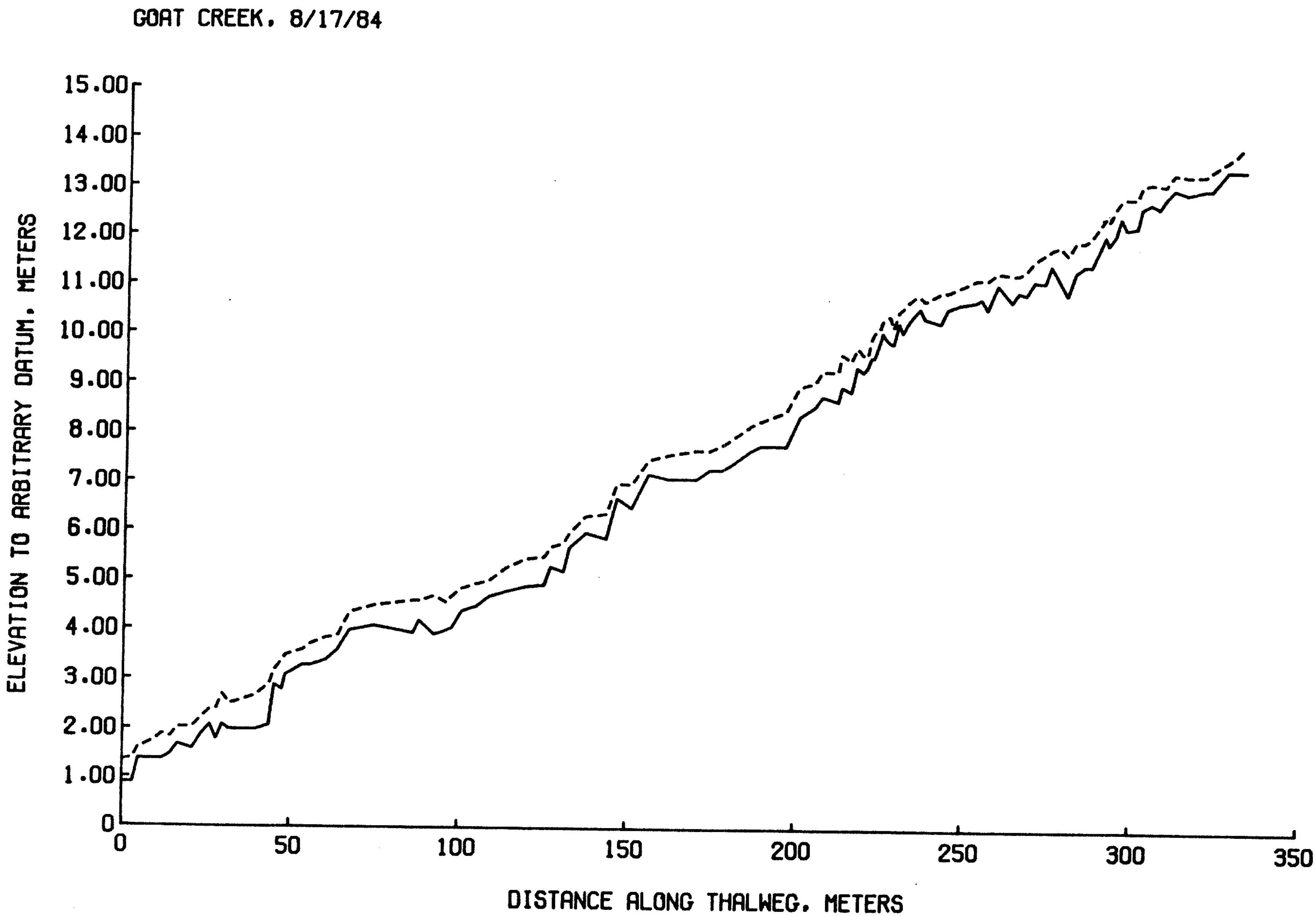

Figure 4. Longitudinal profile of stream thalweg for Goat Creek during summer low flow, 1984. The dashed line represents stream water surface.

type environment comprised of small turbulent pools. Riparian vegetation, with the exception of scattered ground cover, was absent, resulting in increased erosion and poor bank stability.

Tributaries of the North Fork Toutle River within ten miles of Mount St. Helens were the most severely affected; however, Maratta Creek has some pool habitat (Figure 5). Variation in channel topography and water depth was small relative to unaffected tributaries. The course of lower Maratta Creek has developed into a new terrace tributary. All the streams in this area had similar modification. Maratta Creek has cut up to 10 meters in the debris avalanche substrate. Large organic debris, particularly rootwads, exposed by the cutting was patchily distributed within the study section but was relatively scarce throughout the remainder of Maratta Creek. Within the study section, pools were associated with large organic debris and boulder substrate. Portions of lower Maratta Creek migrated horizontally during high flow periods. Although in 1982 and in 1984 the main channel of Maratta Creek was reasonably stable and thalweg sinuosity was relatively low (Appendix 8), the erosive nature of debris avalanche material in the absence of riparian vegetation has resulted in poor bank stability.

Habitat Diversity

The percent composition of individual habitat categories (pool, riffle, glide) and habitat components (scour pool, low gradient riffle, etc.) were determined for each stream surveyed during 1984 (Appendices 9-13). Results indicate: 1) Affected streams on the landslide debris flow and those draining the middle and upper portions of the South Fork Toutle River watershed, exhibited substantially different habitat composition and associated depth relative to impacted tributaries draining the lower portions of each system

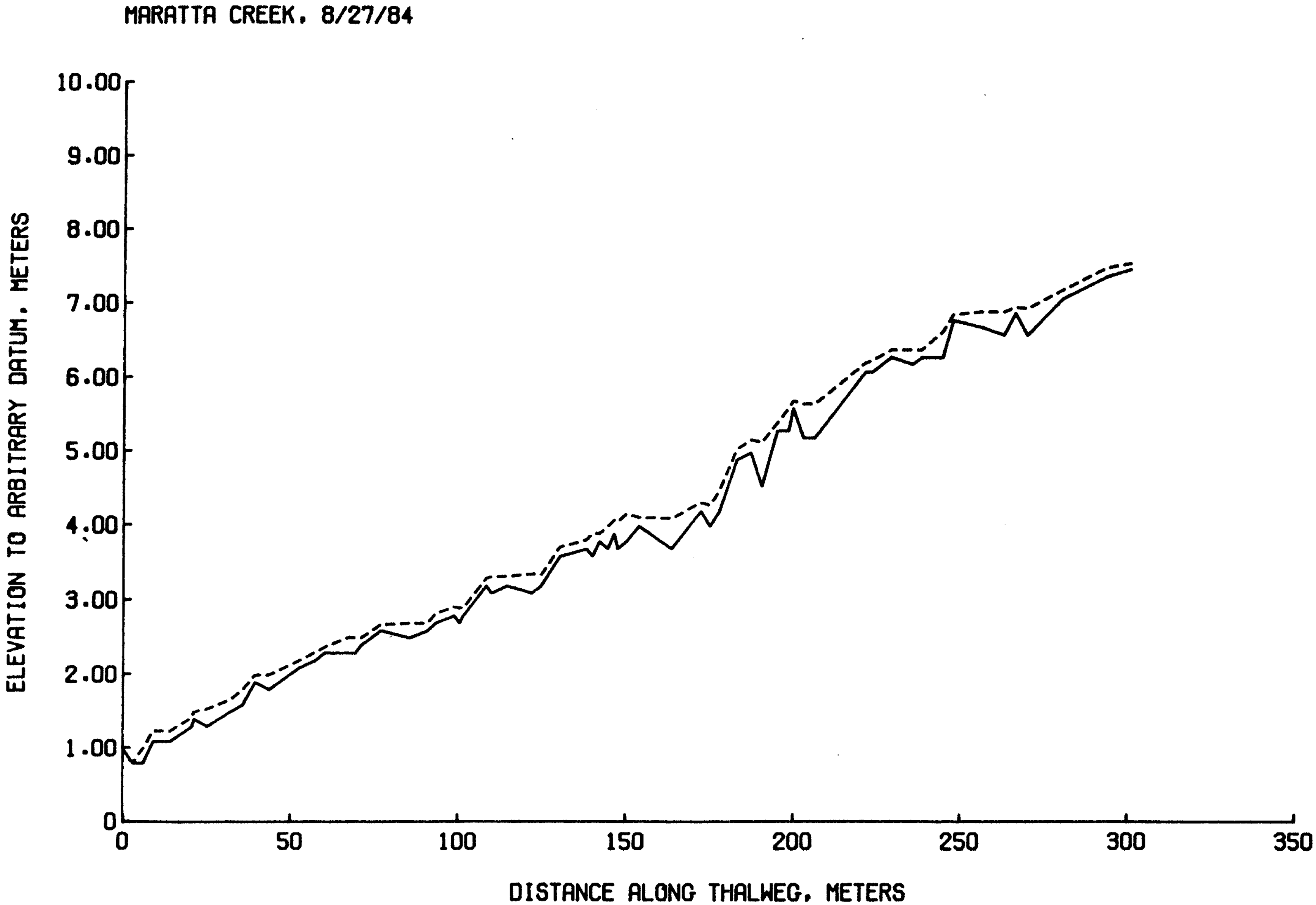

Figure 5. Longitudinal profile of stream thalweg for Maratta Creek during summer low-flow, 1984. The dashed line represents stream water surface.

(Table 3); and 2) Tributaries draining the lower portions of each system possessed habitat compositions resembling unaffected streams.

Pools comprised 4.7 to 47.2 percent of the habitat in landslide debris flow (Maratta Creek) and South Fork Toutle River tributaries (Herrington and Goat Creeks) compared to 61.3 to 90.2 percent in unaffected streams. Although pool habitat comprised 47.2 percent of Herrington Creek, mean pool depth was only 12.2 centimeters, indicating pool development is still in its initial stages. Lateral scour was the dominant pool habitat category in all waters. Mean pool depth in Maratta and Herrington Creeks was 13.4 and 12.2 centimeters, respectively, compared to 19.4 and 20.4 centimeters in unaffected tributaries. The pools in Goat Creek were relatively deep (mean of 31.0 cm) but not numerous as they comprised only 4.7 percent of the channel.

In contrast to other affected streams, tributaries near the confluence of the North and South forks of the Toutle River, and those entering the North Fork Toutle River upstream to the landslide debris flow, were comprised primarily of pool habitat (Hoffstadt Creek 64 percent and Lower Wyant Creek 88.6 percent). These percentages are very similar to those of unaffected streams. Mean pool depth in these streams exceeded that of other affected tributaries, and were similar to unaffected waters. Mean pool depth in Lower Wyant Creek was 18.6 centimeters compared to 19.4 centimeters in an unaffected portion of Wyant Creek approximately 450 meters upstream.

The quantity of riffle habitat comprising upper watershed tributaries (Goat, Herrington and Maratta Creeks) ranged from 41 to 92 percent. Riffle habitat composition in impacted streams such as Lower Wyant and Hoffstadt creeks was 11.4 and 36 percent compared to 9.8 and 38.7 percent in Upper Wyant and Alder Creeks which are unaffected tributaries. Low gradient was the dominant riffle habitat category present in all tributaries. Upper watershed

Table 3. Habitat measurements reported as the percent volume of each habitat component (scour pool, etc.) and habitat category (pool, riffle, glide) comprising an entire study section for impacted and unaffected tributaries of the North and South Forks of the Toutle River, summer low-flow, 1984.

Stream	POOL								RIFFLE					
	Backwater	Lateral Scour	Secondary channel	Plunge	Dammed	Trench	Total	Mean depth (cm)	Low Gradient	Rapids	Cascade	Total	Mean depth (cm)	Glide
Alder Creek[1/]	1.6	57.9	.1		1.8		61.3	20.4	32.4	6.4		38.7	14.2	
Upper Wyant Cr.[1/]	1.6	87.2	.3	1.2			90.2	19.4	5.6		4.1	9.8	11.1	
N.F. Toutle R. tributaries														
Maratta Creek[2/]	1.5	18.0				3.4	22.9	13.4	32.6	2.4	6.0	41.0	11.3	36.1
Hoffstadt Cr.[3/]	6.2	53.4	1.2	3.1			64.0	18.0	36.0			36.0	11.9	
Lower Wyant Cr.[3/]		79.0			9.6		88.6	18.6	8.8		2.6	11.4	11.5	
S.F. Toutle R. tributaries														
Goat Creek[3/]	.5	3.1	.9	.2			4.7	31.0	18.3	6.8	66.9	92.0	35.2	3.3
Herrington Cr.[3/]	1.0	42.0	2.7	1.5			47.2	12.2	23.3	1.4	28.1	52.8	11.5	

[1]Control section unaffected by volcanic activity.

[2]Experienced landslide debris flow impact.

[3]Experienced mudflow impact.

streams possessed substantial amounts of cascade habitat. Cascade riffles were absent in all lower system and unaffected streams with the exception of Upper Wyant (4.1 percent cascade) and Lower Wyant Creek (2.6 percent cascade). Excluding Goat Creek, all streams exhibited remarkable uniformity in riffle depth. Mean riffle depth in four affected streams ranged from 11.3 centimeters (Maratta Creek) to 11.9 centimeters (Hoffstadt Creek). Mean riffle depths in unaffected tributaries such as Upper Wyant and Alder creeks were 11.1 and 14.2 centimeters, respectively.

Cover

The nature of instream (wetted during low discharge periods), in-channel (wetted only during high discharge periods), and streamside cover in affected tributaries throughout the upper North and South Fork Toutle River watersheds, is a function of the type and intensity of impact experienced. Existing instream and in-channel cover in the affected reaches of streams comprising the South Fork Toutle River system and throughout tributaries situated on the landslide debris flow was clearly inferior to that present in unaffected and lower system tributaries (Tables 4 and 5). Excluding cover afforded by rocks and turbulence, instream cover present in Maratta Creek and Goat Creek was generally considered poor. Riparian vegetation afforded no cover in either stream. Both streams were scoured throughout their lower reaches and were devoid of riparian vegetation and remnant large organic debris. Incidental large organic debris present in tributaries which were intensively scoured resulted from the degradation of mudflow and landslide conglomerate which contained logs, trees, and rootwads. Accumulations of large woody debris deposited by receding mudflows in several tributaries of the upper South Fork afford cover for salmonids. There has been very little recolonization of

Table 4. Habitat cover ratings for cover types located within the defined stream channel that are wetted only when instream flows exceed low discharge values in representative sections of impacted and unaffected tributaries of the North and South Forks of the Toutle River, 1984.

	IN CHANNEL COVER						
Stream	Rootwad	Large debris	Small debris	Riparian vegetation	Bank cutting	Rocks	Side channel
Alder Creek[1]	2.87	2.46	2.50	2.04	2.50	2.00	2.11
Upper Wyant Creek[1]	2.60	2.23	1.41	1.67	2.33	1.00	1.50
N.F. Toutle R. tributaries							
Maratta Creek	2.00	1.82	1.00	1.00	0	1.50	1.25
Lower Wyant Cr.	0	2.75	2.80	2.75	0	0	0
S.F. Toutle R. tributaries							
Goat Creek	1.00	1.57	1.00	0	0	1.51	0

[1]Control section unaffected by volcanic activity.

Table 5. Habitat cover ratings for cover types: 1) present during low discharge periods, and 2) existing within the defined stream channel but not wetted during low discharge periods for a representative section of Marrata Creek (debris avalanche impacted), September 1984.

	INSTREAM			IN CHANNEL		
Cover type	Observations	Rating summation	Rating average	Observations	Rating summation	Rating average
Rootwad	2	3	1.50	5	10	2.00
Large debris	9	14	1.55	17	31	1.82
Small debris	1	1	1.00	5	5	1.00
Riparian vegetation	0	0	0	1	1	1.00
Bank cutting	0	0	0	0	0	0
Turbulence	2	2	1.00	0	0	0
Rocks	20	27	1.35	20	30	1.50
Side channel	0	0	0	4	5	1.25

riparian trees on the landslide debris flow and on the upper portions of the South Fork Toutle River mudflow. The recruitment of cover in these areas will therefore be delayed.

Lower Wyant Creek, located near the confluence of the North and South forks of the Toutle River, was inundated by mudflow material. The abundance of high quality cover in Lower Wyant Creek reflects the diminished severity of impact experienced by streams in this area. Residual woody debris, exposed by channel cutting and the recruitment of large organic debris and rocky substrate incorporated within mudflow material, is common in many tributaries entering the lower portions of the North and South forks of the Toutle River. These materials along with surviving and rapidly recolonizing riparian vegetation and standing dead riparian trees have produced cover which is often equivalent or superior in quality and abundance to cover in unaffected streams.

Riparian Vegetation

The recolonization of riparian vegetation promotes channel stability, moderates water temperature by providing shade, and provides large organic debris which contributes to development of pools, riffles and instream cover. The rate of these processes will determine the time frame of habitat recovery in affected tributaries throughout the North and South forks of the Toutle River.

Riparian areas located on the landslide-debris-flow and along tributaries of the South Fork Toutle River, within 5 miles of Mount St. Helens, were nearly devoid of trees and shrubs with scattered grasses covering approximately one percent of the riparian zone (Table 6). Riparian zone boundaries were designed to reflect vegetative cover occupying specific areas

Table 6. Percent of riparian zone possessing vegetative cover, for representative reaches of tributary streams in the North and South Fork Toutle River watersheds, impacted by the May 18, 1980 eruption of Mount St. Helens (1984).

		Percent of riparian zone, within 100 feet of channel bankfull, inhabited by each vertical cover category.				Percent of riparian zone, within 10 feet of channel bankfull, inhabited by each cover category.				
Stream		Grass forb	Less than 3	3 to 12	Greater than 12 vertical feet	Grass forb	Shrub cover	Tree crown cover	Over stream cover	Comments
Maratta Cr.[1]	R. Bank	10-30	1	1	0	11-50	1-10	1-10	0	Wide variety of species for grass/forbs. Variety for all other vegetative cover is very small.
	L. Bank	1-10	1-10	1-10	0	1-10	1-10	0	0	
Goat Cr.[2]	R. Bank	1-10	1-10	0	0	1-10	0	0	0	Very little vegetation exists. Approximately 1 percent of riparian zone has vegetative cover.
	L. Bank	1-10	1-10	0	0	1-10	0	0	0	
Castle Cr.[1]	R. Bank	1-10	1-10	0	0	1-10	0	0	0	Approximately 1 percent of riparian zone has vegetative cover.
	L. Bank	1-10	1-10	0	0	1-10	0	0	0	
Herrington Cr.[2]	R. Bank	10-30	10-30	10-30	1-10	11-50	11-50	11-50	1-10	Alder vertical size and density extremely large in comparison to 1982 status. Vegetation concentrated along immediate stream bank. 30-40% of riparian zone has vegetative cover.
	L. Bank	10-30	10-30	10-30	1-10	1-10	1-10	11-50	0	
Lower Wyant Cr.[2]	R. Bank	1-10	1-10	30-40	10-30	1-10	1-10	70-100	1-10	Outstanding alder growth (size) and density. Very little variety in species. Alders cover entire riparian zone 4-7 trees per m^2.
	L. Bank	1-10	1-10	30-40	10-30	1-10	1-10	30-40	1-10	

[1] Experienced debris avalanche.

[2] Experienced mudflow.

determined to be of primary importance. Surveys within ten feet of the channel bankfull describe the composition and abundance of vegetative cover inhabiting the stream bank. Measurements collected within 100 feet of channel bankfull detail the vertical component of riparian vegetation. Riparian trees exceeding three vertical feet were absent from all landslide debris flow and upper South Fork Toutle tributaries with the exception of Maratta Creek. Vegetation less than three feet in height and scattered grasses occupied from one to ten percent of that area within 100 feet of the established channel. Substantial revegetation has not taken place in this area since 1982.

The revegetation of riparian areas throughout the remainder of the Toutle River watershed is proceeding rapidly. However, a gradient in vegetation development exists between tributaries situated near the confluence of the North and South forks of the Toutle River, and those streams entering both forks of the Toutle River progressively closer to Mount St. Helens. Riparian areas bordering Lower Wyant Creek exhibited a more advanced seral stage than those along Herrington Creek. Grass and shrub cover occupied 11 to 50 percent of the riparian zone of Herrington Creek while similar vegetation covered 1 to 10 percent of the riparian zones of Lower Wyant Creek. Alder, in the categories 3 to 12 feet and greater than 12 feet in height comprised 30 to 40 and 10 to 30 percent of the riparian zone along Lower Wyant Creek. The comparable categories were from 10 to 30 and 1 to 10 percent respectively for Herrington Creek.

Juvenile Salmonid Distribution

The natural recolonization of affected tributaries by salmonid fishes, including anadromous species was examined in the North and South Fork Toutle River watersheds.

Juvenile salmonids originating from natural reproduction inhabit tributaries throughout the South Fork Toutle River watershed (Table 7). Steelhead trout (*Salmo gairdneri*) and cutthroat trout (*S. clarki*), including young of the year, were captured in affected tributaries of the upper South Fork Toutle River within 5 miles of Mount St. Helens. One chinook salmon (*Oncorhynchus tshawytscha*) and six coho salmon (*O. kisutch*) were captured in these streams.

Tributaries of the North Fork Toutle River also supported populations of naturally spawned juvenile salmonids. Deer Creek, a tributary of the North Fork Toutle River less than 2.5 km (1 mile) from the furthest penetration of the landslide debris flow, supported significant numbers of cutthroat and steelhead trout. This stream reach experienced ash fallout, scorched, and mudflow impacts. Young-of-the-year steelhead were present in the ash fallout, scorched portion of Deer Creek. Tributaries on the landslide debris flow (Bear, Coldwater, Maratta and Castle Creeks) had no fish evident.

Table 7. Captures and observations of salmonids in tributaries of the North Fork and South Fork of the Toutle River, 1984.

Stream	Date	Impact	Water temp. (C°)	Survey length (m)	Method	Species	Number captured	Mean length (mm)	Range in length (mm)	Comments
Upper Deer Cr.	8/22	Ash fallout scorch		100	Electroshock	Steelhead Cutthroat	21 18	97.76 140.88	37-211 58-198	Excellent habitat.
Upper Deer Cr.	8/22	Mudflow		90	Electroshock	Steelhead Cutthroat	20 12	141.60 159.50	86-255 110-213	Ponding near deer springs.
Unnamed tributary of S.F. Toutle S32, T9N, R4E	9/17	Mudflow	15	100	Electroshock	Cutthroat Steelhead Chinook	26 6 1	 100[1]	45-270[1] 150-180[1]	Watershed completely logged. No riparian vegetation. Pools formed by boulders and large organic debris. Debris jam 400 m above confluence with S.F. Toutle.
Unnamed tributary of S.F. Toutle S32, T9N, R4E	9/17	Mudflow	14	100	Electroshock	Steelhead Cutthroat Coho	60 7 6		35-160[1] 40-170[1] 80-95[1]	Entire watershed logged. No existing riparian vegetation greater than 6 feet high. Debris jam 100-150 meters from confluence with S.F. Toutle. Large organic debris abundant.
Lower Wyant Cr.	7/17	Mudflow	21.5	300	Observation					Small numbers of fry. Planted by WDF.
Herrington Cr.	7/18	Mudflow	15.5	1500	Observation					Fry are abundant; several 90 to 150 mm individuals. Planted by WDF.
Goat Cr.	7/18	Mudflow	13.5	700	Observation					Fry are scattered; one 90 to 150 mm individual.
Castle Cr.	7/19	Landslide-debris-flow	9.5	1800	Observation					No fish observed. High gradient, boulder/cascade, lower 400 m of channel appears unstable.
Maratta Cr.	9/18	Landslide-debris-flow	23.0	400	Electroshock					No fish observed or captured. Precipitous boulder cascade at confluence with N.F. Toutle constitutes probable barrier to upstream migration.
Coldwater Cr.	9/18	Landslide-debris-flow	19.5	250	Electroshock					No fish observed or captured.
Bear Cr. (N.F. Toutle R.) S33, S34, T10N, R3E	9/18	Landslide-debris-flow	19.0	300	Electroshock					No fish observed or captured. Channel unstable. Pools and large organic debris non-existent. No riparian vegetation present.

[1] Lengths based on visual estimation.

DISCUSSION

Habitat Recovery

The recovery of fish habitat to pre-eruption conditions in tributaries affected by landslide debris flow and mudflow impacts is dependent upon: 1) the restoration of channel stability; 2) an increase in habitat diversity; 3) the recolonization of riparian vegetation; and 4) the recruitment of cover.

Channel Morphology and Habitat Diversity

Channel stability and habitat diversity recovery rates in tributaries of the North and South forks of the Toutle River were directly related to the depth of superimposition and the abrasive characteristics of the mudflow or landslide-debris-flow materials present in the area. Tributaries near the confluence of the North and South forks of the Toutle River (e.g., Lower Wyant Creek) were buried by relatively shallow mudflows less than 5 meters in depth by September of 1982. Vertical degradation exposed old channels at pre-eruption elevations. Large organic debris and riparian trees persisted in many locations. These materials and large woody debris deposited by mudflows helped stabilize channel banks and modulate stream flows. As a result, channels of lower North and South Fork Toutle River tributaries exhibit the most pronounced recovery from impacts. Diversity in habitat parameters characteristic of unaffected streams have increased substantially since the eruption. The consistent increases in pool depth and area typifies this evolutionary process currently underway. Consequently, tributaries in this area possess channel morphologies similar to those of unaffected streams. Since 1981, anadromous salmonids have successfully inhabited tributaries of the lower North and South Fork Toutle River. The progressive restoration of preferred habitat has enhanced the rearing capacity of these streams.

The severity of impacts experienced by tributaries of the North and South forks of the Toutle River increases as one approachs the headwaters of each drainage. The landslide debris flow, an enormous avalanche of fragmental debris, crashed down the North Fork Toutle River valley 21.7 km, completely destroying riparian vegetation, channel morphology, and instream cover. Approximately 90 percent of the upper North Fork Toutle River and tributaries accessible to anadromous salmonids before the eruption of Mount St. Helens were buried to depths up to 195 meters. Mudflows laden with logs and forest debris raced down the South Fork Toutle River drainage, devastating the lower reaches of streams and the riparian vegetation bordering them. Approximately 89 percent of the South Fork Toutle River and its tributaries (upriver from Brownell Creek) which were accessible to anadromous salmonids were buried by mudflow deposits up to 9 meters in depth. Consequently, tributaries of the North Fork Toutle River located on the landslide debris flow, and streams entering the South Fork Toutle River throughout most of its length, are developing stable channels and preferred salmonid habitat very slowly (Figure 6), relative to affected tributaries in the lower portions of each watershed. New reaches of stream channel, which terrace or flow parallel to the Toutle River, have been created in virtually every tributary in this area. New channels which were initially extremely wide have narrowed, with vertical scour creating small canyons.

Due to the extreme thickness of the landslide-debris-flow, tributaries in the upper North Fork Toutle River valley are developing new base elevations. Channel stability appears to be improving as vertical degradation removes small substrate and exposes gravel-cobble size material, boulders, and in rarer instances large organic debris which armor channel banks and serve as flow modulating structures. Superimposition experienced by tributaries of the

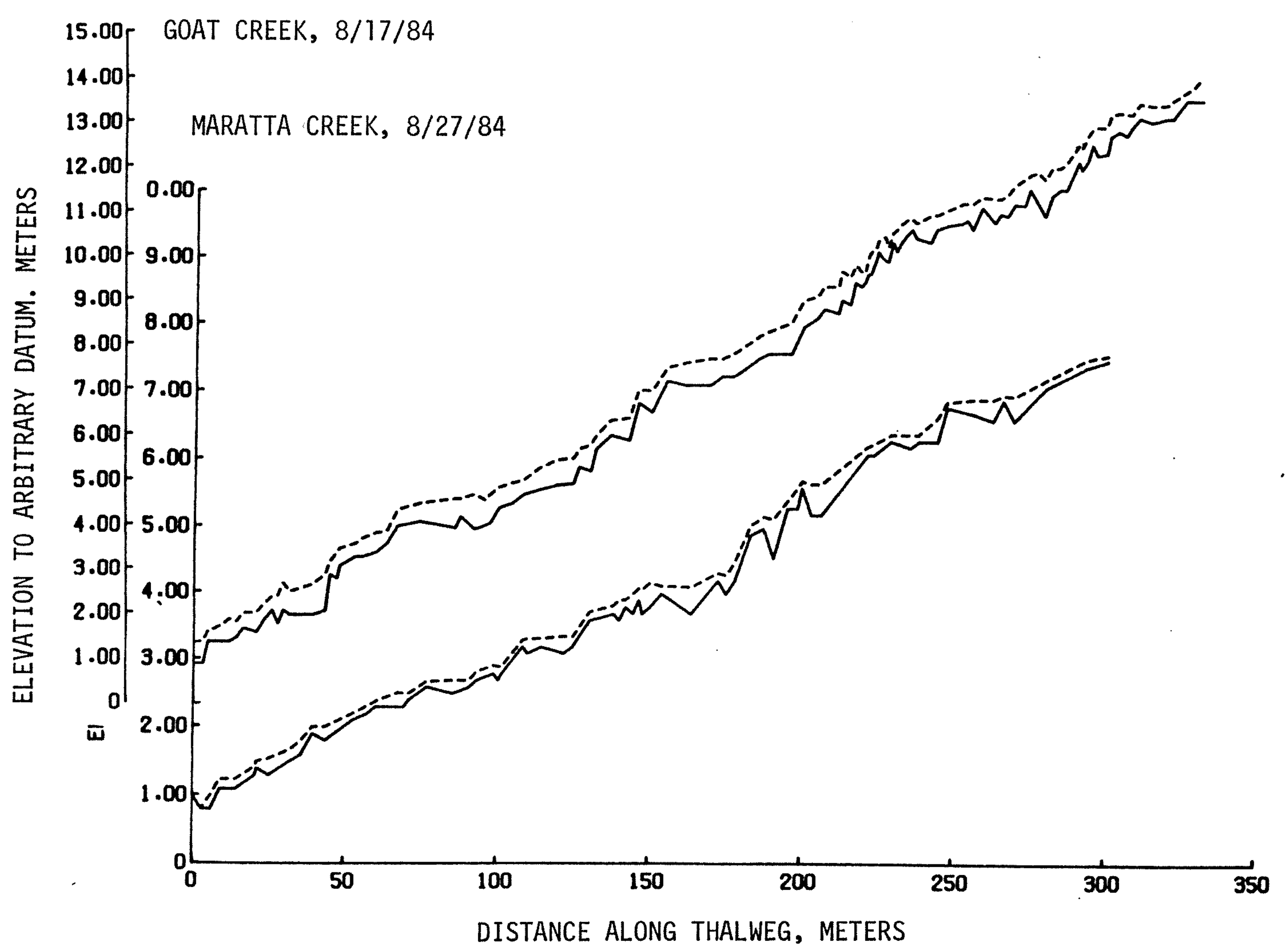

Figure 6. Channel morphologies of tributaries located in the upper portions of the North Fork Toutle (landslide debris flow impact) and South Fork Toutle River (mudflow impact) watersheds. Longitudinal profiles of stream thalweg for Maratta and Goat Creeks during summer low flow, 1984. Dashed lines represent stream water surface.

South Fork Toutle River was less than that received by tributaries of the upper North Fork Toutle River. Consequently, many new channels have been scoured to pre-eruption elevations. Channel stability has ensued with the removal of small substrate and the exposure of larger boulders and some organic debris. Boulders which settled early in the progression of mudflows are particularly abundant in the upper areas of the South Fork Toutle valley. Large organic debris, although infrequent, occurs as individual pieces or in accumulations deposited by receding mudflows.

The recovery process as it relates to channel stability and the development of fish habitat has made significant progress in tributaries on the landslide debris flow and mudflow impacted streams. Channel migration has declined and pool riffle topography characteristic of habitat diversity has clearly increased. However, in areas where large organic debris is absent, channel stability and habitat diversity exhibit a slower rate of recovery. Alternating pool-riffle topography is characterized by limited variation in substrate size, water depth and velocity. Pools typically are small, possessing depths not substantially greater than adjacent riffles with only those few associated with large organic debris exhibiting growth, in volume and depth. The characteristic morphology of pools associated with large organic debris appears similar in affected streams throughout the entire Toutle River watershed, including tributaries possessing channel morphologies resembling unaffected streams. Therefore, the most important process influencing the development of channel stability and preferred salmonid habitat is the recruitment of large organic debris.

Cover

The distribution and survival of rearing juveniles and returning adult anadromous salmonids in third and fourth order streams is closely associated with the presence of cover items which provide refuge during low discharge periods and sanctuary from excessive velocities during high flows.

Tributaries located on the landslide debris flow and mudflow affected streams throughout most of the South Fork Toutle River watershed possess cover material, exposed by channel degradation, that is characteristic of the components found in local deposits. Large organic debris and rootwads, which occur in the greatest abundance and provide cover of the highest quality in unaffected tributaries, are found only sporadically in mudflow and landslide debris deposits and are therefore uncommon constituents of affected streams in this area. Isolated pockets of preferred anadromous salmonid habitat usually result from the rare occurrence of large woody cover material. Rocks, one of the predominant components of upper mudflow and landslide debris flow deposits, are the most abundant existing cover material, creating small turbulent pools and numerous interstices. Riparian trees have not yet significantly recolonized tributaries of the South Fork Toutle River within 10 km (3.9 miles) of Mount St. Helens and tributaries of the North Fork Toutle River located on the landslide-debris-flow. Therefore, the absence of cover associated with riparian trees, including shade, undercut banks and large organic debris, has restricted the development of preferred fish habitat, resulting in a slower rate of recovery relative to affected tributaries in the lower reaches of each system.

Mudflow-affected tributaries near the confluence of the North and South forks of the Toutle River possess a diversity of cover items which approach and sometimes exceed the abundance and quality of cover in unaffected streams. Instream cover has resulted in the development of preferred fish habitat and therefore is not limiting anadromous salmonid distribution or survival in affected tributaries entering the lower 21 km (8.2 miles) of the North Fork Toutle and 4 km (1.5 miles) of the South Fork Toutle rivers.

Riparian Vegetation

The recovery of riparian vegetation, particularly riparian trees, is the most important factor determining the rate of restoration of fish habitat in the North and South forks of the Toutle River. Riparian vegetation enhances channel stability, moderates water temperatures, and provides a source of large organic debris.

Excluding headwater streams of the South Fork Toutle River within 10 km (3.9 miles) of Mount St. Helens, riparian areas bordering mudflow impacted tributaries of the North and South forks of the Toutle River are sustaining rapid revegetation. There is a direct relationship between distance from the mountain and the stage and rate of revegetation. Goat Creek, a tributary of the South Fork, approximately 15.2 km (6 miles) from the mountain, has grassy vegetation covering one percent of its riparian zone. Herrington Creek 21 km (8.2 miles) downstream has 30 to 40 percent of the riparian zone covered by alder trees. Many trees exceed 3.6 meters in height with trunk diameters of 5 centimeters. Lower Wyant Creek enters the South Fork 47.5 km (18.7 miles) downstream from the mountain and 1.5 km (.59 miles) upstream from the confluence of the North and South Forks. Alders exceeding 4.5 meters (14.7 feet) in height and 5 cm (1.9 inches) in trunk diameter occupy up to 100 percent of the riparian zone of this tributary.

The development of channel stability, shade cover and a source of large organic debris is essential to the restoration of preferred anadromous salmonid habitat in the affected tributaries. Riparian revegetation in areas bordering mudflow impacted tributaries is directly correlated to the distance from Mount St. Helens.

Reductions in streambank erosion and increases in channel stability have occurred in mudflow impacted tributaries throughout the North and South Fork Toutle River drainages because the established riparian vegetation has slowed the removal of highly erosive mudflow material.

When groundwater was absent in substantial quantities the removal of riparian trees resulted in substantial increases in summer water temperatures, often exceeding the upper incipient limit for juvenile coho salmon (Martin et al. 1984). Restoration of pre-eruption temperatures will be gradual as the recovery of riparian vegetation progresses. The minimum height of riparian trees required to shade or provide temperature control for third and fourth order tributaries was estimated to be 4.2 m (13.7 feet) by Martin et al. (1984), utilizing a prediction equation developed by Brown (1971). The rate of riparian tree regeneration in mudflow impacted areas depends on the rate of seeding, the species composition of the seeds and soil quality. Temperature control by alder trees, the dominant riparian tree in this area, was projected to come about in six years. Mudflow-impacted riparian areas possessed very little vegetation, according to surveys conducted during the summer of 1982. The revegetation of mudflow affected streamside zones by riparian trees progressed very rapidly from 1982 to the summer of 1984, producing riparian trees exceeding 4.2 meters in height in only two years. It is clear that a gradation in secondary plant succession exists with increasing distance from Mount St. Helens. Regeneration rates of riparian trees, specifically alders, were greater than estimated in 1982 and it is evident that a single recovery rate could not be forecast for all mudflow impacted tributaries. The restoration of pre-eruption temperature regimes in mudflow affected tributaries of the North and South forks of the Toutle River depends not only on the height of riparian trees but also on their density a well as stream orientation and surrounding topography.

Large organic debris (LOD) recruited from riparian trees facilitates the development of preferred anadromous salmonid habitat (pools and riffles), and provides important instream cover. The distribution and survival of juvenile anadromous salmonids is closely associated with the presence of instream LOD (Bisson and Nielsen 1983). The abundance of LOD in mudflow affected tributaries of the North and South forks of the Toutle River appreciates with increasing distance from Mount St. Helens as does the gradation of the riparian revegetation. Tributaries near the confluence of the North and South forks of the Toutle River possessed residual LOD and large accumulations of woody debris deposited by mudflows. Instream organic debris was composed of large rootwads, or tree stems, ranging from 25 cm to 35 cm in diameter (Martin et al. 1984). Riparian trees are rapidly recolonizing these areas, assuring a future source of debris. The incidence of LOD was infrequent at best in mudflow affected tributaries throughout most of the South Fork Toutle River system and in several North Fork Toutle River tributaries. Mudflow components accounted for the majority of this debris, including individual fragments exposed by channel degradation and large accumulations deposited in several small tributaries which formed possible barriers to upstream migration by anadromous salmonids. Given the nature of riparian tree regeneration, the recruitment of LOD in tributaries lacking residual debris will require more time. As the riparian tree regeneration is proceeding at a faster pace than was projected in 1982, the recruitment of LOD in mudflow impacted streams and the associated development of anadromous fishes habitat will occur in less than 50 years. In 1982 the forecast was 50-75 years.

The recolonization of riparian vegetation bordering landslide-debris-flow (North Fork Toutle) and mudflow-affected headwater tributaries of the South

Fork Toutle River has progressed very little since 1980. Excluding rare occurrences of small alders (less than 1 meter in height), riparian trees are completely absent. The vast majority of riparian zones remain bare, devoid of any vegetation. Consequently it is difficult to estimate the period of time required for habitat recovery. Fish habitat recovery will also lag.

Juvenile Salmonid Distribution

Juvenile salmonids, the progeny of naturally reproducing parents, inhabit affected tributaries throughout the North and South forks of the Toutle River watershed excluding streams located on the North Fork Toutle landslide-debris-flow. Adult coho salmon, chinook salmon, and steelhead trout have penetrated into the uppermost reaches of the South Fork Toutle River and have reproduced successfully. Consequently, affected tributaries in this area must possess some spawning and juvenile rearing habitat. Although the large sediment retention structure on the North Fork Toutle River was breached during March of 1982, there is no evidence of migration of anadromous salmonids, either adult or juvenile, into landslide-debris-flow tributaries.

The Recovery Process and Human Intervention

The restoration of salmonid populations in the Toutle River drainage is largely dependent on the recovery of tributary stream habitat. Given the opportunity to recover by natural processes, tributaries on the landslide-debris-flow and mudflow-impacted streams would eventually support the production of anadromous salmonids. Although far from complete, the recovery process has progressed rapidly in some areas producing habitat characteristics similar to those exhibited by unaffected streams in the region. Examination of the various processes involved in the restoration of fish habitat since 1981, coupled with historic evidence describing volcanic events (including their intensity and period), confirms the ultimate success of the recovery process. Opportune management should integrate wild stock production with hatchery stock introductions to maximize the productivity of the natural habitat and accelerate stock restoration in these streams.

Habitat recovery is proceeding very slowly in North Fork Toutle landslide-debris-flow streams and headwater tributaries of the South Fork Toutle River. These tributaries will eventually povide the best salmonid habitat in the entire Toutle drainage and therefore warrant considerable management consideration. Riparian tree planting and placement of large organic debris would expedite habitat recovery and be the appropriate management commitment for these streams at this time.

The recovery of fisheries resources in the Toutle River drainage is not only a function of natural processes and management considerations but human caused perturbations. It is therefore important that fisheries managers carefully evaluate timber management, flood protection programs and the exploitation of salmon stocks by recreational and commercial fisheries.

A recent example which characterizes human derived perturbations on a very large scale involves action by the United States Congress directing the U.S. Army Corps of Engineers to construct a large permanent sediment retention dam to span the North Fork of the Toutle River near its confluence with the Green River. The placement of this structure will result in the inundation of four streams, completely destroying approximately 30 km (18.6 miles) of anadromous salmonid habitat and the isolation of more than ten tributaries, including the North Fork Toutle itself, which historically provided the highest quality salmonid habitat in the entire Toutle River drainage. This will reduce and perhaps destroy the production of anadromous fishes in this area. Consideration of this project is recommended before this plan is implemented.

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Appendix 1. Habitat measurements reported as the percentage of each habitat component and the percentage of each habitat category comprising an entire stream reach during 1984 low flow in Hoffstadt Creek (mudflow impact). Data provided by P. A. Bisson, Western Research and Technology Center, Weyerhaeuser Co.

Habitat category	Habitat component	Percent of representative reach (%) Length	Area	Volume	Volume (m^3)	Mean depth (cm)
POOL		55.5	52.7	64.0	403.5	18.0
	Backwater	8.3	7.1	6.2	39.1	12.6
	Scour	42.9	41.9	53.4	336.6	21.0
	Plunge	1.4	2.0	3.1	19.5	26.3
	Secondary channel	2.9	1.7	1.2	7.6	11.1
RIFFLE	Low gradient	44.5	47.3	36.0	226.9	11.9
	TOTAL	875.8 m	3825.9 m^2		629.7 m	15.7 cm

Appendix 2. Habitat measurements reported as the percentage of each habitat component and the percentage of each habitat category comprising an entire stream reach during 1984 summer low flow in Herrington Creek. Data provided by P. A. Bisson, Western Research and Technology Center, Weyerhaeuser Co.

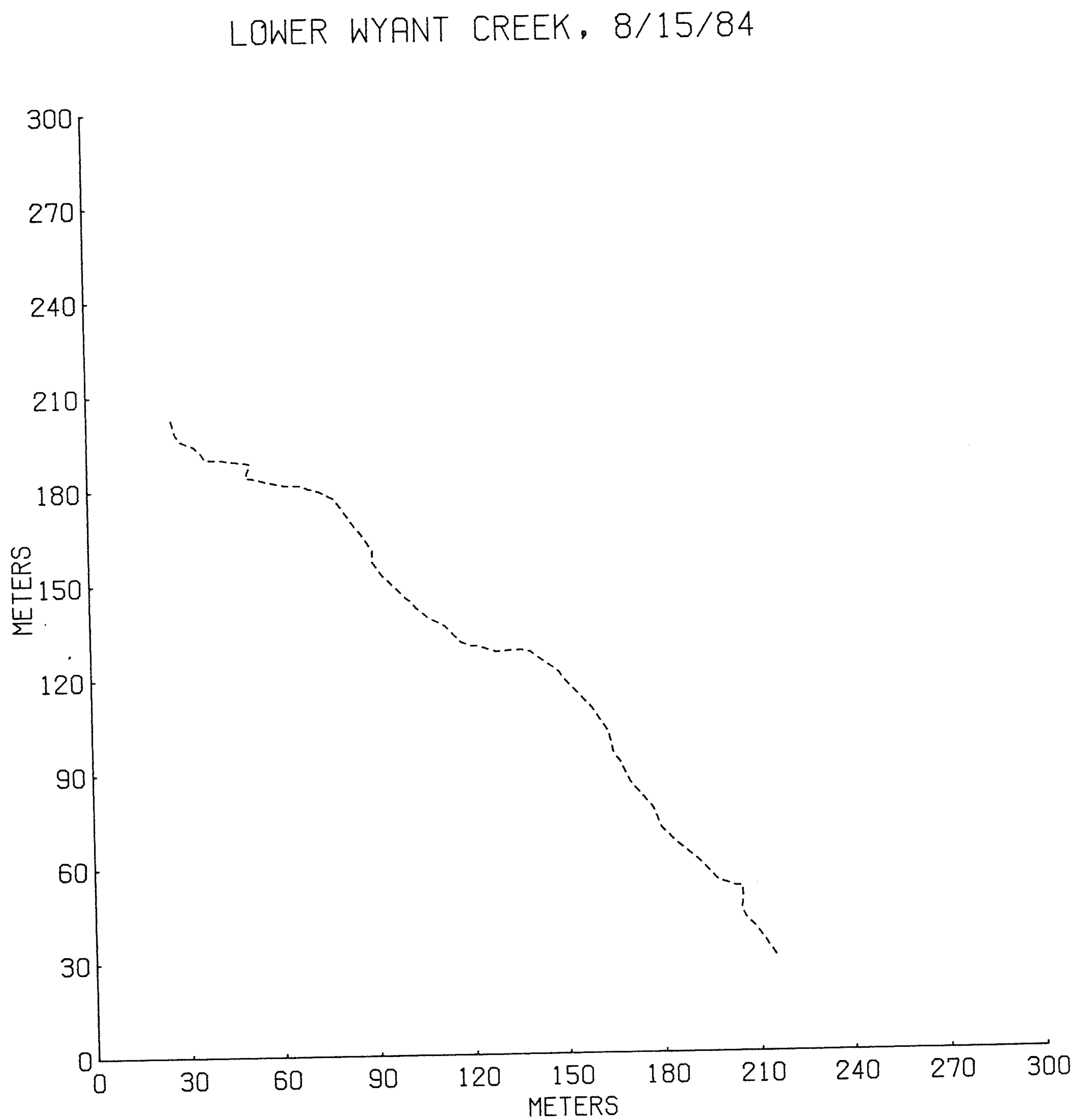
Habitat category	Habitat component	Percent of representative reach (%)			Volume (m^3)	Mean depth (cm)
		Length	Area	Volume		
POOL		46.2	41.1	47.2	313.4	12.2
	Backwater	4.5	1.8	1.0	7.1	7.3
	Scour	31.8	34.1	42.0	278.4	15.3
	Plunge	0.7	0.9	1.5	10.0	23.1
	Secondary channel	9.2	4.3	2.7	17.9	8.0
RIFFLE		53.8	58.9	52.8	350.1	11.5
	Low gradient	25.4	28.2	23.3	154.5	10.9
	Rapids	1.4	1.9	1.4	9.1	9.4
	Cascade	27.0	28.8	28.1	186.5	12.8
	TOTAL	1567.5	4908.2		663.5	11.8

Appendix 3. 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).

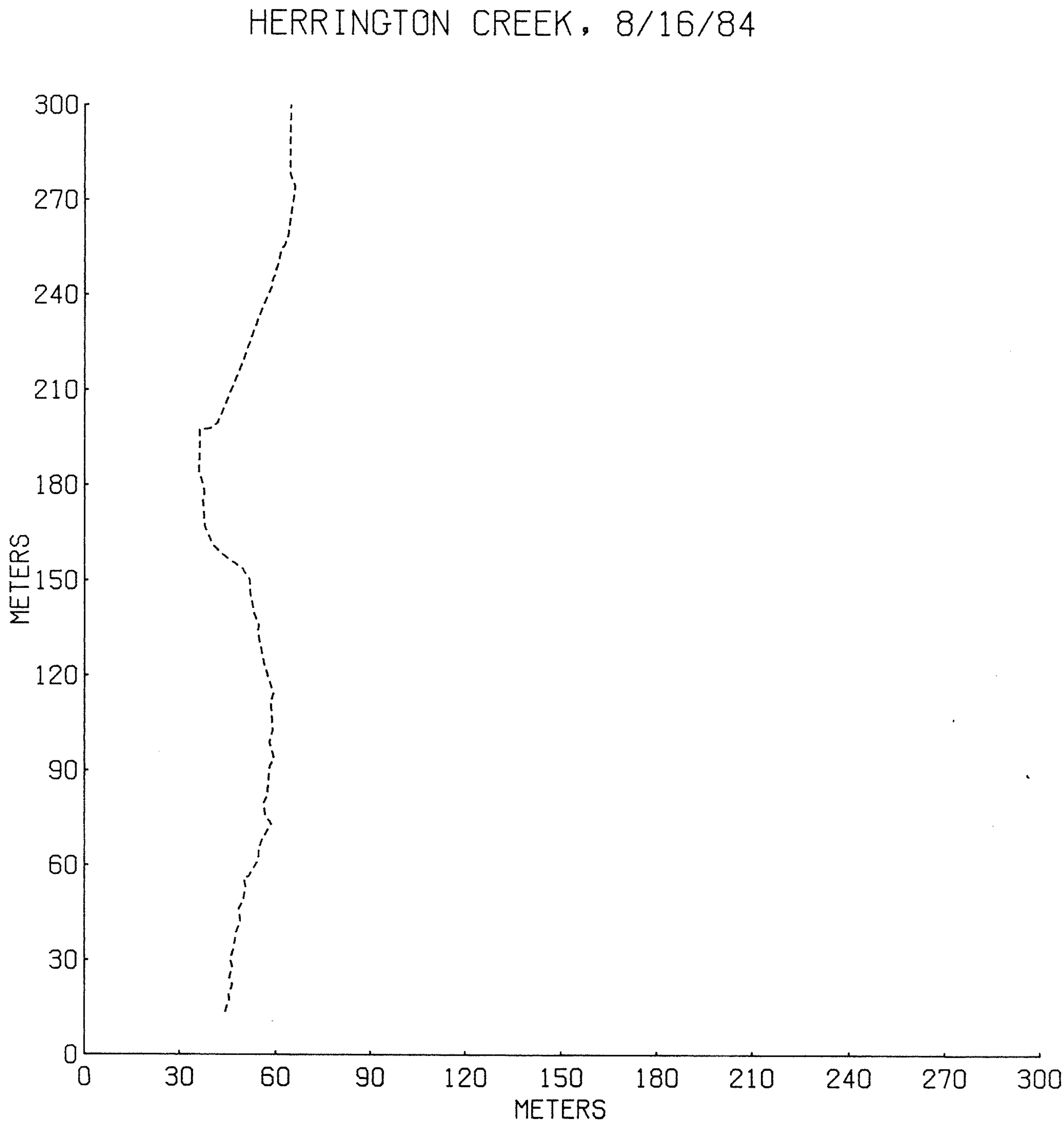
Habitat component	Description
POOLS	Characterized by deeper low velocity waters. Velocity is the decisive parameter.
1. Lateral scour	Lateral scour results from current deflection by instream structures. Often associated with large organic debris, undercut banks and channel curvature.
2. Plunge pools	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 4. Evaluation methodology for individual cover types positioned within established channel boundaries in second to fifth order streams. (Bisson et al. 1982).

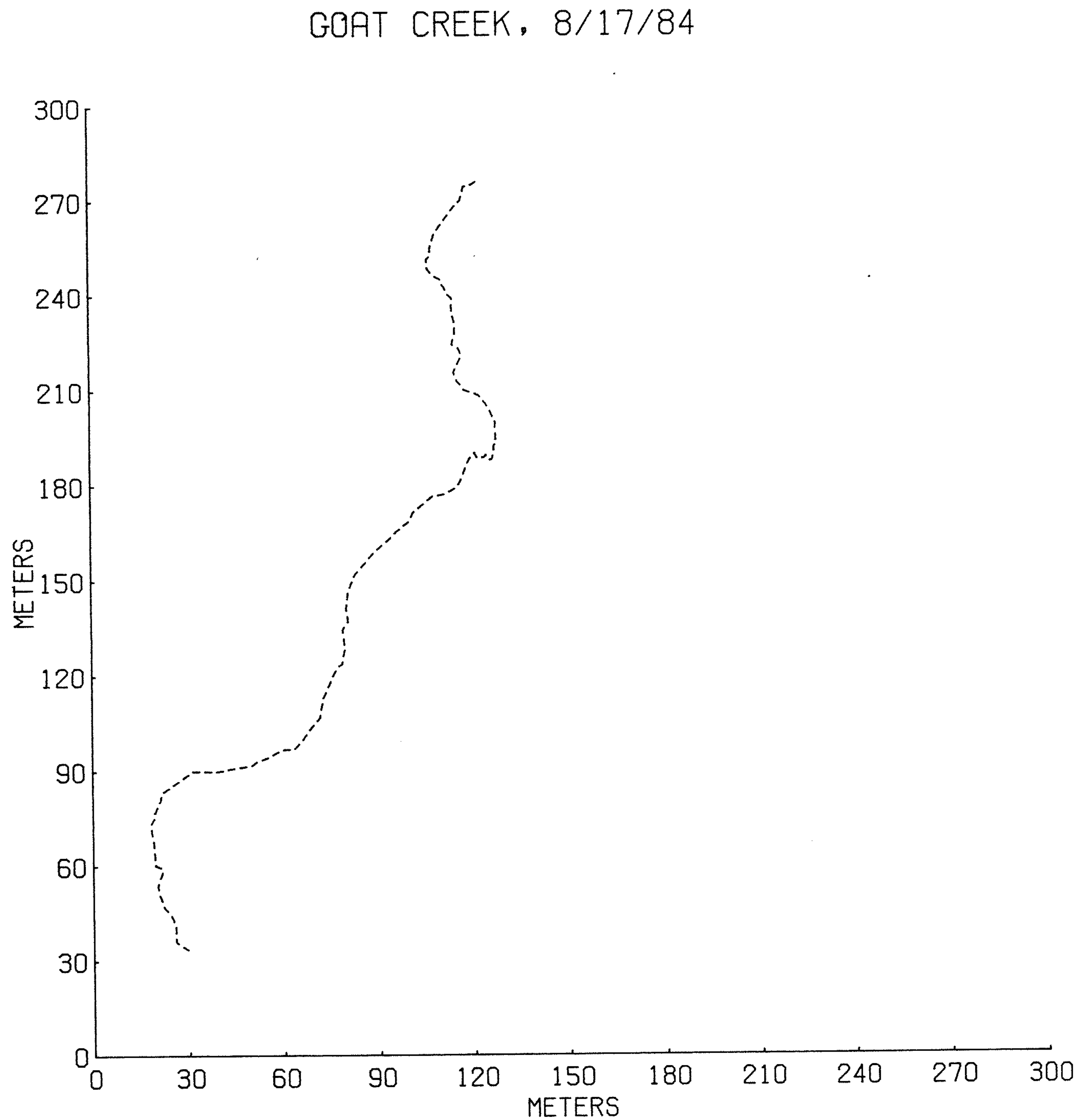
Cover type	Rating	Explanation
1. Rootwads	0	None.
	1	Provides shade cover only.
	2	Limited instream cover.
	3	Excellent instream cover.
2. Large organic debris	0	None
	1	Provides shade cover only.
	2	Limited instream and aerial cover.
	3	Extensive instream cover.
3. Small organic debris	0	None
	1	Limited loosely formed.
	2	Small accumulations.
	3	Large densely compacted.
4. Riparian vegetation	0	None
	1	Provides shade cover only.
	2	Moderately matted in or over stream.
	3	Densely matted, extensive bank cover.
5. Undercut bank	0	None
	1	Provides shade cover only.
	2	Moderate instream cover (wetted).
	3	Extensive instream cover (wetted).
6. Turbulence	0	Water surface smooth.
	1	Rippled water surface.
	2	Moderate turbulence associated with current deflection.
	3	Extensive turbulence associated with plunge pools.
7. Rocks	0	None
	1	Provide limited flow deflection.
	2	Rocks, bedrock and boulders provide moderate flow deflection.
	3	Extensive cover and current deflection.
8. Side channel	0	None
	1	Channel small in size possessing little cover.
	2	Channel of moderate size possessing some cover.
	3	Large channel possessing extensive cover.



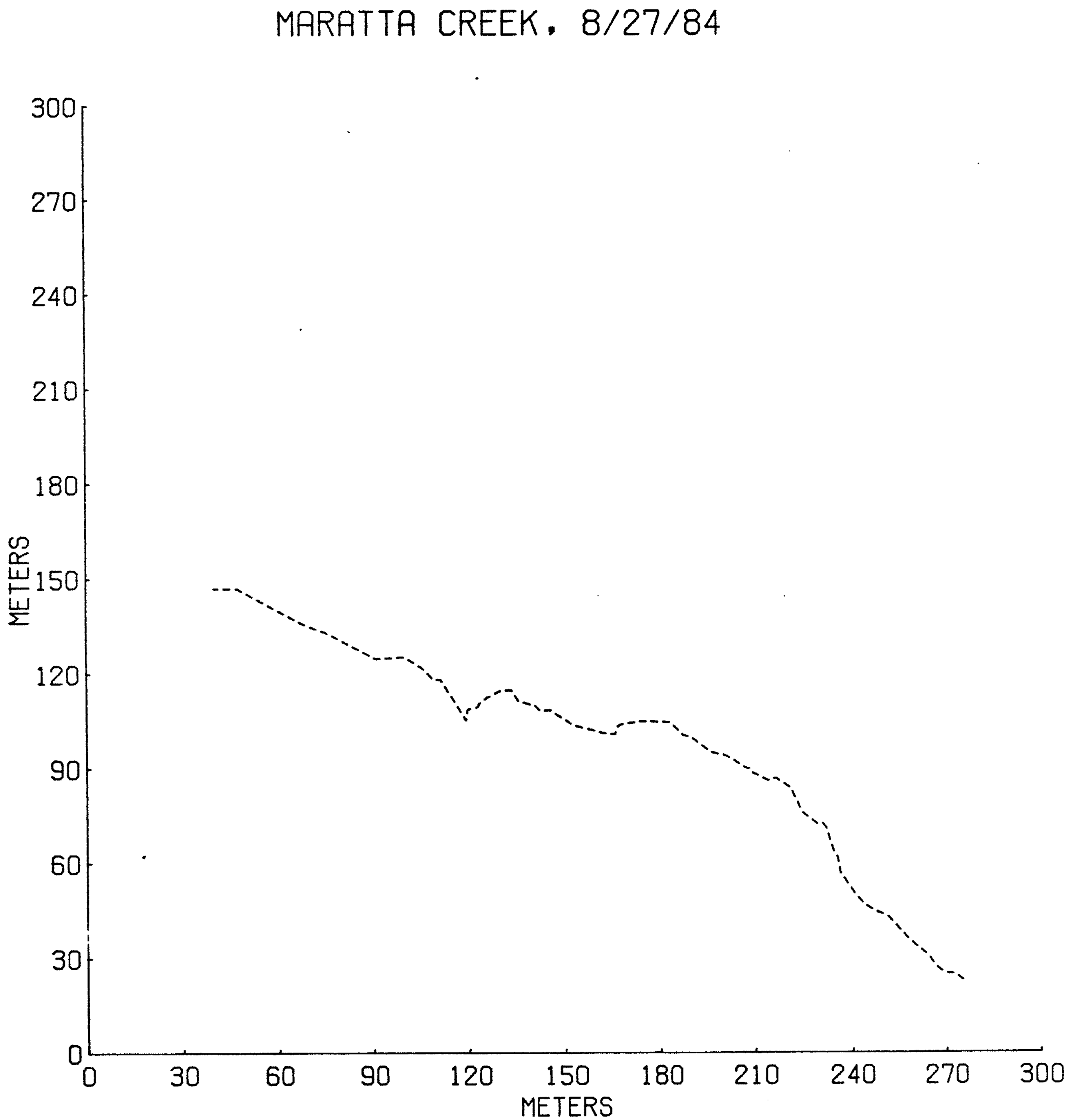
Appendix 5. Planimetric plot of water surface displaying sinuosity for Lower Wyant Creek during summer low-flow, 1984. The dashed line represents stream thalweg.



Appendix 6. Planimetric plot of water surface displaying sinuosity for Herrington Creek during summer low-flow, 1984. The dashed line represents stream thalweg.



Appendix 7. Planimetric plot of water surface displaying sinuosity for Goat Creek during summer low-flow, 1984. The dashed line represents stream thalweg.



Appendix 8. Planimetric plot of water surface displaying sinuosity for Maratta Creek during summer low-flow, 1984. The dashed line represents stream thalweg.

Appendix 9. Habitat measurements and channel component associations reported as: 1) the percentage of each habitat component and habitat category comprising an entire representative stream reach; and 2) the percentage of each habitat component and habitat category associated with existing substrate and cover structures, during summer low-flow, Lower Wyant Creek, 1984.

Habitat category	Habitat component	Percent of representative reach (%)			Volume (m^3)	Mean depth (cm)	Percent volume associated with substrate and cover structures (%)			
		Length	Area	Volume			Large organic debris	Sand	Rootwad	Gravel
POOL		78.0	79.5	88.6	218.4	18.6	68.8	16.2	15.0	0
	Lateral scour	73.9	73.5	79.0	194.6	17.3	65.0	18.1	16.9	0
	Dammed	4.1	6.0	9.6	23.8	29.2	100.0	0	0	0
RIFFLE		22.0	20.5	11.4	28.1	11.5	0	0	0	100
	Low gradient	19.3	18.4	8.8	21.8	9.3	0	0	0	100
	Cascade	2.7	2.1	2.6	6.3	22.4	0	0	0	100
	TOTAL				246.5	15.74	20.46	14.0	16.4	11.5

Appendix 10. Habitat measurements and channel component associations reported as: 1) the percentage of each habitat component and habitat category comprising an entire representative stream reach; and 2) the percentage of each habitat component and habitat category associated with existing substrate and cover structures, during summer low flow, Goat Creek, 1984.

Habitat category	Habitat component	Percent of representative reach (%)			Volume (m^3)	Mean depth (cm)	Percent volume associated with substrate and cover structures (%)		
		Length	Area	Volume			Boulders	Cobbles	Bedrock
POOL		16.2	6.9	4.7	38.3	31.0	41.5	0	58.5
	Backwater	4.7	1.2	.5	4.3	24.3	90.7	0	9.3
	Scour	3.7	2.9	3.1	25.1	54.3	11.2	0	88.8
	Plunge	1.0	.5	.2	1.9	29.5	100	0	0
	Secondary channel	6.7	2.3	.9	7.5	22.3	100	0	0
RIFFLE		79.6	90.1	92.0	754.9	35.22	82.5	17.5	0
	Low gradient	17.3	18.1	18.3	150.3	39.0	0	100	0
	Rapids	9.0	8.6	6.8	55.4	29.8	66.6	33.4	0
	Cascade	53.3	63.5	66.9	549.3	35.2	100.	0	0
GLIDE		4.2	3.0	3.3	26.7	45.1	58.8	41.2	0
	TOTAL				820.4	34.1	79.8	17.5	2.7

Appendix 11. Habitat measurements and channel component associations reported as: 1) the percentage of each habitat component and habitat category comprising an entire representative stream reach; and 2) the percentage of each habitat component and habitat category associated with existing substrate and cover structures, during summer low flow, Maratta Creek 1984.

Habitat category	Habitat component	Percent of representative reach (%)			Volume (m^3)	Mean depth (cm)	Percent volume associated with substrate and cover structures						
		Length	Area	Volume			Boulders	Large organic debris	Gravel	Fines	Sand	Bedrock	Cobbles
POOL		27.5	19.5	22.9	31.5	13.4	65.1	6.0	3.2	3.5	22.2	0	0
	Backwater	4.1	2.3	1.5	2.1	9.0	47.6	4.8	47.6	0	0	0	0
	Scour	19.0	14.2	18.0	24.7	14.8	79.0	7.3	0	4.4	9.3	0	0
	Trench	4.4	3.0	3.4	4.7	15.8	0	0	0	0	100.0	0	0
RIFFLE		45.3	50.7	41.0	56.2	11.3	9.4	0	34.8	0	0	5.3	50.5
	Low gradient	36.4	42.8	32.6	44.5	9.9	0	0	52.6	0	0	0	47.4
	Rapids	3.5	3.0	2.4	3.4	11.4	0	0	0	0	0	0	100.0
	Cascade	5.5	4.9	6.0	8.3	17.8	63.9	0	0	0	0	36.1	0
GLIDE		27.1	29.7	36.1	49.3	16.7	54.0	0	13.8	0	0	0	32.2
	TOTAL				137.0	13.2	38.3	1.4	19.9	.8	5.1	2.2	32.3

Appendix 12. Habitat measurements and channel component associations reported as: 1) the percentage of each habitat component and habitat category comprising an entire representative stream reach; and 2) the percentage of each habitat component and habitat category associated with existing substrate and cover structures, during summer low flow, Upper Wyant Creek (unaffected), 1984.

Habitat category	Habitat component	Percent of representative reach (%) Length	Area	Volume	Volume (m^3)	Mean depth (cm)	Percent volume associated with substrate and cover structures: Large organic debris	Gravel	Rootwad	Sand	Bedrock	Cobble
POOL		74.4	82.3	90.2	343.9	19.4	77.8	4.1	6.6	11.1	.29	0
	Scour	67.9	77.4	87.2	332.4	21.3	79.2	4.3	5.0	11.5	0	0
	Backwater	2.2	2.1	1.6	6.1	17.0	0	0	100	0	0	0
	Plunge	1.3	1.9	1.2	4.4	13.5	100	0	0	0	0	0
	Secondary channel	3.0	0.9	0.3	1.0	6.4	0	0	0	0	100	0
RIFFLE		25.6	17.7	9.8	37.3	11.1	0	49.9	0	7.8	0	42.3
	Low gradient	19.7	12.5	5.6	21.5	10.1	0	86.5	0	13.5	0	0
	Cascade	5.9	5.2	4.1	15.8	17.5	0	0	0	0	0	100
	TOTAL				381.2	16.6	70.2	8.6	6.0	10.8	.30	4.1

Appendix 13. Habitat measurements and channel component associations reported as: 1) the percentage of each habitat component and habitat category comprising an entire representative stream reach; and 2) the percentage of each habitat component and habitat category associated with existing substrate and cover structures, during summer low flow, Alder Creek (unaffected) 1984.

Habitat category	Habitat component	Percent of representative reach (%)			Volume (m^3)	Mean depth (cm)	Percent volume associated with substrate and cover structures			
		Length	Area	Volume			Large organic debris	Rootwad	Cobble	Gravel
POOL		50.5	45.7	61.3	230.6	20.4	76.2	23.8	0	0
	Backwater	4.0	2.0	1.6	6.1	12.1	57.4	42.6	0	0
	Scour	42.1	41.5	57.9	217.7	24.0	76.0	24.0	0	0
	Dammed	1.1	1.4	1.8	6.7	25.2	100.0	0	0	0
	Secondary channel	3.3	0.9	0.1	.1	1.0	100.0	0	0	0
RIFFLE		49.5	54.3	38.7	145.8	14.2	0	0	58.4	41.6
	Low gradient	41.5	43.2	32.4	121.9	14.9	0	0	50.3	49.7
	Rapids	8.0	11.1	6.4	23.9	11.7	0	0	100.0	0
	TOTAL				376.4	18.6	46.7	14.6	22.6	16.1