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Ecogeographic analysis of Lake Tahoe tributaries

Julie Perrochet Martin
San Jose State University

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Perrochet Martin, Julie, M.A.

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ECOGEOGRAPHIC ANALYSIS OF LAKE TAHOE TRIBUTARIES

A Thesis Presented To
The Faculty of the Department of Geography
and Environmental Studies
San Jose State University

In Partial Fulfillment
of the Requirements for the Degree
Master of Arts

By
Julie Perrochet Martin
December 1990

APPROVED FOR THE DEPARTMENT OF GEOGRAPHY
AND ENVIRONMENTAL STUDIES

Dr. Les Rowntree, Professor of Geography

Jeffrey Reiner, Hydrologist-Fisheries Biologist
USDA Forest Service
Lake Tahoe Basin Management Unit

Dr. David Schwarz, Professor of Geography

APPROVED FOR THE UNIVERSITY

ABSTRACT

ECOGEOGRAPHIC ANALYSIS OF LAKE TAHOE TRIBUTARIES

by Julie Perrochet Martin

This thesis describes an ecogeographic analysis of selected tributaries to Lake Tahoe for use in environmental planning. It examines the relationship between stream channel characteristics and physical habitat types in order to provide data for restoration efforts of riparian areas in the Lake Tahoe Basin. Two restoration projects are described to illustrate how the data can be applied to existing situations.

Analysis of the research data has shown that the stream sections with high gradients (4% or greater) are dominated by riffle and step run habitat types, with few pools or runs. The stream reaches with gradients between 1.5% and 4% are dominated by step runs but show more runs and pool habitat types than reaches with higher gradients. Stream reaches with gradients 1.5% or less have an abundance of dammed pools, corner pools, glides, and runs.

ACKNOWLEDGMENT

I would like to thank the USDA Forest Service staff at the Lake Tahoe Basin Management Unit and the Six Rivers National Forest for the use of their equipment and their assistance in the design and completion of this research. My greatest appreciation goes to my supervisor, Jeff Reiner, for his continued support and technical advice. I also thank the field crew, Don Martin and Eric Hildinger, for their ability to consistently produce high quality field data, even in adverse weather conditions. I hope they gain satisfaction in seeing the field data summarized, evaluated, and used for riparian restoration and management. A special thanks goes to my husband for his informed comments and review, patience, and encouragement throughout this work.

JPM

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CHAPTER 1

INTRODUCTION

Intent of Study

In 1980, the United States Congress passed Public Law 96-586 allowing for the government acquisition and protection of environmentally sensitive property in the Lake Tahoe Basin. The law states that the unique character of the Lake Tahoe Basin "is of national significance deserving of further protection and management" and that the environmental quality of the Lake Tahoe Basin is "seriously jeopardized by overdevelopment of sensitive lands." The law defines sensitive lands to include stream environment zones, high hazard lands (characterized by steep slopes and a fragile environmental balance or high erosion potential), unimproved lands previously modified by man which are causing unacceptably high rates of sedimentation, and shore zone areas. The authority to acquire land was given to the Secretary of Agriculture, with federal management responsibilities organized under the United States Department of Agriculture, Forest Service-Lake Tahoe Basin Management Unit (LTBMU).

The LTBMU staff began restoring sensitive lands adversely affected by past management activities, especially stream zones, in 1980. A scientist studying restoration projects, Dr. J. Cairns of Virginia Polytechnic Institute and State University, cites one of the primary reasons for the inability to successfully restore damaged ecosystems is that information about the original system may be inadequate (Cairns, 1988). Unfortunately, detailed baseline data about Lake Tahoe Basin streams have not been available to assist managers and planners in their restoration efforts. Stream zone restoration efforts within the Lake Tahoe Basin have intensified over the last five years, creating an increasing demand for information about the existing conditions of the riparian areas.

Forest Service scientists specializing in stream zone restoration are becoming more aware that baseline data such as the understanding of the spatial distribution of physical attributes of streams is critical to successful restoration work. The information is also necessary for other management actions such as the preservation and protection of sensitive lands and for monitoring stream changes over time. Therefore, an intensive effort to quantify riparian conditions in order to provide baseline data was initiated by the LTBMU in 1988.

The quantification work began with the division of the Lake Tahoe Basin landscape into macro, meso, and micro units. Once geographic scales appropriate for the collection of data for stream restoration planning were determined, classification procedures of the meso and micro units were designed. The results of the classification procedures also provide data for interdisciplinary applications such as monitoring and erosion control, and fisheries, amphibian, and macroinvertebrate studies.

The landscape division process is based on the concept known as "Ecogeographic Analysis," developed by geographer Robert Bailey of the USDA Forest Service (Bailey, 1988). The ecogeographic analysis approach starts with mapping ecosystems of various sizes underlying the area of analysis. This requires a union of ecology and geography. Ecology is needed for the selection of classification criteria and interdisciplinary use. Geographic principles pertaining to the spatial organization and linkages of the physical environment, and the concept of "region" constitute the backbone of the process. The processes of fluvial geomorphology are integrated into this thesis to produce the methodology and understand the research results.

The western and southern portions of the Lake Tahoe Basin hydrologic unit make up the macro unit for this study; information was gathered from ecosystems in selected watersheds that drain into Lake Tahoe. The meso unit is defined at the stream level: The morphology of stream channels of Lake Tahoe tributaries is classified by gradient and substrate into "channel types." The micro units are found within the streams and are defined by fluvial geomorphic principles such as the effects of erosion by running water and the movement of materials through a stream system. The in-stream micro units are referred to as "physical habitat types." Information from the three geographic levels was linked to determine the relationship between channel types and physical habitat types in Lake Tahoe tributaries. The greater the understanding of Lake Tahoe tributaries, the better prepared land managers and planners will be to address the riparian resource issues in the Lake Tahoe region.

Overview of Study

Only streams from the western and southern sections of the Lake Tahoe Basin were considered in this research so that a consistency of geologic and climatological influences on stream structure could be maintained. Two classification systems were applied to seven streams in the macro unit to analyze the physical characteristics of the stream channels. The classification procedures describe the composition of physical habitat within defined channel structures. The two classification systems are explained in detail in Chapter 3.

Other studies which compare physical habitat characteristics to stream channel characteristics are reviewed in the following subchapter. Many of these studies use a concept of ecogeographic analysis without stressing the importance of region. Also, some of the methodologies used were found lacking in terms of their ability to provide adequate information for stream restoration planning. Chapter 2 provides background information about the macro unit and the rest of the Lake Tahoe Basin. A brief description of the seven study streams is found in Chapter 4, and Chapter 5 reviews the methodology used in the collection of stream zone data. The results of the classification procedures are reported in the sixth chapter. A discussion of the results is found in Chapter 7, which also includes discussion on the indication of stream processes at work in the Lake Tahoe tributaries, the importance of using a regional approach, and the usefulness of the information for resource management. Finally, the summary and conclusion are in Chapter 8, which includes topics for further study.

Other Studies That Relate Channel Structure and Physical Habitat Features

Studies relating stream morphology have been done by Platts (1979), Bisson et al (1981), Sullivan (1986), and Fausch (1988). These previous studies have used either habitat units not specific enough for restoration plans, stream gradient only, biological indicators, or population preference to habitat types. The results of these studies were based on data collected from representative reaches. That is, data were collected at specified points distributed throughout a stream or reach. Information collected from these selected points was extrapolated to represent the shape and physical habitat of the stream between the points under an assumption of consistency throughout a stream system. However, data from a few points cannot give an accurate representation of a stream because management practices and channel structure are not often consistent throughout an entire stream.

A study by Reeves and Everest (1986) provides detailed data for the Oregon coastal region. Five western Oregon streams were surveyed to determine if stream type can be used to predict habitat conditions and anadramous salmonid populations. Reeves and Everest (1986) found that the Rosgen stream classification system (Rosgen, 1985) showed more similarity in physical habitat in a given stream type than it did in similarity of fish populations. They also concluded that the Rosgen method of stream classification is inadequate to address fish abundance variations found in western Oregon streams. The Oregon stream study showed Rosgen's stream types **A** and **B** to be dominated by riffles. The lower gradient **C** streams were the most variable type.

Drs. Jeff Kershner (Pacific Southwest Regional Fisheries Biologist meeting, Sacramento February 27-March 1, 1990) and Lynn Decker (Ph.D Dissertation, Utah State University, Logan, 1990) have researched streams in the Sierra Nevada region north of Lake Tahoe. Scientists Decker and Tom Lisle at the Pacific Southwest Research Station studied habitat classification and its association with stream morphology in Hurdy Gurdy Creek on the north coast of California. They found that confined channels have the greatest area of low gradient riffles. Also, semi-alluvial channels have the greatest areas in both cascades and pools and show the greatest diversity of habitat conditions. Lastly, Decker and Lisle determined that braided channels have intermediate distributions of habitat units and have the greatest area of side channels, which is important for winter fish survival (Pearce, 1987).

Geomorphologist and fisheries biologist, K. Overton with the USDA Forest Service, is using the classification systems used in this study on other streams in the north coast area of California. His work is being applied to fisheries management as well as erosion control, frog habitat, and snake habitat studies. Most of the research using the Rosgen and Decker classification systems (Appendices 1 and 2) has been carried out as part of USDA Forest Service management procedures to aid in riparian restoration efforts.

Although Rosgen states that his stream classification system is applicable over a wide range of hydrophysiographic regimes (Rosgen, 1985), the system had not been applied jointly with Decker's system to the Lake Tahoe Basin on a large scale (Reiner, 1989) until the research that constitutes this thesis. Maintaining a regional approach to this type of data collection for use in restoration work is important because channel morphology and the physical habitat components within a stream can be affected by geology, land use history, vegetation, and natural disturbances.

Streams studied in this thesis are on the west and south portions of the Lake Tahoe Basin and are similar in geologic structure, land use histories, and vegetation types. In the future it may be interesting to compare these streams to the streams on the east slope of the basin where differences exist in the amount of urban development and geologic history. However, the data on eastside streams is not yet available, making comparisons speculative at this point in time. The ecogeographic analysis design used in this study should reflect the contrasts in the natural and human history that influence stream structure and habitat composition when applied to two or more regions or macro units.

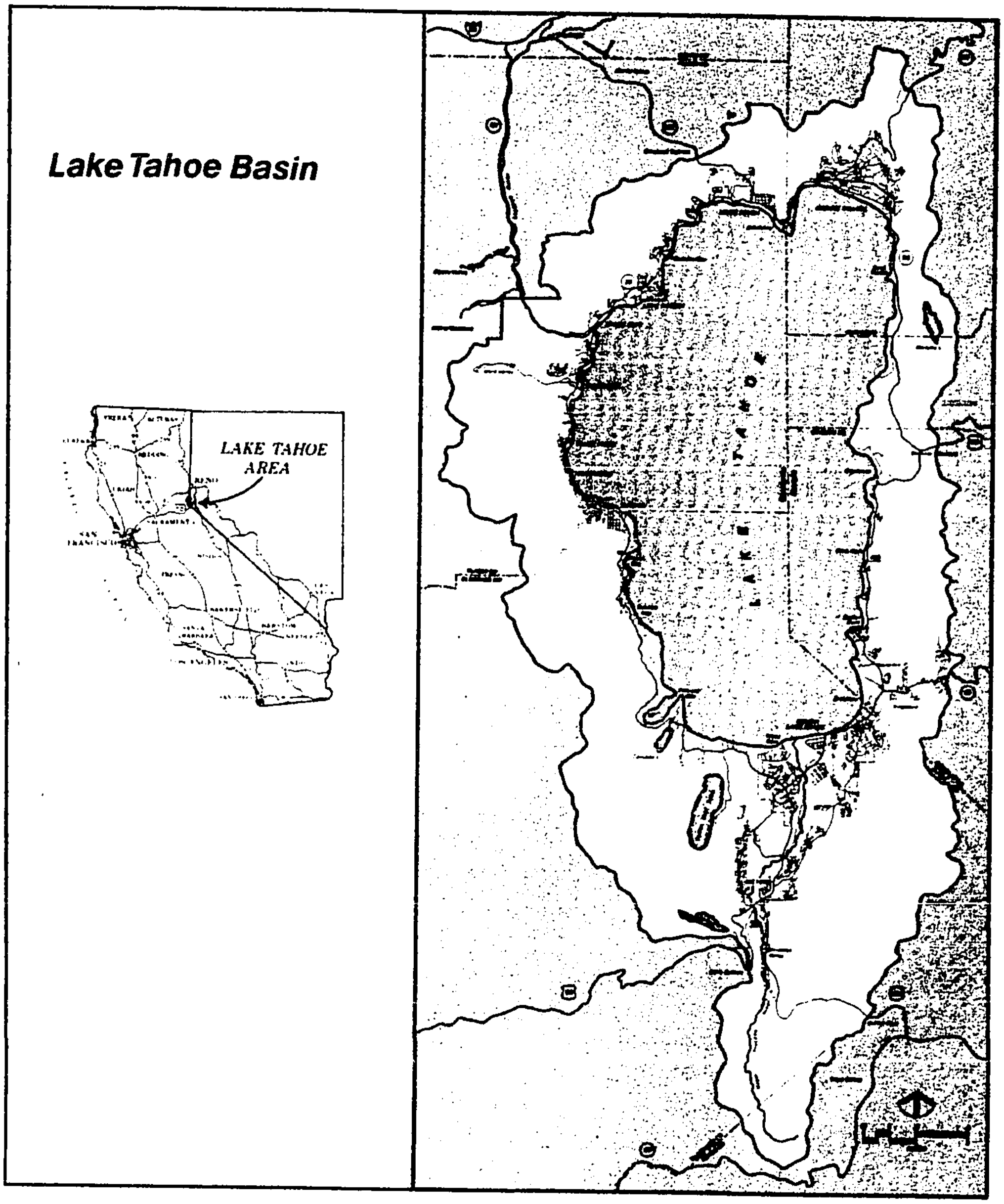


Figure 1. Lake Tahoe Basin

CHAPTER 2

THE REGION - LAKE TAHOE BASIN

Location

The Lake Tahoe Basin lies in the Sierra Nevada physiographic province that divides the Basin-and-Range province and the Pacific province (Pirkle, 1977). More specifically, the Lake Tahoe Basin is in the northern portion of the Sierra Nevada section, most of which is made up by the Sierra Nevada, the great range of mountains that crown much of California's eastern boundary. The Sierra Nevada range extends approximately 360 miles from near Mt. Lassen southward to the edge of Walker Pass (Storer, 1963).

The Lake Tahoe Basin, in the northern portion of the Sierra Nevada range, encompasses about 500 square miles, more than a third of which is comprised by Lake Tahoe. Elevations in the Lake Tahoe Basin range from 6,225 feet (average lake level) to 10,840 feet (Freel Peak).

Geology

Lake Tahoe sits in a fault-formed depression or graben (Burnett, 1968) created within the last several million years. The faulting that produced the lake is related to the Basin-Ranges that extend eastward from the Sierra to the Wasatch Range in Utah (Tahoe Regional Planning Agency and USDA Forest Service joint publication, Soils of the Lake Tahoe Region, 1971). While large granitic blocks on either side of what is now the lake rose to become part of Sierra Nevada and Carson Range, the block now under the lake sank to become a valley (Hampton, 1988). The lake formed naturally when volcanic debris (andesitic mudflow breccia) was deposited at the northwest end of the valley. Younger glacial deposits now cover most of the damming volcanic material (Tahoe Regional Planning Agency and USDA Forest Service joint publication, Soils of the Lake Tahoe Basin, 1971).

While the Lake Tahoe Basin is structurally related to the Basin-Ranges, the basement rock of the Tahoe Basin is predominantly granite related to the rocks found throughout the Sierra Nevada. Therefore, the lithologic boundary of the Sierra Nevada extends eastward to Carson Valley, while the structural boundary of the Great Basin extends westward to the crest along the western side of Lake Tahoe (Burnett, 1968).

In places, the granite has been broken by fault activity and weakened by weathering along the fractures making it less resistant to erosion. Much of the granite bedrock is buried beneath a layer of glacial debris (Alt, 1978) deposited by huge valley glaciers that moved down canyons along the western side of the lake during the Pleistocene epoch. Along the eastern side, glaciers developed only on the shaded side of the highest peaks. The differing glaciation activities account for the contrast between the rugged Sierran crest on the west side of the Lake Tahoe Basin and the subdued rolling topography typical of the Carson Range (Tahoe Regional Planning Agency and USDA Forest Service joint publication, Soils of the Lake Tahoe Region, 1971). The lake level was raised as much as 600 feet by two large glaciers during the last ice age, approximately 10,000 years ago. Periodic flooding occurred down the Truckee River drainage when the glacial ice dams floated, releasing the lake's water. Evidence of the highwater influence exists in the sedimentary benches above Lake Tahoe (Alt, 1978).

Volcanic rock can be found at the northern and northwestern edge of the basin, the extreme southern portion of the basin and at small sections of the east shore of Lake

Tahoe (Hampton, 1988). The headwaters of the Upper Truckee (one of the stream sections studies in this treatise), at Stevens Peak is a volcanic pile 2,000 feet thick. The Stevens Peak volcanic pile may have erupted through faults that formed the graben of the Upper Truckee River (Burnett, 1968). At the headwaters of the Upper Truckee, the volcanic rock consists of mudflow breccias that are only moderately resistant to weathering, allowing a deep soil zone to develop in that area (Burnett, 1968). Portions of the Upper Truckee River headwaters are characterized by open meadows.

Climate

The climate of the Lake Tahoe region is influenced by the marine air from the Pacific Ocean that is dropped (mostly as snow) as it rises over the crest of the Sierra. Average annual precipitation ranges from more than 50 inches on the western side of the region to about 25 inches along the eastern side. The average snowfall at Tahoe City, on the west side of the basin, is 213 inches (Tahoe Regional Planning Agency and USDA Forest Service joint publication, Climate and Air Quality of the Tahoe Region, 1971). The summers are dry, with a frost-free growing season averaging 75 to 120 days.

Streams

There are 63 tributary streams entering Lake Tahoe, the largest being the Upper Truckee River (Hampton, 1988). The basin is drained by the Truckee River, which flows north into Pyramid Lake in the Basin-and-Range province. The streams in the Lake Tahoe Basin are similar to other streams in the Sierra Nevada in that they can fluctuate dramatically with the seasons. Late Spring rains and snow melt bring torrents of water down the streams. For example, mean flow in Blackwood Creek (on the west shore of Lake Tahoe) in water year 1985 ranged from 2.7 to 112 cubic feet per second (cfs). The mean flow data in cfs for Blackwood Creek by month for water year 1985 (U.S. Geological Survey Water-Data Report CA-85-3) is listed in Table 1 below. Not all streams flow year-round. The smaller streams can be intermittent, especially in drought years.

TABLE 1. MEAN FLOW DATA FOR BLACKWOOD CREEK FOR WATER YEAR 1985

Oct. 1984	**4.88**	Feb. 1985	**9.14**	Jun. 1985	**45.5**
Nov. 1984	**15.4**	Mar. 1985	**14.4**	Jul. 1985	**5.75**
Dec. 1984	**9.01**	Apr. 1985	**86.2**	Aug. 1985	**2.70**
Jan. 1985	**7.17**	May 1985	**112**	Sep. 1985	**2.90**

Human Use

The Washoe Indians, a somewhat nomadic tribe of the area, inhabited the region before the settlement by white people. Between the mid 1800's and mid 1900's Lake Tahoe served wealthy California summer recreationists, mostly from San Francisco and the Sacramento Valley. As California's population grew after World War II, summer visits to Lake Tahoe extended to year-round visits. Establishment of year-round casinos at Stateline, Nevada in 1955 and the growth of winter sports added to the number of visitors and residents.

Today, the Lake Tahoe area receives heavy recreational use in terms of skiing, fishing, camping, boating and gambling. The Desolation Wilderness Area (partly in the Lake Tahoe Basin) is the most heavily used (by area) Wilderness Area in the United States (Don Lane, Recreation Specialist, Lake Tahoe Basin Management Unit, personal communication). Natural resource managers at the federal, state, county and city levels are continually seeking ways to minimize negative impacts within the basin, while allowing the maximum number of people to enjoy it. The results of this study, with the emphasis on stream analysis, adds to the information base necessary to meet the need for appropriate regional land management planning.

CHAPTER 3

CLASSIFICATION SYSTEMS

A Systematic Method of Classifying Streams

To begin to arrange the environmental components of the Lake Tahoe Basin region in a systematic way, two kinds of classification systems were used in this thesis research. One system classified stream sections (or reaches) according to stream gradient, dominant particle size and other factors, which are described in detail later in this section. A second classification system defined physical habitat components within the stream.

Stream Channel Classification: A Review of Techniques

The effort to classify streams is not new. In 1899, geographer W.M. Davis classified streams by age (Davis, 1899). Since then, streams have been classified by characteristics such as valley type, depositional layers, and bank stability. Leopold and Wolman classified streams by their patterns: straight, meandering, and braided (Leopold and Wolman, 1970). Biotic schemes (vegetative types, cold water versus warm water dependent species), mode of sediment transport, and measurable features have also been used to organize streams (Rosgen 1985, Hampton 1988). The Kellerhauls, Church and Bray system combines valley, floodplain, and channel features to classify streams (Kellerhauls et al, 1976). Parott, et al, suggest a hierarchical approach based on cartographic scale (Parott et al, 1989).

A classification system defined by David Rosgen was used in this research. The Rosgen system was used because it is based on measurable morphologic features, it is a quantitative system and is reproducible (Rosgen, 1985). The Rosgen system has interdisciplinary applications in such areas as resource planning, fisheries, watershed management, hydraulic engineering, stream restoration, and the determination of bank stability relationships and sediment threshold limits. This system has become standard procedure for use in watershed and fisheries management on national forest lands within California (Kershner (1990), Overton (1988), Reiner (1988)). Within the last three years, the Rosgen system has also been used to study stream systems by the USDA Forest Service outside of California (Reeves, 1986), the California Department of Fish and Game (Bill Snyder, personal communication), and private consultants in Colorado (Rosgen, personal communication).

Rosgen's classification system reflects eight major variables that directly influence stream morphology and related channel patterns: width, depth, velocity, discharge, slope, roughness of channel materials, sediment load, and sediment size (Rosgen, 1985). The system uses criteria that directly measure and/or represent these eight variables. The criteria are: channel gradient (measured as energy slope of the water surface), width to depth ratio (the width at bankfull stage divided by bankfull depth), dominant particle size of bed and bank materials, entrenchment of channel and confinement of channel in valley, and landform features, soil erodibility and stability (Appendix 1).

The Rosgen system was used to delineate Lake Tahoe tributaries into two levels, first by gradient and to a lesser degree by landform and channel measurements (referred to as the "Primary Channel Type" level in this thesis), then by substrate particle size (referred to as the "Subtype" level). Following are descriptions of the Primary and Subtype levels of Rosgen's classification system.

The Primary Channel Type Level

The primary level of classification is based on gradient as well as landform description, sinuosity, and bankfull width-to-depth ratio. At this level there are seven basic categories in which to place a stream section using Rosgen's methodology: **A, B, C, D, E, F,** and **G.** The **A** category describes stream reaches with a gradient of 4% or greater. These reaches are entrenched and confined within the valley. The **B** reaches have gradients between 1.5% and 4%. These reaches vary from moderate to deep entrenchment and are moderately-to-well confined within the valley. The **C** reaches have gradients between 0.1% and 1.5%. Most of the **C** reaches are moderately entrenched, but with only slight confinement. The **D-G** categories describe river deltas, esturine and glacial out-wash conditions, and a Grand Canyon-like river channel with low gradients and complete entrenchment.

<u>Classification by Sinuosity and Bankfull Width-Depth Ratio</u>

In general, **A** channels are less sinuous than **B** channels, which are less sinuous than **C** streams. However, there is enough overlap between **A** and **B** stream reaches and B and **C** reaches to lessen the usefulness of sinuosity as a determining factor in the stream classification. In addition to the problem of overlapping criteria values, the sinuosity is not readily measurable in the field. Sinuosity is measured by the length of the stream divided by the valley length; it can, however, be measured on topographic maps or aerial photographs.

The classification values for width to depth ratio also overlap throughout the **A**, **B**, and **C** categories. All **A** reaches are shown to have a ratio greater than 10. However, the ratio range listed for **B** streams is from 8 to 20, except for the B-1 subtype, which ranges from 5 to 15. In the **C** channels, the ratio value is from greater than 3, 5, or 10 to between 15 and 30, depending on the subtype. Although the ratio is easy to calculate, determining where to measure bankfull width is not always clear.

The Rosgen classification system can be used with topographic maps and aerial photos for general classification needs. However, information collected on site is necessary for accuracy in classification procedures and for classifying to the subtype level.

The Subtype Channel Level

Classification by Dominant Particle Size

An additional label (number or lower case letter) places a stream section into a subtype within the broad **A-G** categories. The subtype, as used in this study, is based on dominant particle size within the stream bed. The larger the number, the smaller the dominant particle size found in a stream section. For example, a B-2 stream section has a mean gradient of 2% with channel materials consisting of large cobble mixed with small boulders and coarse gravel. A B-4 channel has a mean gradient of 2% with channel materials composed of very coarse gravel with cobble mixed with sand and finer materials. The letter "a" denotes a bedrock channel, as in the A-2a subtype.

Physical Habitat Classification: A Review of Techniques

The habitat classification system used in this study (Decker et al, 1989) gives information on the sequence (Figure 2), distribution, and availability of physical habitat based on the division of habitat into three main geomorphic components: riffle, pool, and flatwater. The three categories describe principal geomorphic features in a stream.

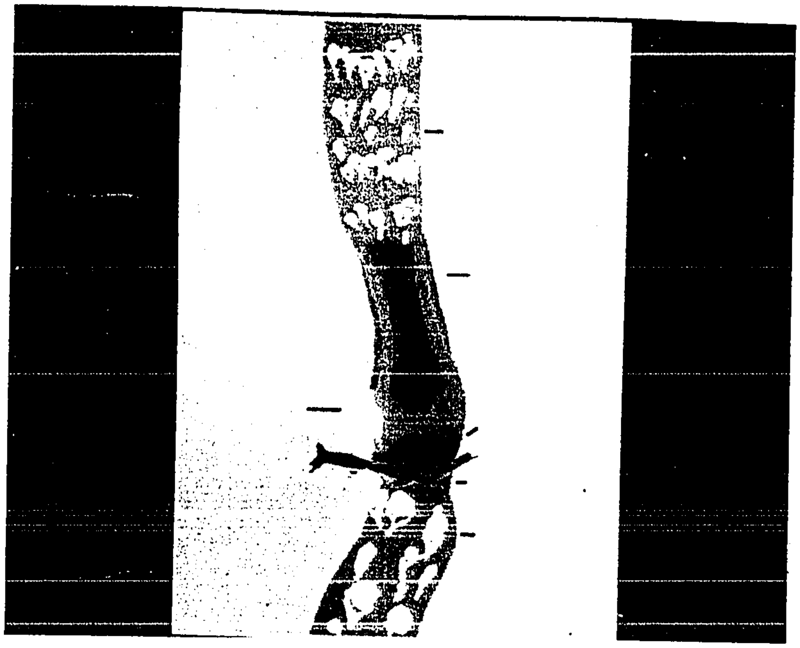
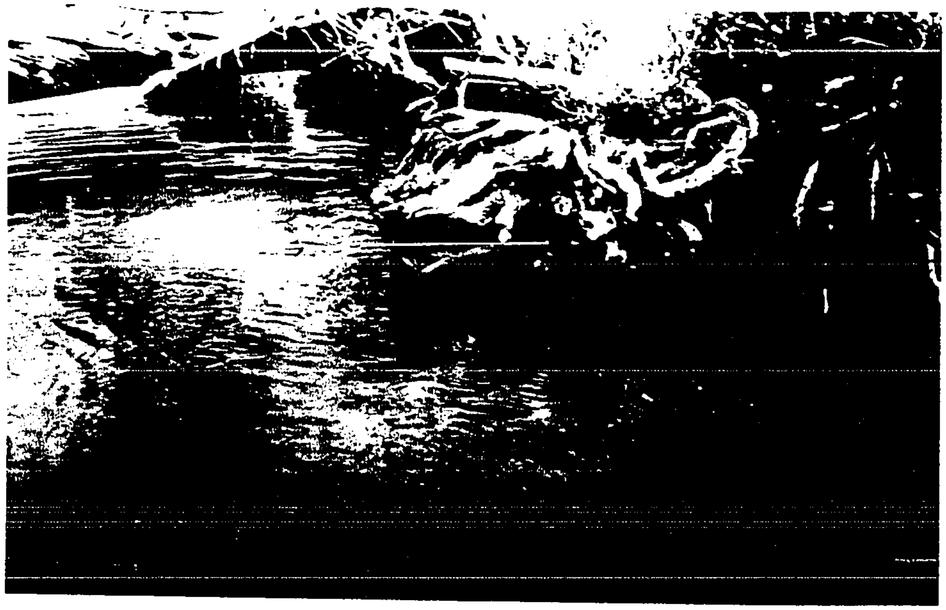


Figure 2. Example of Habitat Type Distribution

A balance of riffles, pools, and flatwater contribute to a healthy riparian system. However, depending on the cause of the habitat formation (log, boulder, gradient, for example), a number of habitat types can exist distributed between pools, riffles, or flatwater. Therefore, the Decker system describes 22 habitat types, each a discrete unit of the three main categories.

There are three types of riffles (defined by gradient), 14 types of pools (defined by position in the stream and cause of scour) and 5 types of flatwater (differentiated on the basis of depth and velocity). Each of the habitat types is referred to by a number, from 1-22 and an associated name (Appendix 2). Streams which may be limited in terms of specific habitat can be identified using the Decker system. The following photographs display examples of selected habitat types.

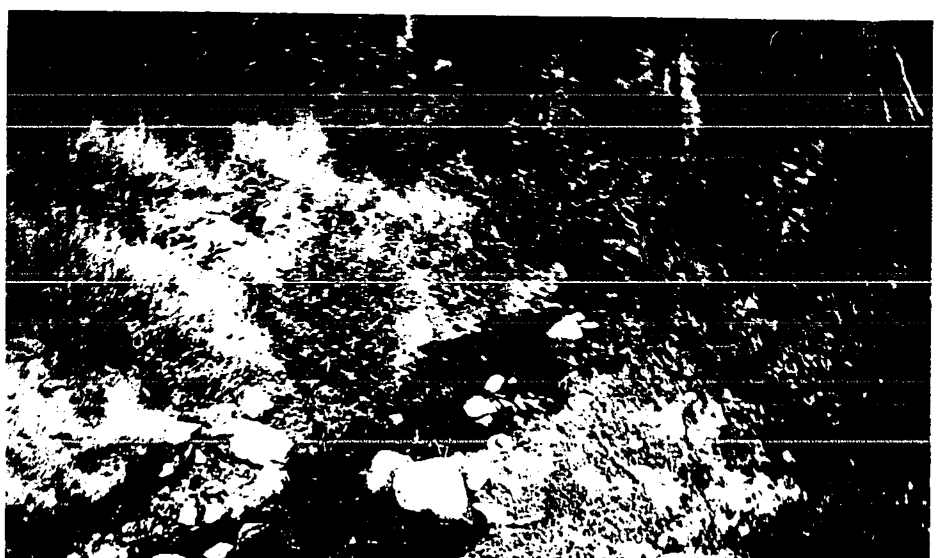
PHOTOGRAPH 1. Lateral Scour Pool-Boulder Formed (Meiss Creek, tributary to Upper Truckee River)



PHOTOGRAPH 2. Lateral Scour Pool-Rootwad Formed (Blackwood Creek)

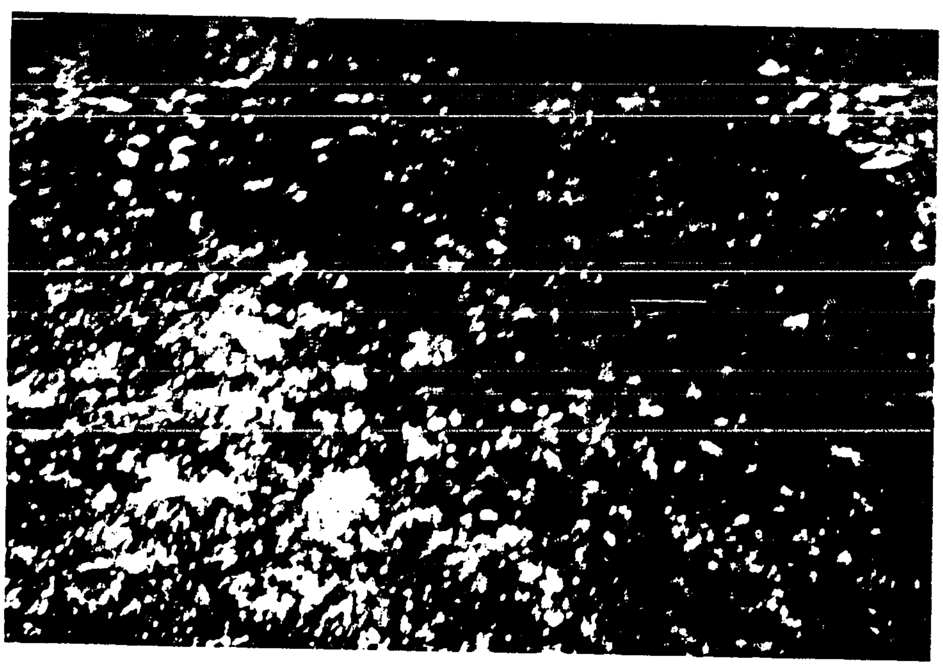
PHOTOGRAPH 3. Corner Pool (Angora Creek)

PHOTOGRAPH 4. Dammed Pool (Angora Creek)



PHOTOGRAPH 5. Step Run (Creek #4 in Meiss Country)

PHOTOGRAPH 6. Glide (So. Upper Truckee River-Meiss Country)



PHOTOGRAPH 7. Low Gradient Riffle (Blackwood Creek)

CHAPTER 4

LOCATION AND BACKGROUND OF STREAMS IN STUDY

Eight continuous sections in a total of seven streams were studied in the Lake Tahoe Basin to investigate the relationships between channel characteristics and physical habitat composition. The streams are located on the south and west sides of the basin. The locations of the streams are shown in Figure 3 and described below. Where human use along a stream has been notable, a brief history of that use is included in the location description. Logging is not mentioned specifically because it occurred on a widespread scale throughout the Lake Tahoe Basin in the late 1880's and early 1900's, affecting all streams and nearly denuding half of the Lake Tahoe Basin (Strong, 1984).

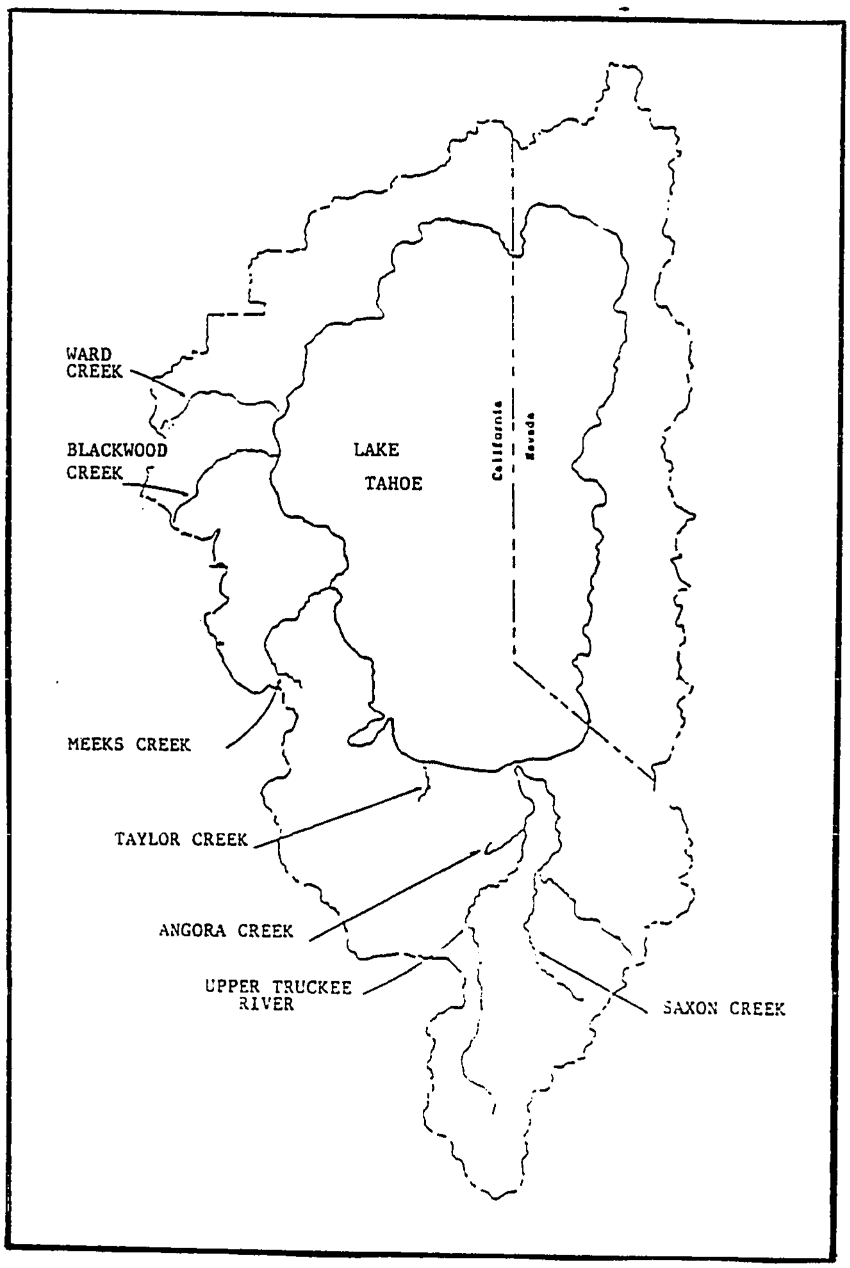


Figure 3. Study Streams in the Lake Tahoe Basin

Angora Creek

Angora Creek, in El Dorado county, is a 4.4 mile long tributary to the Upper Truckee River and has a drainage area of 5.99 square miles. The creek originates at Lower Angora Lake (elevation 7,390 feet) and meets the Upper Truckee River at an elevation of 6,270 feet. The creek is in the southwestern end of the Lake Tahoe Basin. The lower three miles of the creek were classified by channel type and habitat type.

There are homes built in the lower section of Angora Creek and, until the California Department of Parks and Recreation purchased the land around the lowest section of the creek, cattle grazing was permitted in the meadow areas. A resort at Upper Angora Lake contributes little human disturbance to Angora Creek. Most of the use along Angora Creek is recreational hiking, fishing, and cross-country skiing.

BLACKWOOD CREEK

Blackwood Creek is in Placer county, on the northwest side of the Lake Tahoe Basin. It has a drainage area of 11.18 square miles and originates at 7,140 feet elevation. Blackwood Creek was surveyed from its mouth at Lake Tahoe to the headwater area, where gradient exceeded 10%, a total of

5.86 miles. The total stream length is 6.2 miles. The north fork was also surveyed until gradient exceeded 10%, a total of 0.13 miles (709 feet).

The human history in Blackwood Canyon is diverse and has had significant impacts on the stream. For over 100 years, Blackwood Canyon has seen heavy disturbance from grazing, logging, mining, and general recreation. Of these activities, sheep grazing was probably the first to occur (late 1880's) with major logging and mining to follow. After the USDA Forest Service purchased the majority of private land, commercial interests in Blackwood Canyon eventually gave way to public recreational pursuits (Holland, 1986). The USDA Forest Service did extensive restoration work in the stream between 1980 and 1988 to repair some of the resource damage done by the mining activities in the 1950's (USDA Forest Service, Lake Tahoe Basin Management Unit, Watershed Annual Report, 1986-88).

Meeks Creek

Meeks Creek is on the west side of the Lake Tahoe Basin in El Dorado county. It has a drainage area of 8.16 square miles, and originates at an elevation of 7,810 feet. The total stream length is 7.2 miles. The stream connects a series of five lakes in the Desolation Wilderness. Meeks

Creek was surveyed from the boat marina at the mouth of the river to the Desolation Wilderness boundary, a total of 2.46 miles.

The Meeks Creek drainage is a popular entrance to the Desolation Wilderness area. In the past, Girl Scouts of America operated a campground that was accessed by crossing the creek. Grazing has occurred throughout the meadow area.

Saxon Creek

Saxon Creek, in El Dorado county, is on the southern end of the basin. It is a tributary to Trout Creek that meets the Upper Truckee River in the Truckee Marsh at Lake Tahoe. The Saxon Creek drainage is 8.21 square miles, the total channel length is 6.54 miles. The creek originates at an elevation of 8,580 feet and enters Trout Creek at 6,300 feet. Saxon Creek was surveyed from its confluence with Trout Creek to a large boulder field 2.2 miles upstream. Hiking, bicycling, and fishing are the primary uses along Saxon Creek.

Taylor Creek

Taylor Creek joins Lake Tahoe with Fallen Leaf Lake on the south side of the Lake Tahoe Basin, in El Dorado county. The drainage area is 18.34 square miles, including the area above Fallen Leaf Lake. The creek originates at Fallen Leaf Lake (elevation 6,377 feet); however, there is approximately 9 miles of main stream channel which flows into Fallen Leaf Lake from 8,110 feet elevation. The entire stream between Lake Tahoe and Fallen Leaf Lake was surveyed (2.04 miles).

The area around Taylor Creek is a popular hiking, fishing, bicycling, and skiing spot for visitors and local residents. A Forest Service Visitors Center attracts people downstream of Highway 89, and a campground on the south side of the creek brings people to the area upstream of the highway.

Upper Truckee River

The Upper Truckee River is in the southern portion of the Lake Tahoe Basin, in Alpine and El Dorado counties. It is the largest tributary to Lake Tahoe, starting from the north side of Carson Pass (west of Red Lake Peak) at an elevation of 9,200 feet, flowing north to Lake Tahoe. The drainage area is 56.6 miles. The total stream length is 21.5 miles. Two different sections of the river were surveyed: The CRMP section and the Meiss Country section. These sections are described separately and were treated as two distinct streams in the data analysis.

The CRMP area is so named because it is an area under Coordinated Resource Planning and Management (CRMP) study by various Federal, State, County and private entities. The CRMP portion of the Upper Truckee River is in El Dorado county and runs between the Highway 50 bridge at Sawmill Road and the Highway 50 bridge at Meyers, California near the base of Echo Ridge. The total length of stream classified in this section was 3.38 miles.

The CRMP section of the Upper Truckee River is bordered by a golf course, a park, and private, state and national forest lands. The area was previously grazed by cows and is now used by recreationists for hiking, fishing, cross country skiing, and bike riding.

The Meiss Country area is in Alpine County and includes the headwaters of the Upper Truckee River. The area surveyed included 2.98 miles of the Upper Truckee River, 0.38 miles of Meiss Creek (a tributary), and 0.53 miles of an unnamed tributary. Meiss Country is a popular fishing, sightseeing, equestrian, day hiking, and overnight camping area. The area is also used by cross country skiers and dog sledders in the winter. Cows have been grazed in this area for over 75 years.

Ward Creek

Ward Creek is in Placer county in the northwest portion of the Lake Tahoe Basin. Ward Creek originates at the 7,700 foot elevation near Twin Peaks and enters Lake Tahoe near the town of Sunnyside. The drainage area is 9.74 miles, it drains the fourth largest watershed in the Lake Tahoe Basin. The main stem and north fork was surveyed until stream gradient exceeded 10%, a total of 5.92 miles.

A fire in the late 1800's destroyed most of the trees not already logged in the Ward Creek drainage (Leonard et al, 1979). Today, the Ward Creek area receives recreational use such as hiking, skiing, fishing, bike riding, and primitive overnight camping. Homes are built near the mouth and within the lower 1.3 miles of the creek.

CHAPTER 5

METHODS

Data Collection Procedures

Channel morphology and habitat composition data were collected in seven streams in the Lake Tahoe Basin. A two-person field crew was used to collect the data. The crew received three days of intensive training prior to field work through a course such as the "USDA Forest Service, Lake Tahoe Basin Habitat Assessment Procedures Class" given June 22-24, 1989. Information was exchanged daily between the crew and forest service biologist and hydrologist to monitor data quality and quantity. Data were collected from Ward Creek during October and November 1988, and from the other creeks from June through September 1989. Approximately one-half mile of stream was surveyed each day. The channel type and habitat type were classified simultaneously.

Stream Channel Classification

Channel morphology was classified according to the Rosgen Stream Classification system. The gradient of the stream channel was used as the primary determining factor.

Channel entrenchment, valley confinement, sinuosity, channel width to depth ratio (taken at bank-full width), landform features, and soils stability were considered but not measured. If channel characteristics did not readily match all criteria listed in Rosgen's system, gradient and particle size within the channel were used as determining factors. The field guide used to determine stream classification is contained in Appendix 1.

Channel gradient was measured as percent slope using an abney level read from a stadia-like measuring rod to a rod placed upstream. Both rods were placed at water surface level and were read at equal heights. Gradient measurements were taken approximately every 200 feet, over long straight stretches of stream, or when noticeable changes in slope or channel structure occurred. Measurements were first read as degree-seconds, then converted to percent (45 degrees equals 100 percent slope, x degrees = 2.23y percent). It was necessary to recalibrate the abney level approximately every other day to maintain accuracy.

Most streams were surveyed until gradient was greater than 10%. In some study streams, management boundaries determined the area surveyed as in Meeks Creek and the Upper Truckee River (see Chapter 4).

Habitat Classification

The methods used to classify habitat was similar to those described in "Stream Classification and Inventory Procedures for Northern California" (Decker et al, 1989):

> The basic method of habitat typing is relatively simple. Starting at the mouth of a stream and working upstream insures a known starting point. Use a measuring device (tape, rod, optical rangefinder, or hip chain) to measure mean length and width of each unit. Three to five width measurements are sufficient. Along each width measurement transect use a graduated leveling rod (or similar device) to take several depth measurements from bank to bank and estimate mean depth.
>
> As with any classification system an occasional habitat unit may not fit into any one habitat type. In an inventory, a certain amount of subjective decision making is involved and accuracy depends heavily on a basic understanding of stream processes, a good knowledge of the classification system and consistency.

Equipment

An electronic measuring device made by the SONIN Company (New York) was used instead of a hip chain or range finder to measure length and width. In rain conditions a 100 ft measuring tape was used. The location of every fifth habitat type and every channel type was marked with a durable plastic tag (used to mark livestock). The semipermanent tags were used to provide lasting identification for multi-year measurements for monitoring changes in habitat quantity and quality.

Materials used were measuring rod, measuring tapes, electronic measuring device, abney level, plastic tags, Rite-in-the-Rain waterproof paper, waterproof pen, and field forms from the USDA Forest Service Pacific Southwest Region.

PHOTOGRAPH 8. FIELD EQUIPMENT

Mapping Criteria

A channel type had to be thirty times the channel width in order to be separated out as a distinct channel type. Areas that appeared distinct but did not meet the mapping criteria were included into the preceding channel type. A habitat type unit had to be at least as long as it was wide in order to be considered a distinct unit.

Data Compilation

For each habitat unit identified the information on the Field Form in Appendix 3 was recorded. For this study, only channel type, habitat type, mean length, mean width, and average depth were considered. From the data collected, the area and volume of each habitat type was calculated. The individual units were grouped by habitat type within each channel subtype for each stream section surveyed. Next, the percent of the area and volume for each habitat type within each channel subtype was calculated. The values for area and volume were also grouped according to primary channel type (**A**, **B**, and **C**).

In addition to the evaluation of the distribution of the individual 22 habitat types within the channel types, the different habitat types were grouped into larger categories. The categories were riffles, pools, and flatwater. The riffles category contained low gradient riffles, high gradient riffles, and cascades. The pools category consisted of secondary channel pools, all lateral scour pools, dammed pools, main channel pools, plunge pools, confluence pools, and corner pools. The flatwater category included pocket water, glide, run, step run, and edgewater habitat types.

CHAPTER 6

RESULTS

Introduction

The results are described in four subchapters: channel and habitat classification at the Rosgen primary channel type level (channels **A**, **B**, and **C**); and channel classification and habitat classification at the channel subtype level (A-1, A-2, B-1, etc). In this way, the data is presented from the meso landscape layer to the micro layer. The channel classification sections describe the number of reaches, the total linear feet, area, and volume of each primary channel type and subtype found in the streams surveyed. The habitat classification sections describe the results of the habitat classification based on how the habitat types are distributed within the primary channel types and channel subtypes.

The composition of habitat types in each primary channel types and subtype is displayed through the use of histograms and written description. The histograms are found at the end of the chapter. The habitat types are listed by three letter codes that are described in detail in Appendix 2. The codes represent the habitat type name listed in Table 2.

TABLE 2. THREE LETTER CODE WITH HABITAT TYPE NAME ASSOCIATED WITH IT

LGR :	Low gradient riffle
HGR :	High gradient riffle
CAS :	Cascade
SCP :	Secondary Channel Pool
BWB :	Backwater Pool, Boulder formed
BWR :	Backwater Pool, Rootwad formed
BWL :	Backwater Pool, Log formed
TRP :	Trench Pool
PLP :	Plunge Pool
LSL :	Lateral Scour Pool, Log formed
LSR :	Lateral Scour Pool, Rootwad formed
LSB :	Lateral Scour Pool, Bedrock formed
DPL :	Dammed Pool (often caused by a beaver dam)
GLD :	Glide
RUN :	Run
SRN :	Step run
MCP :	Main Channel Pool
EGW :	Edgewater
CCP :	Channel Confluence Pool
LBO:	Lateral Scour Pool, Boulder formed
POW :	Pocket Water
CRP :	Corner Pool

Channel Classification Results at the Primary Channel Type Level

A total of 28.66 miles of stream was assessed in this study. The total area surveyed was 2,058,602.9 square feet. The total volume surveyed was 2,348,437.9 cubic feet.

Within the 7 basic categories in which to place a stream section using the Rosgen Classification, all stream sections in this study were placed in the **A**, **B**, or **C** categories. Fifty five distinct reaches were defined in 8 stream sections (7 different streams). The reaches varied in length from 205 feet (an A-2 reach in Angora Creek) to 17,958 feet (a C-2 reach in the CRMP area of the Upper Truckee River). The number of reaches, length, area, and volume in each primary channel type is displayed in Table 3.

TABLE 3. CHANNEL CLASSIFICATION RESULTS AT THE PRIMARY CHANNEL TYPE LEVEL

CHANNEL TYPE	NUMBER OF REACHES	LENGTH MILES	AREA SQ FEET	VOLUME CU FEET
A	14	2.39	105,067	87,097
B	18	9.44	722,498	630,252
C	23	16.58	123,103	163,089

The **A** Channel Type

In the **A** channel type, subtypes A-1, A-2, A-2a and A-3 subtypes were described in a total of 14 reaches. The combined length in the **A** channels was 2.39 miles. The total area surveyed within the **A** channel type equaled 105,067 square feet and volume equaled 87,096.7 cubic feet. All stream sections surveyed contained **A** channel type reaches except Angora Creek, the CRMP section of the Upper Truckee River, and Taylor Creek.

The **B** Channel Type

In the **B** channels, subtypes B-1, B-1-1, B-2, B-3 and B-6 were described in a total of 18 reaches. The combined length of the **B** reaches was 9.44 miles. The total area and volume surveyed in the **B** channel types was 722,497.8 square feet and 630,251.9 cubic feet, respectively. Channel types **B** were found in all sections surveyed except for Saxon Creek and the CRMP section of the Upper Truckee River.

The **C** Channel Type

Subtypes C-2, C-3, C-4, C-5, and C-6 were mapped in a total of 23 reaches of **C** channel type. The combined length of the **C** sections was 16.58 miles. The total area and volume was 1,231,038.1 square feet and 1,631,089.3 cubic feet, respectively. The **C** channel type was present in all streams surveyed except for Ward Creek.

Habitat Classification Results at the Primary Channel Type Level

There were 1,176 individual micro units identified in this study. The micro units were grouped according to habitat type as well as by the channel type in which they occurred. The micro units were also grouped according to the geomorphic classes of riffles, pools and flatwater to give a broad picture of habitat occurrence (see Chapter 3). The distribution of riffles, pools, and flatwater is discussed in terms of the percent area and volume of occurrence within each primary channel type.

The **A** Channel Type

In **A** channels 14 of the total 22 possible habitat types were mapped. The majority of the area (92.7%) and volume (93.1%) occurred in 3 habitat types: high gradient riffle, cascade, and step run. The percent total area of these habitats was 28.3, 28.5, and 35.9, respectively. The percent volume equaled 15.4, 54.8, and 22.9, respectively. The percent area and volume of the low gradient riffles, main channel pools and dammed pools were each less than 2.2%. All other habitat types (trench pool, plunge pool, lateral scour pool-bedrock formed, dammed pool, glide, run, main channel pool, lateral scour pool-boulder formed, and corner pool) occurred in less than 1.0% of the total area and volume.

The backwater pools, lateral scour pools formed by logs and rootwads, the quiet shallow water of edgewater pools, pocketwater, and confluence pools were not found in the **A** channel type reaches. When grouped into the categories of riffles, pools, and flatwater, it was found that 59.1% of the area and 71.2% of the volume was accounted for by the riffles habitat type. Flatwater habitat types accounted for 36.8% of the area and 23.7% of the volume. The pool habitat types represented less than 5.1% of the area or volume (Table 4).

The **B** Channel Type

All habitat types were represented in **B** channel types except backwater pools formed by boulders and rootwads, edgewater, and pocketwater. The majority of the area (91.7%) and volume (84.6%) were represented by 6 habitat types. These habitat types and corresponding percent area and volume, respectively, were: low gradient riffle (17.4%, 11.0%); dammed pool (9.2%, 17.2%); glide (7.5%, 6.6%); run (10.7%, 8.9%); step run (42.7%, 31.7%); and corner pool (4.3%, 9.1%).

The remaining 8.3% of the area and 15.4% of the volume was accounted for by the following habitat types: high gradient riffle, cascade, secondary channel pool, backwater pool-log formed, trench pool, plunge pool, lateral scour pool-log, boulder, root wad, and bedrock formed, main channel pool, and channel confluence pool. Each of these habitat types occurred in less than 2.1% of the total area, with 8 of these types occurring in less than 1.0% of the total area. In terms of volume, these habitat types each occurred in less than 4.5% of the volume, with 7 types each contributing less than 1.0% of the total volume.

Four habitat types were not found in the **B** reaches: backwater pools-boulder and rootwad formed, edgewater, and pocketwater. In the riffles, pools, and flatwater categories, the majority of the area and volume was found in the flatwater habitat types: 60.9% total area and 47.3% total volume. Pools contributed to 20.3% of the area and 40.2% of the volume in the **B** channels, while riffles accounted for 18.8% of the total area and 12.4% of the total volume.

The C Channel Type

Twenty different habitat types were present in the C channel reaches. Four habitat types contributed to 76.9% of the total area. These habitat types and percent area were: dammed pool (26.3%), glide (28.9%), run (10.7%), and corner pool (10.9%). Five habitat types had percent total area values from 2.0 to 5.6%: low gradient riffle, lateral scour pool-log and rootwad formed, step run, and main channel pool.

The remaining 11 types each represented less than 1.4% of the total area in the C channel types. The 11 habitat types were the high gradient riffle, cascade, secondary channel pool, backwater pool-boulder and log formed, trench pool, plunge pool, lateral scour pool-bedrock formed, edgewater, channel confluence pool, and lateral scour pool-boulder formed.

The habitat types that represented the majority of the area also represented the majority of the volume, as in channel types **A** and **B**. Dammed pools, glides, runs and corner pools represented 76.8% of the volume. However, main channel pools accounted for a greater percentage of volume than glides--6.6% compared to 5.6%, respectively. Only 2 habitat types were not represented in the C channel type reaches, rootwad formed backwater pool and pocketwater.

When grouped by the riffles, pools, and flatwater categories, it was found that the area and volume was accounted for somewhat equally between pools and flatwater. The percent area represented by pools was 51.2% and 45.4% by flatwater. The percent volume for pools was 54.3% and 44.2% for flatwater. Riffles accounted for only 3.4% of the area and 1.4% of the volume in **C** channels.

The distribution of riffles, pools, and flatwater habitat categories in the **A**, **B**, and **C** channel types is shown in Table 4.

TABLE 4. HABITAT CLASSIFICATION RESULTS: RIFFLE, POOL, AND FLATWATER

CHANNEL TYPE	RIFFLE %AREA	RIFFLE %VOLUME	POOL %AREA	POOL %VOLUME	FLATWATER %AREA	FLATWATER %VOLUME
A	59.1	71.2	4.1	5.0	36.8	23.7
B	17.8	12.4	20.3	40.2	60.9	47.3
C	3.4	1.4	51.2	54.4	45.4	44.2

Channel Classification Results at the Channel Subtype Level

The A Channel Type

THE A-1 SUBTYPE. The total area of the A-1 reaches was 1,706 square feet; the total volume was 323.7 cubic feet. One distinct reach of A-1 channel subtype was mapped in this study in one stream (Upper Truckee River-Meiss Country). The total number of feet mapped was 703 feet.

THE A-2 SUBTYPE. The total area of the A-2 reaches was 4,418 square feet; the total volume was 4,170 cubic feet. Two reaches of A-2 channel subtype were found in a total of 2 streams surveyed (Meeks Creek and Upper Truckee River-Meiss Country), in 495 feet.

THE A-2a SUBTYPE. The total area of the A-2a reaches was 33,300 square feet; the total volume was 51,520.9 cubic feet. There were 4 reaches of A-2a found in a total of 3 streams (Meeks, Upper Truckee River-Meiss Country, and Saxon Creek). A total of 2,605 feet were mapped.

THE A-3 SUBTYPE. The total area mapped in A-3 reaches was 65, 643 square feet; the total volume was 31,081.2 cubic feet. The A-3 channel subtype was found in 3 streams (Upper Truckee River-Meiss Country, Blackwood Creek, and Ward Creek), in a total of 7 different reaches. The total number of feet mapped in the A-3 channel subtype was 8,824.

The B Channel Type

THE B-1 SUBTYPE. The total area of the B-1 reaches was 148,847.8 square feet; the total volume was 133,802.8 cubic feet. The B-1 channel subtypes were mapped in 2 streams (Ward Creek and Taylor Creek), in 2 distinct reaches, in a total of 7,646 feet.

THE B-1-1 SUBTYPE. The total area was 14,616 square feet; the total volume was 5640.6 cubic feet. The B-1-1 channel subtype was found in one reach in one stream (Ward Creek). The reach was 1,842 feet long.

THE B-2 SUBTYPE. The total area in the B-2 reaches was 128,502 square feet; the total volume was 150,960.4 cubic feet; and a total of 7,347 linear feet were mapped. The B-2 channel subtypes were mapped in 2 streams (Taylor Creek and Ward Creek) in a total of 4 reaches.

THE B-3 SUBTYPE. The total area mapped in the B-3 channel subtype was 415,783 square feet; the total volume was 333,566.2 cubic feet. A total of 32,150 linear feet was mapped. The B-3 channel subtype was mapped in 5 streams (Angora, Blackwood, Meeks, Upper Truckee River-Meiss Country, and Ward Creeks), in 9 distinct reaches.

THE B-6 SUBTYPE. The total area in the B-6 reaches was 14,749 square feet and the total volume was 6,281.9 cubic feet. A total of 2,141 linear feet in 2 reaches of the B-6 channel subtype was mapped in 2 streams (Angora Creek and Upper Truckee River-Meiss Country).

The C Channel Type

THE C-2 SUBTYPE. The total area of habitat mapped in the C-2 reaches was 21,418 square feet; the total volume was 9,075 cubic feet; and the total liner feet mapped was 1,721. The C-2 channel subtype was found in one reach in one stream (Blackwood Creek).

THE C-3 SUBTYPE. The total area in the C-3 reaches was 953,159.2 square feet; the total volume was 1,350,929.3 cubic feet. The C-3 channel subtype was mapped in a total of 13 reaches in 6 streams (all streams except Ward and Saxon Creeks). The total length of the C-3 reaches was 54,621 feet.

THE C-4 SUBTYPE. The total area in the C-4 subtype was 221,081.4 square feet. The total volume was 243,867.9 cubic feet; the total length mapped was 24,483 feet. Five distinct reaches were mapped in a total of 3 streams (Angora, Meeks, and Saxon Creeks).

THE C-5 SUBTYPE. The total area in the C-5 subtype was 7,749 square feet; the total volume was 4,230.3 cubic feet; and the total length was 2,474 feet. Three reaches of the C-5 subtype were mapped in a total of 2 streams (Angora Creek and Upper Truckee River-Meiss Country).

THE C-6 SUBTYPE. The total area of C-6 channel subtype reaches was 27,670 square feet; the total volume was 22,986.7 cubic feet; and 4,253 feet was the total length. One reach of C-6 channel subtype was mapped in one stream (Saxon Creek).

The number of reaches, length of reaches, area, and volume of reaches mapped in the subtype classification level are displayed in Table 5.

TABLE 5. CHANNEL CLASSIFICATION RESULTS AT THE SUBTYPE LEVEL

CHANNEL TYPE	NUMBER REACHES	LENGTH MILES	AREA SQ FT	VOLUME CU FT
A-1	1	0.13	1,706	324
A-2	2	0.09	4,418	4,170
A-2a	4	0.49	33,300	51,521
A-3	7	1.67	65,643	31,081
B-1	2	1.45	148,848	133,803
B1-1	1	0.35	14,616	5,641
B-2	4	1.39	128,502	150,960
B-3	9	6.09	415,783	333,566
B-6	2	0.41	147,749	6,282
C-2	1	0.32	21,418	9,075
C-3	13	10.34	953,159	1,350,929
C-4	5	4.64	221,081	243,868
C-5	3	0.47	7,749	4,230
C-6	1	0.81	27,670	22,987

Habitat Classification Results at the Channel Subtype Level

The habitat typing results as grouped by the primary channel type reflect habitat distribution based on the gradient of the channel. Reviewing the habitat distribution within the channel subtypes reveals information about the effects of substrate in addition to gradient on stream morphology as described by physical habitat characteristics.

The A Channel Type

THE A-1 SUBTYPE. Three habitat types were represented in the A-1 channels: high gradient riffle, bedrock formed lateral scour pool and step run. Almost all of the area was represented by the riffle and step run habitat types (50.1% and 48.8%, respectively). The lateral scour pool habitat type accounted for only 1.0% of the area in A-1 channels.

The majority of the volume was represented by the step run type at 70.2%. The high gradient riffle represented 26.4% of the volume; the remaining 3.3% of the volume was found in the lateral scour pool habitat type.

THE A-2 SUBTYPE. Five habitat types were mapped in the A-2 channels, the majority of the area (68.4%) and volume (69.8% were represented by the step run habitat type). The dammed pool habitat type accounted for 15.3% of the area and 20.6% of the volume. The high gradient riffle, cascade, and lateral scour pool-boulder formed habitat types each represented less than 8.6% of the area, and less than 8.6% of the volume.

THE A-2a SUBTYPE. Seven habitat types were represented in the A-2a channels. The area and volume were dominated by the cascade habitat type (85.1% area, 91.4% volume). The step run was the second most abundant habitat type (11.9% area, 5.9% volume). The remaining 5 habitat types each represented less than 1.3% of the area and 1.1% of the volume. The habitat types were: lateral scour pool-bedrock formed, dammed pool, main channel pool, lateral scour pool-boulder formed, and corner pool.

THE A-3 SUBTYPE. The A-3 channels contained the greatest number of habitat types of the A reaches. Two types accounted for the majority of the area and volume: high gradient riffle (43.5% area, 43.3% volume) and step run (45.6% area and 44.4% volume). The remaining 10 types each represented less than 3.5% of the area and 3.0% of the volume: low gradient riffle, cascade, trench pool, plunge pool, dammed pool, glide, run, main channel pool, lateral scour pool-boulder formed, and corner pool.

The B Channel Type

THE B-1 SUBTYPE. Thirteen different habitat types were mapped. The step run habitat type accounted for 71.6% of the area and 64.9% of the volume. Six other habitat types accounted for less than 7.0% each of the area and volume: low gradient riffle, secondary channel pool, plunge pool, run, main channel pool, and corner pool. Five of the 13 habitat types present in the B-1 reaches each occurred in less than 1.0% of the channel subtype: secondary channel pool, lateral scour pools-log, rootwad, bedrock, and boulder formed.

THE B-1-1 SUBTYPE. Two habitat types dominated the B-1-1 channel subtype: low gradient riffle (32.0% area, 21.6% volume) and step run (50.9% and 49.3% volume). Seven other habitat types contributed the remaining 16.9% of the area and 29.0% of the volume. These types were high gradient riffle, cascade, trench pool, plunge pool, lateral scour pools-log and boulder formed, and corner pool.

THE B-2 SUBTYPE. The distribution of the habitat types within the B-2 reaches was more evenly distributed than in the other B reaches. Six of the 9 habitat types mapped in the B-2 subtype represented 95.8% of the area and 92.3 % of the volume. The habitat types, with corresponding area and volume values, respectively, were: low gradient riffle (31.4%, 18.3%), glide (10.6%, 9.9%), run (16.3%, 13.6%), step run (19.9%, 14.4%), main channel pool (5.1% 10.6%), and corner pool (12.5%, 25.6%).

THE B-3 SUBTYPE. Eighteen habitat type were mapped with 5 habitat types representing 89.6% of the total area and 80.8% of the total volume. The 5 types were low gradient riffle (16.9% area, 9.9% volume), dammed pool (14.1% area, 29.4% volume), glide (8.6% area, 7.9% volume), run (9.7% area, 7.3% volume), and step run (40.3% area, 26.3% volume). The remaining 10.4% of the area and 19.2% of the volume consisted of high gradient riffle, cascade, secondary channel pool, backwater pool-log formed, trench pool, plunge pool, lateral scour pool log, rootwad, boulder and bedrock formed, main channel pool, confluence pool, and corner pool.

THE B-6 SUBTYPE. Nine habitat types were represented in the B-6 channel subtype. The majority of the area was found in 2 habitat types: glide (32.5%) and run (42.647%). The run habitat type accounted for 49.5% of the volume. The remaining 24.8% of the area and 50.5% of the volume was distributed as follows: low gradient riffle (4.2% area, 4.9% volume), plunge pool (0.1% area, 0.2% volume), lateral scour pool-root wad formed (1.7% area, 3.6% volume), dammed pool (6.3% area, 14.4% volume), glide (7.6% volume), step run

(10.1% area, 13.9% volume), main channel pool (2.3% area, 5.6% volume), confluence pool (0.1% area, 0.2% volume).

The C Channel Type

THE C-2 SUBTYPE. There were 5 habitat types represented in the C-2 reaches. Step run dominated the area (85.6%) and volume (80.8%). The percent area and volume, respectively, for the remaining 4 habitat types were: low gradient riffle (8.7%, 7.4%), lateral scour pool-bed rock formed (2.8%, 5.9%), lateral scour pool-boulder formed (1.6%, 3.4%), and corner pool (1.3%, 2.4%).

THE C-3 SUBTYPE. Eighteen types were mapped, over half of the area and volume occurred in 2 habitat types: dammed pool (25.2% area, 38.3% volume) and glide (27.5% area, 17.5% volume).

The type and distribution of 10 of the habitat types were: low gradient riffle (4.1% area, 1.6% volume), plunge pool (1.4% area, 3.6% volume), lateral scour pool-log formed (2.2% area, 3.0% volume), lateral scour pool-rootwad formed (3.3% area, 3.7% volume), run (10.3% area, 5.3% volume) step run (5.1% area, 2.1% volume), main channel pool (5.0% area, 7.0% volume), lateral scour pool-boulder formed (1.2% area, 1.3% volume), and corner pool (12.0% area, 14.2% volume).

The remaining habitat types each accounted for less than 1.0% of the area and volume: cascade, secondary channel pool, backwater pools-boulder formed and log formed, trench pool, edgewater, and confluence pool.

THE C-4 SUBTYPE. Fourteen habitat types were present in the C-4 reaches. As in the C-3 habitat type, the dammed pool and glide habitat types accounted for the majority of the area (69.3%) and volume (68.4%). The habitat type, areas and volumes, respectively, of the remaining 12 habitat types were: low gradient riffle (0.06%, 0.03%), high gradient riffle (0.03%, 0.003%), cascade (0.005%, 0.002%), plunge pool (1.2%, 1.6%), lateral scour pool-log formed (2.2% 3.2%), lateral scour pool-root wad formed (1.0%, 1.2%), run (11.8%, 6.7%), step run (0.2%, 0.2%), main channel pool (3.5%, 5.1%), confluence pool (0.4%, 0.9%), lateral scour pool-boulder formed (1.5%, 1.9%), and corner pool (8.6%, 10.7%).

THE C-5 SUBTYPE. Seven habitat types were mapped in the C-5 reaches. The glide habitat type accounted for 90.2% of the area and 81.6% of the volume. Except for the main channel pool at 4.4% area, all other habitat types occurred in less than 2.0% of the area. These habitat types were: low gradient riffle, plunge pool, run, lateral scour pool-boulder formed, and corner pool. The volume for those types were also less than 2.0% except for main channel pool (10.5%) and corner pool (4.2%).

THE C-6 SUBTYPE. There were 9 different habitat types mapped in the C-6 reaches. The two most prevalent habitat types were the dammed pool (55.0% area, 68.5% volume) and run (28.7% area, 17.8% volume) habitat types. Four of the habitat types had percent area and volume values between 1.3% and 6.3% (glide, step run, lateral scour pool-boulder formed, and corner pool). The remaining 3 types were present in less than 1.0% of the B-6 channel. These types were the plunge pool, lateral scour pool-log formed, and the main channel pool.

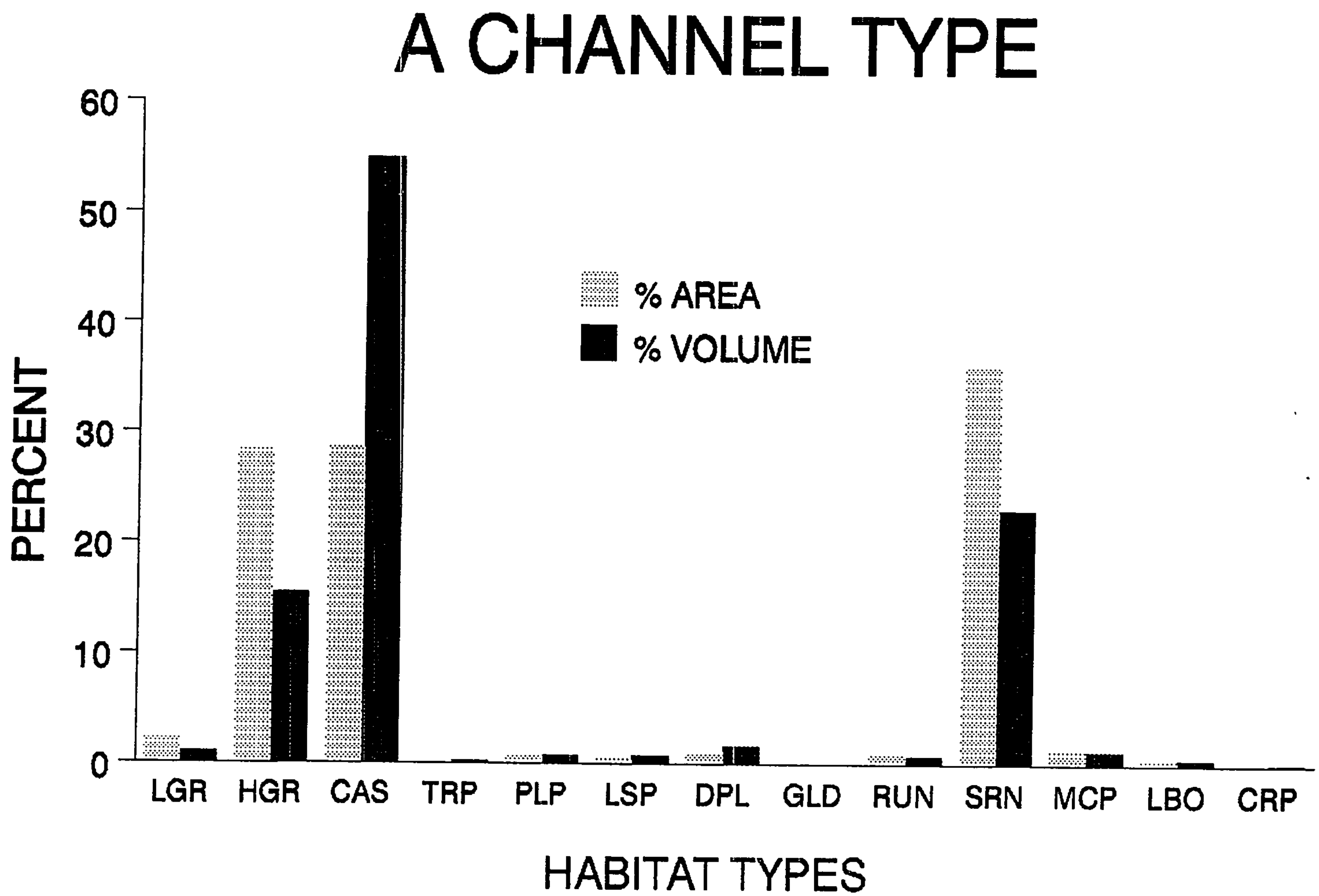


Figure 4. Distribution of Physical Habitat in A Channels

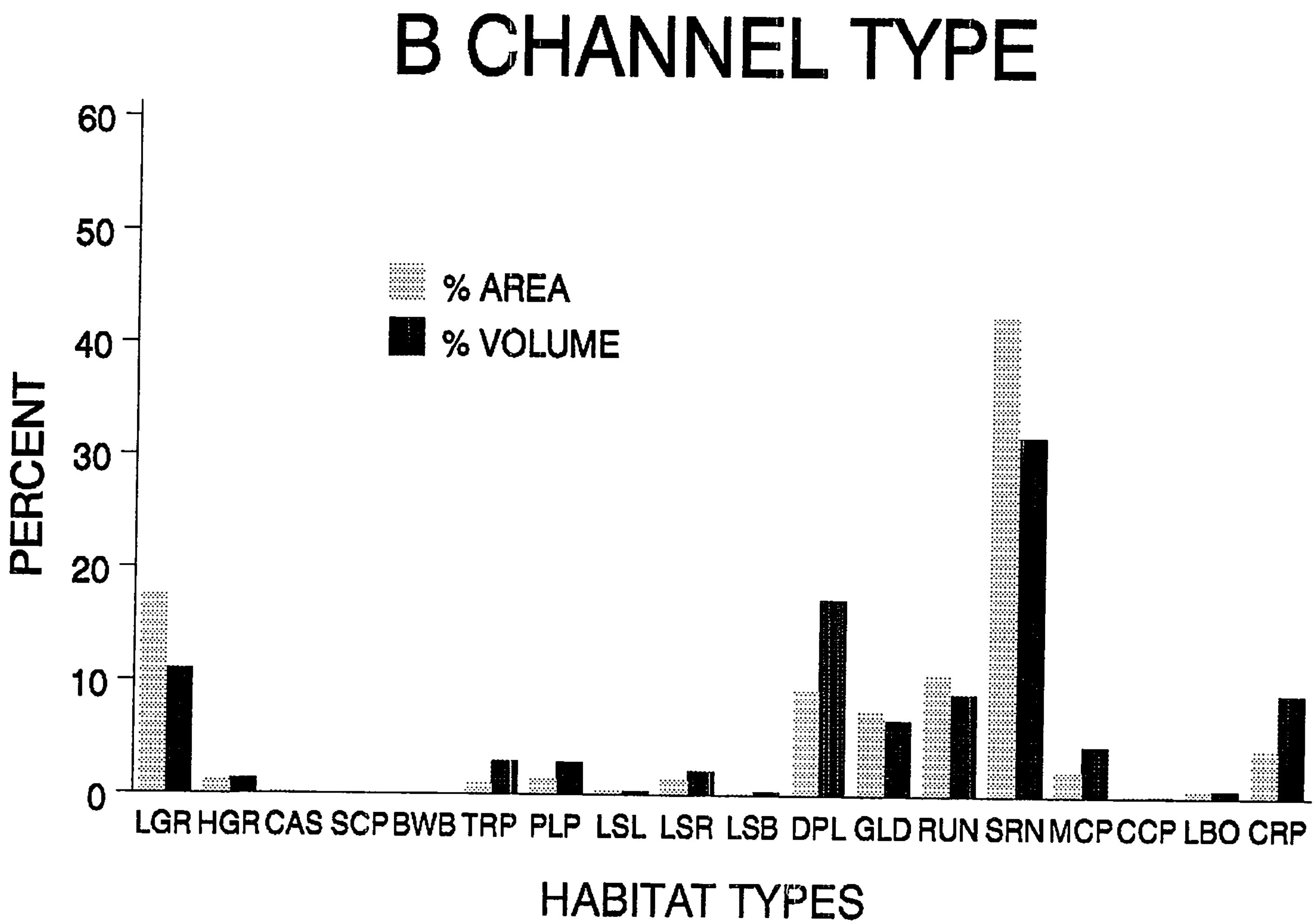


Figure 5. Distribution of Physical Habitat in B Channels

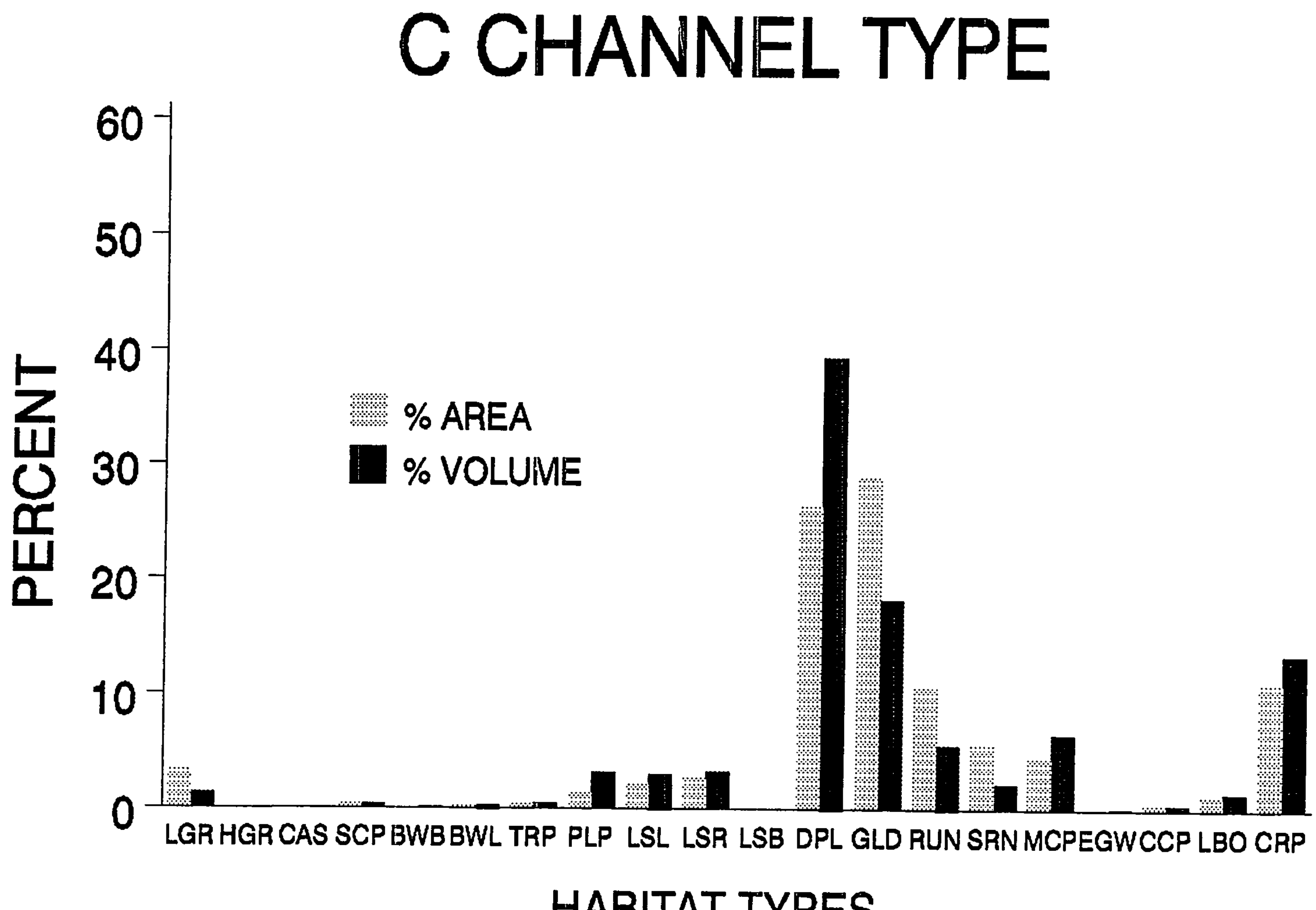


Figure 6. Distribution of Physical Habitat in C Channels

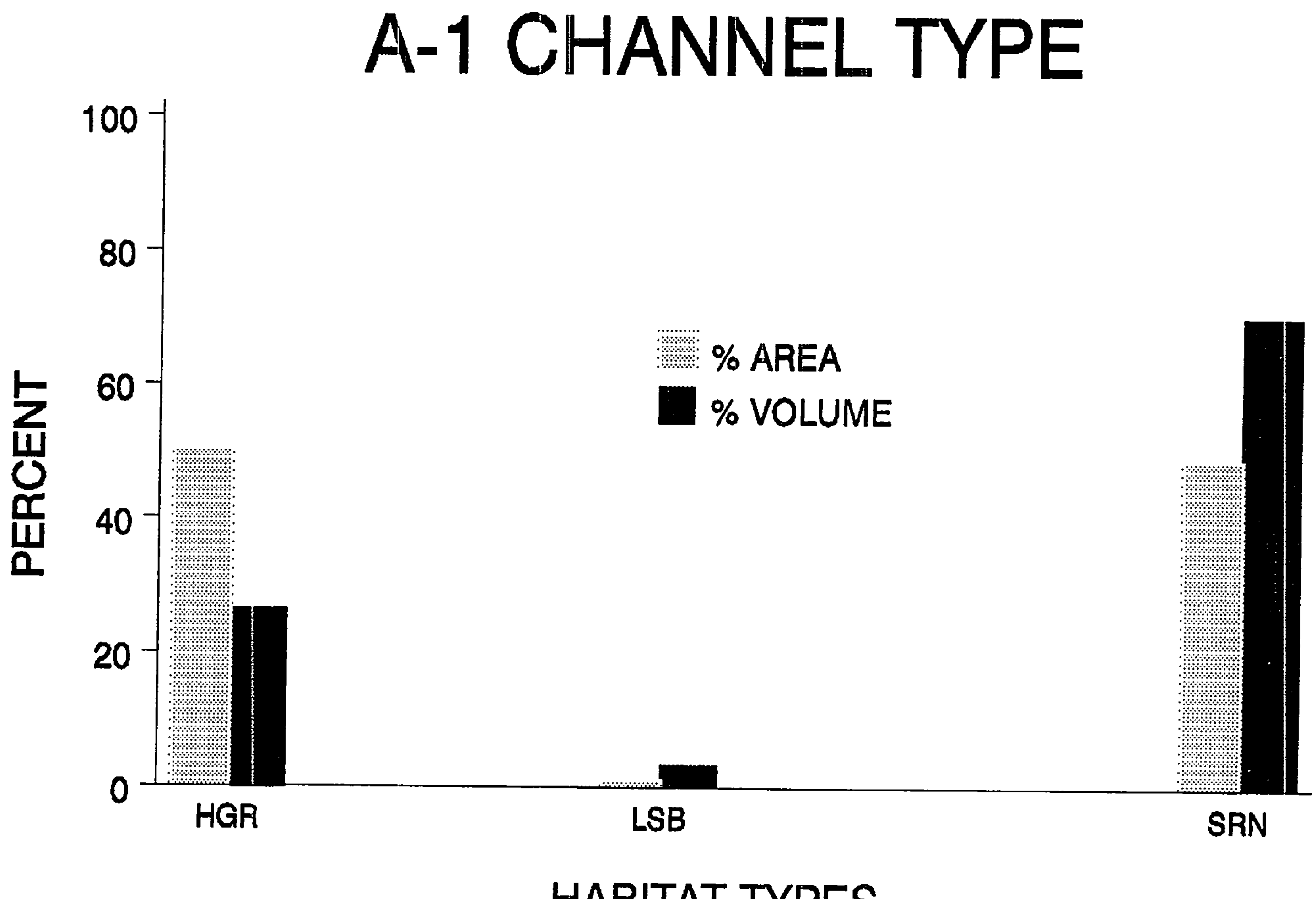


Figure 7. Distribution of Physical Habitat in A-1 Channels

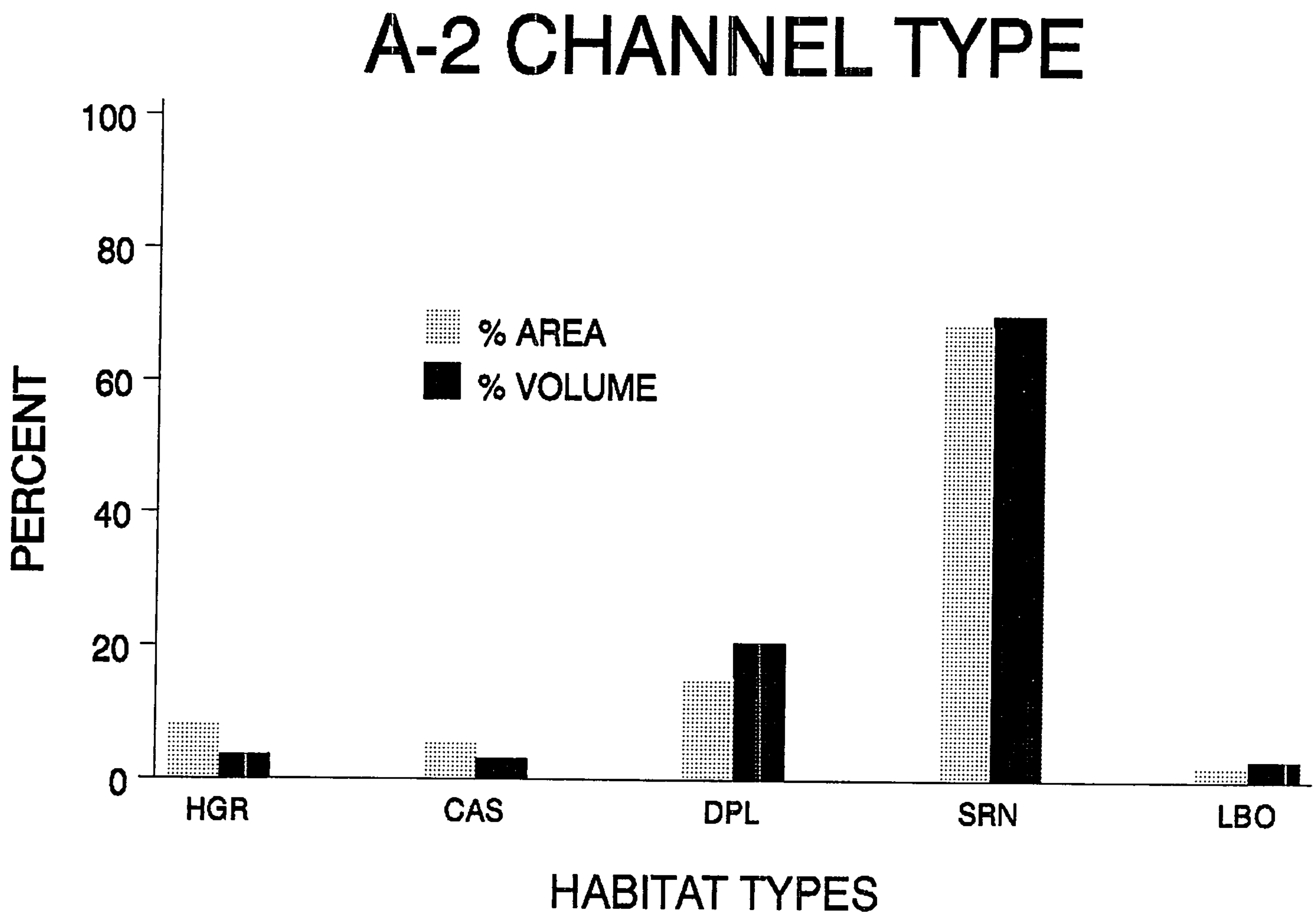


Figure 8. Distribution of Physical Habitat in A-2 Channels

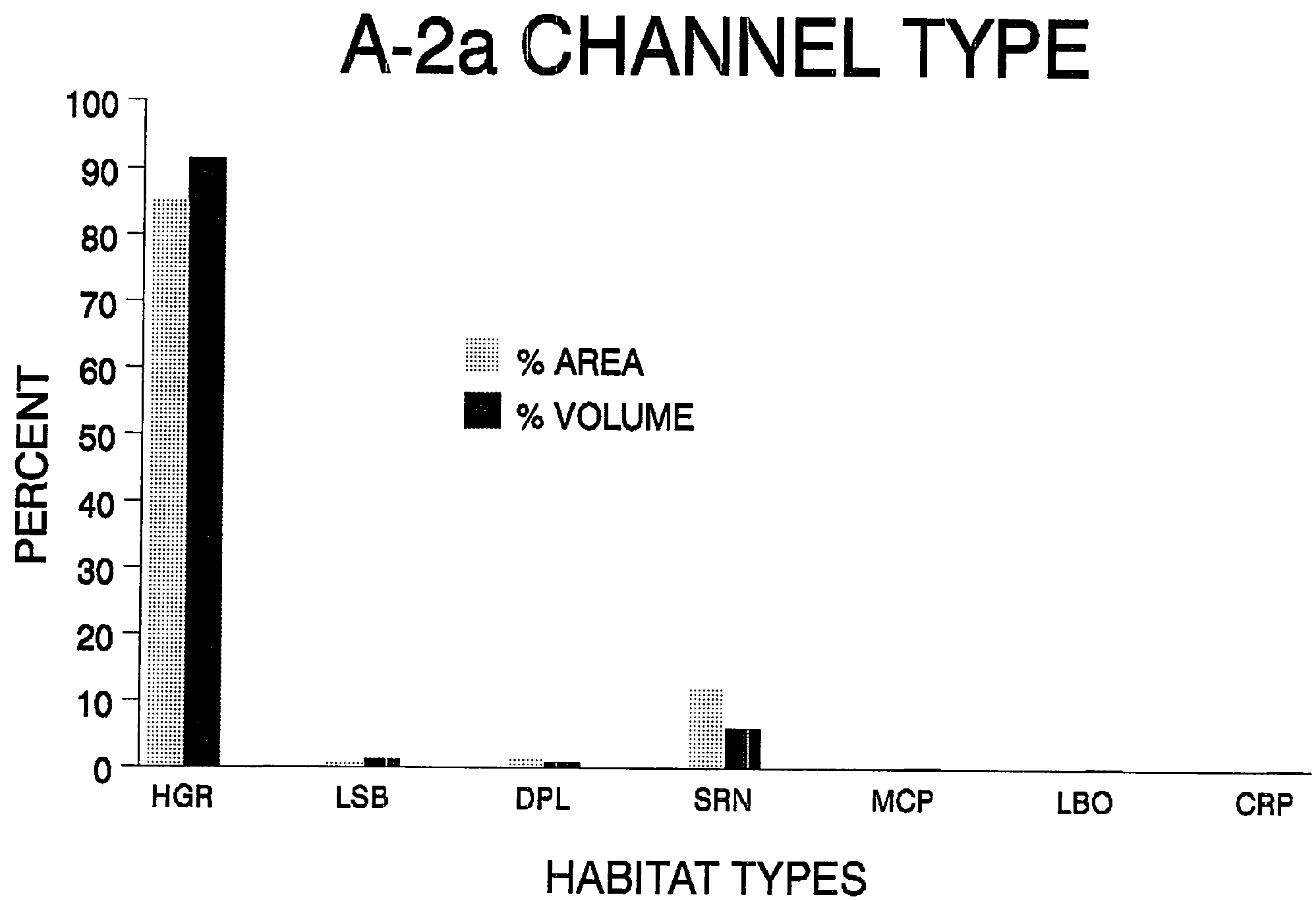


Figure 9. Distribution of Physical Habitat in A-2a Channels

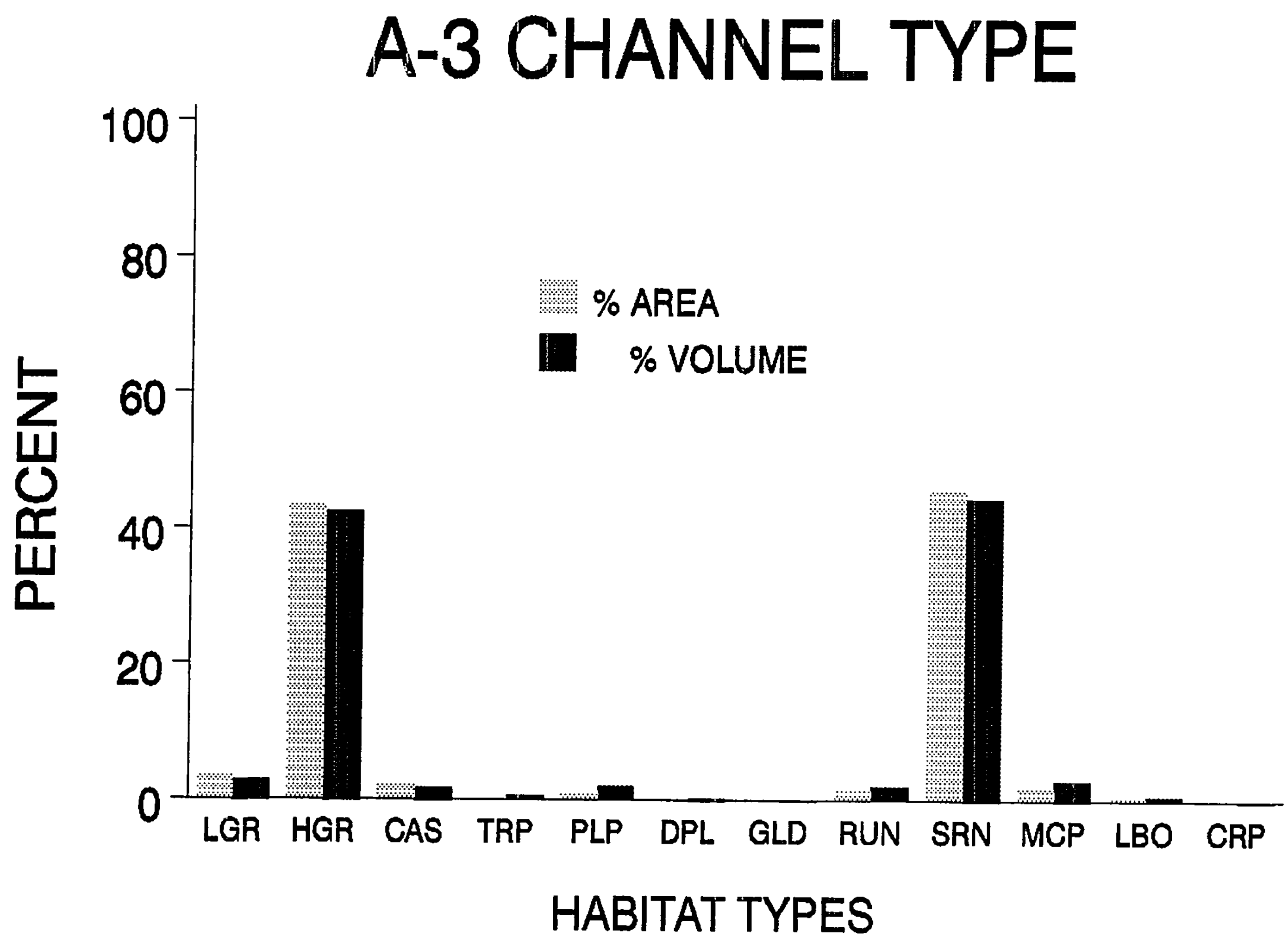


Figure 10. Distribution of Physical Habitat in A-3 Channels

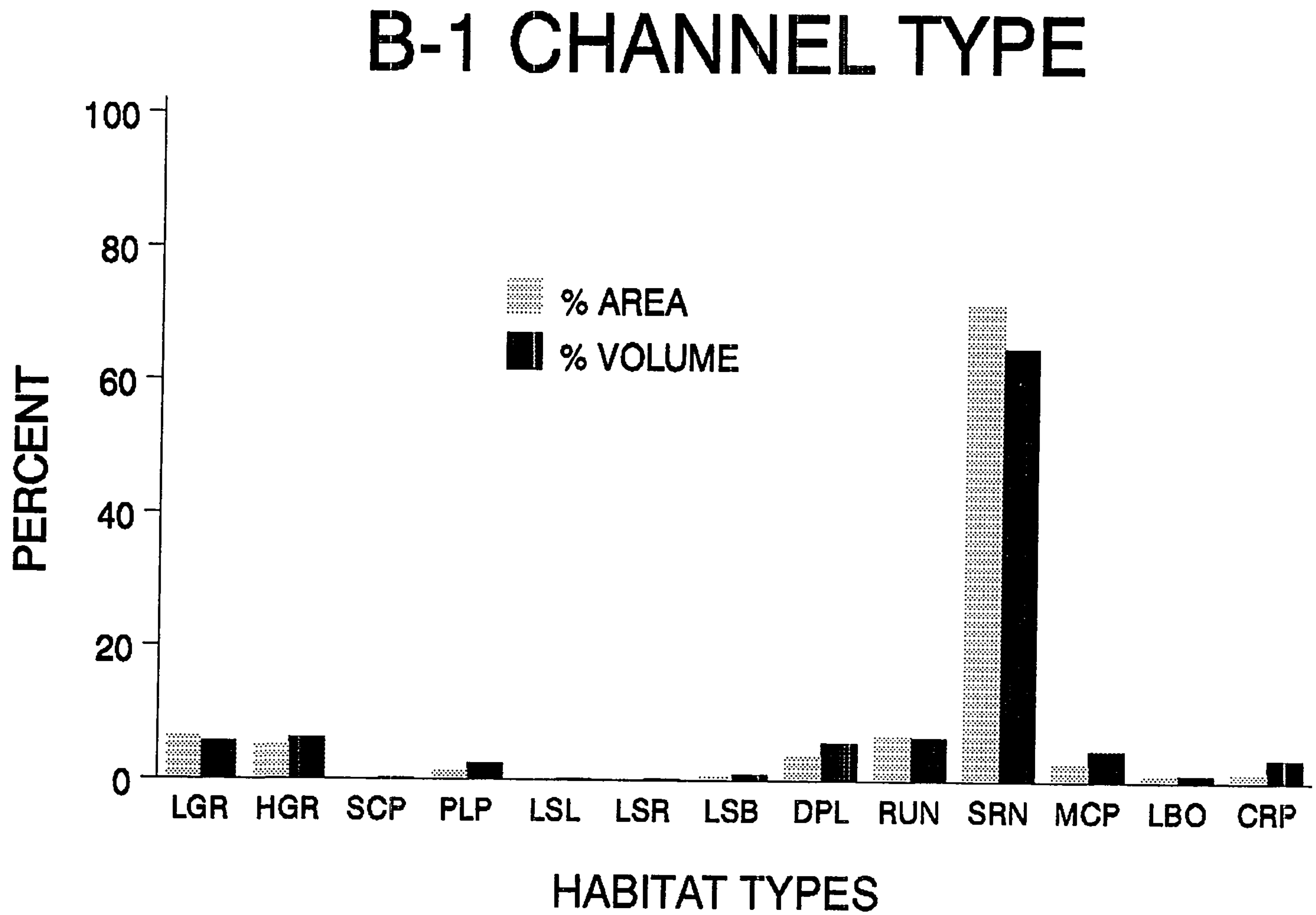


Figure 11. Distribution of Physical Habitat in B-1 Channels

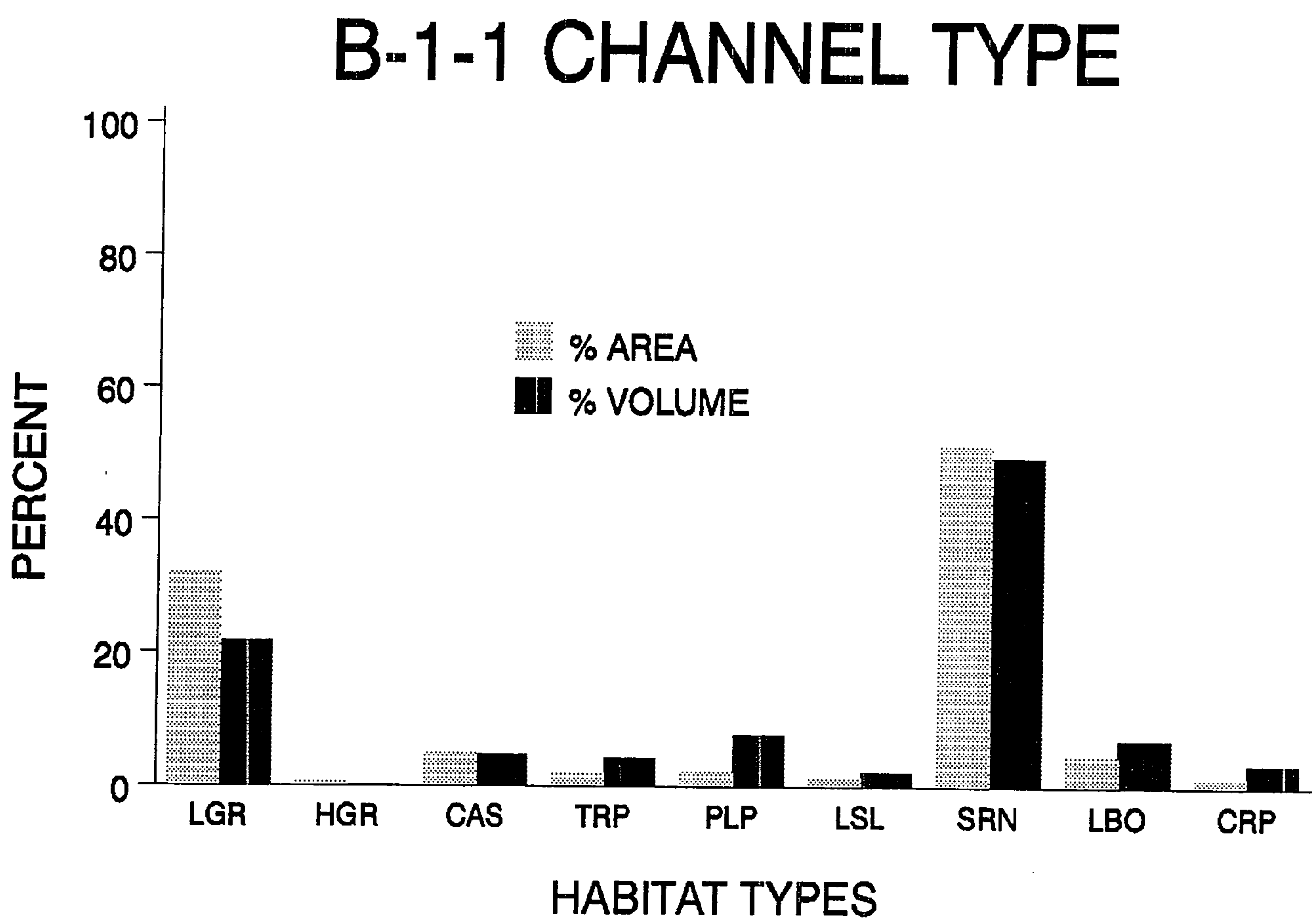


Figure 12. Distribution of Physical Habitat in B-1-1 Channels

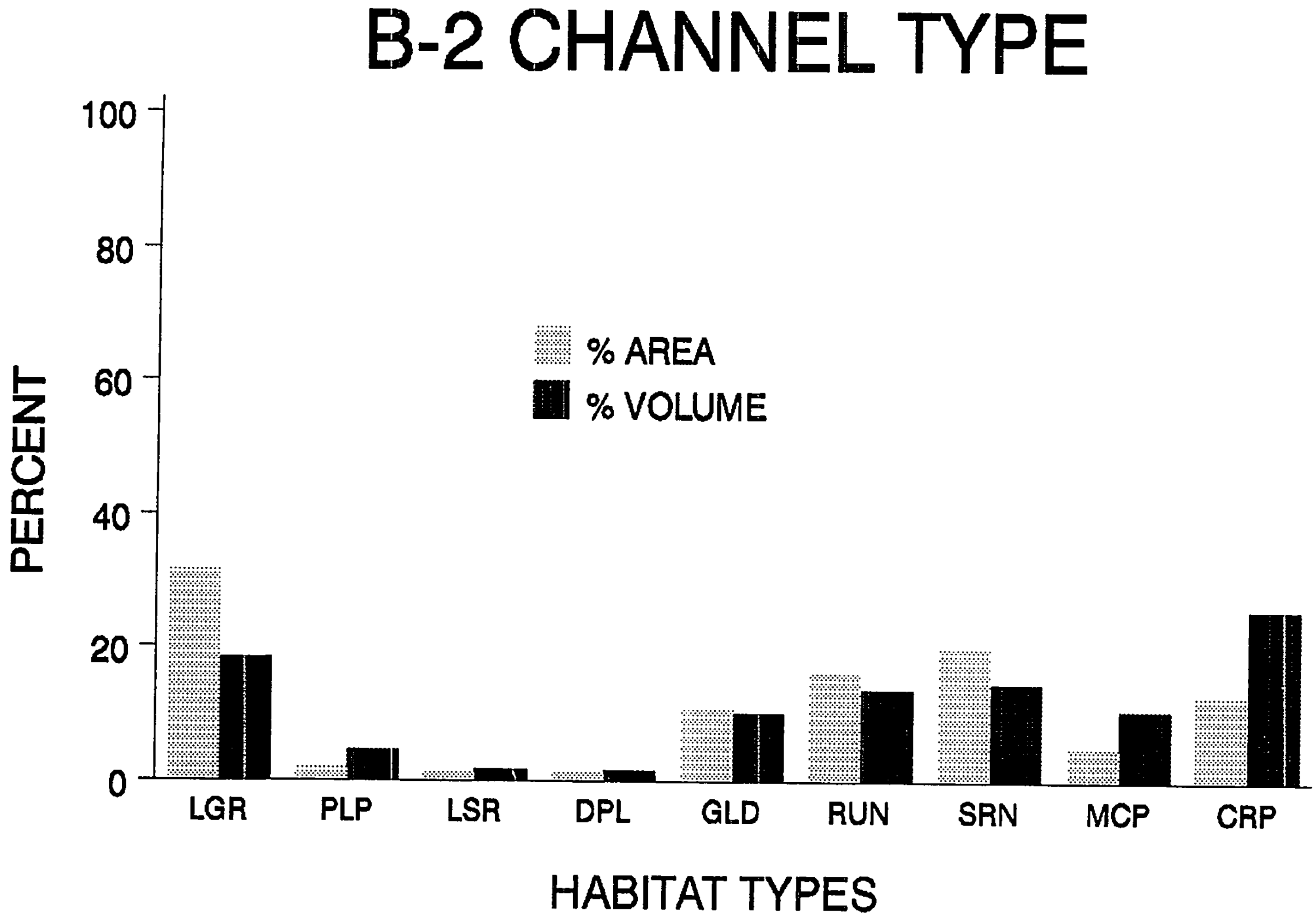


Figure 13. Distribution of Physical Habitat in B-2 Channels

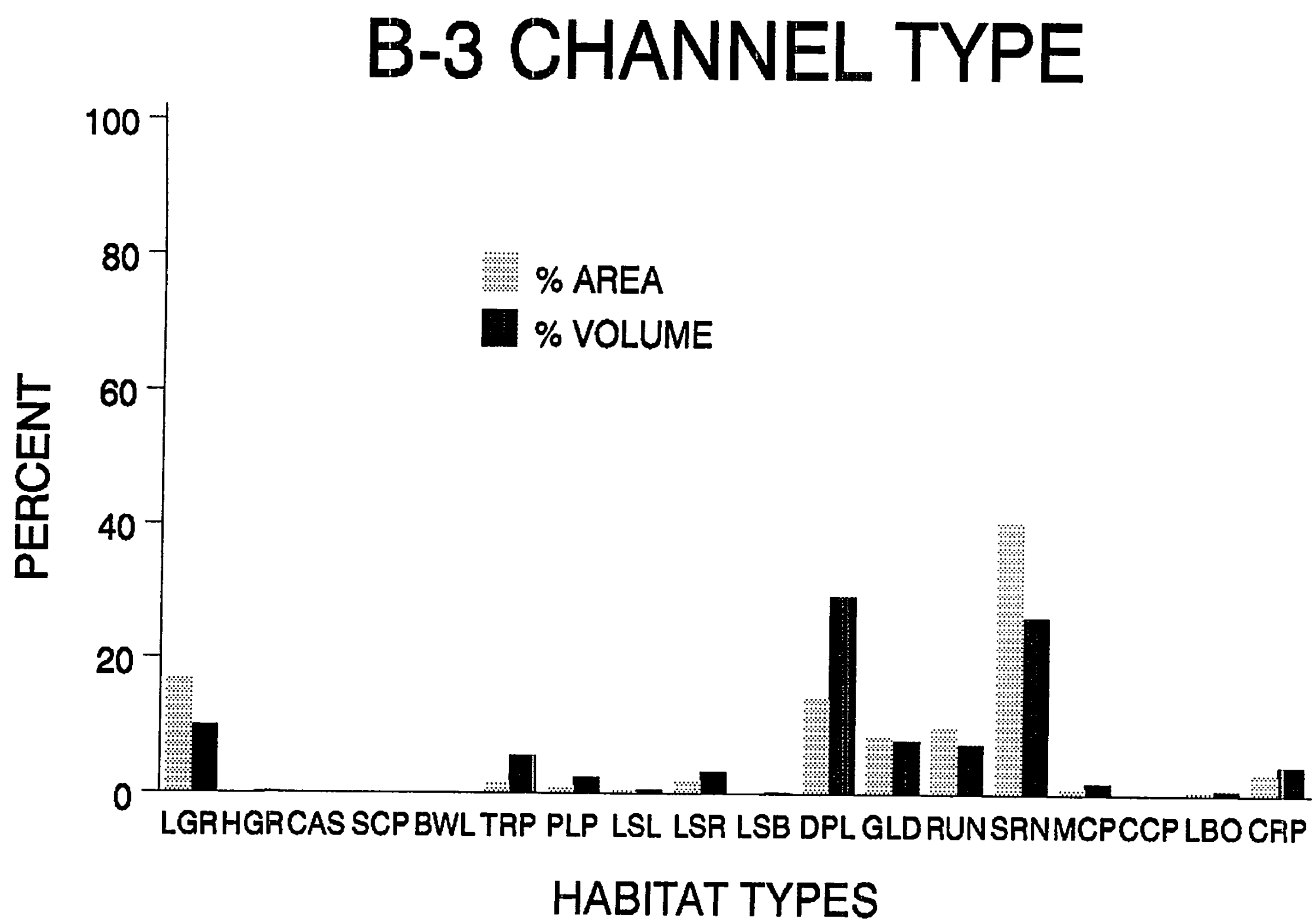


Figure 14. Distribution of Physical Habitat in B-3 Channels

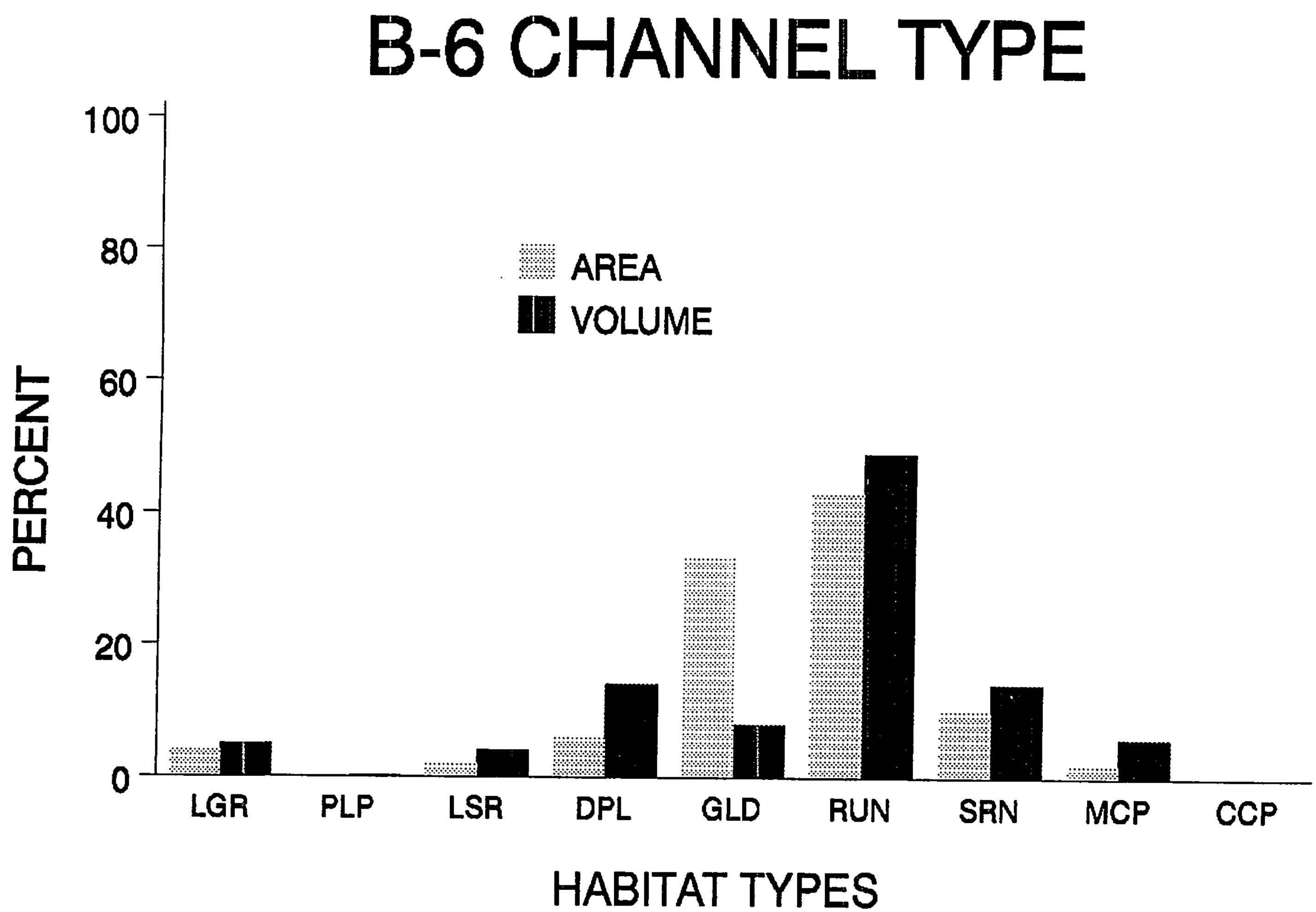


Figure 15. Distribution of Physical Habitat in B-6 Channels

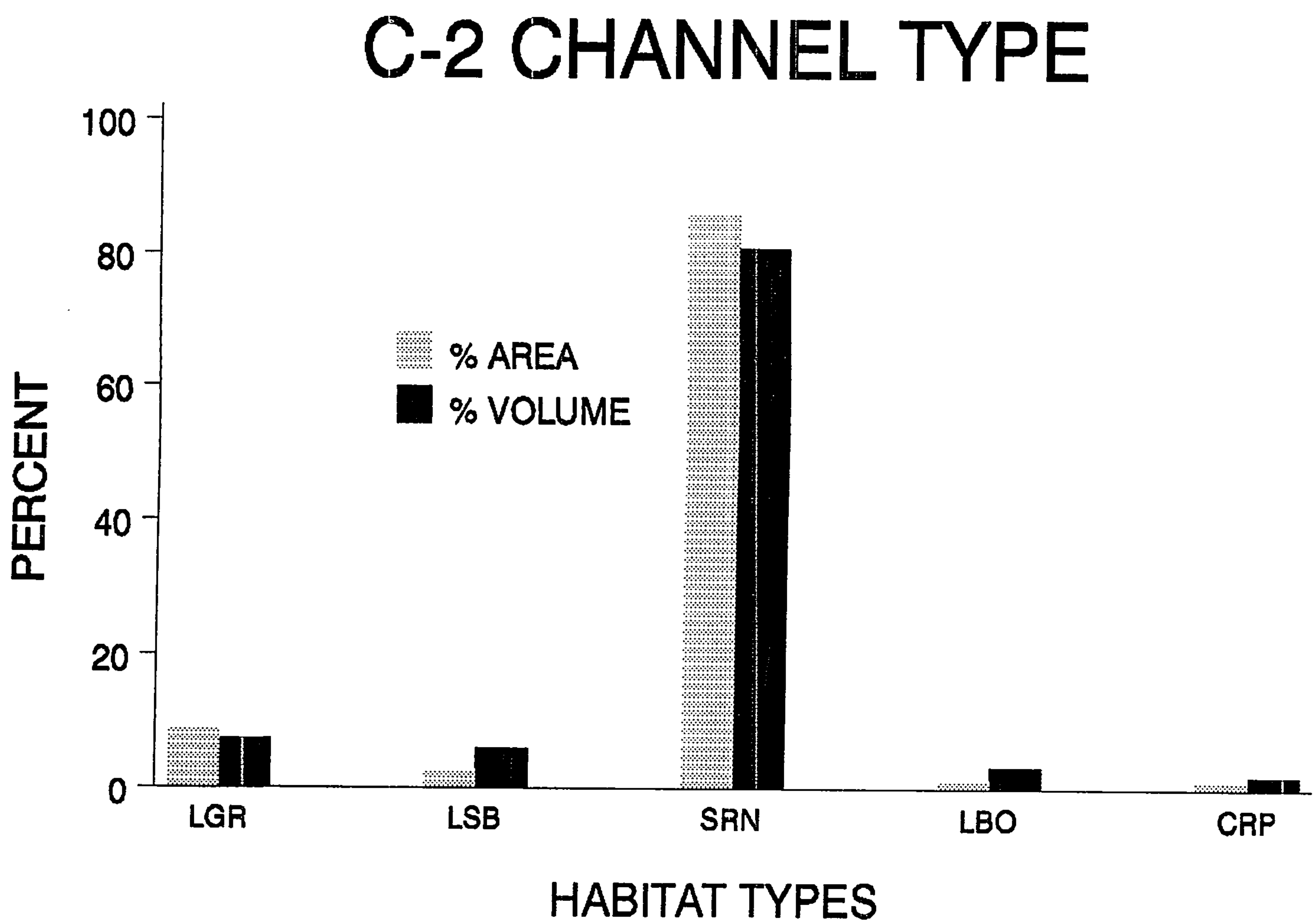


Figure 16. Distribution of Physical Habitat Type in C-2 Channels

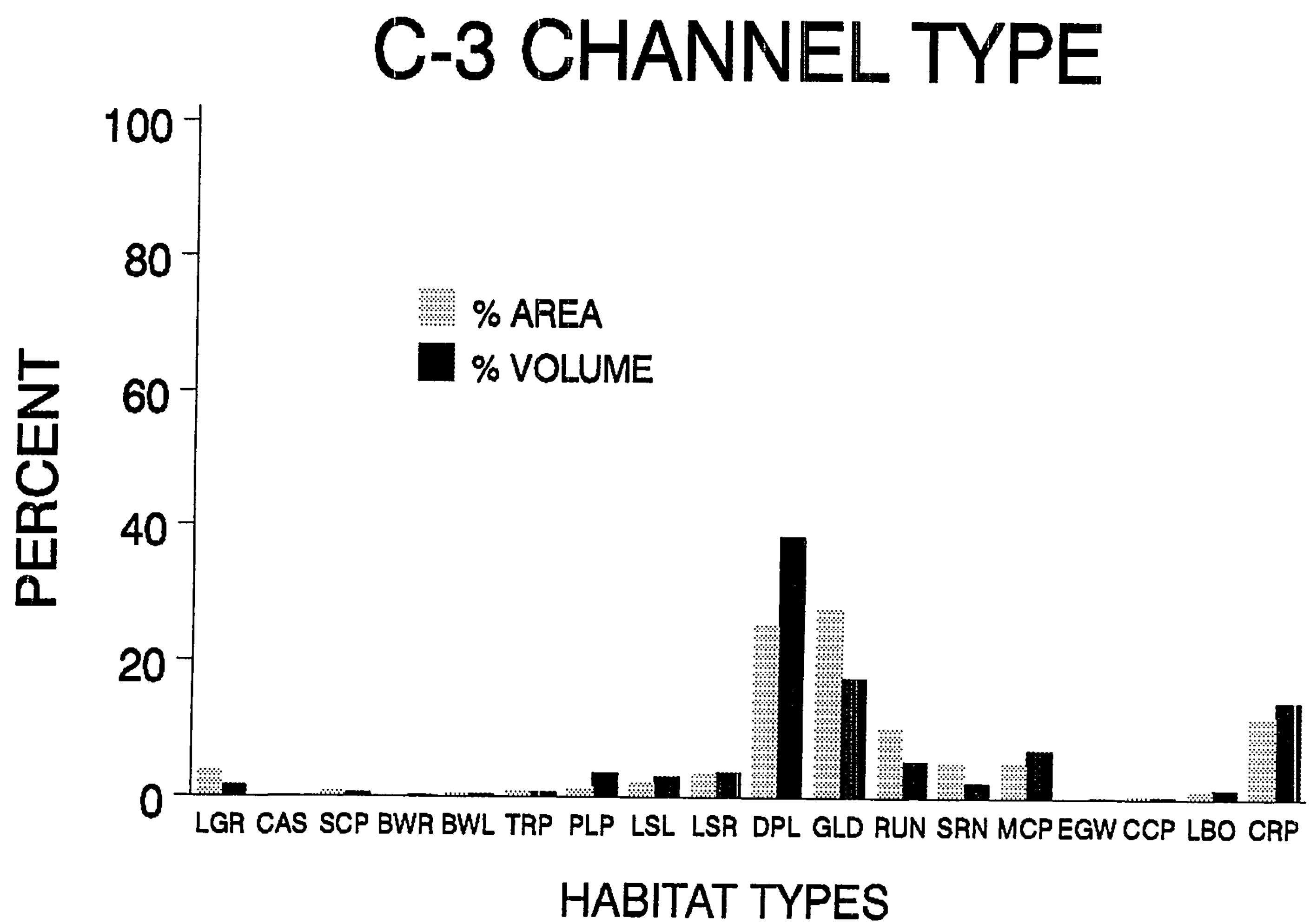


Figure 17. Distribution of Physical Habitat in C-3 Channels

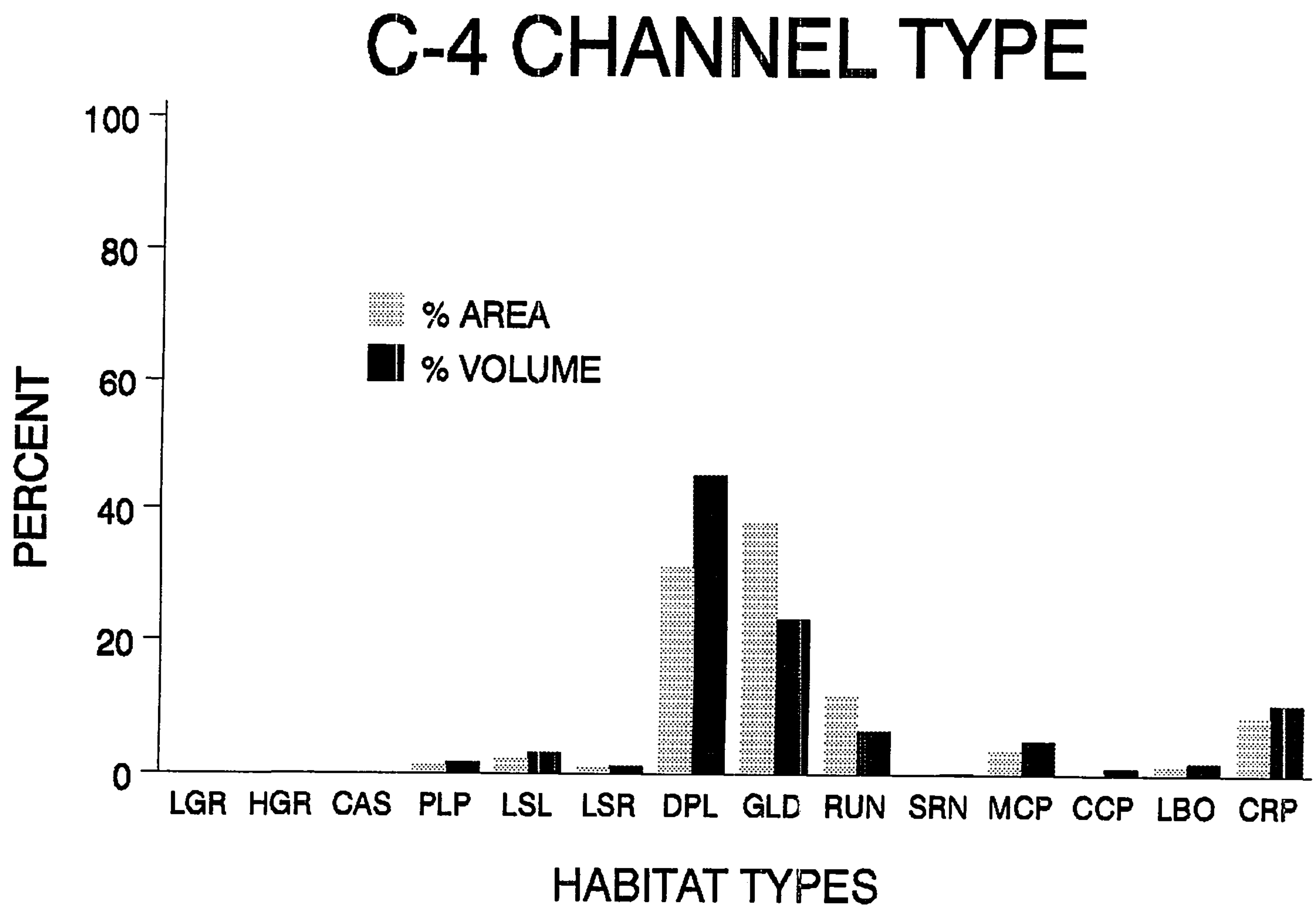


Figure 18. Distribution of Physical Habitat Type in C-4 Channels

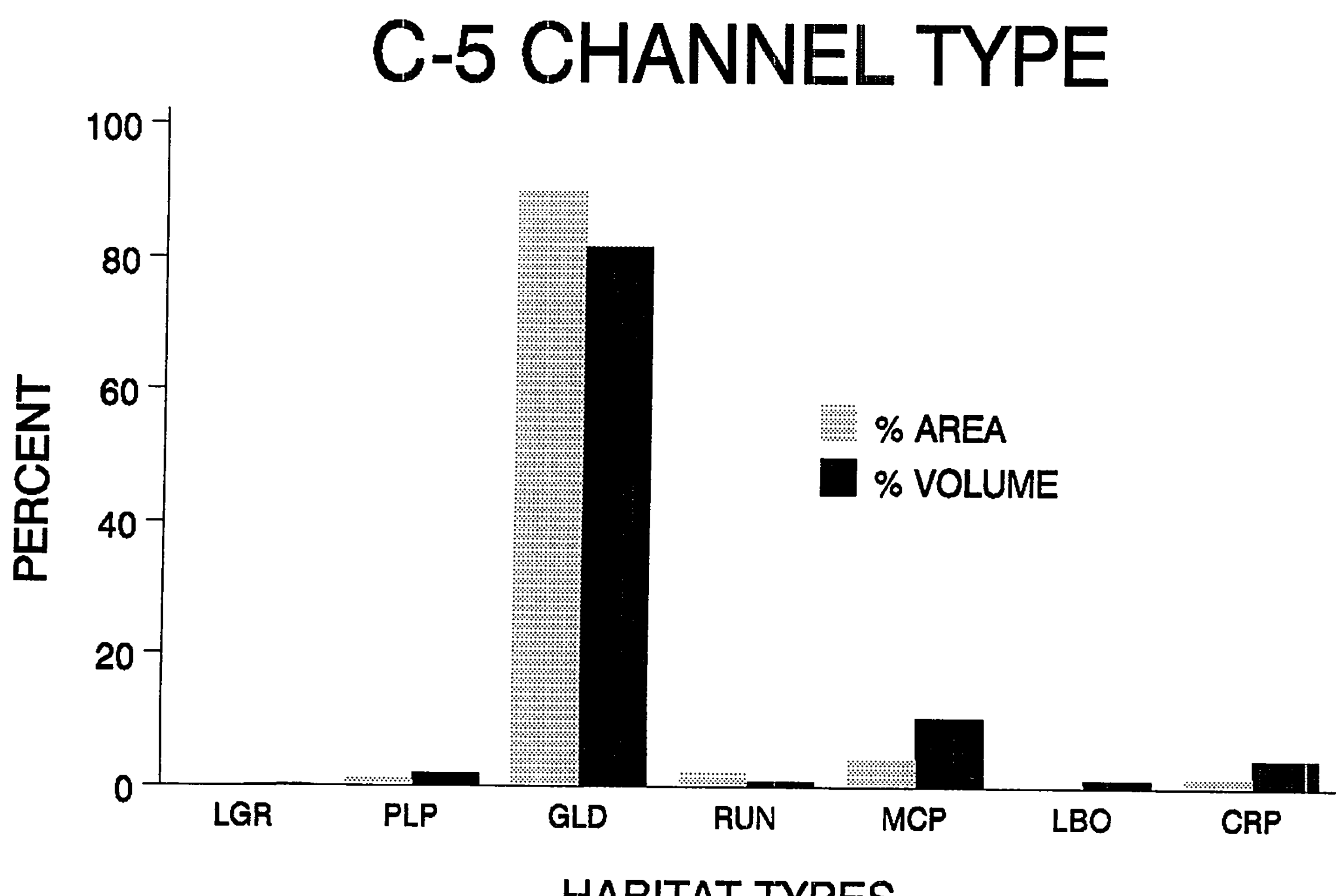


Figure 19. Distribution of Physical Habitat in C-5 Channels

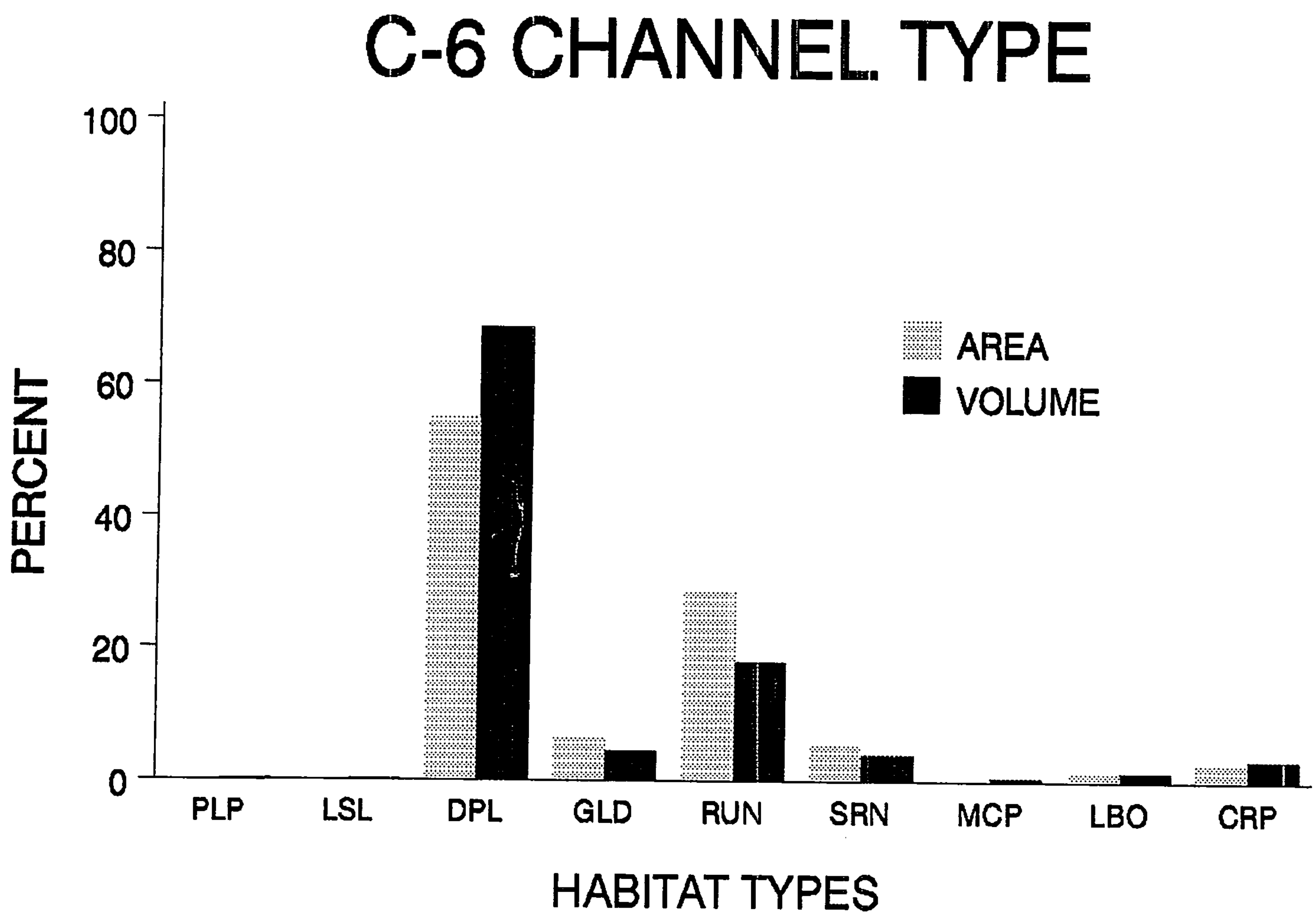


Figure 20. Distribution of Physical Habitat in C-6 Channels

CHAPTER 7

DISCUSSION

Introduction

The following discussion is divided into three sections. The first section is a discussion of the role of stream mechanics in shaping physical habitat features. The second section displays how the results gained from this study can be applied to environmental planning. Two stream restoration projects are discussed, one that has been completed (Blackwood Creek), the other is in the planning phase at the time of this writing (Burke Creek). In both examples, knowledge of the overall habitat distribution in Lake Tahoe tributaries enabled LTBMU restoration scientists to modify or design modifications for sections of streams which have been drastically altered by human activities. The third section discusses the influence of other factors affecting physical habitat composition in streams.

Habitat Distribution as a Function of Stream Processes and Morphology

The Decker classification system defines habitats that are caused by the physical processes at work in a stream. Therefore, applying geomorphic principles relating to stream dynamics to the results can partially explain the distribution of habitat types in Lake Tahoe tributaries. Because dynamic equilibrium operates in a river continuum or system, channel changes are a natural part of stream processes (Beschta and Platts, 1986). Processes such as aggredation, degradation, lateral channel migration, bank erosion, vegetation growth and decline, changes in flood flows, and increased sedimentation and substrate material can all be expected in channels trying to reach equilibrium (Rosgen and Fittante, 1986). A stream expends its energy throughout its system in series of actions and reactions as it tries to achieve equilibrium.

The ability of water to rework channel banks and bed materials, called "stream power," is directly proportional to the product of velocity and slope. (The slope is usually an approximation of the channel gradient.) The greater the velocity and slope, the greater the stream's ability to affect channel banks and bed materials. When a stream has relatively greater power, as in **A** channels, the channels tend to be "steep, straight, with hydraulically smooth bank and beds...." (Beschta and Platts, 1986). Therefore, habitat types such as corner pools and lateral scour pools (which require obstructions along the banks) are not found in **A** channels, as the correspondence between habitat type and channel type results have shown.

As gradient decreases, a greater number of obstructions can be found along the banks and in the beds (the banks and beds become less smooth). Obstructions in streams react with flow to create turbulence that leads to scour activity (the creation of pools) and results in the dissipation of stream energy. The obstruction may be in the form of channel banks (as in **C** channels), boulders, logs, rootwads, bedrock, or man-made objects. The number of pools in Lake Tahoe tributaries was found to increase in the **B** and **C** type channel sections.

The process of deposition of material in a stream in conjunction with the stream's scouring energy also affects the formation of habitat types. Materials are deposited in riffle areas downstream of pools following the dissipation of stream energy. Stream power begins to increase as the flow moves downstream until the flow meets with an obstruction and energy is again dissipated. As the process of energy development and dissipation occurs in the stream channel, a pool-riffle sequence forms through scour and deposition activities.

In this study, pools and riffles were not always abundant in the different channel reaches as defined by channel subtype, and the results of this study concur with Knighton's findings that the pool-riffle sequence tends to be absent from or poorly developed in boulder bed streams. In the boulder bed streams, Knighton found that the pool-riffle sequence may be replaced by a step pool (or step run) sequence (Knighton, 1984). The high percent of volume and area in the **A** and **B** channels represented by the step run habitat type suggest these types occurred in the boulder bed reaches. According to the typing results, the step run habitat was more abundant than any other habitat type (by area) in the A-1, A-2, A-3, B1-1, B-1, B-2, and B-3 channel types. All these channel types include bedrock or boulders as a dominant particle size of channel materials.

Channel materials also influence habitat formation when the materials are uniformly small. Pool-riffle sequences show little tendency to form in channels that carry uniform sand or silt (Knighton, 1984). The study reaches in Lake Tahoe tributaries in which sand or silt was the dominant particle size of the channel material were: B-6, C-4, C-5, and C-6. A lack of riffles and step runs were found in these reaches. The step run habitat type, replacing the pool-riffle sequence, only occupied ten percent of the

B-6 subtype and 0.2% of the C-4 subtype. It did not occur in the C-5 subtype, and occurred in 5.4% of the C-6 subtype.

The study results also support Knighton's observation that as bed material size decreases and discharge into the stream system increases downstream:

> systematic changes in bed configuration may also be expected in that direction, with poorly developed riffles and pools in the headwater reaches [**A** channels] giving way, first to better defined riffle-pool sequence where the material is gravelly [**B** channels], then to a mixture of gravel bed and sand bed forms [**C** channels] and finally to ripple and dunes as the sand fraction becomes dominant.

Each of the three primary channel types identified in this study (**A**, **B**, and **C**) had distinct habitat type distributions within them. In the high gradient **A** channels, the pool habitats were almost nonexistent, with high gradient riffle and step run habitat types prevalent. The area was dominated by the step run habitat type; the volume was dominated by cascade habitat type. The moderate gradient stream reaches (**B** channels) had a more even distribution of riffles, pools, and flatwater habitats. The step run habitat dominated both the area and volume in **B** channels. The low gradient **C** channels showed the greatest diversity of pool and flatwater habitat occurrences. The dammed pools, usually caused by beaver activity, accounted for the greatest amount of volume in **C** channels. The glide habitat type occurred in the greatest amount of area in the **C** reaches. In the Lake Tahoe Basin, the ripple-dune environment, where it exists, would be found at the lake-shore.

Use of Data For Environmental Planning

Knowledge of the distribution of physical habitat types within channel types can assist in the planning of stream restoration and interdisciplinary habitat improvement projects in such areas as urban parks, urban and wildland erosion control, fisheries, amphibians, and invertebrates. When a stream has been so altered that only uniform reaches exist and no longer function as natural stream channels, an understanding of habitat composition in a given channel structure will aid in the design of a new channel. This notion is illustrated in the case studies discussed below: In the Lake Tahoe Basin, the information has been applied in the restoration of Blackwood Creek and Burke Creek. Black-wood Creek is on the west side of the Lake Tahoe Basin; Burke Creek is near Stateline, Nevada on the southern side of the Lake Tahoe Basin.

Blackwood Creek - A Case Study

Major changes occurred in the middle section of Blackwood Creek through an extensive gravel mining operation. Water was diverted to mine the gravel of the streambed. The mining activities left a 1,800 foot section of stream looking like one continuous low gradient riffle in the shape of a bowling lane. Biological sampling of the 1800 foot section revealed that 99% of the fish were utilizing 1% of the habitat. The 1% of the habitat within the reach that 99% of the fish were using was typed as lateral scour pool-boulder formed and plunge pool at the upstream end of the reach. The remaining 99% of the reach was typed as low gradient riffle habitat.

The "bowling lane" reach was classified as a C-2 channel. Review of the distribution of habitat types in other C-2 channels, showed greater habitat diversity than what was found in the "bowling lane" reach. Other C-2 reaches in Lake Tahoe tributaries have an abundance of step run, with some lateral scour, corner pools and few riffle areas (Reiner, 1989).

Habitat diversity and channel stability was improved in the 'bowling lane' reach with the addition of boulder-log combinations to the channel. The boulder-log structures were placed in the channel in groups of two and three on alternating sides of the bank so that during high flows the boulder-log structures act as obstructions to the stream flow in Blackwood Creek, resulting in the creation of lateral scour pools near the ends of the logs. The structures also provide cover and shade to aquatic species. The formation of gravel bars upstream and downstream of the structures will improve sinuosity of the stream flow (Reiner, 1989). Ideally, glide and run habitat will form as transition zones between pool and riffle areas.

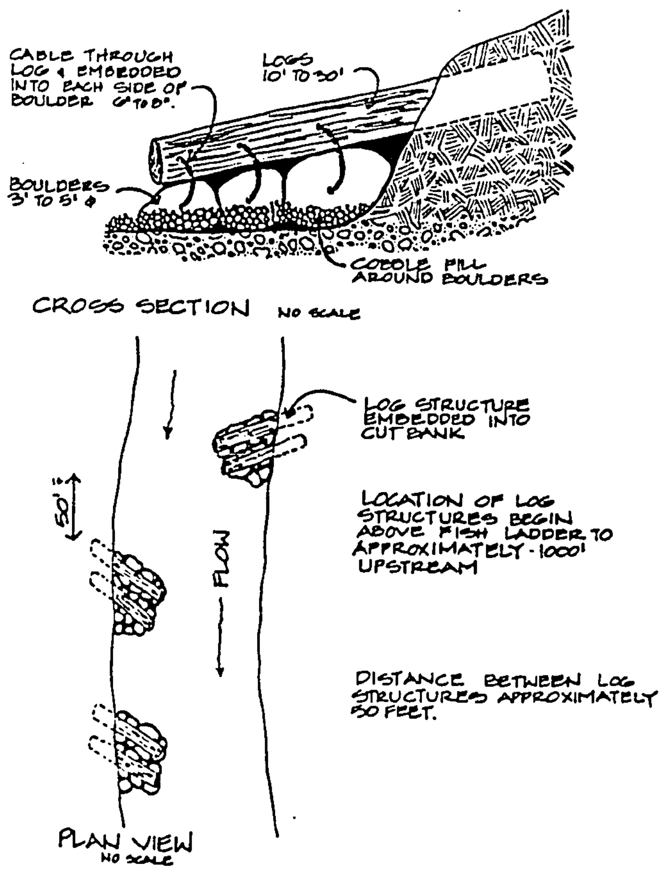
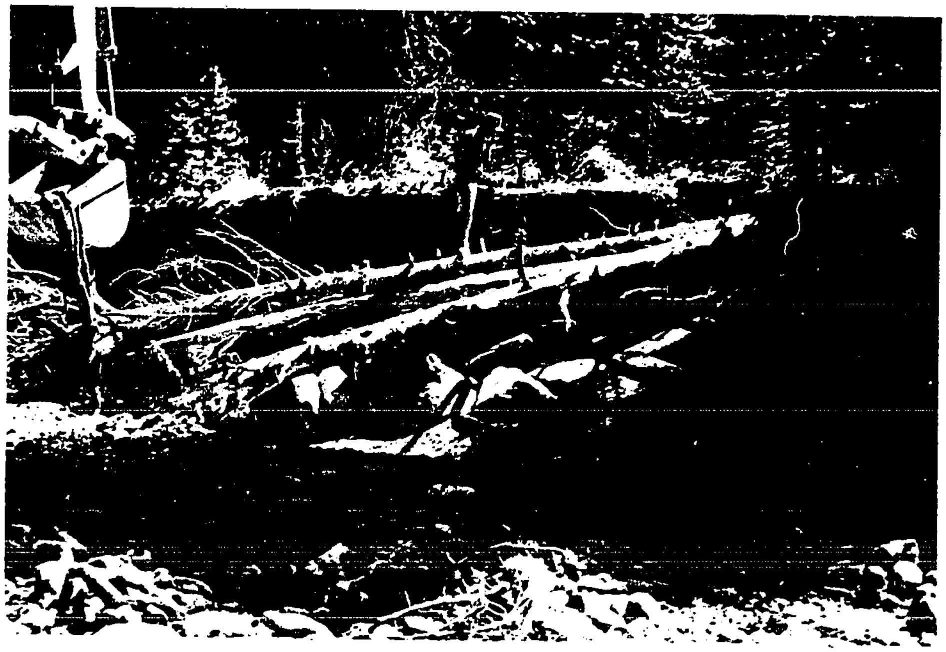


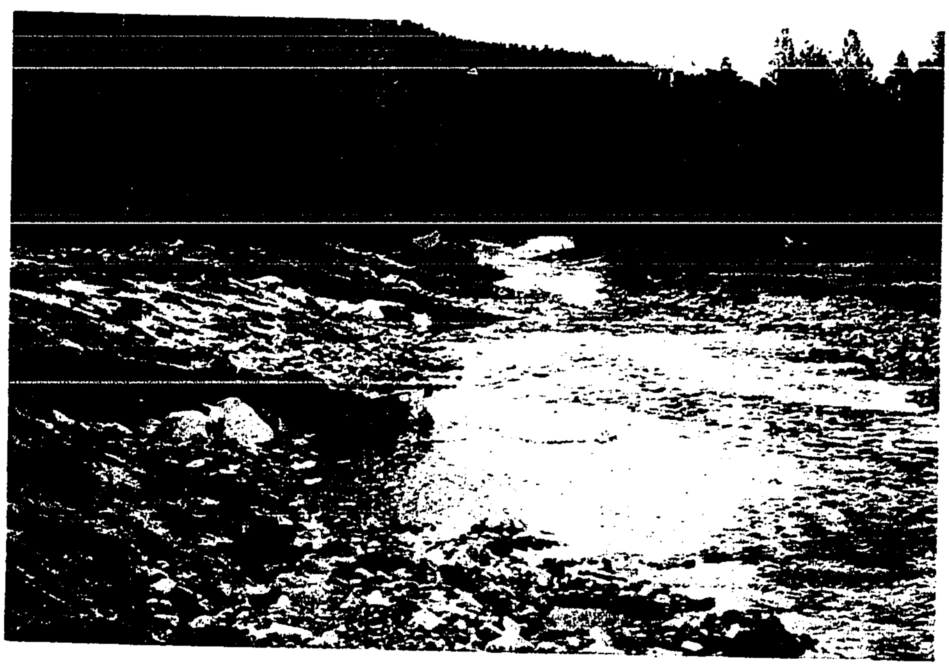
Figure 21. Diagram of Boulder-Log Structure

PHOTOGRAPH 9. Blackwood Creek "bowling lane" Reach Before Restoration Work

PHOTOGRAPH 10. Blackwood Creek with Boulder-Log Structures



PHOTOGRAPH 11. Detailed View of Boulder-Log Structure



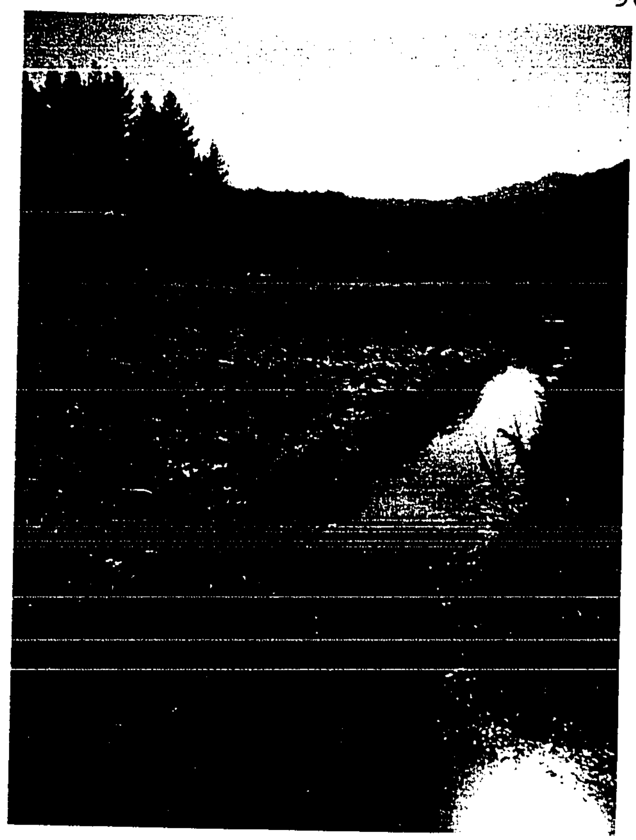
PHOTOGRAPH 12. Boulder-Log Structure in Blackwood Creek

Personal observation in early June 1990 revealed one of the influences of the current four year drought in the region. Due to a lack of high flows, the desired scour effect has not been achieved. However, the presence of developing gravel bars at the end of the structures is initiating a meandering pattern in the channel that had not existed previous to the restoration work.

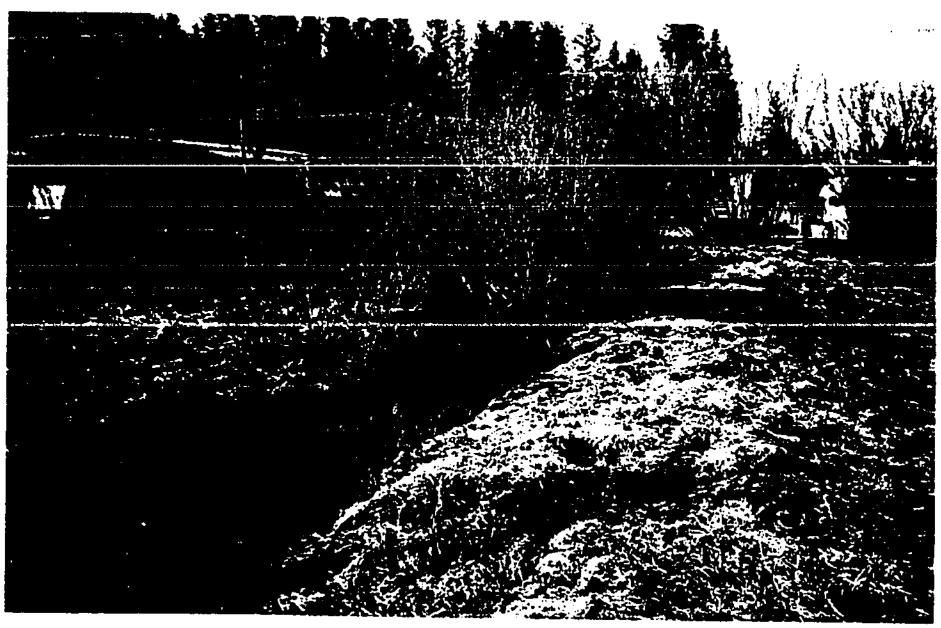
Burke Creek - A Project in Planning

Burke Creek is a project that relocates approximately 700 feet of channelized stream into a new, man-made channel. The new channel will be based on natural stream structure with a habitat composition similar to what has been found in other tributaries, as shown by the results of this thesis.

The stream section planned for relocation is in a C-4 channel type. The results of this study describe the C-4 channel type as being composed of a large amount of dammed pools (most often created by beavers) and glides. Corner pools are the only other pool type occurring in over ten percent of the C-4 channels. Runs account for over ten percent of the area and approximately five percent of the volume. Using this information, the new channel can be designed so as to mimic other C-4 channels in the Lake Tahoe Basin.



PHOTOGRAPHS
13 and 14.
Channelization
of Burke Creek



The Influence of Other Factors Affecting Habitat Composition in Streams

Channel structure plays a part in the composition of the habitat types found within it, but it is not the only factor influencing the habitat structure within a stream. Past and present land use practices (such as logging, grazing, mining, urban development and water diversions) and natural events (such as geologic history, fire history, climate, and landslides) important factors shaping the micro-geomorphology (habitat structure) of a stream. In this study, channel structure was selected as a basis for sorting physical habitat type structure. However, the land use history and natural events must also be looked at to determine the actual cause of habitat conditions before habitat or channel improvements are made.

When using the results of this study to understand habitat availability within certain stream types, it is also important to realize that different regions have different qualities shaping the local stream systems. As geology and climate (which affects vegetation) vary, the structure of a stream may vary. In fact, a 1984 study by Lank and Hubert provides substantial evidence that stream habitat is a function of geologic processes within the drainage basin (Lanka and Hubert, 1987). In the Oregon stream studies by Reeves and Everest (1986) a different composition of habitat occurred from what was found in the Lake Tahoe Basin. While this may be due to different uses of the land, the geology and climate may be significantly different from the northern Sierra Nevada. Outside of the Lake Tahoe Basin, on the southeastern side of the Sierra Nevada, the climate and geology is different enough to form hardpan (a hard substrate of very fine material) on the bottom and sides of streams. The hardpan component acts similar to bedrock and changes the streams ability to scour, thereby changing the number of scour pools found in that region.

Logging practices, such as clear cutting, can influence physical habitat composition in a stream. In the Lake Tahoe tributaries there is a lack of woody debris formed pools; habitat surveys showed that very few pools were formed by logs and rootwads. In **A** channels there are no lateral scour pools formed by woody debris and only 0.7% of the volume or area was represented by plunge pools (which may have been formed by a fallen log, bedrock bench, boulder, or man made structure). In the **B** channels only 1.6% of the available habitat is represented by woody debris forming lateral scour pools, 1.3% of the area is attributed to plunge pools. In the **C** channels, only 4.8% of the habitat is represented by woody debris forming lateral scour pools, 1.3% of the area is represented by plunge pools.

The lack of woody debris formed pools in Lake Tahoe tributaries can be explained by the past logging practices. In the late 1800's when most of the Tahoe Basin was logged, very few trees were left on the banks, floodplains and hillsides to find their way into the streams. Therefore, fewer pools were formed from woody debris obstructions. Studies by geomorphologist, Tom Lisle, at the USDA Forest Service Research Station in Arcata, California, have shown that logging impacts may not show up throughout a river system for over 100 years! (Lisle, 1990, USDA Fisheries Biologist meeting, Sacramento, California, February 26-March 1, 1990.)

The lack of woody debris formed pools in a stream may also be related to a natural absence of large woody debris, as in some **C** type meadow streams where trees don't grow close enough to the banks for recruitment into the stream.

CHAPTER 8

SUMMARY AND CONCLUSION

Summary and Conclusion

Until this study no detailed analysis of the distribution of physical habitat with respect to channel structure existed for the Lake Tahoe region. Never before had continuous stream segments of Lake Tahoe tributaries been quantified in terms of their micro-geomorphic features (i.e. physical habitat types). The ecogeographic analysis approach was successful in providing information on the spatial distribution of stream attributes with attention to regional importance. Baseline data for stream zones are now available for restoration planning. In addition, the results provide land managers and environmental planners with an increased understanding of the relationship between stream structure and habitat features and the geomorphic process at work. Stream changes can be monitored through the repetition of the methodologies presented in this research.

The Rosgen and Decker classification systems were applied to continuous stream sections, and in some cases entire streams, until gradient exceeded ten percent. By using these classification systems a greater understanding of the correspondence between channel morphology and physical habitat was gained. While people familiar with stream structure and mechanics may expect certain habitat features to vary with gradient and substrate, accurate quantification of habitat within stream systems cannot be known without detailed study. This study has delineated stream configuration and physical habitat types, defined by fluvial geomorphic principles, in seven streams in the southern and western portion of the Lake Tahoe Basin to provide baseline data for restoration planning, interdisciplinary management actions, and monitoring activities.

Analysis of the data has shown that certain channel morphologies display groupings of micro physical habitat composition that are different from one another. The high gradient reaches (**A** channels) in the Lake Tahoe area are dominated by riffles and step run habitat types with few pools or runs. The reaches with gradients between 1.5 and four percent (**B** channels) are also dominated by step runs, but show more runs and pool habitats. The step runs are rarely present in the **C** channels (gradients less than 1.5%).

Instead, the **C** channels have an abundance of dammed pools, corner pools, glides, and runs.

The **B** channels have a more even distribution of riffle, pool, and flatwater habitat types than the steep **A** channels. The **C** channels show the greatest range of pool and flatwater habitat occurrences. The dammed pools, usually formed by beavers, account for the greatest amount of volume in the **C** channels. The glide habitat type accounts for the greatest amount of area in the **C** channels.

When habitat distribution was analyzed using channel gradient and stream bed particle size it was found that greater habitat diversity occurred in stream sections with a combination of gravel, cobble, and sand channel materials. These were the A-3, B-3, and C-3 channel types. The stream sections with boulder and bedrock substrate (A-1, A-2, B-1, B-1-1) were found to have the fewest number of different habitat types.

The Rosgen system of stream classification was shown to be a useful tool in describing channel structure and providing an organization of habitat within the Lake Tahoe tributaries.

Topics for Further Study

The information presented in this thesis can be used to assist in planning riparian habitat restoration, interdisciplinary management decisions, and monitoring. However, land use activities, past and present, must also be taken into consideration when making management decisions.

Two questions produced by this study are: 1) What are the impacts of natural land features on stream and physical habitat structure and composition? and 2) What are the impacts of human activities on stream and habitat structure and composition? The difficulty in answering these questions lies in the lack of standardized methods applied over varying geographic regions. Also, there is a lack of suitable control watersheds (where no human activity has occurred), making conclusive analyses of the impact of human uses on the land nearly impossible. However, in 1989 the methods used in this study began to be applied on national forests throughout California. As a data base is developed, complex comparisons can be made between regions and watersheds which may help bring into focus the significant factors determining the variance in habitat distribution found.

LIST OF REFERENCES

Alt, D., and Hyndman, D. 1975. Roadside geology of northern California, Mountain Press Publishing Company.

Bailey, R.G. 1988. Ecogeographic analysis, a guide to the ecological division of land for resource management. Miscellaneous Publication 1465, United States Department of Agriculture, Forest Service.

Beschta, R.L., and Platts, W.S. 1986. Morphological features of small streams: significance and function. Water Resources Bulletin. 22(3):369-379.

Binns, N.A., and Eiserman, F.M. 1979. Quantification of fluvial trout habitat in Wyoming. Transactions of the American Fisheries Society. 108:215-228.

Bisson, P.A., Nielsen, J.L., Palmason, R.A., and Grove, L.E. 1981. A system of naming habitat types in small streams with examples of habitat utilization by Salmonids, Acquisition and Utilization of Aquatic Habitat Inventory Information Symposium. Edited by N.N. Armantrout. Western Division of American Fishery Society Publication.

Burnett, J.L. 1968. Geology of the Lake Tahoe Basin. Geologic studies in the Lake Tahoe area, California and Nevada: annual field trip guidebook of the Geological Society of Sacramento. 1968:1-11.

Cairns, J. 1988. Restoration and the alternative: a research strategy. Restoration and Management Notes. 6(2):65-67.

California Department of Fish and Game, USDA Forest Service, 1987. Instream flow requirements Lake Tahoe Basin, California and Nevada. State of California, Stream Evaluation Report 87-1.

Decker, L., McCain, M., Fuller, D., and Overton, K. 1989. Stream habitat classification and inventory procedures for Northern California. FHR Currents. July 1989.

Fausch, K.D., Hawkes, C., and Parsons, M.G. 1988. Models that predict standing crop of stream fish from habitat variables; 1950-1985. General Technical Report PNW-GTR-

213, Portland, Oregon; USDA Forest Service, Pacific Northwest Research Station.

Hampton, A.M. 1988. Altitudinal range and habitat of Triclads in streams of the Lake Tahoe Basin. The American Midland Naturalist. 120(2):302-312.

Hicks, B.J. 1988. The influence of geology on the response of channel morphology and juvenile salmonid populations to logging in streams of the Oregon coast range. Progress Report No. 2. Department of Fisheries and Wildlife, Oregon State University. Corvallis, Oregon.

Holland, A. 1987. History of Blackwood Canyon. Unpublished, USDA Forest Service, Lake Tahoe Basin Management Unit.

Huryn, A.D., and Wallace, J.B. 1987. Local geomorphology as a determinant of macrofaunal production in a mountain stream. Ecology. 68(6):1932-1942.

Kennedy, G.J., and Strange, C.D. 1982. The distribution of Salmonids in upland streams in relations to depth and gradient. Journal of Fish Biology. 20:579-591.

Kellerhauls, R.M., Church, M., and Bray, D. 1976. Classification and analysis of river processes. Journal of the Hydraulics Division. July:813-829.

Kershner, J. 1990. Speech at USDA Forest Service Southwest Region Fisheries Biologist Conference, February, 1990. Sacramento.

Knighton, D. 1984. Fluvial Forms and Processes. London: Edward Arnold.

Lanka, R.P., and Hubert, W.A. 1987. Relations of geomorphology to stream habitat and trout standing stock in small Rocky Mountain streams. Transactions of the American Fisheries Society. 116:21-28.

Leonard, R.L., Kaplan, L.A., Elder, J.F., Coats, R.N., and Goldman, C.R. 1979. Nutrient transport in surface runoff from a subalpine watershed, Lake Tahoe Basin, California. Ecological Monographs. 49(3):281-310.

Leopold, L.B., and Wolman, M.G. 1970. River channel patterns. Rivers and river terraces. Edited by G.H. Dury, p. 197-237. New York: Praeger Publishers.

Lisle, T.E. 1986. Stabilization of gravel channels by large streamside obstructions and bedrock beds, Jacoby Creek, Northwestern California. Geological Society of America Bulletin. 97:999-1011.

Lyons, J. 1989. Correspondence between the distribution of fish assemblages in Wisconsin streams and Omerniks' Ecoregions. Ammerican Midland Naturalist. 122(1):163-182.

Parott, H., Marion, D., and Perkinson, R.D. 1989. A four level hierarchy for organizing wildland stream resource information. Headwaters Hydrology, American Waters Resources. June:41-51.

Pearce, R.B. 1987. Hurdy Gurdy-California's first basin-wide study of fish habitat. Forestry Research West, April 1987:11-15.

Pirkle, E.C., and Yoho, W.H. 1971. Natural regions of the United States, p. 301-310. Dubuque, Iowa: Kendall/Hunt Publishing Company.

Platts, W.S. 1979. Relationships among streams order, fish population, and aquatic geomorphology in an Idaho river drainage. Fisheries. 4(2):5-9.

Reeves, G., and Everest, F.H. 1986. Stream type as a predictor of habitat conditions and anadramous Salmonid populations in western Oregon streams. Draft Report, Pacific Northwest Research Station-Corvallis Oregon, USDA Forest Service.

Reiner, J. 1989. Fisheries habitat and channel stability in the restoration of Blackwood Creek. Proceedings from Ecological Society of Restoration Conference, Oakland, CA January 22-24, 1988.

Rosgen, D.W. 1985. A stream classification system. Symposium on Riparian Ecosystem and Their Management: Reconciling Conflicting Uses, April 16-18, Tucson, Arizona.

Rosgen, D.W., and Fittante, B.L. Fittante. 1986. Fish Habitat Structures - A Selection Guide Using Stream Classification. Unpublished. USDA Forest Service Paper, Pike and San Isabel National Forests, Lakewood, CO, 80225.

Storer, T.I., and Usinger, R. L. 1963. Sierra Nevada natural history, an illustrated handbook. Berkely, California: University of California Press.

Strong, D. H. 1984. Tahoe, an environmental history, p. 22-25. Lincoln, Nebraska: University of Nebraska Press,

Sullivan, K. 1986. Hydraulic and Fish Habitat in Relation to Channel Morphology. Ph.D. Dissertation. John Hopkins University, Baltimore, Maryland.

Tahoe Regional Planning Agency, and USDA Forest Service. 1971. Climate and Air Quality of the Lake Tahoe Basin.

Tahoe Regional Planning Agency and USDA Forest Service. 1971. Soils of the Lake Tahoe Basin.

United States Department of Agriculture. Forest Service. Lake Tahoe Basin Management Unit, land and resource management plan. 1988

United States Geological Survey and California Department of Water Resources. 1985. Water Resources Data California Water Year 1985. United States Geological Survey Water-Data Report CA-85-3, p. 67.

Ying, T.C. 1971. Formation of riffles and pools. Water Resource Research. 7(6):1567-1574.

Appendix 1

Stream Channel Classification Field Guide

PURPOSE: Used to organize streams into definable reaches.

SOURCE: This system has been adapted from David L. Rosgen's stream classifcation system, 1985, 1988.

GUIDELINES

Gradient is measured as per cent slope at water surface.

Channel Entrenchment refers to the degree to which the stream channel has downcut into the floodplain.

Valley Confinement refers to the degree to which the channel is confined within its valley.

The minimum length of a stream type unit is approximately 30 times the bankfull width.

DOMINANT PARTICLE SIZE
OF
CHANNEL MATERIALS

BEDROCK	—		
BOULDER	> 30 cm,	> 300 mm,	> 11 in.
COBBLE	8 - 30 cm,	80 - 300 mm,	3 - 11 in.
GRAVEL	.5 - 8 cm,	5 - 80 mm,	.2 - 3 in.
SAND	.1 - .5 cm,	1 - 5 mm,	.04 - .2 in.
FINES	< .1 cm,	< 1 mm,	< .04 in.

Stream/ Channel Type	Gradient %	Dominant Particle Size of Channel Materials	Channel Entrenchment and Valley Confinement
A1	4-10	Bedrock	Very deep; very well confined.
A1-a	10 +	Same as A1	
A2	4-10	Large & small boulders with mixed cobbles.	Very deep; very well confined.
A2-a	10 +	Same as A2	Very deep; very well confined.
A3	4-10	Small boulders, cobble, coarse gravel.	Very deep; very well confined.
A3-a	10 +	Same as A3	Very deep; very well confined.
A4	4-10	Predominantly gravel, sand, and some silts.	Very deep; very well confined.
A4-a	10 +	Same as A4	Very deep; very well confined.
A5	4-10	Silt and/or clay bed and bank materials.	Very deep; very well confined.
A5-a	10 +	Same as A5	Very deep; very well confined.

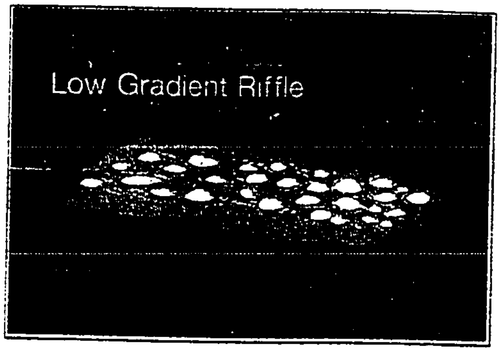
Stream/ Channel Type	Gradient %	Dominant Particle Size of Channel Materials	Channel Entrenchmentnt Valley Confinement
B1-1	1.5-4.0	Bedrock bed, banks, cobble, gravel, some sand.	Shallow entrenchment; moderate confinement.
B1	2.5-4.0 (X = 3.5)	Predominately small boulders, very large cobble.	Moderately entrenched; well confined.
B2	1.5-2.5 (X = 2.0)	Large cobble mixed with small boulders. and coarse gravel.	Moderately entrenched; moderately confined.
B3	1.5-4.0 (X = 2.5)	Cobble bed with mixture of gravel and sand - some small boulders.	Moderately entrenched; well confined
B4	1.5-4.0 (X = 2.0)	Very coarse gravel with cobble mixed sand and finer material.	Deeply entrenched; well confined.
B5	1.5-4.0 (X = 2.5)	Silt/clay	Deeply entrenched; well confined.
B6	1.5-4.0	Gravel with few cobbles and with noncohesive sand and finer soil.	Deeply en- trenched; slightly confined.

Stream/ Channel Type	Gradient %	Dominant Particle Size of Channel Materials	Channel Entrenchment Valley Confinement
C1-1	1.5 or less (X = 1.0)	Bedrock bed, gravel, sand or finer banks.	Shallow entrenchment; poorly confined.
C1	1.0-1.5 (X = 1.3)	*Cobble* bed with mixture of small boulders and coarse gravel.	Moderately entrenched; mod- er- ately confined.
C2	0.3-1.0 (X = 0.6)	*Large cobble* bed with mixture of small boulders and coarse gravel.	Moderately entrenched; well confined.
C3	0.5-1.0 (X = 0.8)	*Gravel* bed with mixture of small cobble and sand.	Moderately en- trenched; slightly confined.
C4	0.1-0.5 (X = 0.3)	*Sand* bed with mixtures of gravel and silt (no bed armor).	Moderately en- trenched; slightly confined.
C5	0.1 or less (X = .05)	*Silt/clay* with mixtures of medium to fine sands (no bed armor).	Moderately en- trenched; slightly confined.
C6	0.9 or less (X= .05)	*Sand* bed with mixture of silt and some gravel.	Deeply en- trenched; slightly confined.

Stream/ Channel Type	Gradient %	Dominant Particle Size of Channel Materials	Channel Entrenchment Valley Confinement
D1	1.0 or greater (X = 2.5)	Braided. *Cobble* bed with mixture of coarse gravel and sand and small boulders.	Slightly entrenched; no confinement.
D2	1.0 or less (X = 1.0)	Braided. *Sand* bed with mixture of small to medium gravel and silts	Slightly entrenched; no confinement.
F1	1.0 or less	Bedrock bed with few boulders, cobble and gravel.	Totally confined.
F2	1.0 or less	Boulder with small amounts of cobble, gravel and sands.	Totally confined.
F3	1.0 or less	Cobble/gravel bed with locations of sand in depositional sites.	Totally confined.
F4	1.0 or less	Sand bed with smaller amounts of silt and gravel.	Totally confined.
F5	1.0 or less	Silt/clay bed and banks with smaller amounts of sand.	Totally confined.

Appendix 2

Habitat Classification System

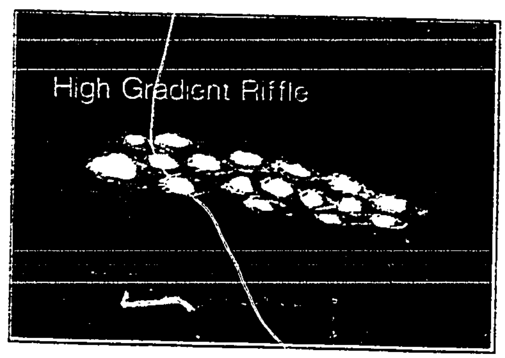


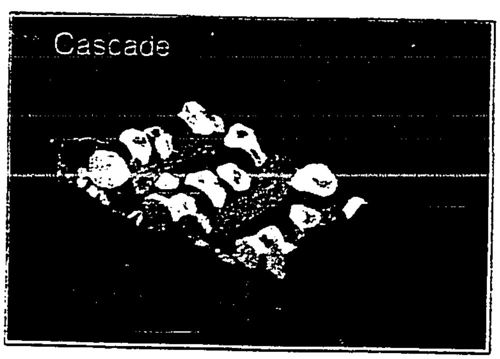
1 — Low Gradient Riffles "LGR"

Shallow reaches with swiftly flowing, turbulent water with some partially exposed substrate. Gradient < 4%, substrate is usually cobble dominated.

2 — High Gradient Riffles "HGR"

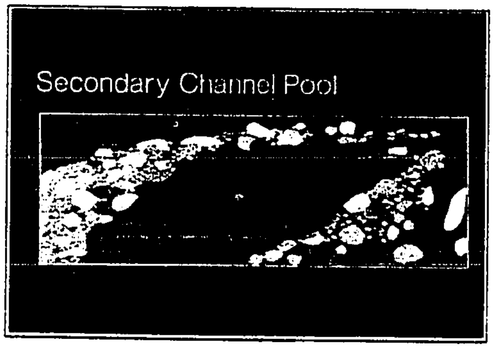
Steep reaches of moderately deep, swift, and very turbulent water. Amount of exposed substrate is relatively great. Gradient is > 4%, and substrate is boulder dominated.





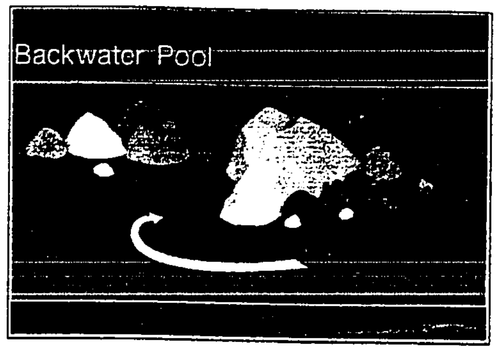
3 — Cascade "CAS"

The steepest riffle habitat, consists of alternating small waterfalls and shallow pools. Substrate is usually bedrock and boulders



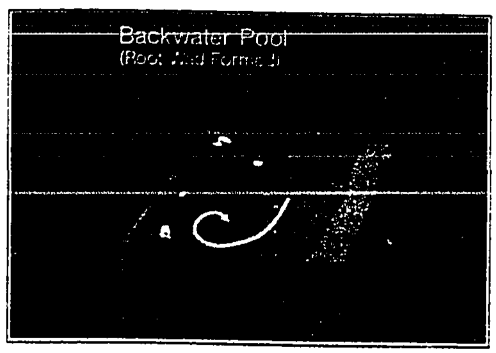
4 — Secondary Channel Pool "SCP"

Pools formed outside of the average wetted channel. During summer these pools will dry up or have very little flow. Mainly associated with gravel bars and may contain sand and silt substrates.

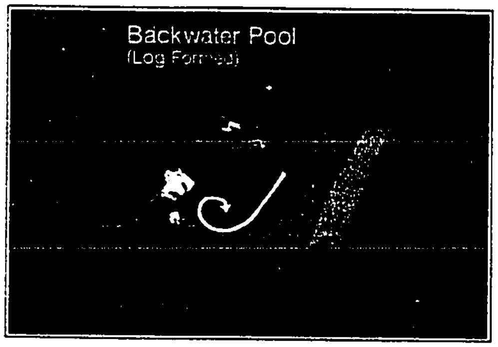


5 — Backwater Pool "BWP" Boulder Formed

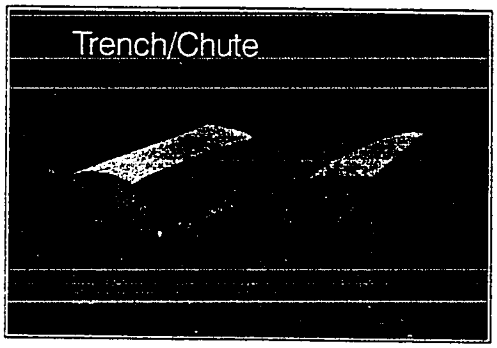
Found along channel margins and caused by eddies around obstructions such as boulders, rootwads, or woody debris. These pools are usually shallow and are dominated by fine-grain substrates. Current velocities are quite low.



6 — Backwater Pool "BWP" Root Wad Formed



7 — Backwater Pool "BWP" Log Formed

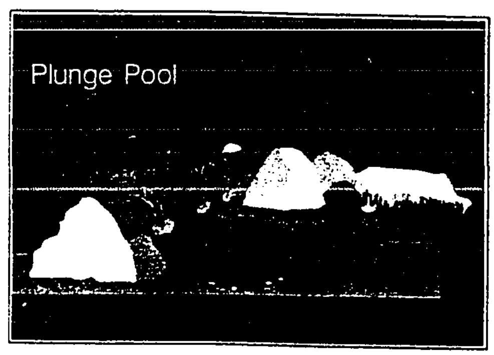


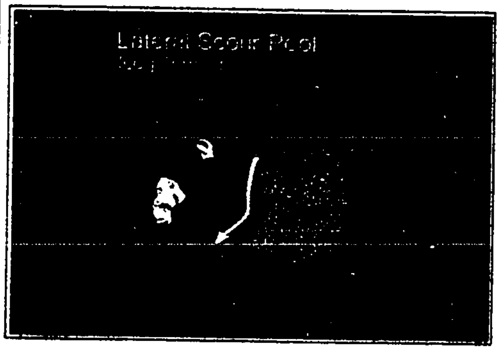
8 — Trench/Chute "TRC"

Channel cross sections typically U-shaped with bedrock or coarse grained bottom flanked by bedrock walls. Current velocities are swift and the direction of flow is uniform. May be pool-like.

9 — Plunge Pool "PLP"

Found where stream passes over a complete or nearly complete channel obstruction and drops steeply into the streambed below, scouring out a depression, often large and deep. Substrate size is highly variable.

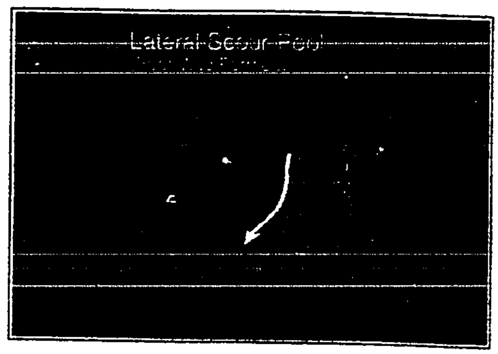




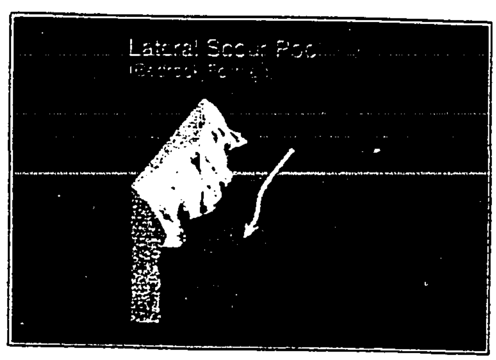
10—Lateral Scour "LSP" Log Formed

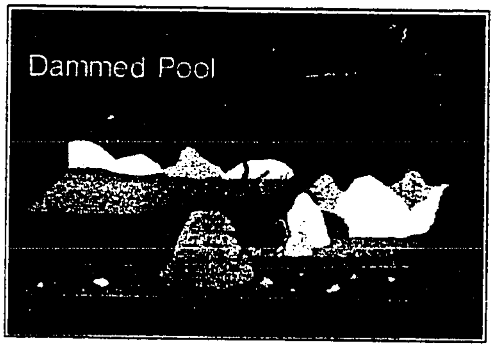
Formed by flow impinging against one stream bank or against a partial channel obstruction. The associated scour is confined to < 60% of wetted channel width. Channel obstructions include rootwads, woody debris, boulders, and bedrock.

11 — Lateral Scour Pool "LSP" Root Wad Formed



12 — Lateral Scour Pool "LSP" Bedrock Formed



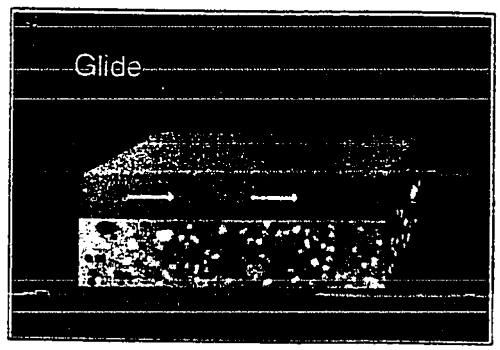


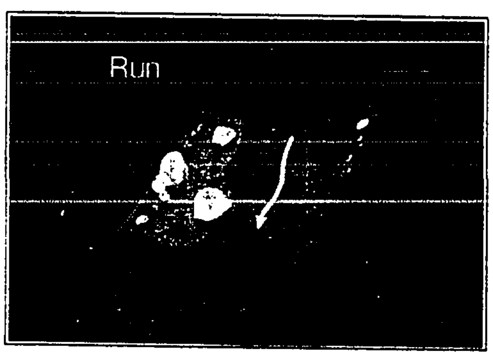
13 — Dammed Pool "DPL"

Water impounded from a complete or nearly complete channel blockage (debris jams, rock landslides or beaver dams). Substrate tends toward smaller gravels and sand.

14 — Glides "GLD"

A wide shallow pool flowing smoothly and gently, with low to moderate velocities and little or no surface turbulence. Substrate usually consists of cobble, gravel and sand.



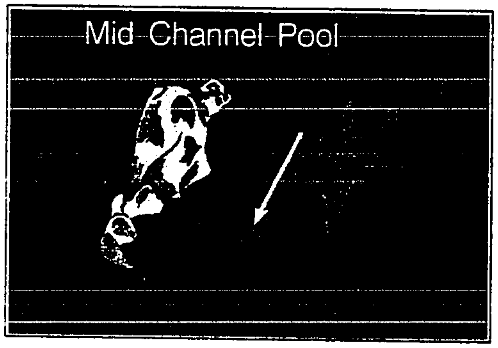


15 — Run "RUN"

Swiftly flowing reaches with little surface agitation and no major flow obstructions. Often appears as flooded riffles. Typical substrates are gravel, cobble and boulders.

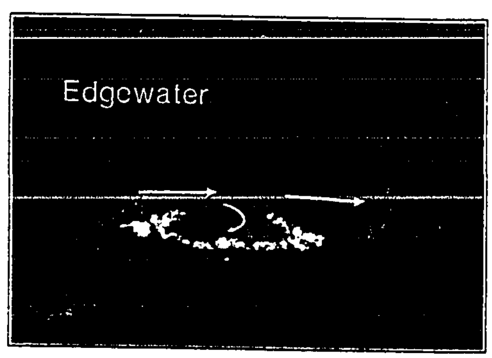
16 — Step Run "SRN"

A sequence of runs separated by short riffle steps. Substrates are usually cobble and boulder dominated.



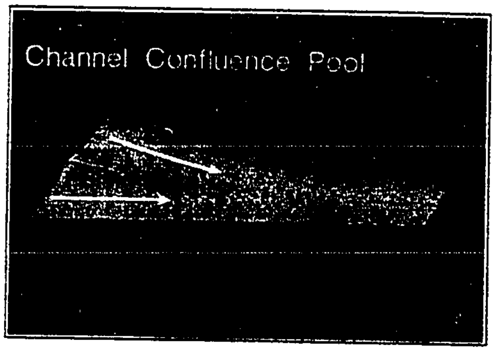
17 — Mid-Channel Pool "MCP"

Large pools formed by mid-channel scour. The scour hole encompasses more than 60% of the wetted channel. Water velocity is slow, and the substrate is highly variable.



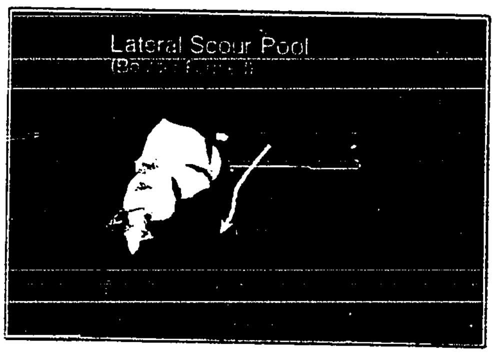
18 — Edgewater "EGW"

Quiet, shallow area found along the margins of the stream, typically associated with riffles. Water velocity is low and sometimes lacking. Substrate varies from cobbles to boulders.



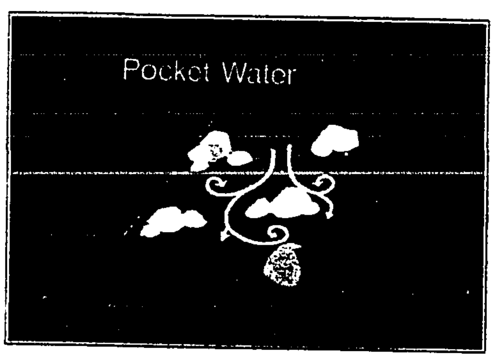
19 — Channel Confluence Pool "CCP"

Large pools formed at the confluence of two or more channels. Scour can be due to plunges, lateral obstructions or downscour at the channel intersections. Velocity and turbulence are usually greater than those in other pool types.



20 — Lateral Scour Pool "LSP"
Boulder Formed

Formed by flow impinging against boulders that create a partial channel obstruction. The associated scour is confined to < 60% of wetted channel width.

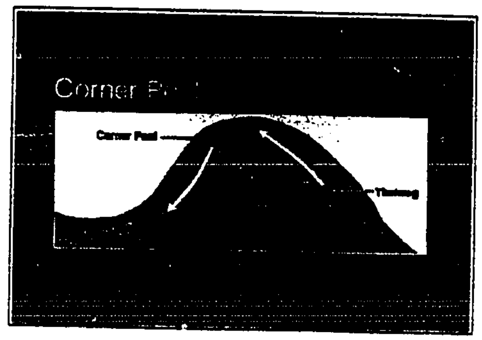


21 — Pocket Water "POW"

A section of swift flowing stream containing numerous boulders or other large obstructions which create eddies or scour holes (pockets) behind the obstructions.

22 — Corner Pool "CRP"

Lateral scour pools formed at a bend in the channel. These pools are common in lowland valley bottoms where stream banks consist of alluvium and lack hard obstructions.



Appendix 3

Habitat Typing Field Form

STEP II - HABITAT TYPING FORM

1. Stream Name____ 2. Form #____of____

3. Date ___/___/___ 4. Channel Type_____________ 5. T______ R______ S______

6. Field Photo: Roll____#_____#_____#_____#_____#_____#_____#_____#_____#_____

measurements in units of(cirle one): METERS FEET (1/10THS) (1/12THS)

7. HABITAT INVENTORY:

a.HABITAT UNIT #									
b.HABITAT UNIT TYPE									
c.SIDE CHANNEL UNIT #									
d.AZIMUTH									
e.MEAN LENGTH									
f.MEAN WIDTH									
g.MEAN DEPTH									
h.MAX DEPTH									
i.Dp @ POOL TAIL CREST									
j.STREAM SHADE %									
k.INSTREAM COVER	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX								
Total %									
undercut banks %									
swd (d<0.3M) %									
lwd (d>0.3M,RW) %									
terr.vegt.(h,0.3M) %									
aqua.vegt. %									
white water %									
boulders (d>30CM) %									
bedrock ledges %									
l.COVER COMPLEXITY									
m.SUBSTRATE COMPOSITION	**								
bedrock %									
boulder (>30cm) %									
cobble (>8-30cm) %									
gravel (>0.5-8cm) %									
sand (1mm-0.5cm) %									
fines (<1mm) %									
n.SUBST. EMBEDDEDNESS %									
o.EXPOSED SUBSTRATE %									
p.TIME-TEMPERATURE (every 5th unit)	-		XXXXXXXXXXXXXXXXX			-		XXXXXXXXXX	
	**								
q.COMMENTS									