United States
Department of
Agriculture

Forest Service

Intermountain
Research Station

General Technical
Report INT-221

February 1987

Methods for Evaluating Riparian Habitats With Applications to Management

William S. Platts
Carl Armour
Gordon D. Booth
Mason Bryant
Judith L. Bufford
Paul Cuplin
Sherman Jensen
George W. Lienkaemper
G. Wayne Minshall
Stephen B. Monsen
Rodger L. Nelson
James R. Sedell
Joel S. Tuhy

THE AUTHORS

WILLIAM S. PLATTS is a research fishery biologist for the Intermountain Research Station at Boise, ID. He received a B.S. degree in conservation education in 1955 from Idaho State University, an M.S. degree in fisheries in 1957, and a Ph.D. degree in fisheries in 1972 from Utah State University. From 1962 through 1966, he worked as a regional fishery biologist and supervisor in enforcement with the Idaho Fish and Game Department. From 1966 through 1976, he was the Idaho zone fishery biologist for the USDA Forest Service, Intermountain Region, and consultant to the Surface Environment and Mining (SEAM) program. He has been in his present position since 1976.

CARL ARMOUR is a fishery biologist for the U.S. Fish and Wildlife Service, Western Energy and Land Use Team, Fort Collins, CO. He received an M.S. degree in fisheries in 1966 from the University of Massachusetts and a Ph.D. degree in fisheries from the University of Idaho in 1969. Experiences include college teaching (1969-70), postdoctoral work at Texas A & M. University (1970-71), industrial consulting (1971-75), and assignment as a Bureau of Land Management environmental specialist and fisheries biologist (1975-78). He has been in his present position since 1978. One of his principal interests is environmental perturbation affecting western range streams.

GORDON D. BOOTH is leader of the Statistics and Computer Science Group for the Intermountain Station at Ogden, UT. He received a B.A. degree in 1960 and a B.S. degree in statistics in 1963, both from Brigham Young University. Then he was granted an M.S. degree in 1967 and a Ph.D. degree in 1973, both in statistics and both from Iowa State University. From 1963 to 1965, he worked as consulting statistician with U.S. Steel Corporation and with Phillips Petroleum Co. From 1967 to 1981 he worked as consulting statistician with the Agricultural Research Service, U.S. Department of Agriculture. He has been in his present position since 1981. His main interests are in the application of statistical methods to natural resource problems—especially time series.

MASON BRYANT is a research fishery biologist for the Forestry Sciences Laboratory, Pacific Northwest Forest and Range Experiment Station at Juneau, AK. He received a B.A. degree from the University of Vermont in 1967. The following 2 years were spent with the U.S. Army. He received an M.S. degree in zoology in 1972 from the University of Maine in Orono. In 1976 he received a Ph.D. degree from the University of Washington and moved to his present position in Alaska.

JUDITH L. BUFFORD is a biological technician (fisheries) with the Pacific Northwest Research Station in Corvallis, OR. She received a B.A. degree in biology in 1976 from Rollins College, Winter Park, FL, and her M.S. degree in marine biology in 1981 from the University of Miami, FL. She has been in her present position since 1981.

PAUL CUPLIN is a fishery biologist for the Bureau of Land Management, Denver Service Center. He received a B.S. degree in fisheries in 1952 from the University of Washington and an M.S. degree in fisheries from Utah State University in 1961. From 1953 to 1971 he was a fishery research biologist, district fishery biologist, and supervisor of fish hatcheries for Idaho Department of Fish and Game. From 1971 to 1980 he was a fishery biologist at BLM Denver Service Center; during 1979 and 1980 he was assigned to the Branch of Remote Sensing. In 1981 he served as fisheries program leader for the Washington Office of the Bureau of Land Management. He returned to the Denver Service Center in 1982.

SHERMAN JENSEN is a soil scientist/physical ecologist, with B.S. and M.S. degrees from Utah State University. His education included a broad scope of physical and natural sciences with primary emphases on soil and botany. He received additional training from the Soil Conservation Service in 1979. In 1981, he established White Horse Associates, an environmental consulting firm in Logan, UT. His primary professional interests include the classification and evaluation of riparian ecosystems, soil and botanical surveys, inventories and planning for mined land reclamation, and ecological studies of interrelationships between physical and biological components of the environment.

GEORGE W. LIENKAEMPER is a geologist for the Pacific Northwest Research Station in Corvallis, OR. He received a B.S. degree in geology in 1969 and an M.S. degree in interdisciplinary studies in 1976 from the University of Oregon. From 1975 to 1978 he worked on various research projects at Oregon State University including the International Biological Programs and the River Continuum Study. He has been in his present position since 1978.

G. WAYNE MINSHALL is professor of zoology at Idaho State University, Pocatello. He received his B.S. degree in fisheries management in 1961 from Montana State University and his Ph.D. degree in zoology in 1965 from the University of Louisville. He was a North Atlantic Treaty Organization (NATO) postdoctoral fellow at Freshwater Biological Association Windemere Laboratory from 1965 through 1966. He joined the staff at Idaho State University in 1966 where he has pursued a teaching and research career in stream ecology.

STEPHEN B. MONSEN is a botanist at the Intermountain Research Station, located at the Shrub Sciences Laboratory, Provo, UT. He received his B.S. degree from Brigham Young University. He has been involved with plant selection, site preparation, and planting practices of range and wildland sites in Utah and Idaho for approximately 25 years. His research has been directed to the restoration of seriously disturbed rangelands and watershed conditions.

Intermountain Research Station
324 25th Street
Ogden, UT 84401

RODGER L. NELSON is a biological technician with the Intermountain Research Station at Boise, ID. He received his B.S. degree in biological sciences from the University of California, Irvine, in 1973, attended graduate school in ecology at the University of California, Davis, and is currently enrolled in the master's in business administration program at Boise State University. Rodger has been with the Intermountain Station since 1978.

JAMES R. SEDELL is a research ecologist with the Pacific Northwest Research Station in Corvallis, OR. He received a B.A. degree in philosophy in 1966 from Willamette University, Salem, OR, and his Ph.D. degree in environmental biology in 1971 from the University of Pittsburgh, PA. He has been in his present position since 1980.

JOEL S. TUHY is currently employed by The Nature Conservancy as its Utah Public Lands Protection Planner. He received a B.S. degree in outdoor recreation resource management in 1977 from Iowa State University and an M.S. degree in forest ecology from the University of Idaho in 1981. During his thesis work, 1978 to 1979 (a valley-bottom community classification in the Sawtooth Valley, ID), he developed the field sampling techniques now generally used for riparian classification in the Intermountain region. He served as principal investigator for riparian classification contracts with the USDA Forest Service in western Wyoming (1980 to 1981) and central Idaho (1981 to 1982). He has been in his present position since 1983.

CONTENTS

Page

Introduction: Riparian Area Evaluation Needs 1
Collection of Riparian Habitat Information 2
  General Field Sampling 2
  Concepts About Populations and Samples 3
  Simple Random Sampling 3
  Stratified Random Sampling 6
  Cluster Sampling 9
  Two-Stage Sampling 11
  Monitoring 14
Measuring Vegetation 17
  Vegetative Use by Animals 17
  Vegetative Overhang 18
  Streambank Stability 19
  Streamside Cover 19
  Electronic Forage Analysis 20
Riparian Community Classification 36
  Field Methods 36
  Office Methods 38
  Final Considerations 38
Riparian Soils 39
  Flood Plain Geomorphology 39
  Soil Genesis 42
  Soil Morphology 42
  Soil Taxonomy 50
  Soil Description 55
  Summary 55
Remote Sensing 55
  Application of Large-Scale Photos for Inventory and Monitoring 56
  Baseline 57
  Ground Data Collection 57
  On-Site Data Collection 57
  Acquisition of Large-Scale Aerial Photographs ... 57
  Monitoring Procedures and Area Management ... 57
  Variables 57
  Sample Size 58
  Results 58
Water Column Measurements 58
  Vegetative Canopy Closure and Density 58
  Light Intensity 60
  Stream Surface Shading From Surrounding Vegetation 61
  Stream Surface Shading From Topographic and Vegetative Features 65
  Solar Heat Inputs Using the Solar Pathfinder™ ... 68
Streambanks 75
  Streambank and Channel Aggradation, Degradation, and Morphology 75
  Streambank Soil Alteration 80
  Streambank Undercut 81
  Stream Shore Water Depth 81
  Stream Channel-Bank Angle 82
Measuring and Mapping Organic Debris 83
  Measuring Woody Debris in Stream Channels ... 83
  Mapping Debris 88
  Measuring Large Woody Debris on Stream Banks 93
Historic Evaluation of Riparian Habitats 93
  Consulting the Historical Record 93
  Interpreting the Records 95
  Problems in Interpretation 95
  Using the Historical Record 98
  Implications to Riparian Research 105
Evaluation of Stream Riparian Area Conditions Using Benthic Macroinvertebrates 105
Planting of Riparian Sites 109
  Factors Influencing Revegetation 110
  Restoration by Natural Means 111
  Site Preparation and Alterations 113
  Seeding Riparian Communities 115
  Plant Selection and Uses 115
  Planting Woody Species 119
References 124
Appendix 1: Statistical Tables 132
Appendix 2: Accuracy, Precision, and Confidence Intervals of Selected Variables 134
Appendix 3: Forms for Recording Hydraulic Geometry and Soil Data 137
Appendix 4: Computer Program for Herbage Phytomass and Utilization Measurements 140
Appendix 5: Flow Chart for HERB-2 163
Appendix 6: Requirements, Example, and Computer Program for Calculating Stream Surface Shading from Topographic and Vegetative Features 164
Appendix 7: Bibliographies, Source Materials, and Repositories for Information on Historical Riparian Conditions 171
Appendix 8: Riparian Types of the Upper Salmon/Middle Fork Salmon River Drainages, Idaho 173
Appendix 9: Riparian Community Types of Eastern Idaho and Western Wyoming 174
Appendix 10: Pool Quality Rating Tables 176

Methods for Evaluating Riparian Habitats With Applications to Management

William S. Platts
Carl Armour
Gordon D. Booth
Mason Bryant
Judith L. Bufford
Paul Cuplin
Sherman Jensen
George W. Lienkaemper
G. Wayne Minshall
Stephen B. Monsen
Rodger L. Nelson
James R. Sedell
Joel S. Tuhy

INTRODUCTION: RIPARIAN AREA EVALUATION NEEDS

Riparian area planning and management is a major national issue today—something that should have been the case a century ago. A century of additive effects of land use has resulted in major impacts on many riparian stream habitats and their fisheries, wildlife, and domestic livestock use. Before scientists can evaluate the influences of various land and water uses on riparian environments, they must first understand these environments. This means being able to detect and measure with confidence the natural and artificial variation and instantaneous conditions of the riparian habitat. These conditions must then be related to the production capability of riparian habitat and any extraneous factors affecting this production potential.

Combined effects of geology, climate, soil, vegetation, flow regimes, and especially human activity, can result in constantly changing riparian habitat conditions. These riparian habitats respond, often dramatically, to management practices that improve their productive capability. Because the riparian component of fish and wildlife habitat can often be manipulated quite quickly, it is often less costly and much easier to immediately benefit a fishery through riparian area rehabilitation than through other stream enhancement activities such as the use of artificial channel flow modification structures.

Land and water managers have inadequate guidelines for determining existing and potential impacts on riparian stream resources in their management programs. Methods that will completely document and monitor riparian ecosystems have not been adequately developed. Therefore, methods need to be constantly refined that will evaluate the productivity of riparian environments and how the stages of this productivity affect the health and survival of the fish and wildlife that depend on it.

Recently there has been an increase in the number of studies evaluating the condition, trend, and potential of riparian habitats with respect to their capability to support life. The success or failure of these studies depends on the precision, accuracy, and comprehensiveness of the data used for interpretation and decision making. This is where the difficulty arises because it is not easy to develop accurate methods that will quantitatively determine the actual or changing states of an ecosystem. Specialists who collect the data must know and be able to dampen those factors that affect the precision and accuracy of their measurements, account for the variability and uncertainties in the data collected, and conduct the study in a manner that will lead to a true answer. Because past measurements can seldom be verified for quality, they must be collected with tested methods using a valid sampling design, followed by proper analysis and interpretation.

Many of the techniques being used today are untested, and some were designed to optimize time rather than accuracy. Difficult decisions, those requiring that data be collected and analyzed over sufficient time, are often being made on inadequate information. Thus, poor resource management decisions will often result. Some of the variables in this report have undergone testing and have their respective precision and accuracy ratings listed.

This report, in combination with Platts and others (1983), is an attempt to compile a comprehensive set of the latest methods for resource specialists to use in managing, evaluating, and monitoring riparian conditions adjacent to streams, lakes, ponds, and reservoirs. The emphasis is on streams. Today's riparian area evaluation methods are far from perfect, and they are not likely to be completely accurate and precise in the near future. Therefore, such methods need constant refinement and new and better techniques need to be developed. We hope this manual hastens the day when riparian evaluation methods will provide the complete mix of data needed for accurate decision making.

COLLECTION OF RIPARIAN HABITAT INFORMATION

General Field Sampling

Information collection is necessary for inventory and monitoring activities associated with riparian management programs. Success for the programs is dependent upon the acquisition and use of information that must be appropriate for planning processes and the design of site-specific management. Unfortunately, widespread problems have resulted in inadequate, improper, or excessive information. This is usually attributed to a poorly thought-out approach to collecting information for specifically fulfilling resource management requirements. Therefore, the objective of this chapter is to present basic guidance for use when field sampling programs are being designed. We have presented information in a section pertaining to a general field sampling program and a second section in which considerations for monitoring approaches are discussed.

Six basic steps should be followed for a field sampling program (fig. 1) if useful information is to be obtained. Before sampling, justification for collecting the information (step 1) must be made. Considerations for establishing justifications include: (1) Is the information already available? (2) Is the acquisition of new information absolutely necessary for activities associated with riparian resource planning and management activities? (3) Would it be possible to measure a substitute condition to obtain essentially the same information at lower cost?

After specific information needs are defined, collection approaches must be determined (step 2). Considerations for this step must include evaluations of the suitability of a technique for achieving appropriate levels of accuracy and precision and the practicality of the technique based on ease of field application, costs, and other factors. Following step 2, pilot sampling (step 3) must be performed. Essentially, this step is a trial run designed to detect and correct problems that could seriously affect sampling. Additionally, this step is necessary for training of field crews and obtaining preliminary data for use in estimating the sample size for a predetermined level of statistical confidence. If problems are detected, which is usually the case (examples: sampling gear performs improperly, inadequate time was allocated for collecting and analyzing samples, more samples must be collected than originally planned), corrective measures must be taken. Step 3 is mandatory because serious flaws in the way sampling is conducted will adversely impact the quality of information that is collected.

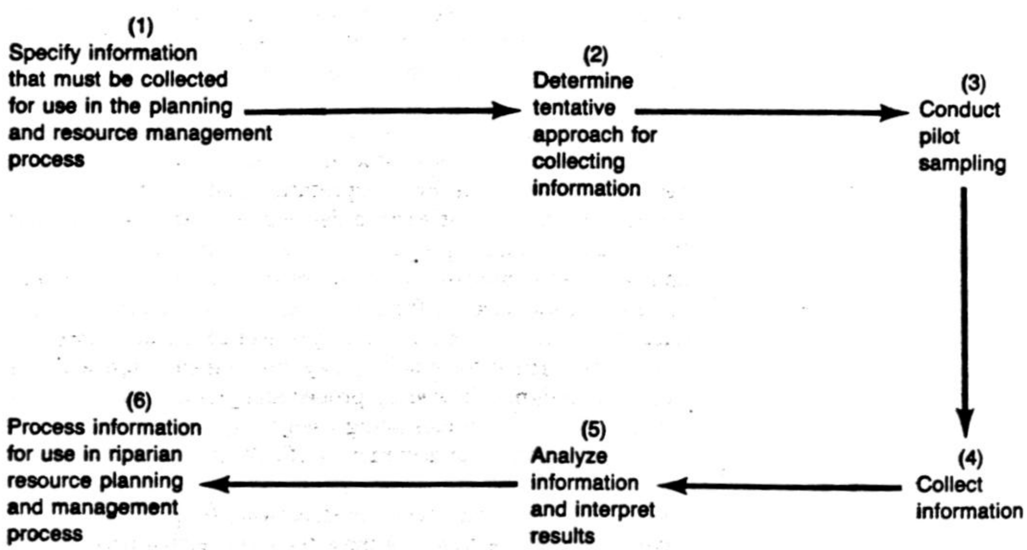


Figure 1—Steps for a field sampling program to obtain useful information for riparian resource planning and management processes.

When information is collected (step 4), it must be recorded accurately and assembled in a usable format for analyses (step 5). When the results are processed for use in planning and management procedures (step 6), careful thought must be given to the best way to present it to resource specialists and administrators. If the information is not presented with clarity and in a useful form, effort and costs expended for the work will be wasted.

Concepts About Populations and Samples

The entire collection of items in which we are interested is called the population. For example, the population might be a 100-ft section of the stream to be divided into 100 cross sections of 1 ft each. If we take measurements on only 20 of these cross sections, the cross sections we measure constitute the sample. The whole purpose of using sampling is to obtain information about the entire population when it is not possible or feasible to measure every element in it. We hope the items in the sample will give us accurate information about the whole population.

Populations can be either finite (with a fixed, countable number of elements) or infinite (with an infinite number of elements). Some populations are technically finite but with so many elements we could not reasonably count them. Such populations are considered to be infinite.

To illustrate, consider the example mentioned above. The 100-ft stretch of stream is the population. We have arbitrarily divided it into 100 cross sections of 1 ft each. Does this mean we have 100 elements in our population? Not necessarily. If we are interested in some characteristic that requires measurement over the entire 1-ft cross section, then the population could be considered finite with 100 elements in it. On the other hand, if we were interested in a characteristic that requires measurement at only a point along the stream (such as stream width measured at a transect), it would be incorrect to consider the population as consisting of only 100 elements. In this case the population should be dealt with as infinite.

The methods that follow will often involve the finite population correction (*fpc*). It is defined as:

$$fpc = (1 - n/N)$$

where:

N = number of elements in the whole population

n = number of elements in the sample.

Notice that if N is large (essentially infinite), the *fpc* approaches 1. In the methods described later, if the population is infinite, we can ignore the *fpc* (that is, consider it equal to 1). This is true because the *fpc* is always used as a multiplier and multiplying by 1 has no effect.

We use "error of estimation" to denote the distance by which our estimate misses the true population value we are attempting to estimate. Although we cannot know the true error of estimation, it would be useful to be quite certain that after our sampling and estimating are complete, we have an error of estimation that is no greater than some upper bound, say B. We will present some statistical methods designed to help us determine how large our sample must be to accomplish this.

Common field sampling procedures are simple random sampling, stratified random sampling, and cluster sampling (table 1). Most of the following computational examples for the procedures were adapted from Scheaffer and others (1979). The information presented here is expected to introduce field workers to some useful procedures; prior to application, a qualified statistician should be consulted.

Simple Random Sampling

A simple random sample (SRS) is, as its name implies, the sampling method that is simplest in concept. For its use, each element in the population (such as plots and transects) must be identifiable as individuals. Sampling must be performed in such a way that every element in the population has the same probability of being in the sample.

Using simple random sampling often results in samples that (1) are widely dispersed, causing considerable travel expense, and (2) leave some areas totally unsampled. Therefore, the most successful use of SRS is in relatively small geographical areas where a degree of homogeneity is known to exist. Simple random sampling could be used in other circumstances, but it would tend to be inefficient and more costly.

Simple random sampling should probably be within ecological types instead of across multiple types. This precaution will tend to reduce the variability and increase the precision of habitat parameter estimates. The precaution is reasonable, for example, when one considers the high variation that occurs between riparian habitat in meadows compared to headwater-timbered areas in an allotment that is heavily grazed.

Table 1—Comparison of simple random, stratified random, and cluster sampling techniques

Sampling approach	Total number of elements or plots (potential samples) in population must be known in advance?	Key features	Application considerations	Appropriate field use
Simple random	Yes - identification of all elements or plots necessary for selection of random sample.	Through random sampling there is an equal chance for sampling of each element. This helps insure that data representative of an overall population will be obtained.	Excessive costs can be incurred if elements are widely scattered through a large geographic area.	Randomly distributed populations in relatively small geographic areas.
Stratified random	Yes - after strata are defined, elements or plots within each stratum are selected randomly for sampling.	Advantages over simple random sampling can be reduced and variance for parameter estimators and costs can be reduced substantially if sampling is restricted to a smaller geographic area. Additionally, conditions between strata can be compared statistically, that is, difference among means.	Within each stratum there must be relative homogeneity and heterogeneity must be maximized among strata. Homogeneity within helps to reduce sample variance.	Populations in homogeneous strata dissimilar from other strata. Recommended if sampling is conducted in recognizable homogeneous strata.
Cluster sampling	All elements are sampled for one-stage sampling. Two-stage sampling requires advance identification of elements for random selection for sampling.	Clusters to sample are selected randomly. Clusters must be alike (homogeneous between) with heterogeneous conditions within.	The sampling approach can be economical because heterogeneity within clusters helps to lower overall sampling costs because travel distance and time can be lessened when a representative sample is obtained. Clusters must have the same number of sampling units to avoid more complicated computations. Two-stage analysis is appropriate when there are too many elements per cluster to sample, or the elements are so similar that counting all of them is wasteful. Prior to using cluster sampling, a statistician should always be consulted.	Populations that are associated with heterogeneous conditions for which ordered, systematic sampling, simple random and stratified sampling is infeasible and there are an adequate number of clusters to sample.

Example 1—Twenty transects ($n = 20$) are placed along a stream in a meadow. They are selected randomly, and stream width is measured at each transect. What are the mean width, the upper bound on the error of estimation (in this case, B), and the 95 percent confidence interval on the population mean (μ)? Assuming that the information is preliminary, how many samples would have to be collected to be reasonably sure B does not exceed 1.07 ft?

Step 1 - Calculate the sample mean and variance of the following 20 measurements on stream width: 10, 16, 11, 8, 9, 11, 3, 13, 10, 7, 5, 12, 9, 12, 11, 20, 11, 12, 14, 10.

NOTE: Almost any scientific calculator has the built-in capability of computing both the mean ($\bar{X}$) and the standard deviation (s) or the variance (s^2). If your calculator computes the standard deviation, the variance is obtained by squaring the standard deviation.

In this case we obtain $\bar{X} = 10.7000$, $s^2 = 13.4843$.

Step 2 - Calculate the bound on the error of estimation (B)

$$B = 1.96 \sqrt{\frac{s^2}{n} \frac{N-n}{N}}$$

In this case, the population is infinite and the *fpc* = 1. Therefore:

$$B = 1.96 \sqrt{\frac{13.4843}{20}} = 1.96 \sqrt{0.6742} = 1.6094$$

where:

$\frac{N-n}{N}$ = the finite population correction (*fpc*)

1.96 = Z value from the normal distribution (see appendix 1) for the 95 percent level. If another level of confidence were used, the number 1.96 would be replaced by the appropriate value from the normal distribution.

Step 3 - Calculate the 95 percent confidence interval for the population mean (μ).

The interval is computed as:

Lower limit $= \bar{X} - B = 10.7000 - 1.6094 = 9.0906$

Upper limit $= \bar{X} + B = 10.7000 + 1.6094 = 12.3094$.

This means we are quite confident (95 percent) that the true population mean is between 9.0906 and 12.3094.

Step 4 - Calculate n' = estimated sample size if B is not to exceed 1.07 ft

$$n' = \frac{(Z^2)(s^2)}{B^2}$$

$$= \frac{(1.96)^2\,(13.4843)}{(1.07)^2} = 45.2453$$

We always round to the next higher number. Therefore:

$n' = 46$

where:

$Z = 1.96$ at the 95 percent confidence level (see appendix 1).

A sample size of $n = 46$ should give us a good chance of obtaining $B \leqslant 1.07$ ft.

Example 2—An inventory was conducted along a 60-mile stretch of a stream. Each 1-mile segment ($N = 60$) was designated as a possible sample site, and 20 sites ($n = 20$) were randomly selected for sampling along both sides of the stream to a distance of 200 ft back from each bank. Snag trees in each sample site were counted. There was an average of 10 trees ($\bar{X}$) per site with a sample variance (s^2) of 8.3731. Estimate the total number of snags in the 60-mile stretch, the bound on the error of estimation (B), the 95 percent confidence interval for the total number of snags in the population, and the estimated sample size if our estimate is to be within 25 snags of the true total.

In this case, each 1-mile segment was a potential sample site and, if chosen for the sample, would be studied in its entirety—not at a single point. This population can be considered finite with $N = 60$. (Of course, we might have chosen to use 120 segments of 0.5 mile each for a finite population of $N = 120$.)

Step 1 - Calculate $\hat{\tau}$, the estimate of the total number of snags in the 60-mile stretch

$$\hat{\tau} = N\bar{X} = (60)(10) = 600 \text{ snag trees}$$

Step 2 - Calculate the estimated variance of $\hat{\tau}$

$$\hat{V}(\hat{\tau}) = N^2\left(\frac{s^2}{n}\right)\left(\frac{N-n}{N}\right) = 60^2\left(\frac{8.3731}{20}\right)\left(\frac{60-20}{60}\right)$$

$$= (3{,}600)(0.4187)(0.6667) = 1{,}004.77$$

Step 3 - Calculate the bound on the error of estimation

$$B = (1.96)\sqrt{\hat{V}(\hat{\tau})}$$

$$= (1.96)\sqrt{1{,}004.77} = 62.1284$$

where:

1.96 = Z for the 95 percent confidence level.

Step 4 - Calculate the 95 percent confidence interval for the total number of snag trees in the population

The interval is computed as:

Lower limit = $\hat{\tau} - B$ = 600 − 62.1284 = 537.9

Upper limit = $\hat{\tau} + B$ = 600 + 62.1284 = 662.1.

Step 5 - Calculate n', the estimated sample size for B not to exceed 25 snags

$$n' = \frac{NS^2}{(N-1)D + S^2}$$

where:

$$D = \frac{B^2}{Z^2N^2}$$

$$= \frac{(25)^2}{(1.96)^2(60)^2} = 0.0452$$

$$n' = \frac{(60)(8.3731)}{(60\text{-}1)(0.0452) + 8.3731} = 45.5$$

Rounding up gives $n' = 46$.

Therefore, a sample of $n = 46$ should give us high probability of estimating the true number of snags within 25 trees.

Stratified Random Sampling

If the population of interest falls naturally into several subdivisions, or strata, stratified random sampling is found to be substantially more efficient than simple random sampling. For example, if the number of shrubs is a management concern in a riparian zone that extends through several homogeneous vegetation types (such as sagebrush, sagebrush-grass, and ponderosa pine-Idaho fescue), this method of sampling is suitable. This procedure requires that the investigator clearly identify each stratum in advance of sampling. Then a simple random sample (SRS) is taken independently within each stratum.

In addition to being more efficient in estimating the overall population mean or total, stratified random sampling provides separate estimates for each stratum. This feature alone might be reason enough for using this method over SRS.

Example 3—Assuming that the following information is collected from three strata, what are the mean number of shrubs per acre, the bound (B) on the error of estimation, and the 95 percent confidence interval for the population mean (μ)? Sample means and variances were calculated for each stratum. Approximately 13 percent of the acres were sampled in each stratum. This is a finite population with three strata such that $N_1 = 155$, $N_2 = 62$, and $N_3 = 93$.

Stratum	Total acres/ stratum (N_h)	Total acres sampled (n_h)	Sample stratum mean $\bar{X}_h$	Total shrubs $N_h\bar{X}_h$	Stratum variance s_h^2	$N_h s_h^2$
1 Sagebrush	155	20	33.900	5,254.500	35.358	5,480.49
2 Sagebrush-grass	62	8	25.125	1,557.750	232.411	14,409.48
3 Ponderosa pine-Idaho Fescue	93	12	19.000	1,767.000	87.636	8,150.15
	310	40		8,578.750		28,040.12

$N = \Sigma N_h = 310$ $\quad n = \Sigma n_h = 40$ $\quad T = \Sigma N_h \bar{X}_h = 8{,}578.750$ $\quad s^2 = \Sigma N_h s_h^2 = 28{,}040.12$

Step 1 - Calculate sample mean

$$\bar{X}_{st} = \frac{T}{N}$$

$$= \frac{8{,}578.750}{310} = 27.673$$

= sample estimate of μ, the population mean number of shrubs per acre

Step 2 - Calculate an estimate of the variance of $\bar{X}_{st}$

$$\hat{V}(\bar{X}_{st}) = \frac{1}{N^2}\Sigma\left[N_h^2\left(\frac{N_h - n_h}{N_h}\right)\left(\frac{s_h^2}{n_h}\right)\right]$$

$$= \frac{1}{(310)^2}\left[(155)^2\left(\frac{(155 - 20)}{155}\right)\left(\frac{35.358}{20}\right)\right.$$

$$+ (62)^2\left(\frac{(62 - 8)}{62}\right)\left(\frac{(232.411)}{8}\right)$$

$$\left. + (93)^2\left(\frac{(93 - 12)}{93}\right)\left(\frac{(87.636)}{12}\right)\right]$$

$$= \frac{1}{(310)^2}(36{,}993.308 + 97{,}264.004 + 55{,}013.499)$$

$$= \frac{189{,}270.81}{96{,}100} = 1.970$$

Step 3 - Calculate the bound on the error of estimation and the 95 percent confidence interval

$$B = (1.96)\sqrt{\hat{V}(\bar{X}_{st})} = (1.96)\sqrt{1.970} = 2.751$$

Step 4 - Calculate the 95 percent confidence interval for the population mean (μ) number of shrubs per acre

The interval is calculated as:

Lower limit: $\bar{X}_{st} - B = 27.673 - 2.751 = 24.922$

Upper limit: $\bar{X}_{st} + B = 27.673 + 2.751 = 30.424.$

Example 4—What should the sample size be for each stratum if we want to be 95 percent confident that the error of estimation has a bound (B) no larger than 2.0?

Step 1 - Calculate the denominator for stratum weights

$$\text{Denominator} = \Sigma N_h S_h$$

$$= (155)\sqrt{35.358} + (62)\sqrt{232.411} + (93)\sqrt{87.636}$$

$$= 921.67 + 945.19 + 870.61$$

$$= 2{,}737.47$$

Step 2 - Calculate the stratum weights

$$w_h = \frac{N_h s_h}{\Sigma N_h s_h}$$

= the proportion of the total sample size, n, that will come from stratum h.

$$w_1 = \frac{921.67}{2,737.47} = 0.337$$

$$w_2 = \frac{945.19}{2,737.393} = 0.345$$

$$w_3 = \frac{870.573}{2,737.393} = 0.318$$

Notice that the weights over all three strata add up to 1.000. To determine the size of sample required from stratum h, multiply the total sample size by w_h. Therefore,

$$n_h = w_h n.$$

We still need to determine the overall sample size, n.

Step 3 - Calculate the numerator for the n' equation

$$\text{Numerator} = \Sigma \frac{N_h^2 s_h^2}{w_h}$$

$$= \frac{(155)^2(35.358)}{0.337} + \frac{(62)^2(232.411)}{0.345} + \frac{(93)^2(87.636)}{0.318}$$

$$= 2,520,700.148 + 2,589,530.099 + 2,383,533.849$$

$$= 7,493,764.096$$

Step 4 - Calculate n'

$$D = \frac{B^2}{Z^2} = \frac{(2.0)^2}{(1.96)^2}$$

= 1.041, where Z = 1.96 comes from the normal distribution (appendix 1).

Finally

$$n' = \frac{\text{Numerator}}{N^2 D + s^2}$$

$$= \frac{7,493,764.096}{(310)^2(1.041) + 28,040.12} = \frac{7,493,764.096}{100,040.10 + 28,040.12}$$

$$= \frac{7,493,764.096}{128,080.22} = 58.508 \text{ or } 59$$

Therefore, an overall sample of n = 59 should give the investigator high probability of obtaining an estimate that is no more than 2.0 shrubs per acre from the population mean being estimated.

Step 5 - Calculate sample size for each stratum

$n_1 = w_1 n' = (0.337)(59) = 19.883$ or 20

$n_2 = w_2 n' = (0.345)(59) = 20.355$ or 20

$n_3 = w_3 n' = (0.318)(59) = 18.762$ or 19

Total 59

NOTE: The weights, w_h, were determined in such a way that the variance of $\bar{X}_{st}$ is minimized for a fixed value of n. Therefore, once we determined an estimate of n, say n', we applied the weights to it to obtain the sample size in each stratum.

Example 5—Using the results of example 4, what is the estimate of the total number of shrubs in the three strata, the bounds on the error of estimation (B), the 95 percent confidence interval for the estimate, and the estimated number of samples that would have to be collected for B not to exceed 400 shrubs?

Step 1 - Calculate the value for $\hat{\tau}$, the estimate of the population total number of shrubs

$$\hat{\tau} = N\bar{X}_{st}$$
$$= (310)(27.673)$$
$$= 8{,}578.630 \text{ shrubs}$$

Step 2 - Calculate the estimated variance of $\hat{\tau}$

$$\hat{V}(N\bar{X}_{st}) = N^2\hat{V}(\bar{X}_{st})$$
$$= (310)^2(1.970)$$
$$= 189{,}317$$

Step 3 - Calculate the bounds on the error of estimation

$$B = 1.96\sqrt{\hat{V}(N\bar{X}_{st})} = 1.96\sqrt{189{,}317} = 852.81$$

NOTE: Although the same symbol (B) is used in examples 4 and 5, its value is different for the mean (μ) than for the total (τ).

Step 4 - Calculate the 95 percent confidence interval for the total number of shrubs in the population

The interval is computed as:

Lower limit: $\hat{\tau}_{st} - B = 8{,}578.63 - 852.81 = 7{,}725.82$

Upper limit: $\hat{\tau}_{st} + B = 8{,}578.63 + 852.81 = 9{,}431.44$.

Step 5 - Calculate n', the estimated sample size for B not to exceed 400 shrubs

The only difference between this case and the estimation of μ in example 4 is in the computation of D. We now have

$$D = \frac{B^2}{Z^2N^2} = \frac{(400)^2}{(1.96)^2(310)^2} = 0.433$$

where Z is from a table of the normal distribution (appendix 1) for 95 percent confidence.

$$n' = \frac{\text{Numerator}}{N^2D + s^2} = \frac{7{,}493{,}764.096}{(310)^2(0.433) + 28{,}040.12}$$
$$= \frac{7{,}509{,}992.786}{69{,}651.420}$$
$$= 107.59 \text{ or } 108 \text{ rounded up}$$

We can apply the weights from example 4 to obtain the sample sizes for each stratum. We get

$$n_1 = (0.337)\ 108 = 36.40 \text{ or } 36$$
$$n_2 = (0.345)\ 108 = 37.26 \text{ or } 37$$
$$n_3 = (0.318)\ 108 = 34.34 \text{ or } 34$$

Cluster Sampling

Cluster sampling should not be confused with cluster analysis, which is a classification and taxonomic technique. Here, cluster sampling refers to a method of collecting a sample when the individual elements cannot be identified in advance. Instead, we are only able to identify groups or clusters of these elements. A sample of the clusters is then obtained, and every element in each cluster is measured.

For example, we may wish to take measurements on individual trees in a riparian area but are only able to identify 1-acre plots along the stream. Each plot can contain a different number of trees, and the individual trees cannot be identified before taking the sample. Cluster sampling allows us to select a sample of clusters, instead of individual trees. We would then measure every tree within each cluster.

Cluster sampling is convenient and inexpensive with regard to travel costs. To gain maximum advantage of this method, elements within a cluster should be close to each other geographically.

If we compare cluster sampling with either simple random sampling or stratified random sampling, we find one major advantage of the cluster method: the cost per element sampled is lower than for the other two methods. Unfortunately, two disadvantages of cluster sampling are: (1) the variance among elements sampled tends to be higher, and (2) the computations required to analyze the results of the sample are more extensive. Therefore, cluster sampling is preferable to the other methods if the cost benefits exceed the disadvantages.

If we have only a few clusters, each quite large, we minimize our costs—especially of travel. However, samples with only a few clusters produce estimates with low precision (that is, high variance). On the other hand, if we increase the number of clusters (making each cluster smaller), the variance is reduced while the cost is increased. The user must find a compromise.

Whether sampling 40 clusters of 0.5 acre each is better than 20 clusters of a full acre each is not clear, although approximately the same number of trees may be measured with either sample. There would be a larger number of the smaller clusters, and therefore they would be dispersed more evenly over the population. The estimates produced would have lower variability than those from fewer but larger clusters. However, the sampler would have to travel to twice as many sites, thus increasing costs. Knowledge of the variability and costs involved would be the key to planning such a study effectively.

Example 6—Suppose that we have 30 clusters of 1 acre each ($N = 30$) in a riparian area. Calculate the average number of cavities per snag tree, the bound on the error of estimation (B), and the 95 percent confidence interval for the population mean (μ). Five clusters (n) are selected for sampling and data are collected for all snag trees in each cluster. Sampling data are tabulated below.

Cluster	Number of snag trees (m_i)	Total cavities (X_i)
1	8	5
2	9	7
3	4	8
4	5	9
5	6	10
	$\Sigma m_i = 32$	$\Sigma X_i = 39$

Step 1 - Calculate an estimate of μ, the population mean, for cavities per snag tree

$$\bar{X} = \frac{\Sigma X_i}{\Sigma m_i} = \frac{39}{32} = 1.22 \text{ cavities per snag tree}$$

Step 2 - Calculate $\bar{m}$, the average cluster size for the sample

$$\bar{m} = \frac{\Sigma m_i}{n} = \frac{32}{5} = 6.4 \text{ snag trees per cluster}$$

An estimate of the total number of snag trees in the 30 clusters is $N\bar{m} = (30)(6.4) =$ 192.0 trees.

Step 3 - Calculate sum of squares

Cluster	m_i	X_i	$\bar{X}m_i$	$(X_i - \bar{X}m_i)^2$
1	8	5	9.76	22.66
2	9	7	10.98	15.84
3	4	8	4.88	9.73
4	5	9	6.10	8.41
5	6	10	7.32	7.18
			Total	63.82

where $\bar{X}$ came from step 1.

Step 4 - Calculate $\hat{V}(\bar{X})$ = estimated variance for $\bar{X}$

$$\hat{V}(\bar{X}) = \left(\frac{N - n}{(N)(n)(m)^2}\right)\left(\frac{\Sigma(X_i - \bar{X}m_i)^2}{n - 1}\right)$$

$$= \left(\frac{30 - 5}{(30)(5)(6.4)^2}\right)\left(\frac{63.82}{4}\right)$$

$$= (0.004)(15.955) = 0.0649$$

Step 5 - Calculate the bound on the error of estimation

$$B = 1.96\sqrt{\hat{V}(\bar{X})} = 1.96\sqrt{0.064} = 0.4994$$

Step 6 - Calculate the 95 percent confidence interval for the population mean number of cavities per snag tree:

Lower limit: 1.22 − 0.4994 = 0.7206

Upper limit: 1.22 + 0.4994 = 1.7194.

Example 7—Assuming that information for example 6 is preliminary, how can we determine the number of clusters to sample if we want the bound on the error of estimation (B) to be within 0.1?

Step 1 - Calculate s_c^2 = estimate of the population variance among clusters

$$s_c^2 = \frac{\Sigma(X_i - \bar{X}m_i)^2}{n - 1}$$

$$= \frac{63.82}{4} = 15.955$$

Step 2 - Calculate

$$D = \frac{B^2\bar{m}^2}{Z^2} = \frac{(0.1)^2(6.4)^2}{(1.96)^2} = 0.1066$$

where:

1.96 is the Z value from the normal distribution for 95 percent confidence.

Step 3 - Calculate n' = total number of clusters to sample

$$n' = \frac{(N)(s_c^2)}{ND + s_c^2} = \frac{(30)(15.955)}{(30)(0.1066) + 15.955}$$

$$= \frac{(30)(15.955)}{19.153} = 24.99 \text{ or 25 clusters rounded up}$$

Two-Stage Sampling

Suppose we have clusters with so many elements in them that it is prohibitive to measure all elements in the cluster. It is natural to think of sampling elements within each cluster—that is, to measure only part of the elements within each cluster. This situation is a common one and is referred to as two-stage sampling.

Another common use of two-stage sampling is when it is apparent that even though there are many elements within a cluster, all elements are so nearly the same that to sample all of them would provide little additional information. The reasonable thing to do might be to measure only a part of the elements available within the cluster.

Two-stage sampling introduces a high degree of flexibility in defining clusters and sampling within them. The give and take between the number of clusters and the number of elements to be sampled within each cluster has been studied in some detail. Unfortunately, the results are complicated and beyond the scope of this publication. Interested readers are referred to one of the more extensive books on sampling (Cochran 1963; Kish 1965).

The following examples serve to give the reader a brief introduction to the concepts of two-stage sampling.

Example 8—Suppose that there are N = 90 clusters in a riparian zone and we can sample 10 clusters (n = 10) and 20 percent of the pools in each cluster. Estimate the mean depth of pools in the population, the bounds on the error of estimation (B), and the 95 percent confidence interval for the population mean (μ). Assume that there is a total of M = 4,500 pools in the 90 clusters. Data for each cluster have been used to calculate the cluster means ($\bar{X}_i$) and variances (s_i^2).

Step 1 - Tabulate data as follows:

Cluster	Total pools (M_i)	Pools sampled (m_i)	Mean depth $\bar{X}_i$	$(M_i)(\bar{X}_i)$	$(M_i\bar{X}_i - \bar{M}\bar{\bar{X}})^2$*
1	50	10	5.40	270.00	900.00
2	65	13	4.00	260.00	400.00
3	45	9	5.67	255.15	229.52
4	48	10	4.80	230.40	92.16
5	52	10	4.30	223.60	268.96
6	58	12	3.83	222.14	318.98
7	42	8	5.00	210.00	900.00
8	66	13	3.85	254.10	198.81
9	40	8	4.88	195.20	2,007.04
10	56	11	5.00	280.00	1,600.00
	ΣM_i = 522			$\Sigma(M_i\bar{X}_i)$ = 2,400.59	$\Sigma(M_i\bar{X}_i - \bar{M}\bar{\bar{X}})^2$ = 6,915.47

*Calculated $\bar{M}$ and $\bar{\bar{X}}$ from Step 2 and Step 3 below

Cluster	s_i^2	$M_i(M_i - m_i) = A_i$	$s_i^2/m_i = B_i$	$(A_i)(B_i)$
1	11.38	2,000	1.138	2,276.00
2	10.67	3,380	0.821	2,774.98
3	16.75	1,620	1.861	3,014.82
4	13.29	1,824	1.329	2,424.10
5	11.12	2,184	1.112	2,428.61
6	14.88	2,668	1.240	3,308.32
7	5.14	1,428	0.643	918.20
8	4.31	3,498	0.332	1,161.34
9	6.13	1,280	0.766	980.48
10	11.80	2,520	1.073	2,703.96

$$\Sigma M_i(M_i - m_i)\frac{s_i^2}{m_i} = 21,990.81$$

Step 2 - Calculate $\bar{M}$ = average number of elements (pools) in each cluster

$$\bar{M} = \frac{M}{N} = \frac{4,500}{90} = 50 \text{ pools}$$

Step 3 - Calculate $\bar{\bar{X}}$ = the estimated population mean depth for pools

$$\bar{\bar{X}} = \frac{N}{(M)(n)}\Sigma M_i\bar{X}_i$$

$$= \frac{90}{(4,500)(10)}(2,400.59) = 4.8012 \text{ ft deep}$$

Step 4 - Calculate the estimated variance for $\bar{\bar{X}}$

A. Calculate:

$$s_b^2 = \frac{1}{n-1}\Sigma(M_i\bar{X}_i - \bar{M}\bar{\bar{X}})^2 = \frac{1}{10-1}(6,915.47)$$

$$= \frac{6,915.47}{9} = 768.4;$$

B. and calculate:

$$\hat{V}(\bar{\bar{X}}) = \left[\left(\frac{N-n}{N}\right)\left(\frac{1}{n\bar{M}^2}\right)(s_b^2)\right] + \left(\frac{1}{nN\bar{M}^2}\right)\left[\Sigma M_i(M_i - m_i)\left(\frac{s_i^2}{m_i}\right)\right]$$

$$= \left[\left(\frac{90-10}{90}\right)\left(\frac{1}{(10)(50)^2}\right)(768.4)\right] + \left[\frac{1}{(10)(90)(50)^2}\right](21,990.81)$$

$$= 0.037095$$

Step 5 - Calculate bounds on the error of estimation

$$B = 1.96\sqrt{\hat{V}(\bar{\bar{X}})} = 1.96\sqrt{0.037095} = 0.3775$$

Step 6 - Calculate the 95 percent confidence interval for the population mean pool depth (μ), which is:

Lower limit: $\bar{X} - B = 4.8012 - 0.3775 = 4.42$

Upper limit: $\bar{X} + B = 4.8012 + 0.3775 = 5.18$

Example 9—If M is unknown in example 8, calculate the estimate of the population mean depth of pools, the bounds on the error of estimation (B), and the 95 percent confidence interval for the population mean depth of pools.

Step 1 - Estimate μ = ratio estimate of the population mean μ

$$\bar{X}_r = \frac{\Sigma M_i \bar{X}_i}{\Sigma M_i} = \frac{2{,}400.59}{522} = 4.599 \text{ ft}$$

Step 2 - Complete tabulations for extension of table for example 8

$M_i^2 \bar{X}_i$	$(M_i \bar{X}_i)^2$	M_i^2
13,500.00	72,900.00	2,500
16,900.00	67,600.00	4,225
11,481.75	65,101.52	2,025
11,059.20	53,084.16	2,304
11,627.20	49,996.96	2,704
12,884.12	49,346.18	3,364
8,820.00	44,100.00	1,764
16,770.60	64,566.81	4,356
7,808.00	38,103.04	1,600
15,680.00	78,400.00	3,136
$\Sigma M_i^2 \bar{X}_i$ = 126,530.87	$\Sigma(M_i \bar{X}_i)^2$ = 583,198.67	ΣM_i^2 = 27,978

Step 3 - Calculate $\bar{M}$ = estimate of average number of pools per cluster

$$\bar{M} = \frac{\Sigma M_i}{n} = \frac{522}{10} = 52.2 \text{ pools per cluster}$$

Step 4 - Calculate estimated variance for μ

A. Calculate s_r^2:

$$s_r^2 = \frac{1}{n-1} \Sigma M_i^2 (X_i - \bar{X}_r)^2$$

$$= \frac{1}{n-1}\left[\Sigma(M_i\bar{X}_i)^2 - 2\bar{X}_r \Sigma M_i^2 \bar{X}_i + (\bar{X}_r)^2 \Sigma M_i^2\right]$$

$$= \frac{583{,}198.67 - 2(4.599)(126{,}530.87) + (4.599)^2 (27{,}978)}{9}$$

$$= \frac{583{,}198.67 - 1{,}163{,}830.94 + 591{,}757.11}{9}$$

$$= \frac{11{,}124.84}{9} = 1{,}236.09;$$

B. and calculate $\hat{V}(\bar{X}_r)$, the estimated variance of $\bar{X}_r$

$$\hat{V}(\hat{\mu}) = \left(\frac{N-n}{N}\right)\left(\frac{1}{n\bar{M}^2}\right)(s_r^2) + \left(\frac{1}{nN\bar{M}^2}\right)\Sigma M_i (M_i - m_i)\left(\frac{s_i^2}{m_i}\right)$$

$$= \left(\frac{90-10}{90}\right)\left(\frac{1}{(10)(52.2)^2}\right)(1{,}236.09) + \left(\frac{1}{(10)(90)(52.2)^2}\right)(21{,}990.81)$$

$$= \left(\frac{80}{90}\right)\left(\frac{1}{(10)(2{,}724.84)}\right)(1{,}236.09) + \left(\frac{1}{(10)(90)(52.2)^2}\right)(21{,}990.81)$$

$$= \left(\frac{80}{2{,}452{,}356}\right)(1{,}236.09) + \left(\frac{1}{2{,}452{,}356}\right)(21{,}990.81)$$

$$= 0.0403 + 0.0090 = 0.0493$$

Step 5 - Calculate bounds on error of estimation

$$B = 1.96\sqrt{\hat{V}(\bar{\mu})} = 1.96\sqrt{0.0493} = 0.435$$

Step 6 - Calculate the 95 percent confidence interval for the population mean (μ) for pool depth, which is:

Lower limit: 4.599 − 0.435 = 4.164

Upper limit: 4.599 + 0.435 = 5.034

Monitoring

The purpose of monitoring is to obtain information for use in evaluating responses of land management practices. Specific steps (fig. 2) must be followed if meaningful results are to be obtained from a monitoring study. Step 1 is the documentation of baseline condition, management potential, and problems attributed to the mix of land use practices adversely affecting a riparian area. Management potential is the level of riparian habitat quality that could be achieved through application of improved management. Potential will vary between sites because of several variables, including rainfall patterns, landform, and history of use. If potential is evaluated to be higher than the response capability of a site, and an objective is made to achieve better conditions than are possible, a management failure will obviously occur. This emphasizes the importance of developing objectives that are compatible with site potential.

Documentation of problems from all land use practices that affect a site requires a thorough analysis. For example, if the objective is to improve habitat to increase numbers of trout, it is possible that complex problems (fig. 3) must be solved or controlled before trout will benefit.

Before completing the objectives for riparian habitat management (step 2, fig. 2), holistic planning by an interdisciplinary group will be necessary because most sites will be subjected to multiple-use management. Therefore, riparian habitat objectives will have to be compatible with those of the overall multiple-use plan. If dominant-use management is to be applied to solely benefit a riparian area, it is advisable to involve individuals in other disciplines to assess potential for response to management. Depending on site-specific problems, the disciplines could include hydrology, plant ecology, and perhaps engineering if structural physical changes (such as rechannelization or installation of stream improvement devices) are considered. When objectives are specified, they must be stated in quantifiable and measurable terms; this is of paramount importance. An example of an objective could be to increase the density of shrubs from 25 to 50 percent. This specifically requires that existing conditions be documented for comparison with future management results.

The design of site-specific management plans for achieving riparian area objectives (step 3, fig. 2) requires multiple-use planning and conflict resolution. For example, suppose that timber harvesting, recreation, and mining are contributing to a degraded riparian habitat. It will be difficult, if not impossible, to design a management plan strictly for application in the area to solve problems caused by outside influences. Key considerations (Armour and others 1983) for a properly designed monitoring program (step 4, fig. 2) include the following:

1. Measurement of response to management is possible to determine through hypothesis testing if objectives are met. This prerequisite depends upon a clearly stated hypothesis (for example, H_o: shrub density increased 100 percent vs. H_a: shrub density increased <100 percent) that tracks with a management objective, and the variable must be responsive to management that will be applied. Additionally, measurement of the response with appropriate accuracy and precision must be feasible. Designation of variables that are difficult to measure and ones for which good measurement techniques have not been perfected should be avoided.

2. Control areas that will not receive management treatments must be included in the study. One precaution that must be taken in selecting control and treatment sites is that they must have the same premanagement characteristics and the same potential for response to management. This precaution is necessary if changes attributable to management are to be detectable. For example, if the objective is to improve overhanging streamside cover by 50 percent in a meadow, a control must be established in a similar meadow, not in an area with different landform features and response capabilities. The recommended approach for selecting control and treatment sites for comparison is to make the selections randomly in areas with similar premanagement conditions.

3. Resources must be available for monitoring through an adequate period to permit management responses to occur. This requirement is frequently neglected. If it is uncertain whether a monitoring program can be completed with adherence to the plan, the program should not be initiated.

4. Management must be consistent with the original plan throughout the study. Noncompliance with this condition is one of the most common problems thwarting studies. The problem occurs when changes are made in management, preventing accurate interpretations of data. An example of the problem could be when the establishment of easier access by fishermen to study sites in a stream has resulted in depletion of fish in treatment and control sites, masking influences of improved habitat conditions. Another example that happens frequently is the trespass of livestock and subsequent overgrazing and habitat change in control sites.

5. Confounding factors that can adversely affect the study must be controlled. These factors are defined as unplanned events or influences that adversely affect results of a study. Factors in this category include institutional influences (such as when an agency changes emphasis away from monitoring and a study is stopped), political pressures (such as when a user group uses influence to stop a study because potential results are disliked), equipment failure problems, changes in personnel conducting the study and inability to find suitable replacements, and biological effects (such as when natural variation is excessive in time and space, and responses to management are masked). Although it is impossible to guarantee that confounding problems will not occur, individuals involved with monitoring should consider them in advance to eliminate as many as possible.

6. Statistical tests to analyze information are designated when the monitoring program is designed and assumptions for proper use of the tests are met. Unfortunately, there has been a tendency for the advance consideration of statistical tests to be neglected, resulting in the collection of data and the expectation that a statistician "can make something out of it" after completion of field work. When this happens, the result is usually a disappointing conclusion that the study was useless. To prevent problems, individuals involved with designing monitoring programs should always obtain assistance from a statistician during the design phase. This will help avoid serious problems that cannot be corrected. Essentially the pilot study (step 5, fig. 2) for a monitoring project is conducted for the same reasons discussed for step 3, fig. 1. To help ensure that meaningful statistical tests are feasible,

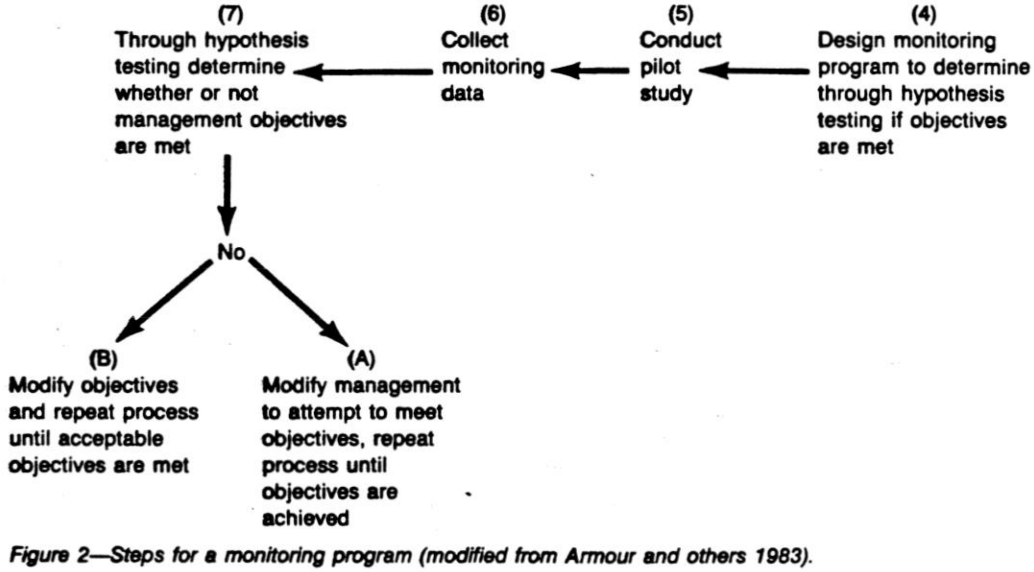


Figure 2—Steps for a monitoring program (modified from Armour and others 1983).

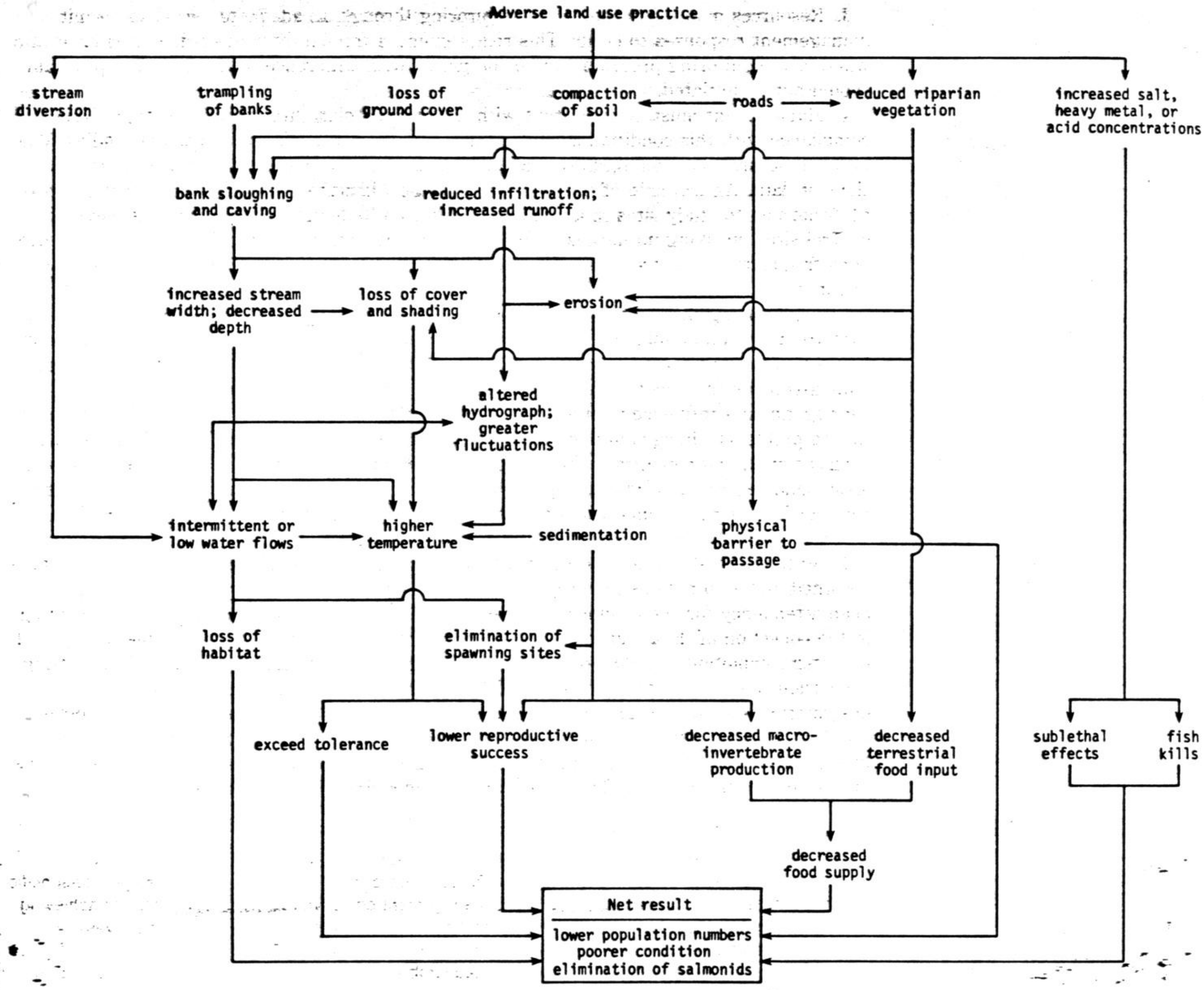


Figure 3—Some cause, effect, and impact relationships of adverse land use practices on salmonids (from Armour and others 1983).

assistance should be obtained from a statistician for this phase to refine approaches for the study. Once the pilot study is completed, assuming that appropriate premanagement data for control and treatment sites have been collected, management can be applied and monitoring (step 6, fig. 2) can proceed with strict adherence to the design specifications. If appropriate premanagement data have not been collected, this requirement must be fulfilled before management is applied. Failure to obtain data from preconditions and postconditions will preclude evaluation if management resulted in the achievement of stipulated objectives. Special considerations for step 6 must include: (1) maintenance of accuracy and precision in collecting data, (2) the expending of equal levels of effort and adherence to the same technical standards in control and treatment sites to prevent bias from influencing results of the study, and (3) the recording and processing of data suitable for retrieval and use in statistical analyses.

Statistical tests are used in step 7 to evaluate with a predetermined level of statistical confidence whether objectives were met. This level might not have to be as high (say, 95 or 99 percent) as would be expected for research, but the price for a lower level is an increased chance for a type I error (claiming a difference when it does not exist). When tests are performed, the determined confidence level must not be arbitrarily altered (say, from 95 to 85 percent) if results do not conform with preconceived perceptions.

Common errors to avoid when using statistical tests include inaccurate data entry, errors in rounding numbers, use of incorrect degrees of freedom, and incorrectly reading statistical tables (such as tables of t and F values).

Based on results of hypothesis testing, it is possible to conclude with a stipulated level of statistical confidence whether objectives are met. If they are not met, there are two options: modify objectives and repeat the process in figure 2 until they are eventually met, or modify management and repeat the process until success is achieved.

One concept that must be emphasized is that monitoring should not result in a strict "pass" or "fail" conclusion. There cannot be a failure if, in the future, negative results contribute to avoidance of management practices that do not work. Therefore, it is equally important to document unsuitable practices to avoid if the art of riparian resource management is to progress.

MEASURING VEGETATION

Vegetation in the riparian ecosystem includes vegetation on a streambank and on a flood plain that has some control over streamside conditions. Riparian vegetation helps to stabilize the streambanks, control nutrient cycling, reduce water velocity, provide cover and food for fish, and intercept and store energy from solar radiation. Riparian vegetation controlling the sunlight reaching the stream limits the energy base for photosynthesis.

Vegetative Use by Animals

We have successfully evaluated this variable on streambanks using channel cross sections (transects) placed perpendicular to streamflow (Platts and others 1983). Vegetative use under a transect line and within 5 ft of the shoreline or to the top of the streambank, whichever is larger, can be rated visually. This use evaluation includes vegetation disturbed (grazed and trampled) during the present growing season, and potential plant growth that does not exist because of past disturbance of vegetation. An example of loss because of use would be in areas where vegetation no longer exists because the streambank was dredged or trampled, or where vegetation was eliminated on a major cattle crossing. The rating, however, applies mainly to recent vegetative use. If use is determined on only one occasion or only once a year, it should be done as soon as possible after harvesting ceases and before plant regrowth can occur.

The vegetative use rating (this mainly applies to herbaceous vegetation) is stratified into four classes:

Rating (percent)	Description
0 to 25—light	Vegetative use is light or nonexistent. Almost all the potential plant biomass at present stage of development remains. The vegetative cover is close to that which would occur naturally without use. If bare areas exist (such as bedrock) they are not a result of loss of vegetation from land uses.
26 to 50—moderate	Vegetative use is moderate and at least half of the potential plant biomass remains. Average plant stubble height is greater than half of its potential height at its present stage of development. Plant biomass no longer on site because of past grazing is considered as vegetation that has been used.
51 to 75—high	Vegetative use is high and less than half of the potential plant biomass remains. Plant stubble height is usually over 2 inches (on many ranges). Plant biomass no longer on site because of past grazing is considered as vegetation that has been used.
76 to 100—extreme	Use of the streamside vegetation is high and only short stubble remains (usually less than 2 inches on many ranges). Almost all the potential vegetative biomass has been used. Only the root system and part of the stem remain. The potential plant biomass that no longer exists because of use is considered as vegetation that has been used.

Once the observer has decided the class (light to extreme), then the actual percentage of use is determined. For example, if the vegetation (grasses and forbs) has been reduced to less than a quarter of potential (usually 2 inches stubble standing height on many ranges), the class rating is between 76 and 100 percent. If the vegetation is removed to almost ground level, the final intraclass rating would be 100 percent. If the vegetation is slightly less than a quarter (usually less than 2 inches stubble height) of its potential and there are no areas without vegetation from vegetative use, then the intraclass rating would be about 76 percent.

Table 2—Comparison of streamside herbage use using the visual method versus the electronic herbage meter

	1979			1980		
Study area	Meter	Visual	Δ%	Meter	Visual	Δ%
Idaho (10 streams)	45	44	1	58	60	2
Nevada (2 streams)	81	68	13	63	57	6
Utah (1 stream)	84	76	8	104	87	17

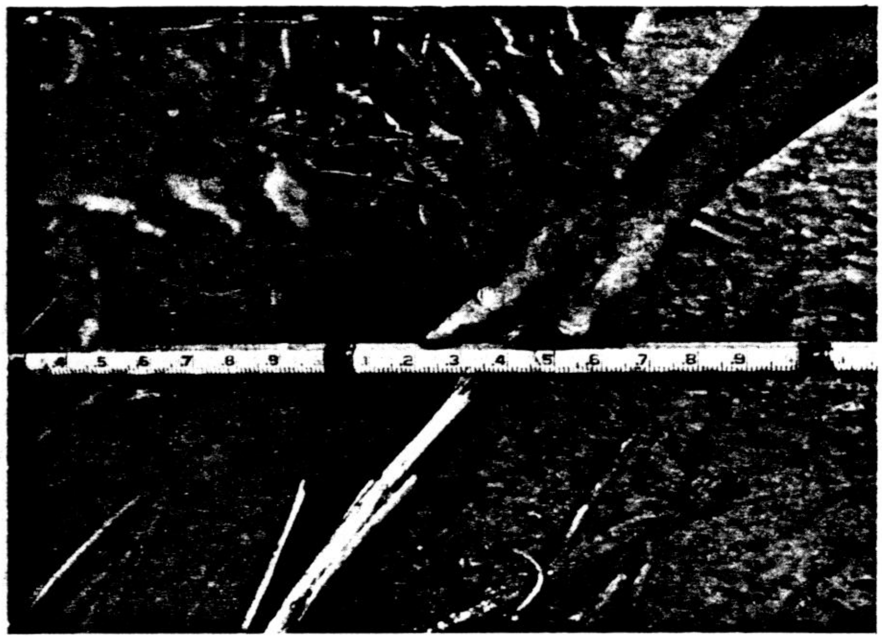


Figure 4—Measuring overhanging streamside vegetation.

In our studies, the 95 percent confidence intervals about the means (±12 percent) are high but still within acceptable limits for most streams studied (appendix 2). Precision and accuracy are good. The observer should be well trained and have ungrazed plots (utilization cages) for constant comparison. Our visual estimates of vegetative use were on average quite close to use estimates obtained with actual measurements using the electronic capacitance herbage meter (table 2).

Vegetative Overhang

Vegetative overhang indirectly provides fish food, directly provides cover, and shades the water from solar radiation (fig. 4). Overhang is a valuable variable to use when evaluating land use effects, such as livestock grazing, logging, and road construction, that have altered or could alter the riparian habitat. Vegetative overhang rates only that vegetation overhanging the water column. This is a direct measurement to the nearest 0.1 ft of the vegetation (excluding tree trunks or downed logs) within 12 inches (vertical) of the water surface and overhanging the water column (fig. 5). That part of the canopy higher than 12 inches enters the evaluation through the canopy closure and density and solar integrator methods. The vegetative overhang is measured along a transect line, beginning at the farthest protrusion of the streambank over the water surface, to the farthest point that vegetation covers the water column. This measurement does not include the undercut. Therefore, bank undercut and vegetative overhang combined give the total immediate overhead cover, excluding other types of cover (such as water surface turbulence).

In our studies the 95 percent confidence intervals around the overhang means (±15.7 percent) are fairly wide, but year-to-year precision and accuracy rate fair (appendix 2).

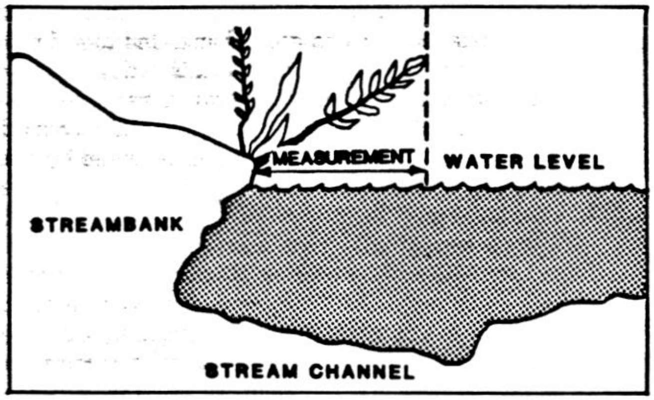


Figure 5—Measurement of overhanging vegetation.

Table 3—Streambank stability rating

Rating		Description
Units	*Percent*	
4	75-100	Over 75 percent of the streambank surface is covered by vegetation in vigorous condition or by boulders and rubble. If the streambank is not covered by vegetation, it is protected by materials that do not allow bank erosion.
3	50-74	Between 50 and 74 percent of the streambank surface is covered by vegetation or by gravel or larger material. Those areas not covered by vegetation are protected by materials that allow only minor erosion.
2	25-49	Between 25 and 49 percent of the streambank surface is covered by vegetation or by gravel or larger material. The area not covered by vegetation is covered by materials that give limited protection.
1	0-24	Less than 25 percent of the streambank surface is covered by vegetation or by gravel or larger material. That area not covered by vegetation provides little or no control over erosion and the banks are usually eroded each year by high water flows.

Streambank Stability

The ability of vegetation and other materials on the streambank to resist soil and vegetative erosion from flowing water and ice is rated in table 3. This rating relates primarily to stability generated by vegetative cover, except in those cases where bedrock, boulder, or rubble stabilizes the streambanks. The rating takes all these sources of protective cover into account and is rated in four classes. Once the class has been determined, the observer decides the actual percentage. The rated portion of the bank or flood plain includes only that area intercepted by the transect line within 5 ft of the stream or to the top of the bank, whichever is the larger. Surprisingly, the confidence intervals around the means (units) from our study sites are quite low (about ± 3 percent). However, year-to-year precision and accuracy rated only fair (appendix 2). Therefore, the user should be cautious in its use.

Streamside Cover

This rating only provides gross evaluation. The measurement is used to evaluate major vegetative type conversions or for information for aquatic classification. For more refined evaluation, the riparian habitat community typing described later has more potential value.

The cover rating considers all material (organic and inorganic) on or above the streambank that offers stream shading and protection from soil erosion and provides escape cover or resting security for fish.

Rating	Description
5	Shrubs are the dominant streamside vegetation.
4	Tree forms are the dominant streamside vegetation.
3	Grass forms are the dominant streamside vegetation.
2	Forbs are the dominant streamside vegetation.
1	Over 50 percent of the streambank transect line intercept has no vegetation and the dominant bank material is made up of such materials as soil, rock, bridge materials, road materials, culverts, and mine tailings.

The only area of streambank rated is that intercepted by the transect line that covers the exposed streambottom, bank, and top of bank.

Initially in determining this rating, all vegetation along the stream that would reach the stream (if it were laid down toward the stream) was used in the analysis. This procedure caused high observer variation and increased confidence intervals. Therefore, we revised it to include only that cover intercepted by the transect line. This decreased the observer error and confidence intervals. The higher level offsite vegetation, not considered in this rating, is accounted for by the canopy closure, density, and solar integrator and shade methods.

The cover rating is effective in evaluating the effects of such activities as channelization, logging, or cattle grazing on riparian habitat. This measurement in our studies had low confidence intervals about the mean (±4.1 percent) mainly because dominant cover tends to be uniform and observers evaluate the same conditions alike even though they may not rate it correctly. Year-to-year precision and accuracy were poor and demonstrate that special emphasis must be placed on attaining accuracy when using this measurement.

Electronic Forage Analysis

Because grazed rangelands frequently cover large areas of land surface, determination of forage production and use by grazing animals must be based on estimation. Estimates are presently obtained through a variety of techniques that not only vary between land management agencies but can also vary between individuals within the same agency. For example, the USDA Forest Service Range Environmental Analysis Handbook, Rocky Mountain Region (1973) describes three methods for estimating forage production based on total plant production, whereas the USDA Soil Conservation Service National Range Handbook (1979) describes five techniques that may be used in combination for estimating livestock use of key forage species in key areas. This inconsistency leads to difficulties in comparing range management information and can cause breakdown in effective communication between research and management personnel.

Such problems become even more acute in evaluating the effects of range management practices on riparian ecosystems. The National Range Handbook even states that "small areas of natural concentration [of livestock], such as those adjacent to water, salt, or shade, are not key grazing areas"; therefore, riparian areas may unconsciously not receive adequate attention in range analyses. On the other hand, the USDA Forest Service Range Analysis Handbook, Intermountain Region (USDA Forest Service 1983), provides clear-cut guidelines for determining the extent of riparian ecosystems and mentions the need for interaction between grazing needs and those of other resource uses, such as fisheries. Those involved in research and management of fisheries resources in the area of overlap between range and fisheries ecology are confronted with some difficulty in determining and applying forage evaluation techniques and relating them back to fishery concerns in diverse geographical settings. Consequently, much needs to be done to standardize herbage evaluation procedures and to promote communication between interacting agencies.

One way to bridge this gap is by adapting the use of electronic capacitance herbage meters to riparian-fishery habitat evaluations. These meters provide for rapid, accurate estimation of standing herbage biomass (phytomass) with low costs in human labor and allow nondestructive analysis of the vegetation sampled. Because capacitance is directly related to vegetative weight, it is a simple matter to estimate phytomass over relatively large areas by double sampling (Cochran 1963). The use of the herbage meter represents a substantial step forward in the standardization of objective and integrated range and riparian-fishery habitat evaluation techniques.

Instrument Design and Limitations—The principle behind electronic capacitance metering of vegetation (Neal and Neal 1973) is based on the high dielectric constant of moisture contained in the vegetation relative to the low dielectric constant of the meter's sensing unit. Two parallel oscillators are initially set to the same frequency relative to a no-yield (zero vegetative weight) reference. When vegetation is subsequently introduced to the meter's sensing field, one oscillator is shifted in frequency by an amount proportional to the weight of the vegetation. The meter displays this frequency shift as a dimensionless number that is used to determine corresponding vegetative weights through regression analysis. It is therefore necessary to keep extraneous electrical conductors (such as basalt rocks or metal stakes) away from the meter when measurements are being taken.

The Neal Electronics models 18-2000 and 18-3000 are similar but slightly different in use. The 18-2000 must be "tuned" with respect to its coarse frequency oscillation each season, and zeroed to no-yield (vegetation absent) by mechanical fine frequency adjustment before each use and at least once during use. The 18-3000 needs only to be switched into "calibration" mode and a reading taken in a no-yield situation to set its oscillators. Both should be reset to zero during sampling if the ambient temperature changes by 10 °F or more. Readings are easily obtained by pushing the "read" button and stepping back to avoid influencing the measurement.

Each of the two meters is approximately 1 ft wide by 1.9 ft long by 2.1 ft high, and rectangular. And at a weight of 23 lb, neither is too heavy to be carried over even terrain for several hours. However, the size and shape of the meters do lead to some difficulties on the uneven terrain associated with riparian areas. Care must be taken to avoid damaging a machine by striking it against any solid objects. This requires periods of carrying it one-handed or overhead, considerably increasing the risk of stumbling and consequent injury to the worker. The wide, four-legged stance of each instrument also makes it prone to toppling over on uneven terrain, but this can be alleviated by holding it securely with a rope of nonconductive material attached to the instrument's carrying handle. Both models have proven to be reasonably durable under conditions normally encountered in riparian areas.

Capacitance measurements can be taken with the machine at any angle, but the user must remain clear of the sensing field during measurement. Vegetation that fits easily within the meter's probe array is most conveniently measured, but taller vegetation can be measured by folding upper projections into the probe array. Care should be taken to include only vegetation that is taller in this manner, and to not include vegetation that extends laterally out of the meter's field.

Field Methods—Streamside herbage data are quickly and easily collected, and little training of field personnel is required. To set up a study or monitoring program with the herbage meter, the first step is to select the sites to be compared. These may consist of sites for which standing phytomass in each are to be compared directly, paired sites in which one is ungrazed to determine potential production for comparison with a similar but grazed site for estimating harvest by livestock, a grazed site used in conjunction with ungrazed utilization cages in which potential production can be estimated, or a streambank pasture where increases in productivity resulting from rehabilitative plantings need to be monitored. Whatever the combination of study sites selected, two sets of data must be collected: a large primary data set, which is measured by the meter for capacitance only, and a smaller secondary data set that is both metered and clipped and weighed to determine the regression relationship of vegetative weights on capacitance readings. The secondary sample can be either a subsample of the primary data set, or an independent sample of vegetation like that of the primary set, depending on whether nondestructive sampling of the primary sample is required.

The size of the primary data set is left to the investigator. Back and others (1968) suggest that little is gained by exceeding 25 meter readings in a site, and that the advantages gained by this estimation technique fall off rapidly as more sample plots are included. The heterogeneity of riparian vegetation requires somewhat greater thoroughness in sampling to adequately determine the productivity of the study site. If plots are to be resampled at a later date (an advantage of the nondestructive technique), their location should be referenced to a permanent marker. Metal stakes can be used for this purpose if located far enough from the plot to avoid interfering with the meter's sensing field. Plastic stakes avoid this problem. If riparian or stream cross-section markers are used, the coordinates of permanent sample plots can be easily established by aligning the center line of the long axis of the meter along the transect line. The location can be permanently referenced by designating a distance away from the stake and the stream with a negative (−) sign and between the stake and the stream with a positive (+) sign (fig. 6). Capacitance of the plot is determined by taking the average of three readings, or by taking only two readings if the same meter reading occurs twice. No extraneous conductive material, especially the investigator's body, should be within 2 ft of the machine during measurement. Enough time elapses after pushing the "read" button before actual measuring begins for the investigator to step back.

The secondary data set can be a subsample of the primary set, or an independent set. In the former case, if selection of secondary plots is accomplished randomly or systematically, the vegetation sampled in the secondary sample will be representative of that in the primary sample. If the secondary data set is an independent sample, care must be taken to assure that it is representative of the vegetation in the primary samples (Reese and others 1980). One way to assure similarity is to ensure that the proportions of shrub and grass (or forb) are similar in each sample and that distances from water are similar; a software package described later is designed to simultaneously conduct these analyses when such

Figure 6—Coordinates of permanent sample plots can be established using cross-section markers.

field data are collected. Similarity cannot be accomplished by similarity of meter readings, because an artificially wide range of meter readings and weights should be obtained to establish an adequate regression relationship (Cochran 1963), and because capacitance for unlike vegetation may be similar but weights may vary. There should be at least one secondary sample plot for every five primary plots (Currie and others 1973; Neal and others 1976), though we recommend a ratio of 1:4 to help ensure development of an adequate regression relationship in the heterogeneous riparian area.

Vegetation within the sensing field of the meter is marked off by positioning a 1- by 2-ft frame around the sampled plot, being careful to remove tall vegetation that extends beyond the meter's field, clipped according to the three-dimensional technique of Currie and others (1973) and weighed in either grams or ounces. Because annual forage production is of principal concern, grasses and forbs within the frame are clipped on a plane (ignoring ground contour) to a 0.5-inch stubble height; litter should be ignored. For shrubby species, only new growth should be removed and included in the weighed sample, because dead wood in the sample plot has little capacitance and would only distort the regression relationship if weighed (Carpenter and others 1973). We have used chiefly fresh vegetative weights, determined concurrently with clipping, in our studies, but dry weights may also be used. Vegetative samples may be ovendried at 140-158 °F until stable weights are obtained (Chambers and Brown 1983).

Auxiliary Habitat Variables—Several auxiliary riparian habitat variables, which were briefly mentioned previously, are also routinely collected. These variables provide additional information about the character of the vegetation being sampled and allow instantaneous comparison of site-specific (primary) and calibration (secondary) samples. The variables also provide evaluations of trends within sites over time. The variables are measured concurrently with the taking of capacitance readings and include coverage, vegetative composition, and shortest distance to stream.

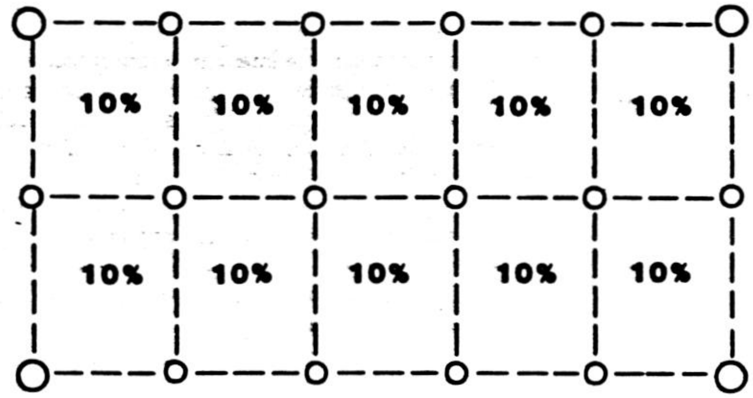


Figure 7—Herbage meter 10 percent surface area plots.

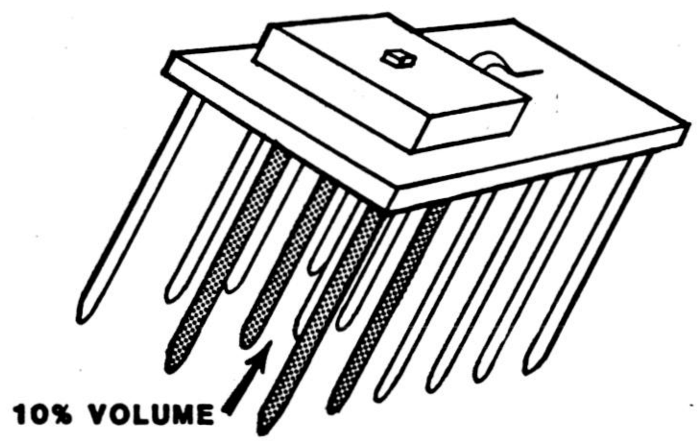


Figure 8—Example of rectangular volumes.

Cover—This is a measure of the actual proportion within an individual sample plot that is covered or not covered by actively growing vegetation. This is a surface area measurement and is visually estimated within the meter's probe array. The probes of the herbage meter form squares, each defining approximately 10 percent of the sample plot (fig. 7). Using these 10 microplots as guides, the percentage of covered and exposed ground within the sample plot can be estimated. When averaged over the entire sample, the percentages of covered and exposed ground within each study site can be estimated.

Species Composition—This measurement evaluates the relative amounts of shrubby and herbaceous species. By imagining individual rectangular volumes for each of the spaces defined by the probes (fig. 8), the volumetric proportion, which totals 100 percent, that each type of vegetation contributes to the biomass of the sample plot can be estimated. This procedure is analogous to separating each sample to life form and determining the contribution of each. It is a somewhat unconventional approach, but is suggested by the "harvest method" of production analysis suggested by Chambers and Brown (1983).

Distance to Stream—Unlike the other measurements described, this variable was not included to provide a precise description of the study plot. The shortest distance from the meter to permanent water derived from the stream is measured to the nearest 0.1 ft, usually from a center probe of one of the meter's faces. Occasionally, however, measuring from a center probe is unrealistic compared to measuring from a corner probe; in such cases, a corner probe may be used. While not intended to be a precisely measured factor, this variable does allow a gross evaluation of the average location of sample plots in each site and in the calibration sample with respect to the nearest stream-derived water. It will also allow some early indications of streambank erosion. A sample field data form of the type we use is shown in appendix 3.

Regression Analyses—Regression analyses with capacitance meters have traditionally been conducted using a linear regression model, and good results have been obtained on planted ranges (Currie and others 1973), native herbaceous vegetation (Neal and others 1976), native shrub ranges (Morris and others 1976), and riparian vegetation (Platts and Nelson 1983). Although linear regression analysis generally provides adequate biomass estimation, it has been suggested that logarithmic transformation of the explanatory variable (X) and response variable (Y) may provide increased precision in some situations (Terry and others 1981), though care in selecting the model of choice is necessary (Nelson and others in press). (These variables have been traditionally referred to as the independent and dependent variables, respectively; the more modern terminology is used here.)

The mathematics of these two models are similar, the former linear on arithmetic graph paper and the latter linear on double-logarithmic graph paper. A computer program has been developed to calculate the regression relationships and estimate both phytomass (yield) and differences in phytomass (yield differential), expressed as a percentage, between study pastures (see appendix 4). It was developed on a Hewlett-Packard 9845T microcomputer and allows data to be entered from a mass storage device (diskette or tape cartridge), performs all double sampling computations for biomass and use estimation from either a linear or logarithmic regression model, and runs basic statistical analyses on up to eight auxiliary habitat variables (see appendix 4). Deciding which model better describes the data is left to the judgment of the individual investigator.

Linear Regression—Linear regression conforms to the general model:

$$\mu = \alpha + \beta X + \varepsilon \tag{1}$$

estimated by the regression equation:

$$\hat{Y} = a + bX \tag{2}$$

where μ is the true mean vegetative weight at meter reading X, which is estimated by $\hat{Y}$, α and β are regression coefficients estimated by a and b respectively, and ε is random error in weights. The coefficient a is the Y-axis intercept, and b describes the average change in weight for a respective change in meter reading. $\hat{Y}$ can be used to estimate either individual vegetative weights for metered plots, or to estimate mean vegetative weights for study sites from mean meter readings. Use of the linear model assumes that vegetative weights are distributed normally with mean μ and variance σ^2 over the range of meter readings.

Initial calculations to fit the model proceed as follows:

$$n_1 = \text{secondary sample size} \tag{3}$$

$$\bar{X}_s = \frac{\sum_{i=1}^{n_1} X_{si}}{n-1}$$

$$= \text{average of the meter readings from the secondary sample} \tag{4}$$

$$\bar{Y}_s = \frac{\sum_{i=1}^{n_1} Y_{si}}{n-1}$$

$$= \text{average of the vegetative weights in the secondary sample} \tag{5}$$

$$\text{SS}(X) = \sum_{i=1}^{n_1} (X_{si} - \bar{X}_s)^2 = \sum_{i=1}^{n_1} X_{si}^2 - \frac{(\sum_{i=1}^{n_1} X_{si})^2}{n_1}$$

$$= \text{sum of squares of deviations of meter readings} \tag{6}$$

$$\text{SS}(Y) = \sum_{i=1}^{n_1} (Y_{si} - \bar{Y}_s)^2 = \sum_{i=1}^{n_1} Y_{si}^2 - \frac{(\sum_{i=1}^{n_1} Y_{si})^2}{n_1}$$

$$= \text{sum of squares of deviations of vegetative weights} \tag{7}$$

$$S(XY) = \sum_{i=1}^{n_1} (X_{si} - \bar{X}_s)(Y_{si} - \bar{Y}_s)$$

$$= \sum_{i=1}^{n_1} (X_{si} Y_{si}) - \frac{[(\sum_{i=1}^{n_1} X_{si})(\sum_{i=1}^{n_1} Y_{si})]}{n_1}$$

$$= \text{sum of cross products} \tag{8}$$

where the subscript s_i denotes the ith value from the secondary sample, X denotes meter readings, Y denotes vegetative weights, and $\sum_{i=1}^{n_1}$ indicates summation of i values of a variable over the range 1 to n_1.

The relevant regression coefficients and comparative statistics are then calculated as follows:

$$b = S(XY)/SS(X) = \text{regression coefficient} \tag{9}$$

$$a = \bar{Y}_s - b\bar{X}_s = Y\text{-axis intercept or constant} \tag{10}$$

$$SE(YX) = \sqrt{\frac{[SS(Y) - S(XY)^2/SS(X)]}{n_1 - 2}}$$

$$= \text{standard error of estimate} \tag{11}$$

$$r^2 = \frac{[S(XY)^2/SS(X)]}{SS(Y)}$$

$$= \text{coefficient of determination} \tag{12}$$

$$C = S(XY)/n_1 - 1 = \text{covariance}$$

$$SE(\hat{Y}) = SD(YX)\sqrt{(1/n_1) + \frac{(X - \bar{X}_s)^2}{SS(X)}}$$

$$= \text{standard error of } \hat{Y} \tag{13}$$

Confidence intervals can be determined for the estimated vegetation weight by:

$$\hat{Y} - t\,SE(\hat{Y}) < \mu < \hat{Y} + t\,SE(\hat{Y}) \tag{14}$$

where μ is the true mean vegetative weight corresponding to the selected meter reading and t is Student's t for the desired probability level with $n_1 - 2$ degrees of freedom (see appendix 1).

For example, suppose we had a secondary data set with the values of meter readings (X_{si}) and vegetative weights (Y_{si}) as shown in table 4. Note that two zero values representing setting the machine to no yield must be included in the linear regression analysis. Then:

$$n = 7$$

$$\bar{X}_s = \frac{83}{7} = 11.9$$

$$\bar{Y}_s = \frac{176}{7} = 25.1$$

$$SS(X_s) = 1{,}703 - \frac{(83)^2}{7} = 718.9$$

$$SS(Y_s) = 8{,}614 - \frac{(176)^2}{7} = 4{,}188.9$$

$$S(XY) = 3{,}759 - \frac{[(83)(176)]}{7} = 1{,}672.1$$

Table 4—Hypothetical secondary meter readings (X_{si}) and vegetative weights (Y_{si}) with corresponding squares, cross products, and sums

	Secondary data		Squares and cross products		
	X_{si}	Y_{si}	X_{si}^2	Y_{si}^2	$X_{si}Y_{si}$
	0	0	0	0	0
	0	0	0	0	0
	17	22	289	484	374
	28	70	784	4,900	1,960
	5	10	25	100	50
	11	23	121	529	253
	22	51	484	2,601	1,122
Totals ($\sum_{i=1}^{n}$)	83	176	1,703	8,614	3,759

and

$$b = \frac{1{,}672.1}{718.9} = 2.3$$

$$a = 25.1 - (2.3)(11.9) = -2.3$$

$$\hat{Y} = -2.3 + 2.3\,x$$

$$SE(YX) = \sqrt{\frac{4{,}188.9 - [(1{,}672.1)^2/718.9]}{5}} = 7.7$$

$$r^2 = \frac{[(1{,}672.1)^2/718.9]}{4{,}188.9} = 0.93$$

$$C = 1{,}672.1/6 = 278.7$$

Consequently, for a hypothetical meter reading of 12:

$$\hat{Y} = 25.3$$

$$SE(\hat{Y}) = (7.7)\sqrt{(1/7) + \frac{(0.1)^2}{718.9}} = 2.9$$

and 95 percent confidence interval:

$$25.3 - (2.571)(2.9) < \mu < 25.3 + (2.571)(2.9)$$

or 15.2 ± 7.5

with $n-2 = 5$ degrees of freedom. These confidence limits are rather wide but should be expected to decrease with larger sample sizes or with a reduction in SE(YX), or with both. This procedure applies only to estimates of weight from individual meter readings, which are assumed to be free of sampling error. Estimation from mean meter readings is addressed later.

Logarithmic Regression—Logarithmic regression is performed similarly following transformation of the variables. Logarithms to any base may be used, but we will restrict ourselves here to natural (base e) logarithms. It is important to eliminate the two zero points from this analysis because the logarithm of 0 does not exist and the curve automatically originates at the origin. Logarithmic regression conforms to the general model:

$$\ln\mu = \alpha_1 + \beta\ln X + \ln\varepsilon \qquad (15)$$

or the mathematically identical definition:

$$\mu = \alpha_2 X^{\beta}\varepsilon \qquad (16)$$

estimated by the regression equations:

$$\ln\hat{Y} = a_1 + b\ln X \qquad (17)$$

or

$$\hat{Y} = a_2 X^{b} \qquad (18)$$

respectively, where μ is true mean vegetative weight at meter reading X, which is estimated by $\hat{Y}$; α_1, α_2, and β are regression coefficients estimated by a_1, a_2, and b_1, respectively; $\alpha_1 = \ln\alpha_2$, $a_1 = \ln a_2$; and ε is random error in weights. $\hat{Y}$ can be used to estimate individual vegetative weights for a given meter reading, or it can estimate mean vegetative weight from mean meter readings; in the latter case, knowledge of ε is sacrificed. Use of this model assumes that data are distributed normally after transformation, with mean μ and variance σ^2 over the range of meter readings.

Initial calculations for fitting logarithmic regression involve transforming the secondary data values to natural logarithms and calculating as for the linear model:

n_2 = secondary sample size less the two zero values (19)

$$\overline{\ln X_s} = \frac{\sum_{i=1}^{n_2} \ln X_{si}}{n_2}$$

= average of the natural logarithms of the secondary meter readings (20)

$$\overline{\ln Y_s} = \frac{\sum_{i=1}^{n_2} \ln Y_{si}}{n_2}$$

= average of the natural logarithms of secondary vegetative weights (21)

$$\mathrm{SS}(\ln X) = \sum_{i=1}^{n_2} (\ln X_{si} - \overline{\ln X_s})^2$$

$$= \sum_{i=1}^{n_2} \ln X_{si}^2 - \frac{(\sum_{i=1}^{n_2} \ln X_{si})^2}{n_2}$$

= sum of squares of deviations of natural logarithms of meter readings (22)

$$\mathrm{SS}(\ln Y) = \sum_{i=1}^{n_2} (\ln Y_{si} - \overline{\ln Y_s})^2$$

$$= \sum_{i=1}^{n_2} \ln Y_{si}^2 - \frac{(\sum_{i=1}^{n_2} Y_{si})^2}{n_2}$$

= sum of squares of deviations of natural logarithms of vegetative weights (23)

$$\mathrm{S}(\ln X \ln Y) = \sum_{i=1}^{n_2} (\ln X_{si} - \overline{\ln X_s})(\ln Y_{si} - \overline{\ln Y_s})$$

$$= \sum_{i=1}^{n_2} (\ln X_{si})(\ln Y_{si}) - \frac{[(\sum_{i=1}^{n_2} \ln X_{si})(\sum_{i=1}^{n_2} \ln Y_{si})]}{n_2}$$

= sum of cross products (24)

where the subscript si denotes the ith value from the secondary sample, $\ln X$ indicates natural logarithms of meter readings, $\ln Y$ indicates natural logarithms of vegetative weights, and $\sum_{i=1}^{n_2}$ summation of i values of a variable over the range 1 to n_2.

The relevant regression coefficients and comparative statistics are then calculated as in the linear model:

$$b = \frac{\mathrm{S}(\ln X \ln Y)}{\mathrm{SS}(\ln X)} = \text{regression coefficient} \quad (25)$$

$$a_1 = \overline{\ln Y_s} - b\overline{\ln X_s} = \ln a_2 = \text{constant} \quad (26)$$

$$\mathrm{SE}(\ln YX) = \sqrt{\frac{[\mathrm{SS}(\ln Y) - [\mathrm{S}(\ln X \ln Y)^2/\mathrm{SS}(\ln X)]}{n_2-2}}$$

$$= \text{standard error of estimate (residual error)} \quad (27)$$

$$r^2 = \frac{[S(\ln X \ln Y)^2/SS(\ln X)]}{SS(\ln Y)}$$

$$= \text{coefficient of determination} \quad (28)$$

$$C = S(\ln X \ln Y)/n_2 - 1 = \text{covariance}$$

Confidence intervals can be computed for estimated natural logarithms of weights using:

$$SE(\ln\hat{Y}) = SS(\ln YX) \sqrt{(1/n_2) + \frac{(\ln X - \overline{\ln X})}{SS(\ln X)}}$$

$$= \text{standard error of } \ln\hat{Y} \quad (29)$$

Because the logarithms of vegetative weights and meter readings are meaningless in a practical sense, it is necessary to convert to arithmetic units. Because the linear model assumes normality of distribution of weights, whereas the logarithmic model assumes a lognormal distribution, it is necessary to apply a conversion factor when converting from logarithmic to arithmetic units with the following manipulations (Baskerville 1972):

$$\hat{Y}_a = e^{[\ln\hat{Y} + (SE(\ln\hat{Y})^2/2)]} \quad (30)$$

Confidence intervals obtained with the logarithmic model are necessarily asymmetric after retransformation to arithmetic units; consequently, they must be determined using Student's t at the desired probability level for $\ln\hat{Y}$ before retransformation:

$$\ln\hat{Y} - t\,SE(\ln\hat{Y}) < \mu < \ln\hat{Y} - t\,SE\,(\ln\hat{Y}) \quad (31)$$

where

$$\text{Lim}(\hat{Y}) = \ln\hat{Y} \pm SE\,(\ln\hat{Y}) \quad (32)$$

where the subscript a indicates arithmetic units, and raising e to a quantity denotes taking the natural antilogarithm of that quantity. Logarithmic limits are then individually retransformed to arithmetic units by a modification of (30):

$$\text{Lim}_a(\hat{Y}) = e^{[\text{Lim}(\hat{Y}) \pm SE(\ln\hat{Y})^2/2]} \quad (33)$$

thus,

$$\text{Lim}_{al}(\hat{Y}) < \mu_a < \text{Lim}_{au}(\hat{Y}) \quad (34)$$

where the subscripts u and l denote upper and lower limits, respectively, and where μ_a is the true vegetative mean for meter reading X and t is Student's t at any desired probability level with $n_2 - 2$ degrees of freedom.

Coefficients of determination are most frequently used to determine the quality of a regression relationship because they indicate the proportion of the variance in a given response variable that is explained by its regression on a given explanatory variable. Additional information is also obtained from the standard errors of estimate because they are based on deviations of observed values of both variables from their value predicted by the regression relationship (residual error). Consequently, two data sets with similar coefficients of determination may have widely different standard errors of estimate. However, it is difficult to compare standard errors of estimate between linear and logarithmic regression analyses because they do not estimate exactly the same quantity in the two models (coefficients of determination, being dimensionless, can be compared). Fortunately, Furnival (1961) has provided an index of fit called Furnival's index (I) that allows comparison of standard errors of estimate for each model. In the linear model, I and $SE(YX)$ are identical; for the logarithmic model we calculate I as follows:

$$I = SE(\ln YX)\,(e^{\overline{\ln Y}}) \quad (35)$$

Consequently, the smaller the value of I, the better the model fits the secondary data. In addition, when comparing the adequacy of the linear and logarithmic models, the one producing the lower residual error provides the better fit, though it may not explain as much of the variation in the response variable.

Using the hypothetical data from the previous example, table 5 with its transformed data can be constructed. Then:

Table 5—Transformed hypothetical recording meter readings ($\ln X_{si}$) and vegetative weights ($\ln Y_{si}$) with corresponding squares and cross products

	Transformed data		Squares and cross products		
	$\ln X_{si}$	$\ln Y_{si}$	$\ln X_{si}^2$	$\ln Y_{si}^2$	$\ln X_{si} \ln Y_{si}$
	2.83	3.09	8.01	9.55	8.74
	3.33	4.25	11.09	18.06	14.15
	1.61	2.30	2.59	5.29	3.70
	2.40	3.14	5.76	9.86	7.54
	3.09	3.93	9.55	15.44	12.14
Totals ($\sum_{i=1}^{n_2}$)	13.26	16.71	37.00	58.20	46.27

$$n_2 = 5$$

$$\ln X_s = \frac{13.26}{5} = 2.65$$

$$\ln Y_s = 16.71/5 = 3.34$$

$$SS(\ln X) = 37.00 - \frac{(13.26)^2}{5} = 1.83$$

$$SS(\ln Y) = 58.20 - \frac{(16.71)^2}{5} = 2.36$$

$$S(\ln X \ln Y) = 46.27 - \frac{[(13.26)(16.72)]}{5} = 1.96$$

and

$$b = \frac{1.96}{1.83} = 1.07$$

$$a_1 = 0.50$$

$$a_2 = 1.65$$

$$SE(\ln YX) = \sqrt{\frac{2.36 - [(1.96)^2/1.83]}{3}} = 0.29$$

$$I = 0.29(e^{3.34}) = 8.18$$

$$r^2 = \frac{[(1.96)^2/1.83]}{2.36} = 0.89$$

$$C = 1.96/4 = 0.49$$

For a hypothetical meter reading of 12 we compute:

$$\ln \hat{Y} = 0.50 + 1.07(2.48) = 3.15$$

$$SE(\ln \hat{Y}) = (0.29)\sqrt{(1/5) + [(-0.17)^2/1.83]}$$

$$= 0.13$$

Applying the necessary correction for nonnormality to convert to arithmetic units we compute:

$$\hat{Y}_a = e^{[3.5 + (0.13^2/2)]} = 23.5$$

$$SE(\hat{Y}_a) = \sqrt{e^{[2(0.13^2) + 2(3.15)]} - e^{[(0.13^2) + 2(3.15)]}}$$

$$= \sqrt{563.29 - 553.85} = 3.07$$

and

$$\text{Lim}_u(\hat{Y}) = \ln(\hat{Y}) + t[\text{SE}(\hat{Y})] = 3.15 + (0.13)(3.182) = 3.56$$

$$\text{Lim}_l(\hat{Y}) = \ln(\hat{Y}) - t[\text{SE}(\hat{Y})] = 3.15 - (0.13)(3.182) = 2.74$$

$$\text{Lim}_{au}(\hat{Y}) = e^{[3.56+(0.13^2/2)]} = 35.46$$

$$\text{Lim}_{al}(\hat{Y}) = e^{[2.74+(0.13^2/2)]} = 15.62$$

so that

$$15.62 < \mu < 35.46$$

for $P<0.05$ with 3 degrees of freedom (d.f.). This confidence interval is obviously too large, which results chiefly from the artificially low sample size leaving only 3 degrees of freedom. Normal sample sizes would yield at least 10 degrees of freedom, at which level $t_{0.05}$ is reduced from 3.182 to 2.228 in the example. The standard error should also decrease with larger sample sizes. For computational convenience, the example also contains some induced rounding error that has exaggerated derived values. Note also that the necessary asymmetry of the interval has been preserved. Expressing the interval as a percent of the mean therefore provides information about the uncertainty but says nothing about its shape.

Had we converted directly to arithmetic units, we would have obtained the following:

$$\hat{Y} = e^{(3.15)} = 23.3$$

$$\text{SE}(\hat{Y}) = 1.13$$

and confidence interval of:

$$\mu = 23.3 \pm (3.182)(1.13) = 23.3 \pm 3.6 \text{ with 3 d.f.}$$

or

$$19.7 < \mu < 26.9 \text{ with 3 d.f.}$$

In this case, the difference in estimates of vegetative weights is small (1 percent). However, failure to use the conversion will always result in an underestimate, possibly as great as 20 percent (Baskerville 1972).

Phytomass Estimation—Standing vegetation biomass (phytomass) can be easily estimated by substituting mean meter readings from primary sampling for X in equations 2 and 17. These biomass estimates can be used to determine similarity in potential yield between pastures or study sites, and if pregrazing similarity is established, differences in phytomass can be used to estimate use by grazing animals.

First consider a hypothetical situation in which two sampled pastures have the primary data subsets shown in table 6 and the secondary data used in the previous example. Thus, the following quantities are obtained from equations 3-7 and 20:

$n_{p1} = n_{p2} = 10$ = sample size of each pasture

$\bar{X}_{p1} = \dfrac{300}{10} = 30$ = mean meter reading of pasture 1

$\overline{\ln X}_{p1} = \dfrac{33.81}{10} = 3.38$ = mean natural logarithms of meter readings of pasture 1

$\bar{X}_{p1} = \dfrac{310}{10} = 31$ = mean meter reading of pasture 2

$\overline{\ln X}_{p2} = \dfrac{34.14}{10} = 3.41$ = mean natural logarithms of meter readings of pasture 2

$$\text{SS}(X_{p1}) = 9{,}360 - \frac{(300)^2}{10} = 360$$

= sum of squares of deviations in meter readings in pasture 1

$$\text{SS}(X_{p2}) = 10{,}018 - \frac{(310)^2}{10} = 408$$

= sum of squares of deviations in meter readings in pasture 2

Table 6—Hypothetical meter readings, natural logarithms, and squared meter readings from two randomly selected pastures to determine similarity in standing phytomass

	Pasture 1			Pasture 2		
	Meter (X_{p1})	$\ln X_{p1}$	X^2_{p1}	Meter (X_{p2})	$\ln X_{p2}$	X^2_{p2}
	25	3.22	625	26	3.26	676
	30	3.40	900	29	3.37	841
	27	3.30	729	28	3.33	784
	28	3.33	784	30	3.40	900
	33	3.50	1,089	35	3.56	1,225
	36	3.58	1,296	34	3.53	1,156
	40	3.69	1,600	43	3.77	1,849
	37	3.61	1,369	39	3.66	1,521
	22	3.09	484	25	3.22	625
	22	3.09	484	21	3.04	441
Totals ($\sum_{i=1}^{n_p}$)	300	33.81	9,360	310	34.14	10,018

where the subscript p denotes the primary sample set, the subscripts 1 and 2 arbitrarily designate a first and second subset, respectively, and other variables are as described previously.

From the results of these equations we need to calculate the appropriate variances and error estimates in order to statistically compare these pastures to test the null hypothesis (H_o): the two pastures are indistinguishable with respect to average meter reading and, hence, potential vegetative yield. The following equations are required:

$$V(X_p) = \frac{SS(X_p)}{n_p - 1}$$

= sample variance (36)

$$SD(X_p) = \sqrt{\frac{SS(X_p)}{n_p - 1}}$$

= sample standard deviation (37)

$$SE(\bar{X}_p) = \sqrt{\frac{SS(X_p)/n_p - 1}{n_p}}$$

= standard error of the mean of the meter readings (38)

$$V(\bar{X}_1 - \bar{X}_2) = \frac{[SS(X_{p1}) + SS(X_{p2})]}{(n_{p1} - 1) + (n_{p2} - 1)}$$

= pooled sample variance (39)

$$SE(\bar{X}_{p1} - \bar{X}_{p2}) = \sqrt{\frac{2[V(X_{p1} - X_{p2})]}{n_p}}$$

= pooled standard error when $n_{p1} = n_{p2}$ (40)

$$SE(\bar{X}_{p1} - \bar{X}_{p2}) = \sqrt{2\left[V(X_{p1} - X_{p2})\left(\frac{(n_{p1} + n_{p2})}{n_{p1} n_{p2}}\right)\right]}$$

= pooled standard error when $n_{p1} \neq n_{p2}$ (41)

$$t = \frac{(\bar{X}_{p1} - \bar{X}_{p2})}{SE(\bar{X}_{p1} - \bar{X}_{p2})}$$

= Student's t with $(n_{p1} + n_{p2}) - 2$ d.f. (42)

From our example, we compute:

$$V(X_{p1}) = \frac{360}{9} = 40.0$$

$$V(X_{p2}) = \frac{408}{9} = 45.3$$

$$\text{SD}(X_{p1}) = 6.3$$

$$\text{SD}(X_{p2}) = 6.7$$

$$\text{SE}(\bar{X}_{p1}) = 2.0$$

$$\text{SE}(\bar{X}_{p2}) = 2.1$$

$$V(X_{p1}-X_{p2}) = \frac{(360\ +\ 408)}{18} = 42.7$$

$$\text{SE}(\bar{X}_{p1}-\bar{X}_{p2}) = \frac{2(42.7)}{10} = 2.9$$

$$t = \frac{(30.31)}{2.9} = -0.34 \text{ with 18 d.f.}$$

Because t is two-tailed for our purposes, the sign can be ignored. From t tables we see that $t_{0.05}$ with 18 d.f. = 2.101, so H_o cannot be rejected at the 95 percent level.

If confidence intervals (for whatever level of probability) are desired for each of the mean meter readings, they are easily calculated as:

$$\mu_p = \bar{X}_p \pm \text{SE}(\bar{X}_p)t \text{ with } n-1 \text{ d.f.} \tag{43}$$

where μ_p indicates the true mean meter reading of a primary subsample. From our example, the following 95 percent confidence limits are obtained:

$$\mu_{p1} = 30.0 \pm 2.0(2.262) = 30.0 \pm 4.5 \text{ with 9 d.f.}$$

$$\mu_{p2} = 31.0 \pm 2.1(2.262) = 31.0 \pm 4.8 \text{ with 9 d.f.}$$

The mean meter reading for each site is inserted for X in either regression model to obtain estimates of mean vegetative weights for the 2-ft^2 plot sensed by the herbage meter. Because the values substituted are mean meter readings rather than individual meter readings, and therefore have their own variance, the simple equation for the variance of the estimated mean vegetative weight cannot be used directly. For the linear model, Cochran (1963) provides a modified equation for the calculation of the variance of weights from double sampling estimation. This variance is defined as:

$$V(\hat{Y}_m) = \text{SE}(YX)^2 \left\{\left[(1/n_{1s}) + \frac{(\bar{X}_p-\bar{X}_s)^2}{\text{SS}(X_s)}\right] + \left[\frac{[V(Y_s)-\text{SE}(YX)^2]}{n_p}\right]\right\}$$

$$= \text{variance of estimated } Y \text{ from double sampling} \tag{44}$$

Therefore:

$$\text{SE}(\hat{Y}_m) = \sqrt{V(\hat{Y}_m)}$$

$$= \text{standard error of estimated } Y \text{ from double sampling} \tag{45}$$

with confidence intervals calculated as before:

$$\mu = \hat{Y} \pm t\ \text{SE}(\hat{Y}_m) \tag{46}$$

for the desired probability level.

Because the logarithmic model is linear after transformation of the variables, the following analogous definitions are derived:

$$V(\ln\hat{Y}_m) = \text{SE}(\ln YX)^2 \left\{\left[(1/n_{2s}) + \frac{(\overline{\ln X}_p-\overline{\ln X}_s)^2}{\text{SS}(\ln X_s)}\right] + \left[\frac{V(\ln Y_s)-\text{SE}(\ln YX)^2}{n_p}\right]\right\} \tag{47}$$

$$\text{SE}(\ln\hat{Y}_m) = V(\ln\hat{Y}_m) \tag{48}$$

where the subscript m denotes an estimate using a mean meter reading.

Conversion of $\ln\hat{Y}_m$ is accomplished with definition (30), substituting $SE(\ln\hat{Y}_m)$ for $SE(\ln\hat{Y})$, and confidence intervals are determined using definitions (31) through (34), inclusive.

From our previous example, the following results are obtained:

Linear model:

$$\hat{Y}_{mp1} = 2.3(30.0) + 2.3 = 66.7$$

$$\hat{Y}_{mp2} = 2.3(31.0) + 2.3 = 69.0$$

$$SE(\hat{Y}_{mp1}) = (7.7)\sqrt{\left[(1/7) + \frac{(30.0-11.9)^2}{718.9}\right] + \left[\frac{(465.4)-(7.7)^2}{10}\right]}$$

$$= 8.7$$

$$SE(\hat{Y}_{mp2}) = (7.7)\sqrt{\left[(1/7) + \frac{(31.0-11.9)^2}{718.9}\right] + \left[\frac{(465.4)-(7.7)^2}{10}\right]}$$

$$= 8.9$$

and 95 percent confidence limits about the true vegetative weights per 2 ft^2 in each site would be:

$$\mu_{p1} = 66.7 \pm (8.7)(2.262) = 66.7 \pm 19.7 \text{ with 9 d.f.}$$

$$\mu_{p2} = 69.0 \pm (8.9)(2.262) = 69.0 \pm 20.1 \text{ with 9 d.f.}$$

Logarithmic model:

$$\ln\hat{Y}_{np1} = 0.50 + 1.07(3.38) = 4.12$$

$$\ln\hat{Y}_{np2} = 0.50 + 1.07(3.41) = 4.15$$

$$SE(\ln\hat{Y}_{mp1} = (0.29)\sqrt{\left[(1/5) + \frac{(3.38-2.65)^2}{1.83}\right] + \left[\frac{(0.59)-(0.29)^2}{10}\right]}$$

$$= 0.30$$

$$SE(\ln\hat{Y}_{mp2}) = (0.29)\sqrt{\left[(1/5) + \frac{(3.41-2.65)^2}{1.83}\right] + \left[\frac{(0.59)-(0.29)^2}{10}\right]}$$

$$= 0.34$$

Note that the mean of the natural logarithms of the primary meter readings is used rather than the natural logarithm of the mean meter readings. This is necessary to adjust for the assumption of non-normality discussed previously. The conversion to arithmetic units proceeds as before:

$$\hat{Y}_{mp1} = e^{\left[4.12 + \frac{(0.30)^2}{2}\right]} = 64.4$$

$$\hat{Y}_{mp2} = e^{\left[4.15 + \frac{(0.34)^2}{2}\right]} = 67.2$$

Confidence limits must be determined first within transformed variables as follows:

$$Lim_u(\ln\hat{Y}_{np1}) = \ln\hat{Y}_{np1} + t[SE(\hat{Y}_{mp1})]$$

$$= 4.12 + (0.30)(2.262) = 4.80$$

$$Lim_l(\ln\hat{Y}_{np1}) = \ln\hat{Y}_{np1} - t[SE(\hat{Y}_{mp1})]$$

$$= 4.12 - (0.30)(2.262) = 3.44$$

and

$$Lim_u(\ln\hat{Y}_{np2}) = \ln\hat{Y}_{np2} + t[SE(\hat{Y}_{mp2})]$$

$$= 4.15 + (0.34)(2.262) = 4.92$$

$$Lim_l(\ln\hat{Y}_{np2}) = \ln\hat{Y}_{np2} - t[SE(\hat{Y}_{mp2})]$$

$$= 4.15 - (0.34)(2.262) = 3.38$$

for $P<0.05$ with 9 d.f. and where the subscripts u and l denote the upper and lower limits, respectively.

At this point, it is acceptable to use definition 33 to produce the required asymmetric confidence intervals:

$$\mathrm{Lim}_u(\hat{Y}_{mp1}) = e^{[4.80+(0.30^2/2)]} = 127.1$$

$$\mathrm{Lim}_l(\hat{Y}_{mp1}) = e^{[3.44+(0.30^2/2)]} = 32.6$$

and

$$\mathrm{Lim}_u(\hat{Y}_{mp2}) = e^{[4.92+(0.34^2/2)]} = 145.2$$

$$\mathrm{Lim}_l(\hat{Y}_{mp2}) = e^{[3.38+(0.34^2/2)]} = 31.1$$

Therefore

$$32.6 < \mu_{mp1} < 127.1$$

and

$$31.1 < \mu_{mp2} < 145.2$$

for $P<0.05$ with 9 d.f. Once again, the confidence intervals are wide because of the artificially small sample size used in the example and because of accumulated rounding errors.

The estimated vegetative weights obtained by the above manipulations represent the average vegetative weight within the sensing field of the capacitance meter. Because weights were collected in grams, and the meter samples a 2-ft^2 area, the above weights were 64.4 g/2 ft^2 and 67.2 g/2 ft^2, respectively. Conversion to pounds per acre is accomplished by multiplying directly by 48. Because these conversion factors are constants (without sampling error) they can also be multiplied by the confidence limits to obtain relevant confidence intervals for phytomass estimates. From our example:

$$\text{Phytomass, site 1} = 64.4(48) \pm 44.8(48) = 3{,}091 \pm 2{,}150 \text{ lb/acre}$$

$$\text{Phytomass, site 2} = 67.2(48) \pm 53.2(48) = 3{,}226 \pm 2{,}554 \text{ lb/acre}$$

Difference in standing phytomass between the two sites is:

$$\left(\frac{67.2-64.4}{67.2}\right)(100) = \left(\frac{3{,}226-3{,}091}{3{,}226}\right)(100) = \left(\frac{3{,}877-3{,}716}{3{,}877}\right)(100) = 4 \text{ percent}$$

Note that phytomass need not be determined to obtain the percent difference in yield; any difference in estimated weights can be used for this purpose alone.

If weights were collected in ounces so that the initial result produced weights in ounces per 2 ft^2, the factor for converting to phytomass is 1,360.777 for a result in pounds per acre.

Computer Processing—A variety of commercially available software packages for microcomputers will perform linear and nonlinear regressions. In many cases, however, these two types of regression must be performed with separate packages. When they are available on the same package, the necessary statistics to adequately compare the relative efficiency of each model are frequently not included. The need to perform double sampling with regression, the need to predict values of the response variable from the mean values of primary sets of explanatory variables with corrections for non-normality and with assumptions appropriate to the logarithmic model, and the desire for computations of confidence statistics add to the need to employ several software packages. This situation clearly leads to inefficiency in data processing and barriers to effective information transfer between resource management professionals.

One software package has been developed by us for comprehensive analysis of biomass and yield differential between sites (see appendix 4). It allows double sampling as well as comprehensive analysis of up to 23 auxiliary habitat variables. The possibility of regressing several sets of paired variables is also included. Riparian habitat data are simply entered into the computer from a mass storage device, and the program automatically performs both regression analyses and phytomass and yield differential estimation using algorithms based on the mathematical relationships discussed previously. Little hands-on work is required of the data processor other than entering the data and the desired statistical confidence level. The flow pattern and relationships of the subroutines are pictured in appendix 5.

Expansion—This software package was principally designed for the livestock-fishery interaction studies currently being conducted by the Intermountain Research Station, Forestry Sciences Laboratory, Boise, ID. However, potential expansion of the basic program should cover a variety of potential double-sampling studies. Variables have been dimensioned to allow the comparison of up to 10 data sets of 25 habitat or resource variables each, and regression analyses can be conducted on any two of the 25 individual habitat or resource variables. Although outputs are made in terms of phytomass and units appropriate to range analyses, print statements can be made, by an experienced programmer, to reflect whatever sorts of data are being evaluated. For example, an investigator could use the logarithmic routine to regress rainbow trout length versus rainbow trout weight from a secondary sample set to estimate individual or average weights from a large primary data set containing only trout lengths. This would require only statements to bypass the linear regression routine, eliminating the conversion of vegetative weights to pasture yield, and modifying the print statements to output appropriate terms.

Portability—The program supporting this chapter (appendix 5) was written on a Hewlett-Packard 9845T. The HP-9845T is a competent machine, but it is several years old. Agencies and persons purchasing new machines will most likely be purchasing hardware with considerably greater flexibility. We are adapting this program for use on an IBM-PC with PC-DOS, which will be much more suitable to modern machines, especially those using PC or MS-DOS. (For additional information, please contact the senior author.) In the meantime, however, it seems prudent to include a few comments, chiefly syntactical, for those who may wish to convert this program to IBM or similar format.

Modern IBM microcomputers incorporate BASIC language interpreters with many extended features. While this improves programming on a given machine, it can reduce portability. Table 7 contains a brief list of BASIC statements used in HERB-2 and IBM equivalents. In general, transferring the program to another machine should be fairly straightforward provided the programmer knows the idiosyncrasies of the target computer, and has sufficient main memory.

Table 7—Some important HP-9845 BASIC and IBM advanced BASIC statement equivalents

HP-9845	IBM BASIC
CLEAR	CLS
MAT(VAR) = ZER	No equivalent, DIM statement zeros array
PRINT USING	PRINT USING
a. with image statements, one code line per printed lines	a. with image statements to a device using several code line and suppressing line feed where needed
b. with IMAGE line	b. no equivalent
IMAGE	No equivalent
PRINT LIN(#)	PRINT
	a. repeated desired number of lines (#)
	b. LOCATE (screen position)
LET	LET (not required in assignment statements)
PRINTER is (DEV#)	PRINT to screen, LPRINT to default printer
PRINT PAGE	PRINT
LINPUT	INPUT
ASSIGN#(n) to FILENAMES	OPEN#(n) FOR (I/O/APPEND) or FILENAMES
READ#(n)	INPUT#(n)
REDIM	No equivalent
SCRATCH	NEW

RIPARIAN COMMUNITY CLASSIFICATION

Riparian areas are important islands of diversity within extensive forest and rangeland ecosystems. Abundant water, forage, and other amenities attract a proportionately greater amount of use and conflict in riparian areas than their small aggregate area would indicate. These areas are thus receiving increasing attention from land managers in the Western United States.

Riparian areas often support complex mosaics of plant communities, associated with soil and hydrologic variation. The purpose of classification into habitats—defining taxonomic units that comprise closely similar communities—is to segment and describe this diversity as a basis for sound management. The constituent communities of a taxonomic unit are predicted to respond to management in nearly the same way. Units are defined at a level of detail suitable for multidisciplinary applications, but not in such great detail that the classification is difficult to use.

Riparian habitats are generally characterized by environmental processes markedly different from those that prevail on upland sites. For this reason, many western forest and rangeland classification concepts are not valid in riparian areas. The remainder of this section highlights some of these differences and presents some key concepts underlying riparian classification.

Riparian areas are geomorphically active, with periodic natural disturbances affecting soil and hydrologic characteristics. Water tables may be subject to fluctuation at relatively frequent intervals. At any one location, succession seldom proceeds to a long-term (several hundred years) stable end point. Disturbances that interrupt succession generally recur before such an end point can be reached. Therefore, the concept of "climax," as implied in forest and rangeland habitat classifications, is generally not applicable to riparian classifications.

The fundamental unit of riparian classification is the community type, defined by present rather than potential (climax) vegetation. However, riparian community types represent more than current floristic units. These types can be fairly well correlated with soil and environmental characteristics. Inferences can be drawn regarding environmental gradients and successional relations between types. Therefore, riparian community types represent "types of habitat" but cannot be termed "habitat types." The latter term refers to areas of land capable of supporting long-term stable (climax) communities, a situation seldom realized in riparian areas.

Grouping of community types can be done based on similar characteristics that affect management or use. Western forest and rangeland habitat types are grouped into "series" that share the same potential climax overstory. Grouping of riparian types may be based on common overstory or understory. The latter seems to have more utility because herbaceous layers are generally better than overstory as indicators of current soil-hydrologic properties that affect management decisions.

Methods used to develop a riparian classification center on a concomitant study of vegetation, soil, and environmental factors (Poulton and Tisdale 1961). The following discussions focus on specific field and office methods employed successfully in western Wyoming (Norton and others 1981) and central Idaho (Tuhy and Jensen 1982). Emphasis is placed on vegetation analyses because floristic data are used to generate and name the community types.

Field Methods

Field sampling provides the raw data upon which the classification is based. Field methods involve the following activities:

1. Within the overall study area, identify a range of subareas to receive sampling emphasis.
2. In each identified subarea, select individual communities or stands for sampling.
3. In each selected community, locate a certain type of sample plot.
4. In each plot, record information relevant for floristic clustering and soil/environmental correlation.

Subarea Identification—When developing a classification over a broad geographical area, it is not possible to observe or sample every riparian habitat. Within a large study area it is necessary to select subareas, such as certain stream drainages or other wetlands, for sampling emphasis. Streams and wetlands should be chosen to encompass the variation in vegetative, geologic, soil, and environmental characteristics over the area of concern. The selection process is aided by maps, aerial photos, ground reconnaissance, and conversations with people who know the area. This process is done once at the start of the project, though decisions may be modified several times as field work progresses.

Schedules should be formulated, insofar as logistics allow, so that sampling occurs when vegetation is at its optimum phenological stage. "Optimum" here refers to full leaf and flower or fruit. Generally, sampling will progress from lower to higher elevations during the course of a field season.

Sample Site Selection—Within each identified subarea, distinct vegetation communities are selected for sampling. The approach of "subjectivity without preconceived bias" (Mueller-Dombois and Ellenberg 1974) has been used successfully for this purpose.

Communities are subjectively selected for sampling rather than by systematic or random (objective) methods. The selection is thus based on judgment of the investigators. To be sampled, communities must meet two criteria:

1. The community should be homogeneous. This is generally a visual determination, avoiding obvious ecotones and changes in vegetative composition or structure.
2. The community should occupy an area at least three times that of the plot (see following section). This minimizes influences from adjacent communities.

Investigators begin by sampling each community encountered in each identified subarea. As field work progresses through a number of locations, investigators recognize recurring community patterns. Replicate examples of closely similar communities are sampled. The investigators formulate hypotheses that these recurring communities will form the basis for community type units.

Such hypotheses can bias subsequent decisions of what or where to sample. Sample site selection "without preconceived bias" means that communities are not rejected if they do not conform to the classification system hypothesized to date. Investigators should accept new working hypotheses for the classification as soon as further knowledge suggests a modification or change.

As work progresses and classification concepts emerge, frequent and widespread communities need not be sampled seemingly forever. However, minor community differences may be significant and should not be ignored.

Nature of Sample Plots—Exact location of a plot within a community should depict the "central tendency" of that community. Transitional areas near community borders are best avoided.

Existing riparian classifications have used the metric system, with a 50-m^2 macroplot in the form of a 5- by 10-m rectangle. This size and shape was selected because:

1. The 50 m^2 is equal to or greater than the minimal area for shrub and herb strata as suggested by Mueller-Dombois and Ellenberg (1974). This area is generally too small for sampling overstory tree strata, but these are infrequent in riparian areas. Where mature trees do occur, plot sizes of 375 m^2 or 500 m^2 may be used to conform with forest sampling methodology in the West (provided plots are homogeneous and little-influenced by adjacent communities).
2. As small a representative area as possible is desired. This is so that plots fit in communities that are arranged in intricate mosaics, without encountering heterogeneity or ecotones.
3. Plot shape is rectangular in response to the common elongation of riparian communities parallel to a stream channel. In cases of extreme elongation, such as a streambank fringe, the standard shape (but not area) may be modified.

Plot Data—Constructing a classification from a series of sample plots requires information relevant for clustering. Floristic grouping requires that in each plot at least the following information be recorded:

1. A complete plant species list. Unknown specimens are usually collected for later identification. A set of voucher (truthing) specimens should also be collected during the project.
2. A quantitative factor that describes each species' role in the community. Canopy cover is the most common factor used. Frequency and density are other factors that may be applicable.

Canopy cover for each species is generally estimated visually within the 50-m^2 macroplot. Such estimates are easy to obtain and easy to "see" when using the classification to identify an unknown community. A series of microplots 20 by 50 cm each can occasionally be nested in the macroplot to calibrate ocular cover estimates.

The height of each species, or at least of each stratum, may be useful in defining community types. Production and use measurements may be useful for management, but they are not vital to build the classification.

A number of environmental characteristics are also recorded for each plot. These include elevation, slope, aspect, and valley-bottom width (where applicable). Also noted are physiognomy, disturbance, and types of adjacent communities. Soil investigations and water-table measurements also occur, and their description appears in the subsequent section on riparian soils.

At any particular sample site there is a tradeoff between rapidity and amount of information gathered. For classification purposes, it is generally more useful to analyze a greater number of samples in less detail than to analyze a few in great detail.

Office Methods

The classification is derived using office procedures that manipulate and synthesize field data. After initial plant taxonomy work, the methods center on the derivation of community types via floristic clustering techniques. Final considerations include synthesis with environmental characteristics, nomenclature, and report preparation.

Plant Identification—Plants must be correctly identified before any data tabulation or manipulation occur. Unknown specimens should be identified to species if possible. Vegetative specimens may be identifiable to genus only. Voucher specimens should also be confirmed.

Taxonomic problems are noted at this time. These are usually mentioned in the final classification report.

Floristic Clustering—Sample plots are grouped into units that exhibit similar vegetative composition and structure. The initial grouping is generally based on classification hypotheses formulated during field sampling.

Subsequent tabular display of floristic data can more clearly show similarities and differences between plots. Association tables used for this purpose (see Mueller-Dombois and Ellenberg 1974, pp. 177-193) portray the magnitude (such as canopy cover) of all species within a series of plots. By shifting species and plots (rows and columns) in the table, investigators can visually identify the groups of similar plots. Recent computer programs have made table manipulation much easier than tedious handwritten techniques.

Mathematical cluster analysis procedures may be used to refine or validate the results of tabular classification, or perhaps both. Cluster analysis involves several steps:

1. Reduce the data set by removing scarce or incidental species from consideration. For example, investigators may disregard species with less than 5 percent overall constancy, or those that were never observed with more than 1 percent canopy cover, or both. There are times, however, when species should not be disregarded, such as occurrence of treatment and endangered species or occurrence of "ice cream" plants used heavily by livestock.
2. Decide whether clustering will be done using species presence-absence data or quantitative data (such as canopy cover). Quantitative data usually require some type of transformation so that large values do not overwhelm consistent differences in smaller values.
3. Construct a matrix of similarity or dissimilarity, using any of a substantial number of coefficients. The matrix shows the level of similarity (or dissimilarity) between every plot-pair in the data set.
4. Then use any of a number of clustering procedures to generate a dendrogram, showing at what level of similarity (or dissimilarity) sample-plot clusters are connected. Marshall and Romesburg (1977) developed a polythetic agglomerative procedure named CLUSTAR that has been used in previous riparian classifications.

Although cluster analysis employs objective, mathematical techniques, each step listed above requires decisions that may be subjective on the part of the investigator. Cluster analysis is a tool able to show groupings that may not be apparent during association table procedures. However, final classification decisions rest with the ecological expertise and field experience of the investigators.

Final Considerations

The synthesis of floristic units with soil and environmental characteristics defines the final community types. Types should not be formally recognized unless they are represented by at least four, but preferably 10 or more, sample plots. Communities that recur infrequently within the area of concern should be considered as incidental. Community recurrence is vital to recognizing classification units. This is the major reason for sampling a large number of communities in just enough detail to enable their classification.

Once the final community types are defined, they must be named. Nomenclature is almost exclusively based on vegetative indicator species in shrub (if present) and herbaceous strata.

Indicator species are often, but not always, the dominants in their respective strata. An indicator species, particularly in the herbaceous layer, should have both high constancy and high fidelity. A species with high constancy but lower fidelity (that is, more widespread) is less desirable for naming community types, but may need to be used.

Riparian classifications are ultimately tools for managing riparian areas. A report or manual to be used by management personnel is the necessary end product of all the above methods. At a minimum such a document will contain: (1) keys to initially identify unknown communities; (2) descriptions of each community type that include floristic, environmental, and management implications; and (3) vegetative synthesis tables that show species constancy and average cover in each community type.

Several ecologically based riparian classifications have been completed in the Intermountain West. Work continues toward the goal of classifying riparian habitats throughout the Intermountain Region of the USDA Forest Service. Knowledge gained from such classifications can foster the sound management of these small but productive and sensitive habitats.

RIPARIAN SOILS

Interpretations regarding the genesis, function, and dynamics of riverine riparian ecosystems include general concepts of flood plain geomorphology, soil genesis, soil morphology, and soil taxonomy common to riparian positions in the Northern Rocky Mountain Physiographic Province (Arnold 1975). These concepts stem from both the scientific literature and intensive investigations of riparian ecosystems in mountainous regions of Utah (Jensen 1981), Wyoming (Tuhy and Jensen 1982; Jensen 1984), and Idaho (Jensen and Tuhy 1982). Although the concepts are common to riverine riparian positions in the Northern Rocky Mountain Physiographic Province, they may not be consistent across provincial boundaries.

Riverine riparian ecosystems are defined as the composite of terrestrial subsystems spanning from the apparent bank of stream channels in medial positions of valley bottoms to the lower edge of upland positions. The definition excludes permanently flooded (aquatic) classes of the Palustrine System as defined by Cowardin and others (1979). A useful working definition for riparian soils is the collection of polypedons distinguished by characteristics indicative of saturation by ground water during a significant period of the growing season within the rooting depth of native vegetation. The definition logically includes terrestrial areas supporting obligate phreatophyte plant species.

Soil morphology is a response to climatic, hydrologic, and biologic processes acting upon geologic material. Geomorphic position, relative to environmental gradients, is primarily responsible for determining the rate and degree to which these processes influence the soil system. The approach to subsequent development is to elucidate the processes responsible for the genesis of soil and the causative relationships resulting in spatial distribution of contrasting soil types in riparian areas.

Flood Plain Geomorphology

The genesis of fluvial valley bottoms is primarily a response to fluventic processes. The "energy signature" of a stream may be conceptualized as a "power line" concentrated as a force directed parallel to the ground surface over an elongated, often sinuous area (Kangus 1978). The energy potential of such a system is a function of stream discharge and the difference in elevation between two points.

The longitudinal slopes of streams decrease as an inverse function of discharge (Bloom 1978). In valley systems, discharge generally increases in a downstream direction as a result of the intersection of lower order tributaries, runoff from contiguous uplands, and subsurface discharge from alluvial aquifers. Consequently, the slopes of streams generally decrease in a downstream direction.

The competence of a stream refers to the maximum size particle that it will move. The competence of a fluvial system increases as a function of flow velocity. A small, fast-flowing stream can move a relatively large particle. While the competence of such a stream is great, the amount of material transported is small. Variability in the competence of stream and flood waters results in a sorting of fluvial sediments from coarse to fine in a direction of decreasing flow velocity.

Streams move most of the annual sediment load during short intervals of peak discharge resulting from snowmelt, rainfall, or both. The sediment-carrying capacity of a stream increases exponentially as a function of discharge. A tenfold increase in discharge may increase the sediment load a hundredfold to a thousandfold. A large, slow-moving stream may carry a large quantity of suspended sediments, although its competence is low.

Flow characteristics of fluvial systems in western montane regions are often modified by the engineering habits of beavers. Flow velocity, competence, and channel geometry are affected. Beaver channels may extend the aquatic environment to distal portions of the valley bottom. The still or slowly moving water of beaver ponds and channels favors proliferation of aquatic or emergent vegetation, or both, and the deposition of relatively fine-grained sediments.

Other factors affecting the hydraulic gradients of fluvial systems and subsequent geomorphic development of valley bottom positions include mass wasting of contiguous valley slopes, debris jams, and human engineering practices.

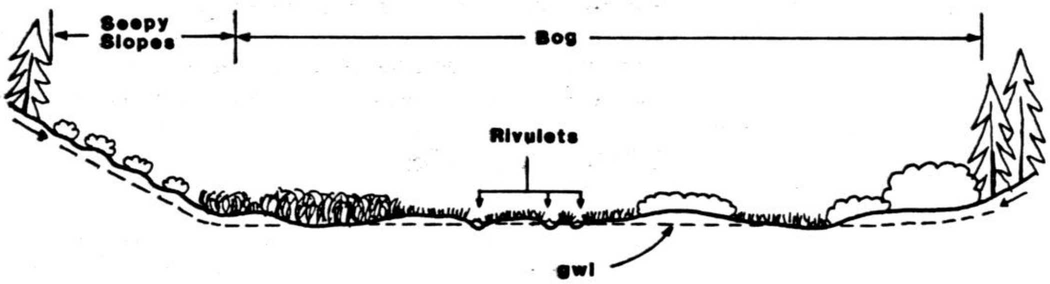


Figure 9—General form of headwater positions.

Valley Bottom Conformations—Three general geomorphic forms of riverine valley bottoms have been identified in the Northern Rocky Mountain Physiographic Province (Tuhy and Jensen 1982): glaciated headwaters, narrow V-canyons, and broad valleys. (More detailed descriptions of the typical composition and structure of geomorphic forms are discussed later under soil morphology.)

Glaciated headwaters constitute the initial convergence of drainage sources for many montane streams. General positions constituting riparian ecosystems in glaciated headwaters include seepy slopes and bogs. Alternatively, the headwaters of some drainages may have the form of narrow V-canyons. Seepy riparian positions in glaciated headwaters may extend considerable distances up moderate to steep valley slopes and are normally sustained by dispersed subsurface flow originating from snowmelt or discharge from bedrock aquifers. Seepy slopes grade to broadly concave, nearly level bog positions. Surface flow in bogs is often limited to small rivulets. A general schematic of headwater positions is presented in figure 9.

Narrow V-canyons are associated with steep-gradient, low-order stream segments. Streams in these positions may be actively downcutting into consolidated geologic material. Upstream segments of narrow V-canyons may be headcutting toward headwater positions of drainages, while downstream segments may be approaching the graded condition characteristic of broad-valley streams. Valley walls rise abruptly and confine channels to narrow, relatively straight stretches. Riparian areas in V-canyons are generally restricted to narrow bands contiguous to stream channels. The general form of narrow V-canyons is illustrated in figure 10.

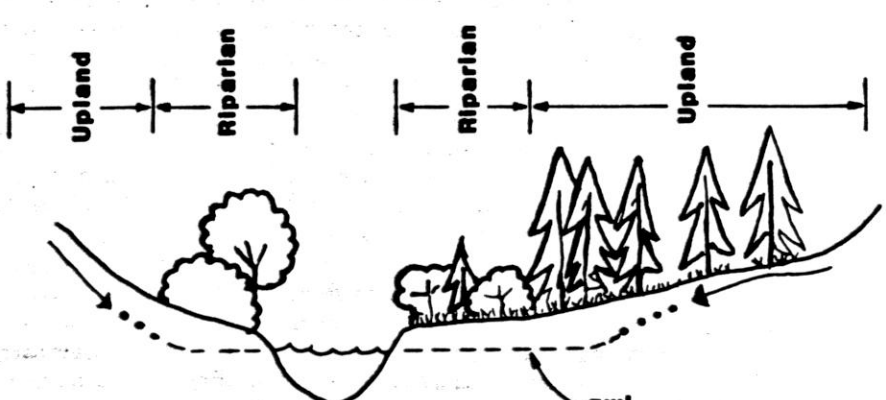


Figure 10—General form of V-canyons.

Broad-valley systems are generally associated with sinuous, low-velocity streams characterized by seasonal overbank flooding. Seasonal flooding and the movement of stream channels across broad valleys result in a high degree of geomorphic diversity in the form of stream bars, levees, low-lying wetlands, and riparian meadows. The apparent dominant sources of alluvial ground water in broad-valley systems are upstream alluvial positions. Surface and subsurface drainage from contiguous sideslopes may also contribute significant volumes of water, especially during runoff. Ground water level (gwl) in broad-valley systems is normally approximated by stream stage elevation during periods of base flow. The general form of broad-valley systems is illustrated in figure 11.

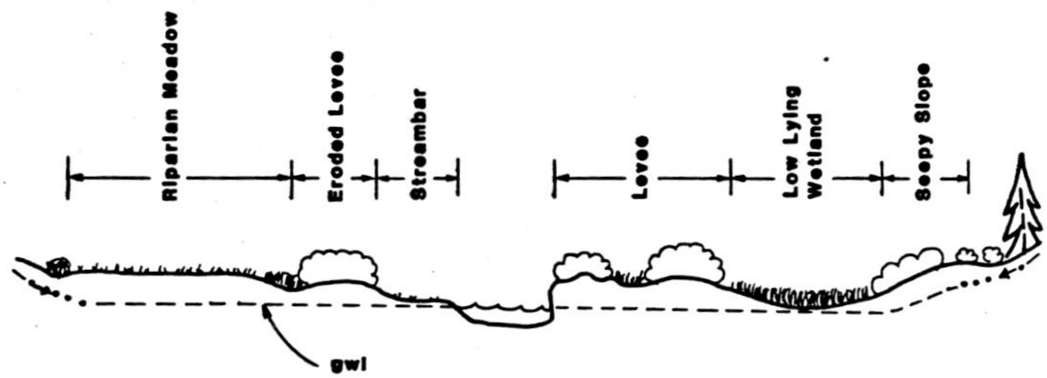


Figure 11—General form of broad-valley systems.

Distribution of Sediments—The distribution of mineral sediments comprising alluvial positions is a response to three general modes of depositions: sedimentation from adjacent upland positions, vertical accretion, and lateral accretion. Erosion of soil and mineral materials from residual upland positions constitutes the initial source of flood plain sediments. Sediments may be transported to alluvial positions under the influence of water, gravity, or wind. Alluvial (water) transport dominates in broad-valley systems with shallow to moderately steep sideslopes and at the intersection of lower order tributaries. Alluvial sedimentation commonly results in smooth, convex topography that gradually dips toward the medial line of the valley bottom. Colluvial (gravity) deposition is normally limited to narrow, V-canyon positions where streams are downcutting into bedrock materials. Colluvial deposition results in short, steep transitions from the stream channels to uplands. Colluvial sediments normally include angular rock fragments eroded from contiguous uplands. The influence of eolean (wind) sedimentation is generally not apparent in flood plain positions in the Northern Rocky Mountain Physiographic Province.

Vertical accretion occurs when stream discharge becomes greater than channel capacity and bank overflow occurs. The shallow, low-velocity sheet of floodwater has little competence relative to channel flow. Sediments are deposited on the flood plain and are generally sorted from coarse to fine in a direction away from the channel axis. Depositional events associated with floodwaters of contrasting competence result in the deposition of distinct strata of contrasting texture and coarse-fragment content. Vertical accretion is most apparent in broad-valley systems associated with low-gradient, sinuous streams.

Lateral accretion is a redistribution of sediments deposited by vertical accretion or by sedimentation from adjacent upland positions. As a stream meanders across its flood plain, channel banks are undercut and eroded. Fluvial erosion is most effective opposite convex point-bars where banks are most nearly perpendicular to the direction of streamflow. As a bank is undercut and collapses, sediment is carried downstream and redeposited. Lateral accretion is a principal process of channel modification and lateral movement across the flood plain in broad-valley systems. Normally, little evidence of lateral accretion is evident along riparian systems associated with streams entrenched in narrow, V-canyon positions. The effect of lateral accretion is to obliterate evidence of vertical accretion.

The accretion of organic matter (OM) is an important factor determining microtopography and drainage characteristics in some riparian ecosystems. The process is most apparent in headwater positions where dispersed drainage maintains conditions conducive to OM proliferation and limits the degree of OM mineralization. Deep accumulations of OM, often stratified with layers of mineral sediments, are common throughout headwater positions and, less extensively, in broad-valley positions. Major sources of OM are bryophytes and fibrous roots of herbaceous plant species.

Soil Genesis

Soil is a product of ecosystem processes acting upon environmental states. A process represents an energy flux into or through an open system. In this case, the system is a thin, unconsolidated surface mantle upon which most terrestrial life is dependent.

Processes affecting the soil system include erosion and deposition, organic matter production and mineralization, flocculation and dispersion of ped structure, physical weathering and sedimentation, eluviation and illuviation, oxidation and reduction, and dissolution and precipitation of soluble minerals. The degree to which processes affect a system is influenced by the state of the system. The state of a system is defined by its composition, position, temperature, and pressure. By assuming relatively consistent temperature and pressure, a description of state reduces to that of composition and position.

The composition of soil in riparian areas includes both mineral and organic materials. Water is conventionally considered a distinct component integral with the soil system. The texture and coarse-fragment content of mineral material may vary spatially on the site level of resolution and vertically within a single profile. The distribution of sediments is in response to spatial and temporal variability in alluvial transport mechanisms. The mineral composition is further determined by geologic parent material that may vary at local or regional scales. Organic matter content and form varies in response to complex interactions between biologic, soil, and hydrologic factors.

The position of materials relative to environmental gradients is important in determining the degree to which processes affect soil genesis. The position within valley bottoms is important where processes originate from point or line sources (erosion and deposition) and where the composition of the system is spatially heterogeneous (such as is most common in natural systems). In riparian ecosystems, the position of soils relative to fluvial and alluvial ground water geometries is the dominant factor controlling the rate, degree, and form of soil genesis.

Stream bars may be considered both the initial state from which soil genesis proceeds and the limit to which it may regress. Processes normally associated with progressive development are deposition of sediments and OM production. Processes that determine the form of subsequent development include eluviation, illuviation, oxidation, reduction, dissolution, precipitation, flocculation and dispersion of ped structure, and the degree of OM decomposition and mineralization. Erosion is generally associated with regressive development.

Soil morphology is a study of the form, composition, and structure of soil. A history of processes affecting riparian systems is well-documented in the morphology of soil.

Soil Morphology

The morphology of riparian soils often reflects both the mode of sediment deposition and the form of in situ pedogenesis. Pedons characterized by vertical accretion generally occupy an intermediary position between channel and upland positions. Morphological characteristics indicative of vertical accretion are (1) distinct horizons of contrasting textural classes, (2) OM content of mineral horizons that decreases irregularly with depth, and (3) buried organic horizons.

Pedons characterized by lateral accretion are generally adjacent to the channel axis but may extend to the periphery of the valley bottom where stream channel positions have been displaced over time. Morphologic characteristics indicative of lateral accretion are (1) relatively thick horizons containing rounded rock fragments, (2) low OM content in mineral horizons that either decreases regularly with depth or is homogeneous throughout the stratum, and (3) the absence of buried organic or dark mineral horizons formed at the surface within the depth affected by lateral accretion.

In situ pedogenesis requires some degree of temporal stability. In time, in situ development may mask those characteristics associated with vertical and lateral accretion. In situ pedogenesis is characterized by (1) an accumulation of OM in surface horizons and a regular decrease in OM content deeper in the soil profile, (2) moderate to strong ped structure in surface horizons resulting from flocculation of mineral sediments, (3) mottles resulting from oxidation and reduction of soil mineral material, (4) eluviation and illuviation of mineral and organic components in response to percolation of surface water, and (5) dissolution or precipitation of soluble minerals by infiltrating surface water or by fluctuating alluvial ground water levels (gwl).

Although in situ development is observable to some degree in most riparian soils, it is most apparent in soils above the floodwater level. These soils are often contiguous to upland positions or may occur where vertical accretion has built up surface elevations above normal flood stage. The rate of in situ pedogenesis is greatly affected by soil moisture status.

The OM content of riparian soils varies from near 100 percent in deep organic deposits to less than 1 percent in recent fluvial deposits. The distribution of mineralized OM with depth in soil profiles is often irregular, in contrast to the regular decrease with depth common in soils of upland positions. The distribution of OM within the soil profile is indicative of the rate of fluvial deposition relative to OM production.

Organic matter decomposition is a biologically induced process greatly affected by soil-water content. Decomposition proceeds at a slow rate under anaerobic conditions, more rapidly under wet aerobic conditions, and most rapidly under fluctuating soil moisture status. The degree of OM decomposition in surface and subsurface horizons reflects consistency in soil moisture content.

Flocculation is the aggregation of soil-sized particles (sand, silt, and clay) into peds, the fundamental unit of soil structure. Soil materials incorporating relatively high proportions of mineralized OM and approximately equal proportions of sand, silt, and clay (loamy textural classes) are most affected by flocculation. The degree of ped formation in riparian soils generally increases toward mesic positions characterized by frequent wetting/drying cycles. The elemental composition of cations concentrated near the surfaces of mineral and organic components also affects the degree of ped formation.

The presence or absence of gaseous or dissolved oxygen in soil systems also affects the rate of oxidation/reduction reactions and biologically induced nutrient cycling. The taxonomic classification of riparian soil is based, in part, upon the presence or absence of spots of contrasting colors (mottles) resulting from the segregation of iron and magnesium from soil mineral components. Mottles of high chroma (bright colors) indicate alternating oxidation-reduction processes, while mottles of low chroma (gray colors) are indicative of prolonged reducing conditions.

Some fine-textured subsurface horizons permanently saturated with ground water are of low chroma throughout the matrix and are of blue to green hue (gleyed horizons). These horizons are indicative of permanent anaerobic conditions. Gleyed soil materials often change color when exposed to the atmosphere for even short periods.

Eluviation of mineral, organic materials, or both from surface horizons and illuviation of transported materials in subtending layers are responses to percolation of water through the soil profile. The expression of eluviation and illuviation may be thin films of transported OM or clay-size particles on the walls of soil pores and ped faces in subsurface horizons. The degree of temporal stability necessary for expression of eluviation and illuviation is not common in riparian ecosystems although it may be noted in positions bordering uplands.

The dissolution and precipitation of soluble minerals may be in response to downward percolation of surface water or upward inundation by ground water. Calcium carbonate (lime) and calcium-magnesium carbonate (dolomite) are slightly soluble constituents of many soils. In contrast with upland positions, the concentration of carbonates in riparian positions often decreases with depth in the soil profile as a result of dissolution by alluvial ground water. The characteristic distribution is sometimes accentuated by eolean deposition of fine-grained carbonate sediments from contiguous uplands.

Descriptions of soil genesis and morphology typical in headwater, V-canyon, and broad-valley positions in the Northern Rocky Mountain Physiographic Province were formulated based on interpretations of principal processes affecting distinct positions of riparian ecosystems. The broad range of environmental gradients typical in natural systems results in an infinite degree of variation in morphological characteristics. The following descriptions illustrate the effect of prominent forms of soil genesis but do not include all situations that could be encountered in field investigations.

Glaciated Headwater Positions—These positions constitute the initial convergence of drainage sources for many montane streams. Drainage sources in headwater positions include the melt from snowfields that may endure through most of the warm season, the leakage of bedrock aquifers from extensive exposures of water-bearing geologic strata, or the point discharges of springs. The characteristic dispersed flow and near-saturated surface conditions in headwater positions are conducive to the proliferation of OM. Near-anaerobic conditions in subsurface strata may limit the degree of OM decomposition and mineralization. The morphologies of soils typical on seepy slopes and bogs in headwater positions are depicted in figure 12.

The most apparent process affecting both seepy slopes and bogs in headwater positions is OM proliferation. Surface layers on seepy slopes (fig. 12a) are often relatively undecomposed (fibric) OM in the form of bryophytes and interwoven matting of fibrous roots of herbaceous (generally *Carex* spp.) plants. The undecomposed state of OM in surface horizons may be the result of prodigious annual production and a relatively short season for biological degradation rather than the anaerobic conditions normally associated with fibric OM. Surface horizons are normally wet through most or all of the growing season but saturated for only short periods. Subtending OM is often moderately (histic) to completely (sapric) decomposed and is saturated by flowing water through most or all of the growing season. The flowing water is generally aerated to a degree conducive to biologically mitigated decomposition of OM. The thickness of organic horizons on seepy slopes varies as a complex function of factors affecting biological production and decomposition, and may extend to depths greater than 40 inches. Where organic epipedons are relatively thin, mineral horizons darkened by mineralized OM may subtend organic layers. Subtending mineral material is generally gleyed, indicating prolonged anaerobic conditions. Basal mineral material may be glacial till, glaciofluvial deposits, colluvium, or residuum underlain by weathered bedrock.

Surface horizons of bog soils (fig. 12b) are often relatively undecomposed (fibric) OM. The sum thickness of organic layers ranges from a few inches to greater than 6.6 inches. Thin layers of mineral sediments reflecting sedimentation from contiguous upland positions are often stratified in organic layers. OM is generally subtended by fine-grained, gleyed, mineral material with slow to very slow permeability.

Although the ground water level (gwl) may be well below the organic surface through much of the growing season, the wicking action (capillary rise) through OM often results in near-saturated conditions at the surface throughout much of the biologically active season. In bogs, the vertical accretion of OM acts to extend the vertical (and consequently the horizontal) limits of capillary rise above the gwl. Thus, the proliferation of OM effectively expands the limits of near-saturated conditions.

The accretion of OM in broadly concave positions results in lateral encroachment of near-saturated conditions upon nearby uplands. The presence of decadent conifers surrounded by boggy communities is indicative of OM accretion. Large logs—often preserved so that the species of origin is recognizable, buried deep within saturated OM in central positions of bogs—give further testimony supporting the process of OM accretion. As evidenced by standing-dead conifers within some bog communities, temporal changes in the surface elevations of bog systems may be rapid.

Riparian ecosystems in headwater positions function to reduce sediment transport and to regulate flow to lower drainage positions. Surface organic horizons on both seepy slopes and bogs effectively filter sediments delivered from upland positions. The dispersed, slow flow of water through bogs effectively regulates discharge rates to down-drainage positions.

The morphology of soils in headwater positions is indicative of primary succession in response to inundation by flowing (seepy slopes) or slowly circulating (bogs) drainage water. These ecosystems seem relatively stable under consistent hydrologic regime.

The hydrologic regime of headwater positions may be altered through drainage or by affecting the hydrologic source responsible for sustenance of the riparian ecosystems. Drainage may be a response to head-cutting by streams in lower V-canyon positions, chan-

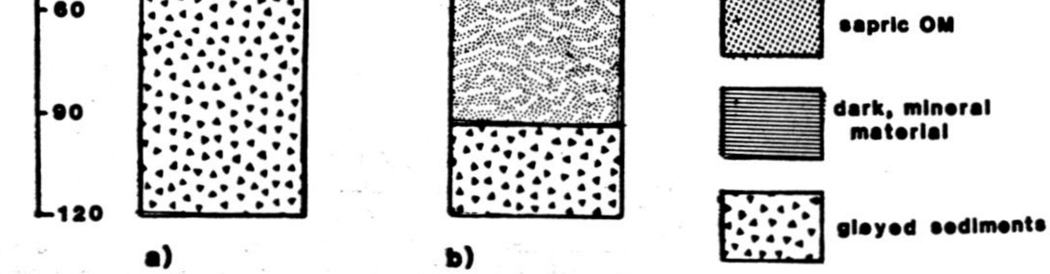


Figure 12—Soil morphology typical in headwater positions: (a) seepy slope, (b) bog soil.

neling resulting from trampling by livestock, or direct manipulating in construction activity. Hydrologic source characteristics may vary in response to short-term or long-term changes in climate or in response to manipulations associated with resource use management. Increased rates of runoff and sedimentation from uplands as a response to logging, mining, grazing, or construction activities may also affect the integrity of headwater ecosystems.

V-canyon Positions—Narrow, V-canyon positions occur predominantly along low-order tributaries of drainage systems. V-canyon positions are associated with steep gradient streams, often with banks rising abruptly to upland positions. The principal processes apparent in V-canyon positions are fluvial erosion and alluvial/colluvial deposition.

Erosional processes proceed toward down-cutting through subtending, consolidated geologic material and head-cutting toward drainage sources. Colluvial sedimentation is in response to the fluvial down-cutting. Typical soil profiles contiguous to stream channels in V-canyon positions are depicted in figure 13.

The morphology of soil in relatively level bank positions (fig. 13a) reflects erosion/sedimentation associated with high-velocity stream flow. In these positions, layers of sand are sometimes found stratified between layers of decaying leaves. Subtending materials are principally unstratified rounded gravel, cobble, stones, and boulders. The composition of these positions is generally a result of lateral accretion acting to redistribute colluvial sediments and sediments eroded from upstream, V-canyon positions. High streamflow velocities and seasonal catastrophic flooding are conducive to the transport of finer grained sediments.

In contrast, soils on steep-banked sites (fig. 13b) are a result of alluvial/colluvial deposition from contiguous valley slopes. The surface is often covered with litter. A thick surface horizon somewhat darkened by mineralized OM and with granular structure is sometimes present. Subtending material includes angular rock fragments eroded from contiguous valley slopes. Occasional surface horizons buried beneath thick strata of colluvial sediments are indicative of mass wasting.

Although close to stream channels, these soils are among the driest. Surface strata are often excessively drained with low water storage capacity. The combination of relatively deep gwl's and coarse-textured material (low capillary rise) generally limits riparian vegetation to deep-rooted, shrubby species (*Alnus*, *Cornus*, and *Betula* spp.). Herbaceous riparian vegetation is often absent on these positions.

The apparent natural function of V-canyon positions is the fluvial transport of sediments. Fluvial erosion and transport are maintained at a steady state by interrelationships between channel slope and discharge. The effect of human-caused disturbance in narrow V-canyons may be insignificant relative to that of natural catastrophic flooding. In contrast,

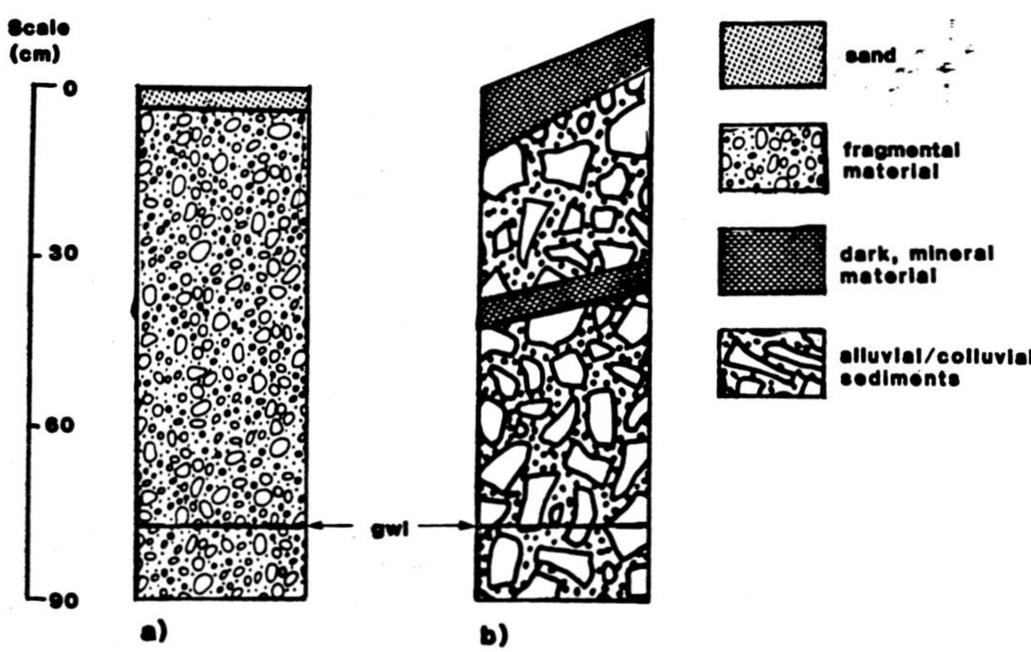


Figure 13—General morphologies of soils common in V-canyon riparian positions: (a) relatively level bank position; (b) steep bank position.

alteration of stream discharge through retention or diversion of upstream sources may affect erosion and transport mechanisms responsible for maintenance of riparian ecosystems in V-canyons. The probable responses to reduction in discharge are increased fluvial sedimentation and accumulation of alluvial/colluvial sediments from contiguous uplands.

Broad-Valley Positions—Soils in broad-valley positions include a greater range in morphological characteristics than do soils in headwater and V-canyon positions. The broad range in characteristics results from spatial variability in valley-bottom geomorphology and its influence upon processes affecting soil genesis. The general form and relative position of stream bars, levees, low-lying wetlands, and meadows are illustrated in figure 14.

Mineral sediments in broad-valley positions may be categorized as one of three basic forms: alluvial sediments from associated uplands, fluvial sediments, or valley fill.

Alluvial sediments from adjacent uplands are generally characterized by relatively fine-grained materials reflective of advanced levels of in situ pedogenesis. Alluvial fans and aprons originating in ephemeral upland washes are examples. Surface horizons in lateral positions of valley bottoms often comprise alluvial sediments.

Fluvial sediments are characterized by a matrix of soil-sized material (sand, silt, and clay), often including rounded rock fragments. Fluvial sediments overlie fragmental valley fill across the valley bottom in all terrestrial positions except stream bars. Depth to the gwl in broad-valley systems generally corresponds with the thickness of this finer grained material over valley fill. Primary factors affecting pedogenesis in broad-valley systems are the thickness and texture of fluvial or alluvial sediments.

Valley fill is characterized by a matrix of rounded gravel and cobble (rubble), normally with sandy material filling interstitial voids. The level of valley fill approximately corresponds with stream base-flow elevation. The relatively high permeability of valley fill promotes equilibration of alluvial ground water and streamflow levels. The often diffuse transition between valley fill and fluvial sediments corresponds with the transition between soil and "not-soil" (USDA-SCS 1975). Following are discussions of distinct landform positions common in broad-valley systems.

Stream bars. Stream bars are considered as both the initial state from which soil genesis proceeds and the limit to which it regresses. The obvious process dominating the genesis and resultant morphology of stream bar soils is fluvial erosion and sedimentation. The extent of stream bars is influenced by the geometry of active stream channels and temporal variability in stream stage level. Shallow, wide streams with substantial differences between normal flood stage and base flow logically are associated with expansive stream bars. Deep, relatively narrow streams with consistent stage levels are not normally associated with stream bars in undisturbed systems. The progressive development of stream bars is illustrated in figure 15.

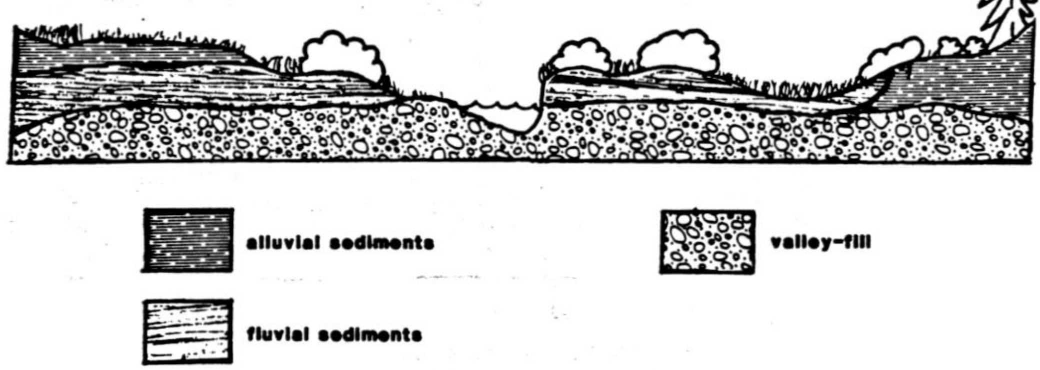


Figure 14—Schematic of geomorphic types in broad-valley systems.

The primal state of stream bars (fig. 15a) is a severely eroded position comprised of fragmental valley fill material and with little or no indication of pedogenic development. The gwl is normally near the mineral surface. However, vegetation may be dominated by mesic species due to low water storage and negligible rise of capillary water above gwl characteristic of fragmental materials.

Given a change from erosional to depositional processes (fig. 15b), sandy fluvial materials may be deposited. The somewhat greater water storage capacity of these sandy materials promotes establishment of more vigorous vegetation, which decreases the potential of subsequent erosion. More vigorous vegetation also results in the accumulation of mineralized OM in thin surface horizons. As seasonal deposition continues, the surface is built up above the normal flood stage (fig. 15c). The presence of buried horizons, darkened by mineralized OM, indicates seasonal deposition of mineral sediments interspersed by periods of relative stability.

Assuming that the natural flux of sediments through broad-valley systems approaches a state of dynamic equilibrium (sediment influx is approximately equal to sediment outflux), the area of stream bars is expected to remain approximately constant in undisturbed systems. As new stream bars are formed by the lateral displacement of stream channels, sedimentation on remnant stream bars results in development toward more stable riparian forms. An increase in the number or extent of stream bars is a primary indicator of disturbance in broad-valley systems.

An increase in the area of stream bars may be a response to degradation of streambanks or decreased streamflow through established channels. The degradation of streambanks and channel geometry may be a direct response to livestock grazing, construction, recreation, or all three. Accelerated rates of streambank sloughing are most often attributed to cattle grazing and result in a change in channel geometry toward broader, shallower streams. Expansive stream bars are often associated with stream crossings frequented by livestock or recreational vehicles. A decrease in discharge resulting from retention or diversion of streamflow may result in diminishing stream area and subsequent increase in the surface area of low-lying stream bars. The effect is most dramatic where channels are broad and shallow.

Channel levees—Levees are normally contiguous to stream channels or stream bars, but may occur throughout broad-valley systems due to displacement of stream channels across the valley bottom. The form of levees is convex and surfaces are generally higher than immediately adjacent positions toward valley edges. Microtopography is often hummocky or undulating, with shrubs (generally *Salix* spp.) dominating on convex positions and herbaceous vegetation in concave channels between hummocks. The lateral migration of stream

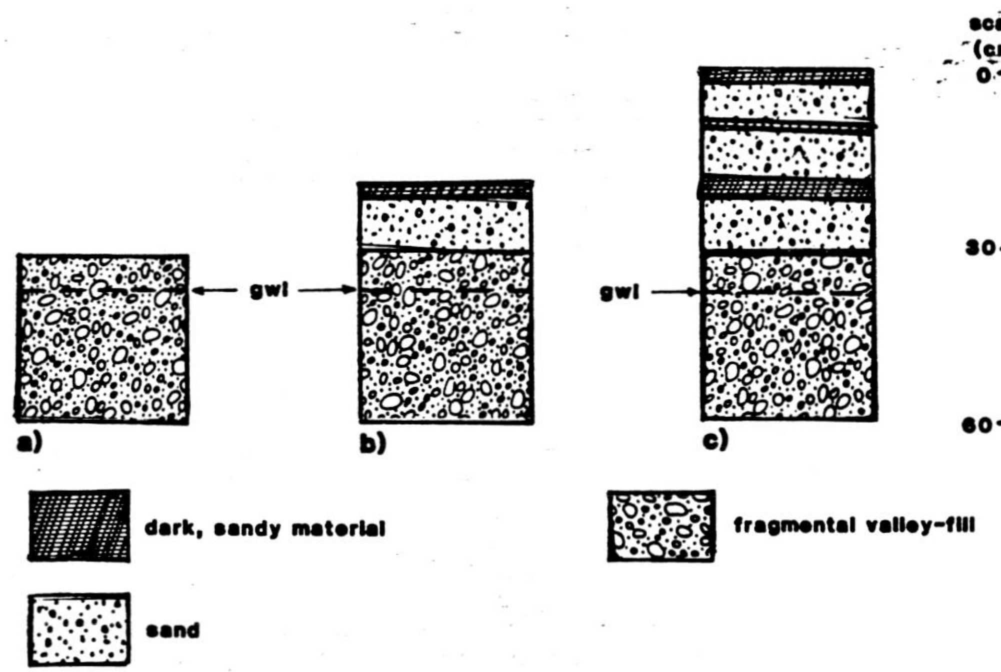


Figure 15—Progressive development of stream bar soils.

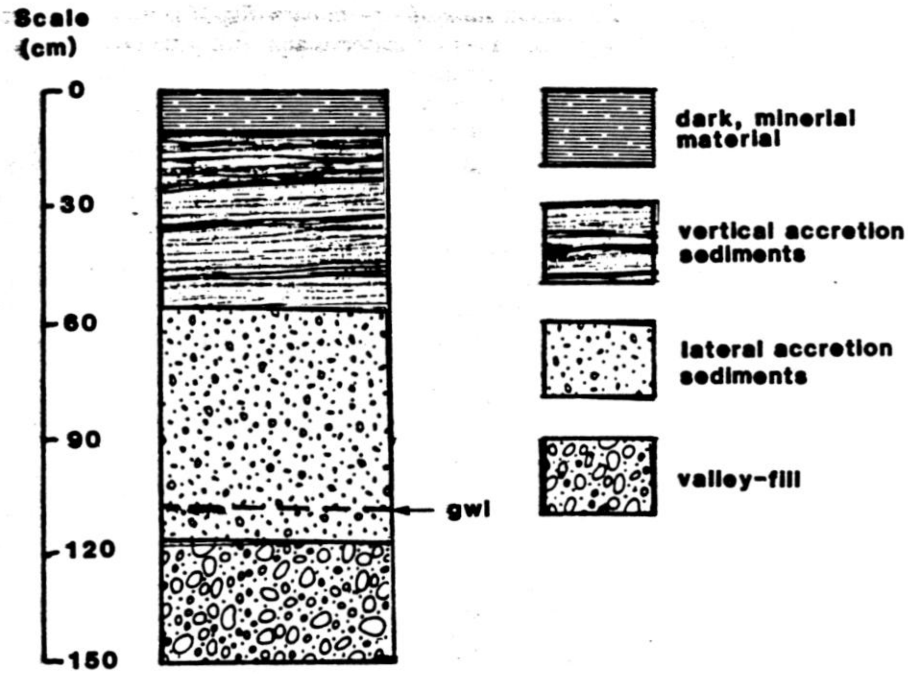


Figure 16—Soil morphology for a typical channel levee.

channels may result in expansive areas of remnant channel levees characterized by undulating or hummocky topography. Processes affecting the genesis and morphology of these soils include sedimentation and processes of in situ pedogenesis. The soil morphology typical of levee positions is depicted in figure 16.

Surfaces are often covered with a thin layer of litter from the previous year's vegetation. Surface mineral horizons are generally darkened by mineralized OM. Subtending horizons may indicate a single episode of vertical accretion, repeated episodes of lateral accretion, or a combination of both modes of deposition.

The apparent function of channel levees is to regulate the rate at which water is distributed across the flood plain during active flood stage. As stream levels rise, channels between convex hummocks fill and may result in dispersed routing of floodwaters to lateral positions of the valley bottom. Channels between hummocks also function to convey runoff from uplands to stream channels. Channel levees act to maintain the integrity of stream channels.

A reduction in vegetative cover may affect both the form and stability of levees. Intensive grazing by livestock, wildlife, or both results in broadening of channels and accentuation of hummocks. Reduction in shrub cover along streambanks may promote streambank sloughing and the formation of stream bars. Dense willow stands associated with stream levees are a favorite source of building materials for beavers.

Low-lying wetlands—These include divorced ox-bows, beaver ponds, channels, and backwaters and may occur anywhere in broad-valley systems. Alluvial ground water constitutes the primary hydrologic source for sustenance of these systems. The genesis of low-lying wetlands may be in response to inundation of drier sites through alteration of the geometry of alluvial aquifers or through the eutrophication of aquatic systems. The activity of beavers may result in localized alteration in the geometries of streams and associated alluvial aquifers.

Surface elevations are generally at or near gwl and forms are concave. Eutrophied aquatic positions in broad-valley systems are similar to bogs in headwater positions. As in headwater bogs, OM proliferation is a primary process affecting soil morphology. Sedimentation of fine-grained mineral materials is generally also apparent. Soil morphology common in low-lying wetlands of broad-valley systems is depicted in figure 17.

Soils of low-lying wetlands that were formed in response to inundation by alluvial ground water (fig. 17a) are typically composed of mineral soil materials or organic materials and are confined to thin surface horizons. What may be apparent is the influence of vertical accretion, lateral accretion, forms of in situ pedogenesis remnant of previous hydrologic

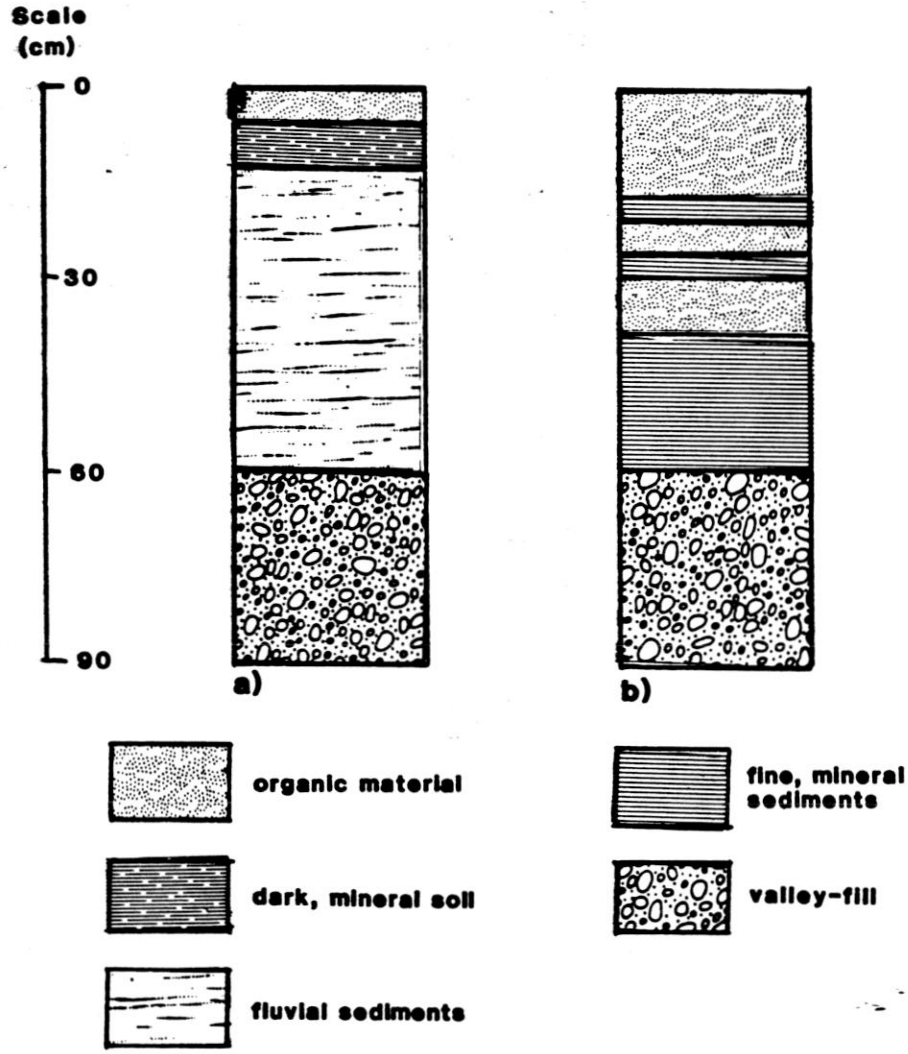


Figure 17—Soil morphology common in inundated low lying wetlands: (a) inundated position, (b) eutrofied aquatic position.

regimes, or all three. Mottles are common through the depth inundated, although gleyed colors associated with anaerobic conditions are uncommon.

Surface horizons of eutrophied aquatic positions (fig. 17b) are often composed of slightly to moderately decomposed organic material. The thickness and degree of OM decomposition in surface strata are primarily dependent upon the degree of saturation by alluvial ground water. Subtending strata are often alternating layers of fine-grained mineral and organic materials that indicate repeated inundation by low-velocity floodwaters and intervals conducive to OM proliferation. Subtending materials are dominantly fine-grained, often gleyed, mineral sediments. Fragmental valley fill normally underlies low-lying wetlands.

Low-lying wetlands function to regulate the discharge and quality of runoff entering streams. Eutrophied aquatic positions may discharge runoff directly to streams through small rivulets or indirectly through recharge of alluvial aquifers. Both modes of discharge effectively reduce sediment load of runoff entering stream systems. High levels of microbiological activity and organic products normally associated with eutrophied aquatic positions may also function to reduce the flux of organic and mineral nutrients entering stream systems through adsorption, chelation, degradation, and assimilation.

Given continued sedimentation and consequent vertical accretion of ground surfaces, the succession of these soils is toward more mesic conditions.

Seepy slopes within broad valleys are generally similar to those described for headwaters. The occurrence of these types corresponds with relatively consistent discharge areas of springs, seeps, or runoff from contiguous uplands. Seepy slopes occur to a more limited extent in broad valleys than in headwater systems.

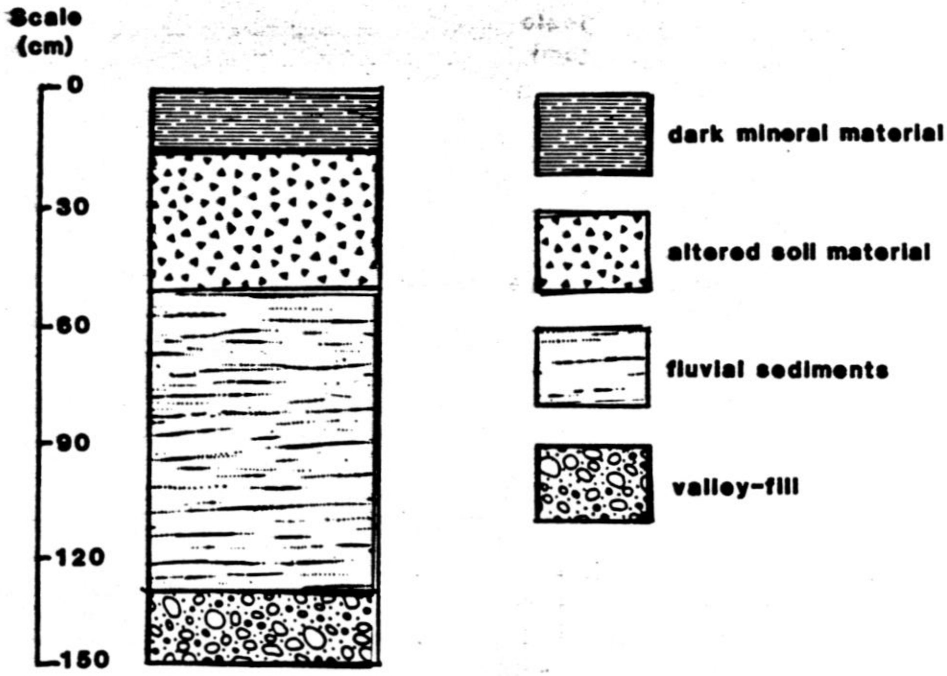


Figure 18—Soil morphology typical of mesic meadow positions.

Riparian meadows—These positions are common where alluviation from contiguous uplands or tributary drainages have affected flood plain geomorphology. Surfaces are generally slightly inclined toward the medial axis of the valley bottom and are smooth. These positions are wet throughout runoff periods but are seldom affected by stream flood waters. Processes apparent in the morphology of soils are those of in situ pedogenesis. The morphology of typical soil in mesic meadow positions is depicted in figure 18.

Morphological characteristics typical of mesic meadow positions are indicative of relatively advanced stages of pedogenic development. Common are relatively thick surface horizons darkened by accumulation of mineralized OM and aggregated into moderate to strong ped structure. The subtending stratum may be enriched by illuvial clay or aggregated into strong ped structure, or both. Undifferentiated alluvial material underlies altered horizons, if present. Alluvial material is generally unaffected by in situ forms of pedogenesis other than oxidation/reduction resulting from annual fluctuations in gwl. Valley fill underlies mesic meadows at a depth generally greater than 3 ft.

Riparian meadows constitute a final stage in progressive pedogenesis of riparian soils. Given continued alluviation from contiguous uplands and subsequent increase in depth to the gwl, these positions may develop soils and vegetation similar to those of uplands. More commonly, riparian meadows may regress to more fundamental riparian forms.

Erosion is the principal process responsible for regression of riparian meadows to more fundamental forms. Where adjacent to streams, the high banks associated with riparian meadows are extremely susceptible to sloughing. Grazing by domestic livestock increases the rate of streambank sloughing.

Soil Taxonomy

Soil taxonomy is a hierarchal system of classification developed by the Soil Conservation Service for making and interpreting soil inventories. A major purpose of the system is to differentiate taxa within a conceptual structure that promotes understanding of functional relationships: those between differing types of soils and those between soils and factors responsible for their character (USDA-SCS 1975). Diagnostic criteria for the classification are physical and environmental properties believed to influence or reflect genetic soil processes. The object of classification is the polypedon, an area of soil that differs in one or more properties from contiguous areas of the landscape to such a degree that the combination of all properties may result in different responses to management. While the polypedon is a tangible entity with distinctive size, composition, and structure, the taxonomy is a conceptual formulation based on apparent soil-forming processes.

Soil taxonomy defines six categories within the classification system. In order of decreasing hierarchal rank and increasing number of differentiae and classes, the categories are:

- order
  - suborder
    - great group
      - subgroup
        - family
          - series

Soil orders are based on morphological evidence of differences in the degree or type of dominant soil-forming processes. The current approximation of soil taxonomy distinguishes 10 soil orders. Names of soil orders may be recognized by the "sol" ending (Entisol, Mollisol, Histisol, and so forth).

The differentiae for suborders vary with the order and include important properties that influence soil genesis and plant growth. Currently, 47 suborders are recognized. Names of suborders have two syllables. The first syllable denotes the suborder differentiae and the second syllable the order.

At the great group taxonomic level, distinguishing criteria consider the collective nature of the soil. Soil moisture and temperature regimes are dominant factors of soil genesis and are properties of the whole soil rather than of specific horizons. About 185 great groups are currently distinguished in the United States. The name of a great group consists of the name of a suborder and a prefix that consists of one or two formative elements suggesting something about the diagnostic properties.

The categories of order, suborder, and great group emphasize evidences of processes that seem to dominate the course or degree of soil genesis. Subgroups designate classes that reflect subordinate processes that further affect the morphology resulting from more dominant processes. These subordinate processes may be dominant in higher categories of the taxonomy but, in a particular soil, only modify the marks of other processes. Three general types of subgroups are identified: (1) the central concept for the great group; (2) intergrades or transitional forms to other orders, suborders, or great groups; and (3) extragrades or soils with some properties that are not representative of the great group and do not indicate transitions to other higher categories.

The names of subgroups consist of the name of the great group modified by one or more adjectives. Subgroups representative of the central concept for the great group are designated as "typic." Intergrade subgroups are named by prefixing the adjective form of the name of the appropriate taxon to the great group name. Similarly, the names of extragrades consist of an adjective denoting the character of the aberrant property attached to the great group name.

Soil families are generally defined by particle-size distribution, mineralogy, temperature regime, and depth. These properties are important factors affecting water-handling characteristics, aeration, and management of soil.

The series is the lowest category of the hierarchal classification. Differentiae used for series are mostly the same as those used for classes in other categories, but the range permitted in one or more properties is less than is permitted in higher categories. Names of soil series are abstract place names generally corresponding to a place near where the series was first recognized. There is little value in applying the series category to classification of wetland soils, primarily due to the lack of defined series for Aquic suborders and subgroups. Although definition of series may be important for future designation of riparian soils, the present state of understanding does not merit the degree of resolution afforded by soil series.

Soil orders most common in riparian positions of the Northern Rocky Mountain Physiographic Province are Entisols, Mollisols, and Histisols. Criteria for the taxa (to the subgroup level) common in riparian positions of the Northern Rocky Mountains are summarized in table 8.

The following discussions of differentiating criteria cover discrete soil orders. Taxa discussed are common in riparian positions associated with low-order streams in mountainous regions of the Intermountain West but are not expected to be consistent in physiographic provinces other than the Northern Rocky Mountains.

Entisols—Entisols are young mineral soils (recent) characterized by the absence of diagnostic horizons indicative of advanced stages of soil genesis. The absence of pedogenic horizons may be a response: (1) to anaerobic environments that restrict chemically and biologically mitigated processes, (2) to inert parent material such as gravel and coarse sand

Table 8—Distinguishing taxonomic criteria to the subgroup level

Classification	Taxonomic Criteria
Order	**Order**
Suborder	**Suborder**
Great Group	**Great Group**
Subgroup	**Subgroup**
Entisols	No pedogenic horizons
Aquents	Saturated to surface
Cryaquents	Cool temperature regime
Typic	None
Fluvents	Deposited by periodic flooding
Cryofluvents	Cool temperature regime
Aquic	Saturated within 50 cm
Mollic	Epipedon of OM accumulation
Typic	None
Orthents	Other Entisols
Cryorthents	Cool temperature regime
Aquic	Saturated within 50 cm
Typic	None
Mollisols	Mollic epipedon (ep)
Aquolls	Saturated to surface at some time
Cryaquolls	Cool temperature regime
Cumulic	Epipedon >40 cm thick
Histic	Histic ep over Mollic ep
Typic	None
Borolls	Cool temperature regime
Cryoborolls	Cool temperature regime
Aquic	Saturated above 1 m
Argic	Illuvial clay accumulation
Argiaquic	Argic and Aquic
Cumulic	ep >40 cm thick (fluvial)
Pachic	ep >40 cm thick (colluvial)
Typic	None
Histisols	Organic soils
Fibrists	Least mineralized OM
Borofibrists	Cool temperature regime
Terric	Includes mineral horizon
Fluvaquentic	Two or more mineral horizons
Typic	None
Hemists	Moderately mineralized OM
Borohemists	Cool temperature regime
Terric	Includes mineral horizon
Fluvaquentic	Two or more mineral horizons
Typic	None
Saprists	Most mineralized OM
Borosaprists	Cool temperature regime
Terric	Includes mineral horizon
Fluvaquentic	Two or more mineral horizons
Typic	None

in stream bar positions, (3) to insufficient time as for recently deposited sediments, or (4) to active erosion proceeding at a rate equal to or greater than that of pedogenic processes. At the suborder level, Entisols are distinguished as Aquents, Fluvents, and Orthents.

Aquents are saturated at or near the soil surface for most of the growing season. The near-anaerobic conditions that characterize Aquents restrict mineralization of organic matter, flocculation of ped structure, eluviation and illuviation, oxidation, and precipitation of soluble minerals. Aquents are usually grey in color (reduced) and may include brightly colored, prominent mottles in surface horizons. Thin strata of relatively undecomposed (fibric) organic material are also common. At the great group level, soils are Cryaquents on the basis of having a cool soil-temperature regime. At the subgroup level, soils identified are mostly Typic Cryaquents. This rather broadly defined subgroup includes wet and cold soils with little evidence of advanced soil development.

Fluvents are Entisols with characteristics other than those of Aquents in which the organic carbon content decreases irregularly with depth. Fluvents include those soils with distinctly segregated horizons characteristic of repeated episodes of fluvial deposition. At the great group level, taxa are Cryofluvents.

Three subgroups of Cryofluvents are common. Aquic Cryofluvents are saturated within 20 inches of the surface for significant periods of most growing seasons. Aquic Cryofluvents are intergrades to Aquents. Mollic Cryofluvents are not saturated within 20 inches of the surface for significant periods and have a surface horizon appreciably darkened by mineralized organic matter. Although the color, structure, and base saturation of the surface horizon are definitive of a mollic epipedon, the thickness of the horizon is less than that required for Mollisols. Mollic Cryofluvents are intergrades to Mollisols. Typic Cryofluvents represent the central concept for the great group.

Orthents are Entisols with characteristics other than those described for other suborders, and they are normally restricted to positions transitional from riparian to uplands. Although sediments comprising Orthents may be alluvial in origin, they normally lack the distinctly stratified layers typical of soils formed by repeated fluvial deposition. At the great group level, taxa are Cryorthents. Subgroups identified are Aquic and Typic Cryorthents. Aquic Cryorthents are saturated within 20 inches of the surface for significant periods of the growing season, while Typic Cryorthents are not saturated and represent the central concept of the great group.

Mollisols—These soils are characterized by a horizon formed at the surface (epipedon) that is appreciably darkened by mineralized organic matter to the extent definitive of a mollic epipedon. Accessory properties of the mollic epipedon include recognizable ped structure and a cation exchange complex dominated by basic cations (Ca, Mg, Na, and K). At the suborder level, taxa common in riparian positions of the Northern Rocky Mountains are Aquolls and Borolls.

Aquolls are wet to the surface for some period of the growing season. Characteristics associated with wetness include distinct and prominent mottles at or near the base of the epipedon, matrix colors of low chroma that indicate a prolonged reducing environment, and ground water present at such a shallow depth that the capillary fringe reaches the soil surface (except in noncapillary pores). Because the genesis of the mollic epipedon requires aerobic conditions favorable to biologically mitigated mineralization of organic matter, the period of time the soil is saturated may be somewhat less than that of Aquents. The concept of Aquolls here includes a fluctuating ground water level, although the taxonomy is not explicit on this point. At the great group level, Aquolls have been identified as Cryaquolls based on soil temperature regime.

Three subgroups of Cryaquolls are common. Those with an overthickened mollic epipedon (greater than 16 inches thick) are Cumulic Cryaquolls. The overthickened epipedon may be the result of long-term organic matter production and concurrent mineralization and redistribution within the soil profile, or by concurrent rates of sedimentation approximately equal to those of organic matter production and mineralization. Histic Cryaquolls have an organic surface horizon overlying the mollic epipedon. Histic Cryaquolls are saturated to the surface for most of the growing season and are intergrades to the Histisol order. Typic Cryaquolls are definitive of the central concept of the great group.

Mollisols described for riparian positions that are not saturated to the surface for significant periods during the growing season are Borolls at the suborder level. Borolls are cool to cold and more or less freely drained. At the great group level, these soils are classified as Cryoborolls, denoting cold temperature regimes with short, cool summers. Genetic influences other than accumulation of mineralized organic material in the surface horizon are often not apparent.

Six subgroups of Cryoborolls have been identified in riparian positions in the Northern Rocky Mountains. Aquic Cryoborolls are saturated within 3 ft of the soil surface for greater than 90 consecutive days. Argic Cryoborolls have a subsurface horizon of illuvial clay accumulation. Argiaquic Cryoborolls have characteristics of both Aquic and Argic subgroups. Cumulic Cryoborolls have an epipedon thicker than 16 inches and an irregular decrease in organic carbon content with depth that indicates fluvial deposition. Pachic Cryoborolls have an epipedon greater than 16 inches thick and a regular decrease in organic carbon content with depth. The Pachic subgroup is common at the base of steep slopes, and the overthickened epipedon is the result of alluvial/colluvial deposition from upslope positions. Finally, the Typic subgroup defines the central concept of the great group.

Histisols—Histisols occur where organic matter proliferation dominates both the mineralization and erosional processes. The order is most commonly associated with seepy slopes and bog positions in glaciated headwaters and low-lying, concave positions in broad valleys. Histisols are uncommon in V-canyons.

Generally, Histisols are soils in which at least half of the upper 32 inches is greater than 50 percent organic material. The cumulative thickness criterion may be modified when organic material rests on rock or fragmental material. Subsequent classes are determined by the degree of organic matter decomposition, soil temperature regime, and presence or absence of mineral horizons. At the suborder level, soils common in riparian positions of the Northern Rocky Mountains are Fibrists, Hemists, and Saprists.

Fibrists are organic soils in which the botanic origin of the dominant organic material is recognizable. These are the least decomposed of organic soils and are generally permanently saturated in fibric horizons. Bryophytes and fibrous roots of monocot species are commonly the source of fibric OM.

Organic soils with intermediately decomposed OM are Hemists. The organic matter is of high fiber content, but the botanic origin of the material is generally not apparent. Hemic horizons are saturated most of the time when temperatures are greater than biologic zero.

Saprists are organic soils in which the dominant OM is almost completely decomposed. The fiber content is low, and the botanic origin is not apparent. A fluctuating soil-moisture regime or flowing ground water, containing sufficient dissolved oxygen for biologic oxidation processes, characterizes sapric horizons.

At the great group level, taxa are Borofibrists, Borohemists, and Borosaprists. The classifications are based on the cool (frigid) soil temperature regime. At the subgroup level, Histisols are Terric, Fluvaquentic, and Typic. Terric taxa have a mineral horizon 12 inches or more thick between 12 and 52 inches deep from the surface. Fluvaquentic subgroups have two or more thin (less than 12 inches thick) mineral horizons within 52 inches of the surface. This taxon is indicative of periodic fluvial deposition interspersed with interludes of organic matter proliferation. Typic subgroups do not have mineral horizons thicker than 2 inches within 52 inches of the surface and are the central concept for the great groups.

Family Differentiae for Mineral Soils—Particle-size class, mineralogy, and soil temperature regime are differentiae for mineral soils at the family level of classification. Particle size refers to the grain-size distribution of the whole soil and is not the same as soil texture, which refers only to particles smaller than 0.08 inch in diameter. The control section for which the particle size is defined normally extends from 10 inches to 3 ft below the surface, although the control section may be defined differently for soils with horizons of illuvial clay accumulation. Strongly contrasting particle-size classes within a single pedon may also be noted in the family classification. Detailed descriptions of particle-size classes, control sections, and criteria for strongly contrasting classes are discussed in chapter 18 of "Soil Taxonomy" (USDA-SCS 1975). Particle-size classes described in the Northern Rocky Mountains range from fragmental (stream bar positions) to fine, although most soils are coarse-loamy and fine-loamy. Particle-size classes are a direct response to the competence of the flowing water responsible for depositing the sediments.

Mineralogy classes are based on the approximate mineralogical composition of selected size fractions of the same control section that is used for defining particle-size classes. Alluvial material constituting flood plains may originate from contiguous uplands or from geological material located well upstream in headwater positions. Alluvial riparian soils are mostly of "mixed" mineralogy class. The class denotes materials with <40 percent of any single mineral type other than quartz or feldspar.

Soil-temperature classes are used as family differentiae unless the name of a higher category taxon carries the same limitation. Because the frigid temperature class is implied in all boric suborders and cryic great groups, repetition of temperature class at the family level is redundant and is thus omitted.

Three examples of family classifications for mineral soils common in riparian positions are:

1. Coarse-loamy, mixed, Typic Cryaquent.
2. Fine-loamy over sandy-skeletal, mixed, Aquic Cryoboroll.
3. Fragmental, mixed Aquic Cryofluvent.

Family Differentiae for Organic Soils—Family differentiae normally applied to organic soils in riparian positions include particle-size, mineralogy, soil temperature, and soil reaction classes. Particle-size modifiers are used only in Terric subgroups of Histisols. The number of particle-size classes used for organic soils is considerably less than for mineral soils, although criteria for the broader classes are identical to those defined for mineral soils. Similarly, application of mineralogy classes is normally restricted to Terric subgroups.

Rules for family designation of soil temperature classes are identical to those for mineral soils.

Reaction classes are used to indicate the pH of undried organic materials. Classes are (1) euic - pH is 4.5 or greater, and (2) dysic - pH is less than 4.5. Examples of family classifications of organic soils are:

1. Loamy, mixed, euic, Terric Borofibrist.
2. Sandy, mixed, euic, Fluvaquentic Borosaprist.
3. Dysic, Typic Borohemist.

Soil Description

Soil descriptions serve as a basis for taxonomic classification and for interpretations as to use and management. A complete explanation of standards and guidelines for conducting soil descriptions is given in chapter 4 of the "Soil Survey Manual" (USDA-SCS 1981). Field descriptions often require considerable qualitative and quantitative judgment on the part of the investigator. Judgments should be calibrated at frequent intervals, especially when investigators have little experience in taxonomic soil description. While field descriptions may be of sufficient detail and accuracy for classification and general interpretation, analytical laboratory tests may be necessary for validation and for specific interpretations. Standard forms for conducting soil descriptions are presented in appendix 3 of this publication.

Summary

Soil genesis is a response to climatic, hydrologic, and biologic processes acting upon geologic material. Geomorphic position, relative to fluvial and alluvial ground water geometries, is a primary factor determining the rate and degree to which processes affect the soil system. A history of processes affecting riparian ecosystems is evident in the morphology of soils.

Biologically mitigated processes often dominate the genesis of soil in glaciated headwater positions. Surface horizons on seepy slopes are generally organic soil material. Bogs in concave headwater positions may be organic soil material to depths greater than 6.6 ft. These positions function to reduce sediment flux to lower drainage positions. Management of headwater positions should be designed to maintain hydrologic sources responsible for sustenance of riparian ecosystems and to limit disturbances that may lead to drainage.

Fluvial erosion and alluvial/colluvial sedimentation are principal processes in V-canyons. Coarse-textured soils containing high volumes of rounded or angular rock fragments characterize fluvial and alluvial/colluvial positions, respectively. A significant reduction in upstream discharge may result in degradation of these systems through relatively fine-grained sedimentation and debris jams.

A dynamic equilibrium between fluvial erosion and sedimentation characterizes undisturbed broad-valley systems. Stream bars, channel levees, low-lying wetlands, and riparian meadows are distributed in response to geomorphic position relative to alluvial and fluvial ground water geometries. Management resulting in disturbance of the equilibrium between erosion and deposition or a change in drainage characteristics may result in alteration of the distribution or the proportional area of distinct riparian types in broad-valley ecosystems, or in both distribution and area.

Riparian areas are open systems that function to regulate the flux of water, sediments, and nutrients between upland and aquatic ecosystems. The genesis of undisturbed riparian ecosystems is toward conformity between form and function. The structure and function of unique riparian types, as expressed in soil morphology, are a response to the same processes that they function to regulate. Interpretations of soil morphology may be useful for developing management alternatives for riparian ecosystems.

REMOTE SENSING

Remote sensing is the collection and analysis of information about lands and resources, using a device not in physical contact with the lands or resources. Remote sensing includes techniques ranging from analysis of satellite, Side Looking Air Borne Radar, and thermal infrared scanning data, to interpretation of aerial photography.

The size and shape of riparian areas can often be determined from satellite digital analysis or interpretation of small-scale airphotos. However, large-scale airphotos at scales ranging from 1:1,000 to 1:4,800 are needed to interpret detailed information on streams and riparian vegetation. The 1:1,000 scale is best for ease of photo interpretation and good resolution, but it is difficult to achieve stereo coverage at 1:1,000 scale due to 9 × 9 film recycling speed and safe, low-level aircraft speed. The compromise scale of 1:2,000 is acceptable and achievable.

Color infrared photographs (CIR) are especially valuable for vegetation analysis. Color tones, along with shape, size, pattern, shadow, texture, and site, are used to identify individual trees and shrubs in riparian areas. Color infrared film can be overexposed by ½ f stop to penetrate clear water in streams and lakes (Cuplin 1978).

Types of riparian vegetative information that can be collected on the ground are vegetative type and subtype; width of riparian area; species composition of shrubs, trees, grasses, and forbs; the amount of bare soil; plant density; condition class; reproduction; trend; structure; and potential.

Interpretation of large-scale air photos combined with ground truthing produces a list of variables that can be readily studied: vegetation type and subtype, width of riparian vegetation zone, riparian area acreage, structure, percent ground cover of trees, shrubs, and herbaceous vegetation, percent bare soil, and density of large shrubs and trees. Stream variables that can be measured from air photos are stream width, stream channel stability, streambank stability, flood plain width, and stream shade.

Subtle changes in riparian vegetation are difficult to detect on air photos. Conversely, catastrophic changes due to flooding can be easily monitored and the amount of riparian area loss readily calculated.

Application of Large-Scale Photos for Inventory and Monitoring

Ground sampling or familiarity with the riparian vegetation photographed is essential for accurate photo interpretation. Vegetation transects and tree-shrub circular plots are transferable in general terms to large-scale photos. Trees and some shrubs can be readily identified by species; grasses and forbs cannot be readily identified by species.

Variables that may or may not be photo-interpreted from 1:2,000 scale color infrared air photos combined with on-the-ground data collection are as follows:

Variable	Photo interpreted or calculated
Vegetation type and subtype	Yes
Riparian area width and acreage	Yes
Plant species composition	
Trees	Yes
Shrubs	Yes, some shrubs such as willow and baccharis
Grasses	No
Forbs	No
Ground cover (in percentage)	
Trees	Yes
Shrubs	Yes
Herbaceous vegetation	Yes
Bare soil	Yes
Density	Yes, large trees, some shrubs such as cottonwood and willow
Reproduction	Yes, young trees and shrubs but not seedlings
Condition class	No
Trend	Yes, as related to change in the amount of ground cover and bare soil
Potential	No
Structure	Yes, height of trees and shrubs
Streambank shade	Yes
Stream width	Yes
Flood plain width	Yes
Streambank stability	Yes
Streambed silt	Yes
Stream channel stability	Yes

Baseline

The original large-scale air photos of a riparian area provide an overview of existing conditions in terms of the readily interpreted variables. Subsequent photos over time provide the means of detecting change. Subtle change due to below- or above-normal precipitation may not be as evident as the catastrophic change caused by a 100-year flood.

The most easily detected subtle change in a riparian area would be a reduction in foliar cover and an increase in bare soil. This change may be obvious upon inspection of the baseline photo compared with the monitoring photo taken 5 to 10 years later. The cause of the change may be answered only by on-the-ground inspection. Thus, the photos offer the opportunity to monitor change but do not provide the cause.

Ground Data Collection

Ground data sites should be accessible and representative of the riparian vegetation and stream conditions. One site per stream may be sufficient for a 1- to 3-mile stream segment for air photo interpretation. If there are significant differences in a stream segment, additional data collection sites should be established.

On-Site Data Collection

The first step in on-site data collection is to take color print 35-mm photographs of the stream riparian area (upstream, across stream, and downstream) at the site where the air photo target is placed. Then a stream inventory should be conducted along one-tenth mile of stream segment. Dominant and subdominant herbaceous vegetation, shrubs, trees, and percent bare soil are then determined. Additional field notes may assist in photo interpretation.

Acquisition of Large-Scale Aerial Photographs

Most photo interpretation can be accomplished with a minimum of equipment. The 9- by 9-inch photos, which are easy to work with, are identified by date, fiducial marks, agency, photo scale, state symbols, roll number, and exposure number. Photos can be easily filed and extra prints ordered as needed for field use. The 9 by 9 format photo covers approximately 52 acres or 1,500 ft^2 at a scale of 1:2,000. At this scale riparian areas on first, second, and third order streams are easily photographed with a good margin of upland vegetation.

Assistance on an air photo acquisition should be sought from a remote sensing coordinator. A Bureau of Land Management publication "Aerial Photography Specifications" (USDI, BLM 1983) is available from the Branch of Remote Sensing, Denver Service Center, Denver, CO. This publication provides detailed specifications for acquiring aerial photographs via contract. The photographer should be provided a U.S. Geological Survey quadrangle map that shows the beginning and end of each stream-riparian area to be photographed. Flight lines on the maps will indicate to the photographer the direction of airplane travel and midpoint and width of each flight line according to the photo scale that is requested.

Although the 9 by 9 format is preferred, there are now procedures that allow acquisition of 35-mm aerial photos for small riparian areas. These procedures would not be suited for large riparian-stream areas unless the photographer is very experienced and the topography conducive to aerial photography. The procedure uses a hand-held 35-mm camera and small bubble-type helicopter to acquire the photographs (Meyer and others 1982). The right door of the helicopter is removed to allow for near-vertical photographs.

Monitoring Procedures and Area Management

Using the large-scale photos and the ground data baseline inventory, the researcher or manager identifies the riparian-stream segment and describes the segment's existing conditions. Resource needs and concerns are then identified.

After identifying the objectives and goals for the area, the manager then needs to determine where improvements can be made and changes can be measured, such as increasing the amount of ground cover, narrowing stream width, or increasing the number of trees and shrubs.

Variables

Variables that can be used to easily detect change are:

1. *Ground cover*—An increase or decrease in ground cover, such as trees, shrubs, and herbaceous vegetation, and in bare soil can be detected by visual observation of large-scale air photos.

2. *Stream width*—This can be easily measured on large-scale air photos and is an early indicator of improving or degrading stream conditions. Stream width increases under heavy livestock grazing and narrows during the recovery period of no livestock grazing.

3. Stream channel and streambank stability.

4. Riparian area width and acreage.

Sample Size

The sample size used to determine change should be large enough to represent the changes that have occurred. A representative site can be identified on both baseline and monitoring air photos.

Results

If results are uncertain, other comparative areas should be analyzed. Managers need to determine if objectives were achieved from the changes detected.

WATER COLUMN MEASUREMENTS

The water column is the medium of support and movement for fish and other aquatic organisms and is strongly controlled by its bordering riparian vegetation. This vegetation reduces water velocity, which in turn reduces the erosion of banks and channels by increasing column and channel roughness. The amount of sunlight, which is the energy base for photosynthesis and stream temperature, is also controlled by the surrounding vegetation.

Vegetative Canopy Closure and Density

The concave spherical densiometer, model B (Lemmon 1956a and b) can be used on permanent points or transects to estimate relative vegetative canopy closure or canopy density caused by vegetation (fig. 19). Vegetative canopy closure is the area of the sky over the selected site (stream channel) bracketed by vegetation. Canopy density is the amount of the sky blocked within the closure by vegetation. Canopy closure can be constant throughout the season if fast-growing vegetation is not dominant, but density can change drastically if canopy vegetation is deciduous.

The concave mirror surface of the densiometer has 37 grid intersections forming 24 squares. At a probability level of 95 percent, tests show that average measurements of the same overstory area can be expected to be within ±2.4 percent of the mean (Lemmon 1956a and b). Because the instrument has a concave reflecting surface resulting in a field that includes lateral as well as overhead positions, an overlap of side readings occurs when readings are taken from the same point. To account for this bias, the modifications developed by Strichler (1959) are used and modified to better measure canopy closure and density. Strichler uses only 17 of the line intersects as recording points by taping a right angle on the mirror surface as shown in figure 19. Closure and density can be recorded on any selected site. Because the canopy over the stream is so important, the stream is used as an example of the densiometer's use.

For Stream Orders 1 Through 4—The densiometer is held in the hand on the transect line perpendicular to the right streambank 12 inches from and 12 inches above the shoreline. A tripod can be used for more accurate measurements. The arm from the hand to the elbow is horizontal to the water surface. Reasons for this position are: (1) it is easier to

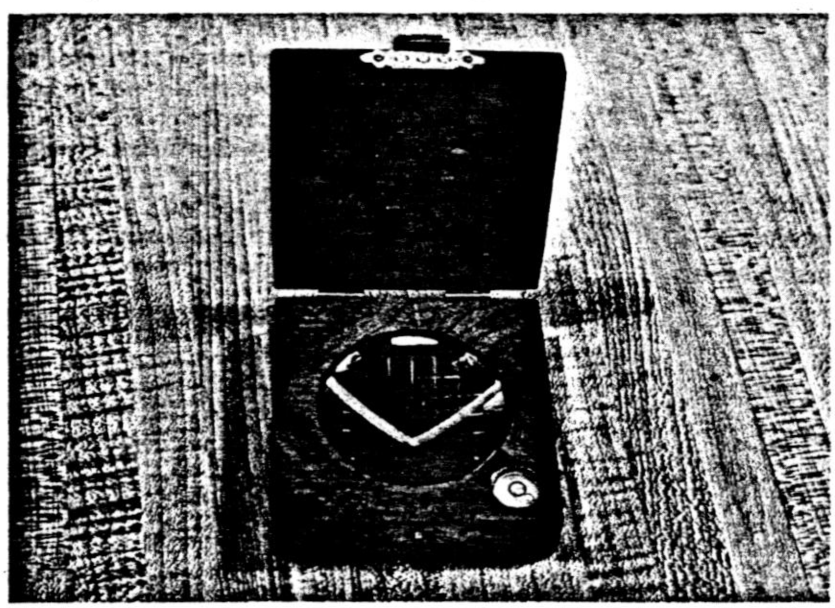


Figure 19—The concave spherical densiometer, model B.

read the densiometer than if it were held directly on the bank; (2) the point of measurement can be repeated; (3) the cone of overhead observation is more directly overhead and takes in only a small area beyond the bank; (4) low overhead canopy overhanging the water column within 12 inches of the water surface has significant fishery cover benefits; and (5) the identical measurement settings eliminate parallax bias.

The densiometer is held away from the observer with the bottom of the V pointed toward the recorder. The observer's head reflection should almost touch the top of the grid line. Room is left to observe all points at the 12 o'clock position at the top grid line (fig. 20). The densiometer must be kept level using the level bubble. The grid between the V formed by the tape encloses 17 points. The number of points (line grid intersects) that are surrounded by vegetation (canopy closure) or are intercepted by vegetation (canopy density) are counted within the V outlined area (maximum of 17). Each horizontal-vertical line intersect (point) has a value of 1.5 percent when four different recordings are made on streams of order 4 or less. On stream order 5 and larger where eight recordings are required, each point has a value of 0.75 percent.

The same procedure used previously on the right bank is used on the transect line in the center of the stream, one recording taken facing upstream and one facing downstream. The densiometer is held level over the transect line 12 inches above the water surface. The last reading is taken at the left shoreline. Readings have then been taken that simulate each of the four cardinal directions.

The points counted for each reading are totaled and multiplied by 1.5 to obtain the percentage canopy closure or canopy density, whichever is desired. The average of all closures or density measurements on all transects on the stream reach being studied are

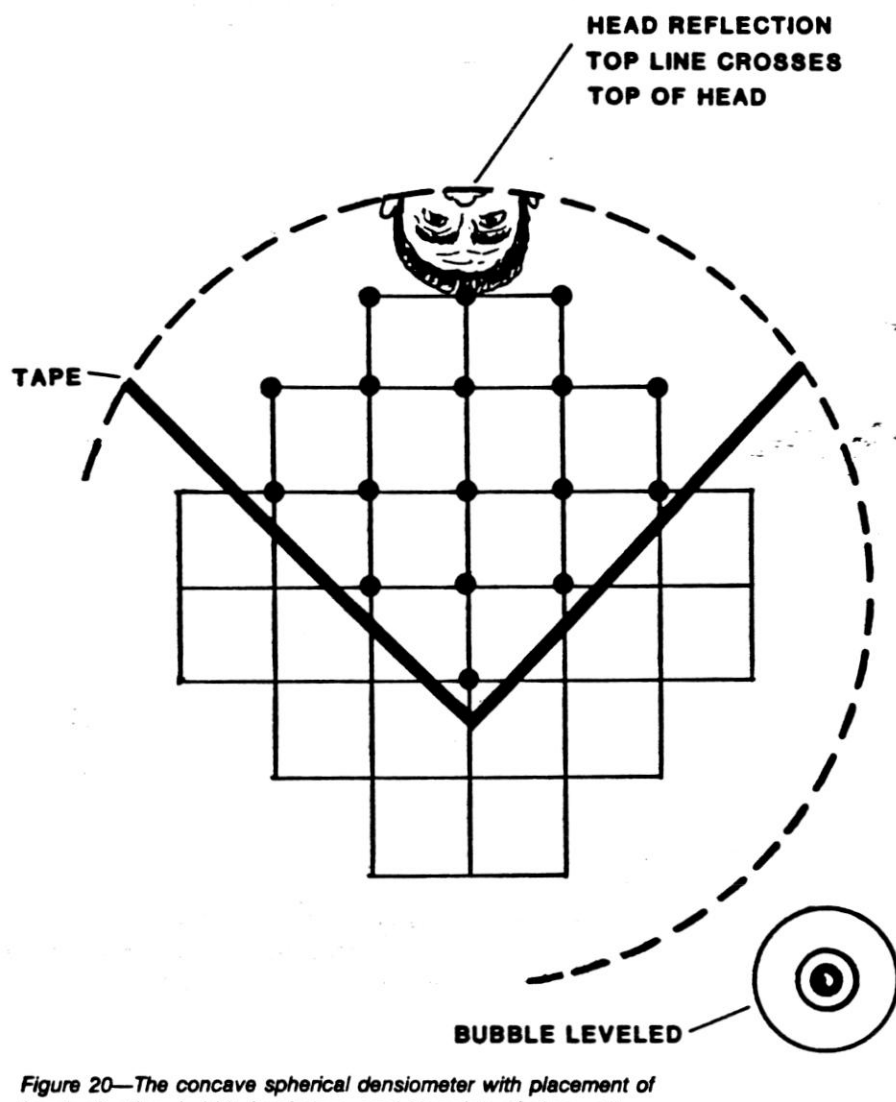


Figure 20—The concave spherical densiometer with placement of head reflection, bubble level, tape, and 17 points of observation.

totaled and averaged to obtain the overall closure or density measurement. Then, 1 percent is deducted from scores between 30 and 65 percent, and 2 percent for those scores over 66 percent. No deduction is made for scores between 0 and 29 percent.

Stream Orders 5-7—The same procedure is used as in stream orders 1 through 4, except that eight recordings are made on these wider streams. This is required so that the two stream shore readings do not overinfluence the midchannel readings. The streambank readings are done the same as for stream orders 1 through 4. Two readings are taken at each quarter, half, and three-quarter interval across the transect. One reading is taken facing upstream and the second one downstream, identical to the readings explained previously for the midpoint of the transect. The eight recordings are totaled and multiplied by 0.75 to obtain percentage closure or density. Then 1 percent is deducted from scores between 30 and 65 percent, and 2 percent for those scores over 66 percent. No deduction is made for scores between 0 and 29 percent.

Light Intensity

Measuring light intensity provides a means of estimating how effective the canopy is at shading the stream. This method is easy to use, requires no instruments, and is often accurate enough for estimating intensity of sunlight under vegetation canopies (Wellner 1979). The method works best under tight canopies that exert little filtering effect on the passage of light, such as coniferous trees. But it can also work under deciduous vegetation during full-leaf conditions. This method works best where the light pattern beneath the canopy is essentially a mosaic of patches of full sunlight and deep shade. If these conditions are not met or if more precise measurements are needed, the solar integrator or canopy density techniques should be used.

Light intensity is evaluated as follows:

Light conditions	Intensity rating
Direct sunlight	100
Filtered sunlight	50
Shade	7

Measurements are made visually on randomly selected transects using a white disc 3 inches in diameter. The light intensity is measured at each shore, each quarter point, and at the midpoint of selected transects on small streams of orders 1 through 4. For larger streams, more measurements will be needed to properly represent the transect. At least 100 observations (one observation is one single measurement) are collected from the area studied to account for variation between observations. For year-to-year comparisons, the light readings should start at the same time (say, 1100 hours) and end at the same time (say, 1300 hours) during the same period each year. Light intensity is measured only when the sun is clearly visible, only between the hours of 1100 and 1300, and during the period solar energy is the most influential (usually July and August).

The determination of average light intensity through the study area is made by multiplying the percentage of the total number of observations that were full sun by 100, the percentage of the total that were filtered sunlight by 50, and the percentage of the total shaded measurements by 7, and then dividing the sum by 100.

$$\text{Mean light intensity} = \frac{A(x) + B(y) + C(z)}{100}$$

where:

A = percentage of "full sun" observations
B = percentage of "filtered sunlight" observations
C = percentage of "shaded" observations
x = 100 (full sun)
y = 50 (filtered)
z = 7 (shaded).

For example, suppose that 10 percent of the total observations were direct sun, 25 percent were filtered sun (partial shade), and 65 percent were completely shaded. Mean light intensity would then be:

$$\text{Mean light intensity} = \frac{(10)(100) + (25)(50) + (65)(7)}{100}$$

$$\text{Mean light intensity} = \frac{2,705}{100}$$

$$= 27.05 \text{ or } 27 \text{ percent of full sunlight}$$

Wellner (1979) used a similar method (identical except Wellner did not use a filtered category) in coniferous forested canopies for comparison with the Shirley radiometer on 18 sample plots. The results showed no difference greater than 6 percent of full sunlight; 15 were less than 3 percent different and six were less than 1 percent different. For most field studies, this method will therefore produce fairly reliable results.

Stream Surface Shading From Surrounding Vegetation

Interception of the sun's rays by riparian vegetation strongly influences stream temperatures. Techniques are therefore needed to determine or predict the heat the stream receives and the effects that existing or potential riparian vegetation would have on solar heat transfer.

Quigley (1981) has developed a deterministic model that represents a theoretical approach to the estimation of stream surface shade during the most critical periods of the year. His approach can be applied to any specific stream reach for any given hour, day, month, or year, to determine the percentage of the water column being shaded. For management purposes, it is usually only necessary to determine heat input and output during critical periods. The computer program in appendix 6 makes this complicated analysis simple and fast, but the procedure that follows can also easily be performed in the field with a hand-held calculator.

Stream surface shade varies with stream, vegetation, and shading characteristics. The determination and description of each characteristic are necessary before stream surface shade can be estimated. Overstory vegetation, mountains, cliffs, undercut banks, and logs or brush lying across streams must be considered in determining the amount of shade. This technique covers only the influence of overstory vegetation. The other shading components can be accounted for by using the solar integrator technique discussed later.

Stream Characteristics—Average stream width (W) and the average distance of the shading vegetation to the stream shore (Y) need to be determined (see table 9 for variable definitions). The stream orientation angle (R) is determined from U.S. Geological Survey quadrangle maps using the directions from figure 21. Characteristics can vary between streambanks. Therefore, each bank should be treated separately if this difference is large or if one streambank creates most of the shade because of stream orientation (east-to-west-flowing streams may have the south bank contributing all the shading).

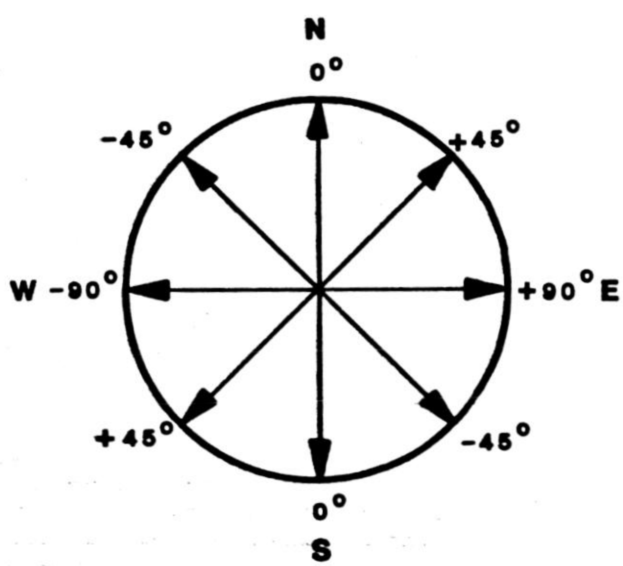


Figure 21—Stream orientation in degrees.

Table 9—Definitions of variable measurements

Stream Characteristics
1. Stream width (*W*) = the average wetted width of the stream surface through the stream reach evaluated.
2. Vegetation to stream distance (*Y*) = the average distance from the base of the vegetation to the stream's edge.
3. Stream orientation (*R*) = the degrees the stream deviates from a north to south orientation. If the orientation is toward the east, it is positive; toward the west, it is negative. The range is between 0 (north to south) to 90° (east to west). Some streams are oriented such that the sun may rise and set on the same side of the stream during part or even all of the year. For example, an east-to-west flowing stream bordered by high vegetation could be shaded during the entire winter.
Vegetation Characteristics
4. Overstory (vegetation) height (*T*) = the average maximum existing or proposed height of the streamside shading vegetation in the reach being analyzed.
5. Vegetation density (*D*) = the average screening of incoming sunlight by the shading vegetation. Density accounts for both the continuity of vegetation along the streambank and the filtering effect of leaves and stands of vegetation along the stream. For example, if only 50 percent of one side of the stream has vegetation and this vegetation actually screens only 50 percent of the sunlight, then the vegetation density for this side is only 0.25.
6. Crown measurement (*C*) accounts for vegetation overhang. It is the average of the maximum diameter of the vegetation immediately adjacent to the stream. The crown measurement for hardwoods is the crown diameter; for softwoods it is the crown radius to account for their tapered form.
7. Vegetation offset is the average distance of the vegetation stems or trunks from the water's edge. Together with crown measurement, the net overhang vegetation is determined
Shadow Characteristics
8. Shadow length = a function of the height of vegetation and the angle of the sun's rays (T (tan Z)).
9. Zenith angle (*Z*) = the angle of the sun's rays when measured from the vertical and varies according to time of year (declination of the sun, *d*), time of day (hour angle, *h*), and latitude (*L*) according to the relationship: $\cos(Z)$ zenith angle $= \sin(L)\sin(d) + \cos(L)\cos(d)\cos(h)$
10. Declination of the sun (*d*) = the angle of the sun's rays hitting the surface of the earth. The time of year directly predicts the angle of the sun above or below the equator. The angle increases in the Northern Hemisphere from December 21 to June 21 and decreases from June 21 through December 21.
11. Hour angle (*h*) = the angle of the sun as related to longitude. The sunrise/sunset hour angle is a measure of time expressed as an angle, between solar noon and sunrise/sunset. At noon, local standard time, the sun is directly overhead (0°). Hour angle gets progressively larger (positive) from noon as the sun moves toward evening. At sunrise it has its largest daylight negative angle, and the angle progressively approaches 0 as the sun approaches solar noon. Solar noon is when the sun is at its zenith.
12. Latitude (*L*) = the angular distance north and south of the equator measured in degrees or a measure of the angle between horizontal surfaces along the same longitude at the equator and at the site. Latitude is readily obtained from many sources, such as U.S. Geological Survey quadrangle maps. Latitude is used by the in-stream water temperature model with the time of year to track the sun.
13. Azimuth angle (*A*) = the orientation of the shadow from south. This angle is a function of time of year, time of day, and the zenith angle. At solar noon, the azimuth angle is zero; between sunrise and solar noon, it is negative; and between solar noon and sunset, it is positive. Therefore, all streams that reach azimuth angles are between −90° and +90°. If the stream meanders greatly, then the analysis can be separated into multiple steps (subreaches) and the results combined for a weighted stream-reach shade average. The stream azimuth is important to orient the shadows with respect to the water surface. The east side of the stream is always on the left side because the azimuth is always measured looking south for streams located in the north latitudes. Note that an east-west oriented stream dictates the east or left side by whether the azimuth is a −90° (left-hand is the north side) or +90° (left-hand is the south side).
14. Altitude angle = the vertical angle from a level line at the streambank to the general top of the local terrain when looking 90° from the general stream-reach azimuth. There are two altitude angles—one on the left and one on the right side of the stream. The altitude is 0 for level plain topography and greater than 0 for hilly or canyon terrain. The altitudes for opposite sides of the stream are usually different. The solar shade model allows for separate altitudes for both sides of the stream. This angle can be obtained easily either from field measurements or from spot-check calculations using U.S. Geological Survey topographic maps and is used to determine local sunrise and sunset times.

Vegetative Characteristics—The average height of the overstory vegetation (T) causing the shading, the vegetative density (D), and the crown width (C) of the shading vegetation must be determined. Vegetative density is measured using the same methods discussed earlier under canopy closure and density measurements. The crown width is the crown diameter for brush and hardwoods, and the crown radius for conifers. The crown measurement accounts for that area of the overhead vegetative canopy that creates shade in the stream direction.

Shadow Characteristics—Shadow length (fig. 22) is determined from the height of the vegetation causing the shade and the angle of the sun's rays intercepted by this vertical vegetation, called the zenith angle (Z). Shadow length is equal to the vegetative height multiplied by the tangent of the zenith angle—$T(\tan Z)$. The tangent, sine, and cosine functions can easily be obtained with a scientific hand-held calculator.

The zenith angle varies according to the time of year depending on the declination of the sun, d (table 10), the time of day depending on hour angle, h (table 11), and the increasing angle as the sun's apparent location is shifted either direction from solar noon.

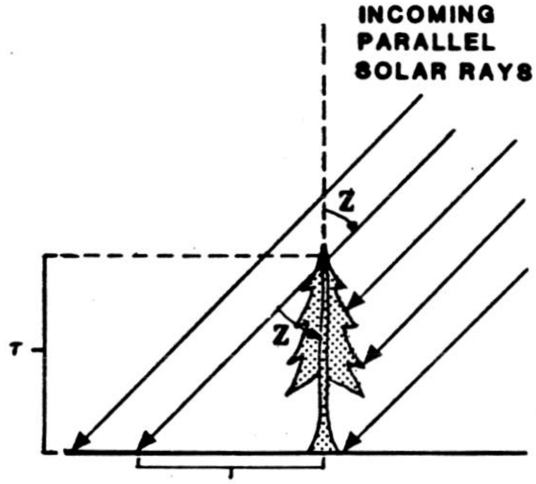


Figure 22—Zenith angle (Z) and shadow length.

Table 10—Approximate solar declination, d, for various dates (Quigley 1981)

Date	d(°)	Date	d(°)
Mar. 1	−8	July 1	23
Mar. 21	0 (vernal equinox)	July 15	21
Apr. 1	4	Aug. 1	18
Apr. 15	9	Aug. 15	14
May 1	15	Sept. 1	9
May 15	19	Sept. 21	0 (autumnal equinox)
June 1	22	Oct. 1	−3
June 21	23 (summer solstice)	Oct. 15	−8

Table 11—Hour angle (h) for 0800-1700 local standard time (Quigley 1981)

Local standard time	h(°)	Local standard time	h(°)
0800	−60	1300	15
0900	−45	1400	30
1000	−30	1500	45
1100	−15	1600	60
1200	0	1700	75

Stream Surface Shade Model—The percentage of the stream surface that is shaded when vegetation is continuous is determined by:

$$\text{Percent of stream surface shaded} = \left(\frac{100}{\text{mean stream width}}\right) \times \left[\left(\text{Shadow length}\right) \times \left(\text{Angle of shadow}\right) - \left(\text{Distance from shore that shadow begins}\right)\right]$$

and to account for the density of the streamside vegetation:

$$\text{Percent of actual stream surface shaded} = \frac{(\text{Vegetative density}) \times (\text{Percent stream surface shaded})}{100}$$

and in alphanumeric functions:

$$P = \left(\frac{100}{W}\right) \times \left[T\,(\tan Z)\,(\sin A - R)\right] - \left(Y - \frac{C}{2}\right)$$

$$S \text{ (by day, hour, period, etc.)} = \frac{D \times P}{100}$$

where:

P = percent shaded
W = average stream width
T = average overstory height
Z = zenith angle
A = azimuth angle
R = stream orientation
Y = vegetation to stream distance
C = crown radius or diameter.
D = canopy density.

Applying the Shade Model—The percentage of the stream shaded over a given stream section can be estimated at any time or period of time for any specific dates (table 12). For example, shade cover to protect stream temperatures may be most needed during the thermally critical periods of July and August, between the hours of 1100 and 1600. By determining the percentage of the stream being shaded each hour within this period, summing, and dividing by the number of separate determinations (in this case, 5), the mean stream surface shade (S) can be determined for the period (table 12). Further, the percentage of stream surface shaded can be determined for selected dates throughout the year to determine the most critical shading periods. The procedures are explained more thoroughly in the following example.

Given:

1. Average stream width (W) = 25 ft (use either meters or feet, but be consistent throughout the calculations).
2. Average streamside vegetative density (D) = 40 percent.
3. Average overstory vegetative height (T) = 30 ft.
4. Average vegetation to stream distance (Y) = 5 ft.
5. Hardwoods crown diameter (C) = 20 ft.
6. Average stream orientation (30° west of south) (R) = 30°.
7. Latitude (L) = 42°N.
8. Sun declination on August 1 (d) = 18°.
9. Date of analysis is August 1 at 1000 hours, h = 30°.

Procedures:

Step 1 - Determine zenith angle. It is easier to obtain this angle from prepared table 12; if tables are not available, calculate as follows:

$$\begin{aligned}\text{Cos (zenith angle)} = {} & \text{(sin latitude)(sin solar declination)} \\ & + \text{(cos latitude)(cos solar declination)} \\ & + \text{(cos hour angle)}\end{aligned}$$

Table 12—Zenith and azimuth angles and percent stream shade for the example stream at lat. 42° N. on August 1 (Quigley 1981)

Hour	Hour angle (°)	Zenith (°)	Azimuth (°)	Stream shade (pct)
1000	−30	35	−56	40
1100	−15	27	33	30
1200	0	24	0	19
1300	15	27	33	9
1400	30	35	56	23
1500	45	45	72	40
1600	60	56	84	40
Mean				29

$Z = (\sin 42°)(\sin 18°) + (\cos 42°)(\cos 18°) + (\cos -30°)$.

$Z = 35°$ for 1000 hours.

Repeat by determining Z for each hour angle for 1100 to 1600.

Step 2 - Determine azimuth angle. It is easier to obtain these angles from prepared tables, but they can be calculated as follows:

$$\text{Sin (azimuth angle)} = \sin A = \frac{(\text{cos declination}) \times (\text{sin hour angle})}{\text{sin Zenith angle}}$$

$$\sin A = \frac{(\cos 18°) \times (\sin -30°)}{\sin 35°}$$

Azimuth angle = −56° for August 1 at 1000 hours.

Repeat for each hour between 1100 to 1600.

Step 3 - For August 1 at 1000 hours:

$$\text{Percent shaded area } (P) = \left(\frac{100}{W}\right) \times \left[T\,(\tan Z)\,(\sin A - R)\right] - \left(Y - \frac{C}{2}\right)$$

$$P = \left(\frac{100}{25}\right) \times \left[30(\tan 35°)(\sin -56° - +30°)\right] - \left(5 - \frac{20}{2}\right)$$

$P = 100$

then

$$\text{Actual stream surface shaded } S_{(1000)} = \frac{D \times P}{100}$$

$$S_{(1000)} = \frac{(0.40)(100)}{100}$$

$S_{(1000)} = 40$ percent

Do the same for each hour from 1100 to 1600. The amount of the stream surface shaded = $S = 29$ percent.

Stream Surface Shading From Topographic and Vegetative Features

An in-stream water temperature model that predicts stream temperatures by computer analysis and that is more accurate than the ones discussed previously has been developed by Theurer and others (in 1984). The computer model can predict average daily and diurnal temperature fluctuations throughout a drainage system. The model differentiates stream shading from both topographic and vegetative features and relates this to effects on stream temperature. The overall model evaluates solar radiation as a function of latitude, time of year, basin topographical characteristics, and prevailing meteorological conditions. The solar shade factor portion of the model is a part of the computer program in appendix 6.

The solar shade factor is a combination of topographic and riparian vegetative shading as modified from Quigley (1981). Topographic and riparian vegetative shading is distinguished for each side of the stream. The analysis is modified to include the intensity of the solar radiation throughout the entire day.

Topographic shade dominates the shading effects because it determines the local time of sunrise and sunset at the site. Riparian vegetation is important for shading between sunrise and sunset only if it casts a shadow on the water surface. Topographic shade is a function of (1) time of year, (2) stream reach latitude, (3) general stream reach azimuth, and (4) topographic altitude angle. (See fig. 23.) The riparian vegetative shade is a function of (1) height of vegetation, (2) crown measurement, (3) vegetation offset, and (4) vegetation density. (See table 9 for definitions.) The model allows for conditions on each side of the stream to be evaluated separately and combines topographic and riparian shade to get total shade.

The Model—The solar shade model is calculated in two steps. First the topographic shade is determined according to the local sunrise and sunset times for the specified time of year. Then the vegetative shade is calculated between the local sunrise and sunset times. The vegetative factors consist of four basic vegetative values: crown measurement, height, offset, and density.

The model determines level-plain and local sunrise and sunset times, which then allow topographic shade to be computed. The model then keeps track of time and the amount of shadow cast throughout sunlight time for the sun side(s) of the stream; this allows vegetative shading to be determined. The two combined constitute the total shading. The model determines the actual solar radiation intercepted by all obstacles and expresses shade factors as a ratio of the intercepted amount to the total amount.

Model Solution—The program was developed for the HP-41C desk-top portable computer and appears in appendix 6. The shade program allows the user to specify up to 12 time periods and the physical, topographic, and vegetative shade factors for up to three reaches at a time. Independent physical shade factors are expected for each side of the stream. Of course, if there is no essential difference between sides, the same factors may be used for each side.

For each requested period and reach, the solar shade program predicts the time averaged: (1) local combined sunrise/sunset altitude, (2) topographic shade factor, (3) riparian shade factor, and (4) total shade factor.

The five necessary stream geometry input data for each reach are latitude, stream azimuth, average stream width, topographic altitude angle, and riparian vegetation.

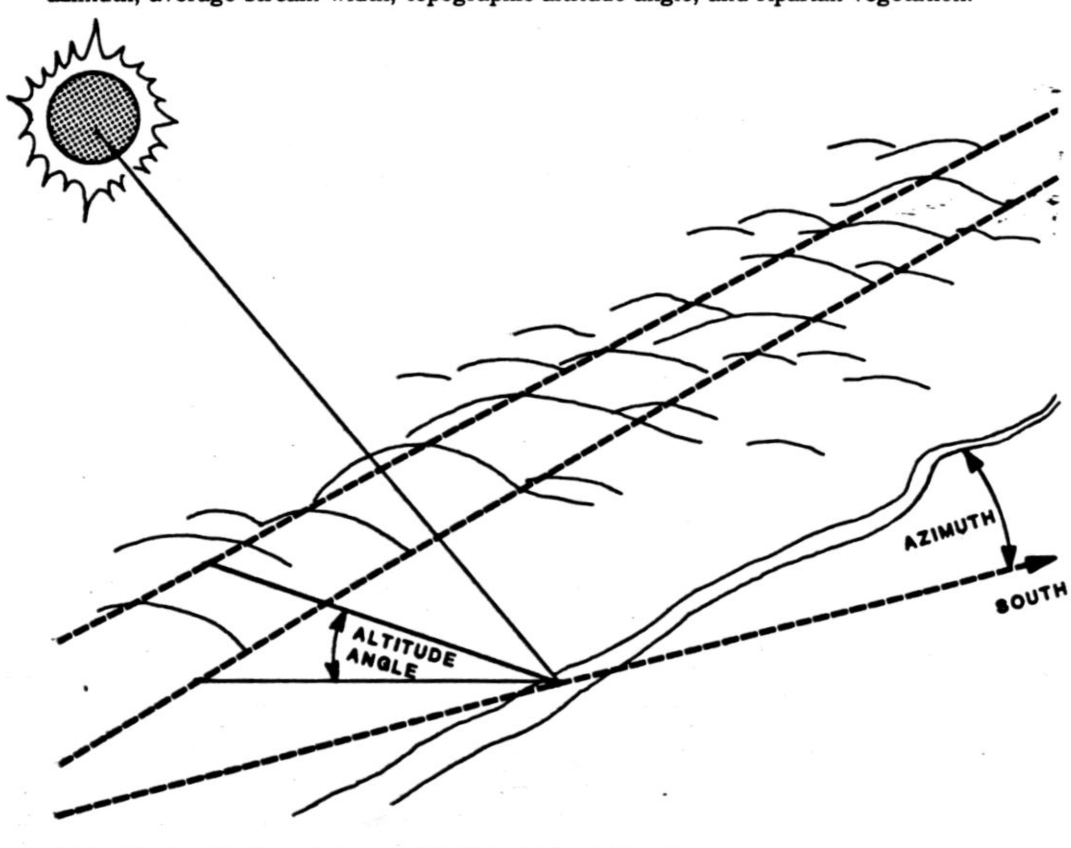


Figure 23—Local solar and stream orientation angular measurements (from Theurer and others 1984).

The observer has control over the selection of time periods. The user can select predefined periods by months or can define a period that better meets the needs of the study. The user can select which single month or group of months (month loop) but must also specify what daily increment is to be used. Obviously, 1-day increments are the most precise but are not always warranted. If the user selects the daily period option, then only one period grouping can be used at a time, but the daily increment is still selected.

The observer can also select whether to use an annual distribution of vegetative density or select the actual density directly for each reach for a given period. If the annual distribution option is selected, the user must provide the yearly minimum and maximum values for each reach and stream side. The model calculates the actual value as a function of the Julian day. The minimum is assumed in the winter, the maximum in the summer. Leaf-out in the spring and leaf fall in the summer are also assumed. If the density for each selected reach is chosen, then no variation in time is assumed for that particular run.

The solar shade program is interactive and prompts for all input. The variable name list in table 13 defines each input/output variable involved. During the input sequence, numbers appear as a part of the variable name. They pertain to the reach identification number. East and west bank designations are referenced according to the stream azimuth, looking south regardless of the direction of the flow. Therefore, the left side is always the east bank and the right side is the west bank. This is still true for a due-east orientation (azimuth of −90°); the left or north side, by convention, is designated the east bank.

The procedure to use the solar shade program is:

1. Clear the HP-41C
2. Execute "SIZE 101"
3. Load the solar shade program
4. Execute "ASN S O L S H A D Σ+"
5. Execute "SOLSHAD"
6. Repeat step 5 as needed.

Model Run Example—A stream reach is located at lat. 42°30′ N. and is oriented from true northeast to southwest at 30°20′ azimuth. The valley is mountainous with a topographic altitude—analogous to Quigley (1981) zenith angle—of 25° on both sides. The above measurements were obtained from U.S. Geological Survey quadrangle maps and have been confirmed in the field. The field trip determined that the west side was farmed leaving no riparian vegetation, but the east side was heavily forested with large evergreen trees along the stream. The average crown measure was 19.7 ft, stream width was 32.8 ft, the offset vegetative distance was 4.9 ft, the average tree height was 19.7 ft, and the left bank had only 20 percent open spaces. Because the trees were several stands deep from the bank, 100 percent of the sunlight was filtered. Because the riparian vegetation consisted of evergreens that were several stands deep from the bank, the vegetative density was assumed to be a constant 0.80.

Table 13—The variable name list in typical sequential order

		Input
LAT	=	latitude, degrees·minutes
AR	=	stream reach azimuth, degrees·minutes
B	=	average stream width, meters
aTE	=	east side topographic altitude, degrees·minutes
VCE	=	east side crown measurement, meters
VHE	=	east side height, meters
VOE	=	east side offset, meters
VDE	=	east side density, decimal
aTW	=	west side topographic altitude, degrees·minutes
VCW	=	west side crown measurement, meters
VHW	=	west side height, meters
VOW	=	west side offset, meters
VDW	=	west side density, decimal
		Output (time period averages)
aS	=	local combines sunrise/sunset altitude, degrees·minutes
ST	=	topographic shade factor, decimal
SV	=	riparian vegetation shade factor, decimal
SH	=	total shade factor, decimal

Table 14—Program output from the shade model example

Month		Sunrise/set altitude	Shade factor (decimal)		
Name	No.	(deg.min)	Topo.	Veg.	Total
May	5	21.31	0.0911	0.2950	0.3862
June	6	20.53	.0838	.2719	.3557
July	7	21.14	.0872	.2838	.3711
Aug.	8	21.55	.1019	.3151	.4170
Sept.	9	21.29	.1281	.3430	.4711

The fisheries specialist is interested in water temperatures because steelhead trout (*Salmo gairdneri*), spring chinook (*Oncorhynchus tshawytscha*), and fall chinook spawn in the stream. The specialist also needs information from May through September and is willing to use monthly time periods with 2-day increments. The HP-41C printer displays the input sequence and the corresponding output. The output is summarized in table 14. While the output varies from May to September, there is not a large variation between successive months. Therefore, the 2-day increment was valid and probably could have been increased to 3 or even 4 days to reduce computation time.

Solar Heat Inputs Using the Solar Pathfinder™

Direct solar radiation, reflected radiation from the channel and water, atmospheric temperature, and riparian reflection are the major sources of heat absorbed by water. Of these, the most important to streams, and the one most under our control, is the proportion of solar radiation intercepted by vegetation as modified by local topographic features.

Evaluating the effects of stream surface shading by vegetation or topographic features requires tracking the shadows cast throughout the solar energy receiving period. Only shadows that intercept the water surface are of immediate interest. The procedure used must account for the obstacle intercepting the sunlight and the length of the shadow this obstacle casts over the water. The two methods discussed previously will determine the contribution of overstory vegetation to stream surface shade, but they are time consuming and can involve some laborious mathematical solutions. Another, simpler approach is to use the Solar Pathfinder™. Part of this section is taken from "The Solar Pathfinder™—The Energy Evaluator," a manual from Solar Pathways, Inc., 7800 Highway 82, P.O. Box 914, Glenwood Springs, CO.

The Solar Pathfinder takes a theoretical approach to integrating all of the effects of azimuth, topographic altitude, height of vegetation, sunrise/sunset angle, latitude, time of year, and hour angle, to determine the influences of solar radiation (see Solar Pathways, Inc. 1983). The Solar Pathfinder allows all the vegetation and topography contributing shade to be permanently recorded at any time and displayed immediately. One recording documents the solar radiation input into the stream over the entire year, by month, half-hour intervals, or any other timeframe of interest. A record of all obstacles providing shade is obtained and can be compared with future readings to evaluate shading changes over time.

Description—The Solar Pathfinder consists of a transparent dome that reflects a clear panoramic view of the area around the site. This allows the shading objects to be identified and mapped. A built-in compass and bubble level permit orientation of the instrument. A pivoting base on a tripod allows the instrument to be used at heights that best fit the user. Worksheets are provided to facilitate a quick estimate of the absolute energy available to enter the stream surface using known radiation values. Monthly sunrise and sunset times, sunrise and sunset directions, interim shading patterns, and the energy-loss consequences of each shadow cast can then be determined.

Operation—The image of surrounding obstacles is viewed by looking directly down into the dome of the instrument (fig. 24). The sun need not be shining to use the instrument; if it is the operator may stand at any position around the dome using his or her shadow to cover the dome so as not to stare at the sun's reflected image on the dome surface. Staring at the sun's image can be harmful to the eyes and should be avoided. If the observer's shadow falls across the area to be measured, this area can be profiled by changing the observer's position and, if needed, shading the sun spot area with the hand. Only that area of the dome in the site panorama that coincides with the measurement area on the Sunpath Diagram™ is needed for analysis.

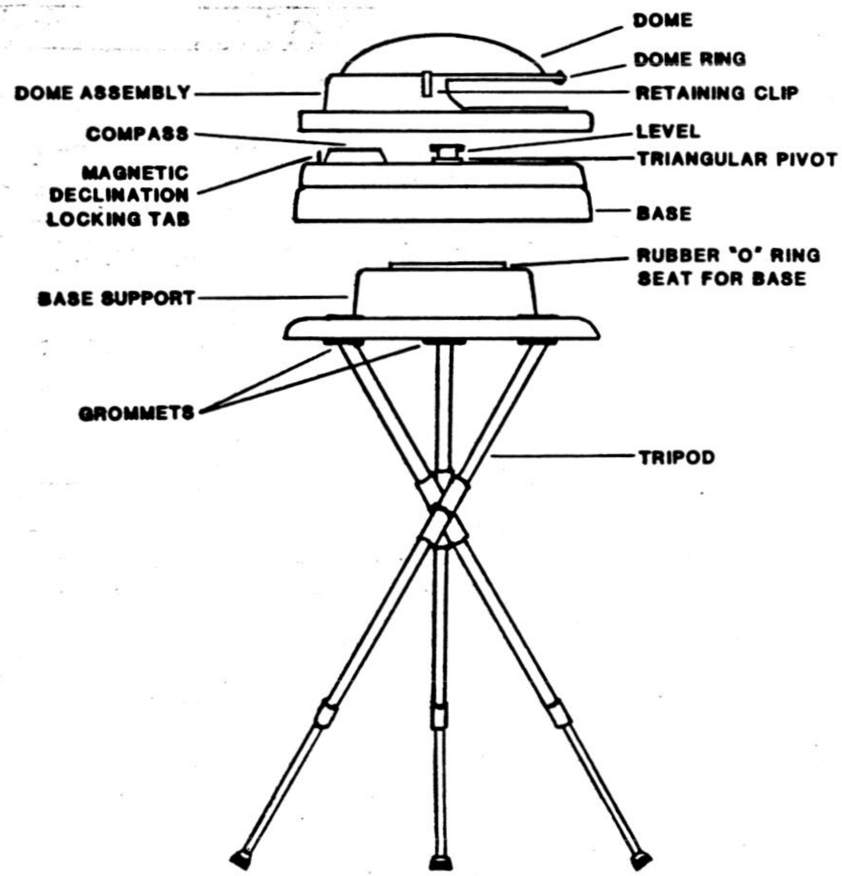


Figure 24—A schematic drawing of the Solar Pathfinder™ with parts identified.

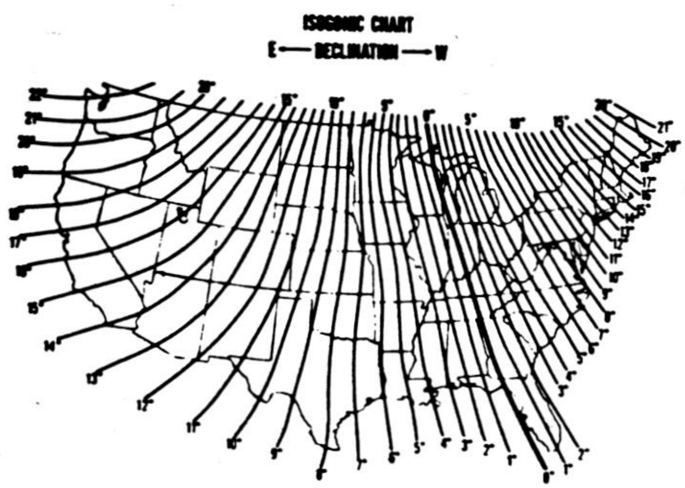


Figure 25—Isogonic chart for the conterminous United States.

The Solar Pathfinder diagrams have been prepared to correspond to the latitude requirements of the selected study areas. Therefore, the proper diagram must be used.

A monthly Horizontal Sunpath Diagram is inserted on the operating face. The instrument must be referenced to true south, in contrast to magnetic south. This is accomplished using a built-in declination adjustment. This setting is subject to accidental change and should be checked frequently. The adjustment (declination) between true and magnetic south can be determined from figure 25. The Solar Pathfinder has a bubble level within the base support. Once level, the south-seeking compass needle is pointed directly at the south reference point.

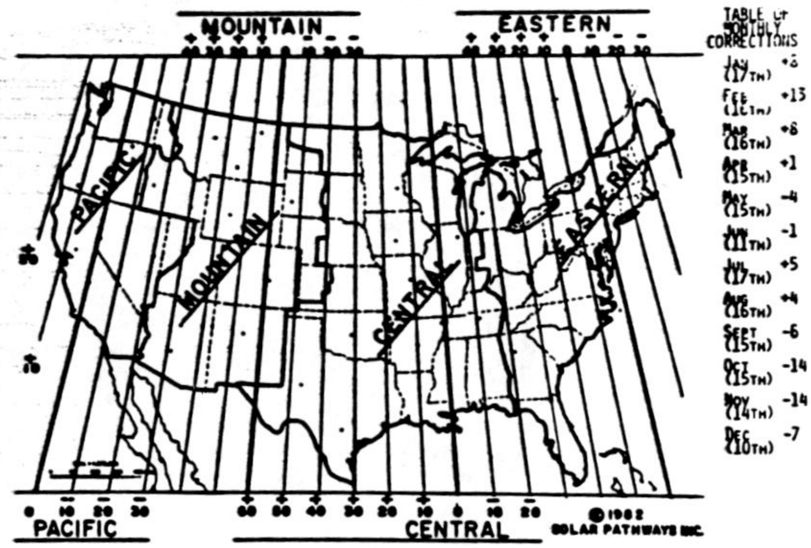


Figure 26—Corrections needed in minutes to correct solar time to standard time. Standard time is equal to solar time plus or minus the two corrections (monthly and longitudinal).

The Sunpath Diagram allows the recorder to plot the solar interceptor profile that is used to obtain percentage solar availability for an average day, hour, or half-hour during any given month. Viewing from between 12 and 18 inches above the dome, and within 10 to 15 degrees of the vertical centerline, provides acceptable accuracy. Shading obstacles are mapped through coincident sighting of the reflected image from the outer surface of the dome with the image on the diagram card. Clouds are not considered an obstruction.

The monthly Horizontal Sunpath Diagram contains a sunpath arc for each of the 12 months and a solar time grid. To change solar time to standard time, two corrections are needed, one for time of year, and one for minutes of time from the Standard Meridian for a given time zone (fig. 26). For example, in San Francisco in November, solar time from the Pathfinder is 3:20 p.m. and the monthly correction (from the right hand edge of fig. 26) is −14 minutes, while the longitudinal correction (from map portion of the same figure) is +10 minutes. Therefore, Pacific standard time is really 3:16 p.m., a difference of 4 minutes. One hour is subtracted to convert to daylight savings time.

Data Collection and Calculation—The boundary between the unobstructed sky and all intercepting objects that appear on the horizon is traced in white grease pencil on the diagram. To avoid breaking the white lead, a light tracing is made under the dome and darkened later after removing the diagram from the dome.

The average percentage of monthly total radiation that will fall on the selected area is taken directly from the diagram (the small white numbers on the monthly curves). The solar radiation received at the site is estimated by adding the unshaded (unobstructed sky) half-hour numbers across the arc of the selected month or group of months or by subtracting these shaded numbers from 100 percent (fig. 27).

In the example in figure 27, during the month of July the numbers in the obstructed, or "under horizon" portion, are equal to 8. One hundred minus 8 means 92 percent of the potential solar radiation was reaching the site if canopy density was 100 percent. Using table 15 for Boise, ID, in July, the average British thermal units (Btu's) of heat per square foot per day available to the water (a horizontal surface) are 2,611. Then 2,611 × 92% = 2,402, so 2,402 Btu's were available to each square foot of surface water on the average each day in July. The Btu conversion table takes into account relative humidity and sunshine-cloud ratio. These tables are available for areas throughout the United States.

Interpretation—Streams, because of turbulence, usually experience mixing of waters from top to bottom. Thus, water temperatures are considered uniform throughout any given cross-section at any given instant for most streams. But canopy density can change with the seasons (such as leaf drop), canopy closure can change with land-use activities (such as logging and grazing), and the average afternoon air temperature is greater than the daily air temperature. Such potential modifying factors must be taken into consideration in the interpretation of the data collected. In addition, different streams are suscep-

Figure 27—An example of the border between the sky and vegetation and topography interceptor areas as related to the monthly sun-path arcs.

Table 15—Some examples of energy values hitting horizontal surfaces by month by selected sites (Btu/ft²/day)

Site	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Boise, ID (Lat. 43.6)	485	839	1,303	1,825	2,275	2,461	2,611	2,195	1,736	1,137	628	437
Cedar City, UT (Lat. 37.7)	881	1,179	1,634	2,091	2,466	2,704	2,502	2,240	1,967	1,459	992	785
Elko, NV (Lat. 40.8)	689	1,034	1,462	1,899	2,302	2,532	2,622	2,314	1,892	1,322	812	616
Missoula, MT (Lat. 46.9)	312	574	981	1,382	1,781	1,932	2,326	1,880	1,357	812	409	267
Pocatello, ID (Lat. 42.9)	539	881	1,370	1,819	2,279	2,478	2,598	2,238	1,768	1,202	689	476
Pullman, WA (Lat. 46.7)	454	671	1,095	1,681	1,998	2,529	2,603	2,035	1,578	944	542	354
Reno, NV (Lat. 39.5)	800	1,149	1,648	2,158	2,521	2,700	2,690	2,404	1,996	1,430	911	705
Rock Springs, WY (Lat. 41.6)	734	1,088	1,530	1,943	2,343	2,573	2,546	2,238	1,832	2,186	826	650
Salt Lake City, UT (Lat. 40.8)	638	988	1,453	1,893	2,361	2,559	2,588	2,253	1,842	1,293	787	570
Spokane, WA (Lat. 47.7)	314	606	1,040	1,494	1,917	2,082	2,356	1,941	1,434	840	397	255

tible to different limiting factors at different times. Some streams may lose fish biomass because they are too cold in the winter (anchor ice and ice flows), while other streams may lose fish biomass because they heat too much during the critical parts of the summer. Therefore, timing can play an important role. The Solar Pathfinder allows you to stratify or select those specific periods in which the data are needed to make a temporal or instantaneous analysis of the effects of solar radiation or even an estimate of the riparian canopy available to produce organic energy (such as leaf fall) to the stream.

Topographic shade dominates the amount of shade a stream receives because it determines the time of sunrise and sunset with respect to the stream surface. We usually have little control over topographic features. The riparian vegetation is usually the most important shading feature between sunrise and sunset that we have some control over.

Evaluating Critical Periods—To evaluate the effect of riparian vegetation on intercepting solar or reflected radiation during critical periods, the sun's path must be determined. The path must then be related to the interception of the sun's rays by surrounding riparian vegetation to determine the effects of any proposed use or treatment. For instance, if logging were proposed in a riparian area, the location and amount of solar energy-intercepting-vegetation proposed for removal needs to be determined so that changes in the amount of solar radiation reaching the stream can be evaluated to determine tradeoffs on a before-the-fact basis. This means that the topographic-vegetative boundary image drawn on the Solar Pathfinder diagram must be refined to include the typing of the solar energy interceptor (obstacle). Thus, the types and the effectiveness of the solar blocking obstacle can be identified.

The topographic-vegetative profile plotted in figure 28 is further stratified into its solar interceptor types, and each interceptor type rated as to its ability to intercept all of the solar rays. Topographic features (streambanks, mountains, and so forth) usually have a density of 100 percent with respect to sunlight penetration. The riparian vegetative density is obtained from canopy density measurements described previously.

In figure 28 for the January sunpath arc, in which back-reflected radiation may be more important than direct solar radiation, the direct average solar radiation reaching the stream surface is (2 + 4 + 5 + 6 + 7 + 8 + 8 + 9 + 9 + [8 × 0.1] + [8 × 0.1] + [7 × 0.1] + 6) = 78.3 percent. At Boise, ID, in January, there are 485 Btu's being received per square foot per average day. So each square foot at the site would receive an average of 380 Btu's per square foot per day. A more detailed analysis (not appropriate here) would be needed to determine whether the incoming radiation under a canopy of this type is more important in the winter than the back-reflection of heat (especially during nighttime conditions or under a much denser canopy where the stream surface would only be receiving 10 percent of the available solar energy).

In July, the direct average solar radiation reaching the stream would be 93.2 percent. If this stream were susceptible to temperature problems, little relief would be obtained from existing riparian vegetation. Measures may therefore need to be implemented to increase the amount and height of the streamside vegetation.

A more refined analysis of the vegetation can be made in certain situations, such as logging, to better determine which trees or groups of trees are being eliminated from the riparian habitat and what effects on solar radiation their removal might have. Furthermore, the user may want to identify the gaps in riparian vegetation along the selected sun arc to determine what method would best fill these gaps. While this may be done directly from the diagram cards, it may help the evaluation considerably to also evaluate these gaps directly in the field. This can be done by using a clinometer in conjunction with the Solar Pathfinder angle estimator diagram (fig. 29). This grid gives a direct reading for azimuth (degrees east or west of true south) and altitude or the elevation above the point on the horizon you are considering. The radial lines measure azimuth and the concentric lines measure altitude. Both are recorded in degrees.

Because each hour of time passes through 15 degrees of azimuth, it is easy to write the time of day (solar time) directly on the diagram. For example, 0 degrees or straight south would be 12:00 noon. At 15 degrees east it would be 11:00 a.m., and so on. The same approach is used to record the time by azimuth as the sun moves west of 12:00 noon. Thus, for any given time, the horizontal direction of the sun is quickly determined from the Solar Pathfinder angle diagram.

The true position of the sun at any given time can be determined by merely plugging in the altitude of the sun for any selected day, at any selected latitude, for any given time from tables found in meteorological books in local libraries. A fairly accurate approximation can quickly be obtained (for the monthly average only) by overlaying a reversed negative (so the black portion of the diagram becomes transparent and you can see through it) of the Pathfinder Sunpath Diagram.

Using the first method of getting the altitude from the tables, the user only has to line up the clinometer with the correct azimuth angle and shoot the correct altitude angle (see table 16). That point selected by the clinometer is where the sun would be on that certain time and day. This allows the user to plot the path of the sun during the critical period. For instance the pathway could be visually plotted on August 1 between the hours of 10:00 a.m. and 2:00 p.m. when 48 percent of the total daily radiation would be hitting the surface of the water.

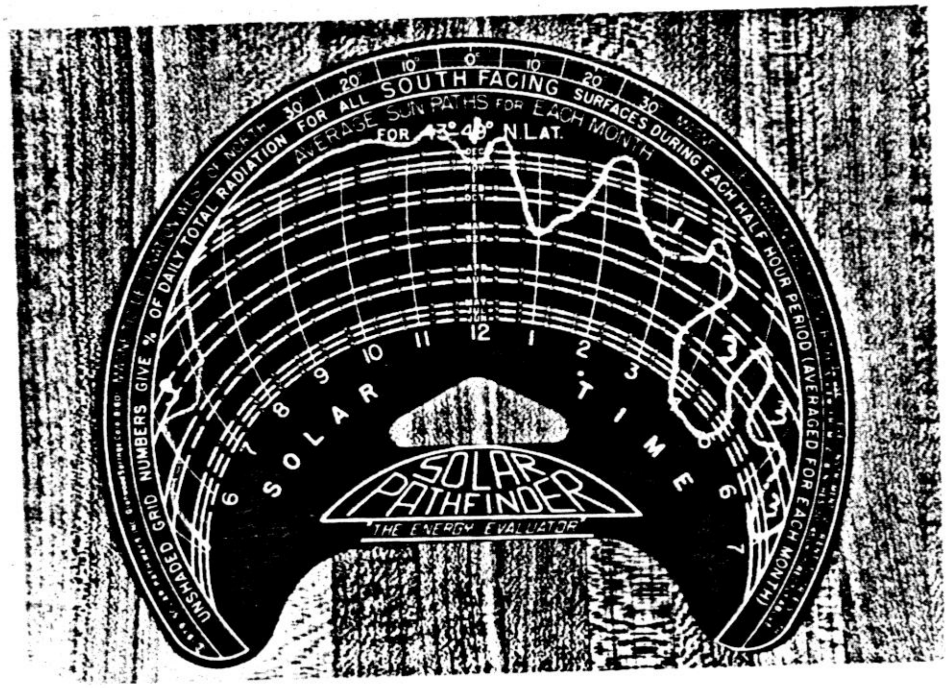


Figure 28—The sky-obstacle border with topographic (1), conifers (2), and deciduous (3) classified as to density. (1 = 100% winter and summer, 2 = 90% summer and winter, 3 = 80% summer, 45% winter.)

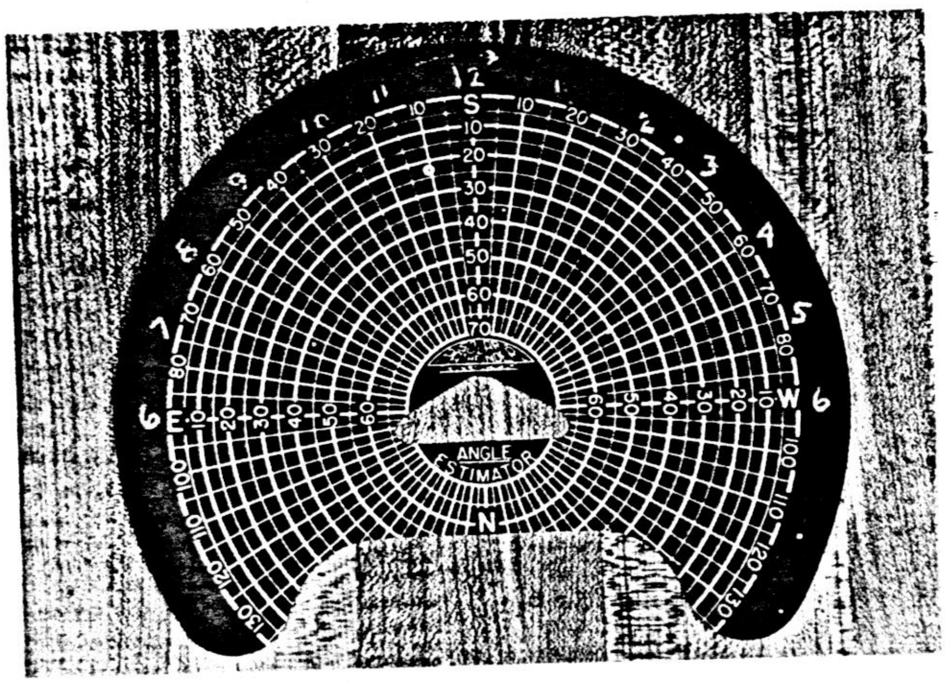


Figure 29—The Solar Pathfinder™ angle estimator graph with solar time recorded on it.

Thus, the observer could visualize what the consequences would be if trees or brush intercepting the sun's path were cut or burned. In addition, the observer could better visualize what type of plantings are needed to fill these holes that allow solar heat to directly enter the stream. Consequently, past, present, and proposed vegetative removal or even future vegetative growth can be effectively evaluated.

Table 16—The sun's altitude and azimuth at selected northern latitudes on August 1

Local standard time	Altitude angle (°)	Azimuth angle (°)
	35° N. latitude	
0800	34.5	−88.6
0900	46.7	−78.9
1000	58.4	−65.2
1100	68.4	−42.0
1200	73.0	0.0
1300	68.4	42.0
1400	58.4	65.2
1500	46.7	68.9
1600	34.5	88.6
1700	22.3	83.1
	40° N. latitude	
0800	34.3	−85.2
0900	45.5	−73.8
1000	56.1	−58.4
1100	64.5	−34.8
1200	68.0	0.0
1300	64.5	34.8
1400	56.1	58.4
1500	45.5	73.8
1600	34.3	85.2
1700	22.8	85.1
	45° N. latitude	
0800	33.7	−81.9
0900	44.0	−69.1
1000	53.2	−52.6
1100	60.2	−29.7
1200	63.0	0.0
1300	60.2	29.7
1400	53.2	52.6
1500	44.0	69.1
1600	33.7	81.9
1700	23.1	87.2
	50° N. latitude	
0800	32.8	−78.6
0900	42.0	−64.8
1000	50.0	−47.7
1100	55.8	−26.0
1200	58.0	0.0
1300	55.8	26.0
1400	50.0	47.7
1500	42.0	64.8
1600	32.8	78.6
1700	23.3	89.4
	55° N. latitude	
0800	31.7	−75.5
0900	39.7	−60.9
1000	46.5	−43.7
1100	51.3	−23.2
1200	53.0	0.0
1300	51.3	23.2
1400	46.5	43.7
1500	39.7	60.9
1600	31.7	75.5
1700	23.2	88.5

STREAMBANKS

A streambank is that portion of the channel-bank cross-section that controls the lateral movement of water. The bank often has a gradient steeper than 45° and exhibits a distinct break in slope from the stream bottom (fig. 30). Banks can also have a distinct change in substrate materials from those making up the bottom because of the different tractive forces and types of vegetation that control the scouring and deposition. Riparian vegetation plays an important part in controlling how the tractive forces form the streambank and in the degree of streambank stability. Therefore, riparian vegetation plays an important part in determining how the streambanks handle water and their ability to produce productive fisheries and high water quality.

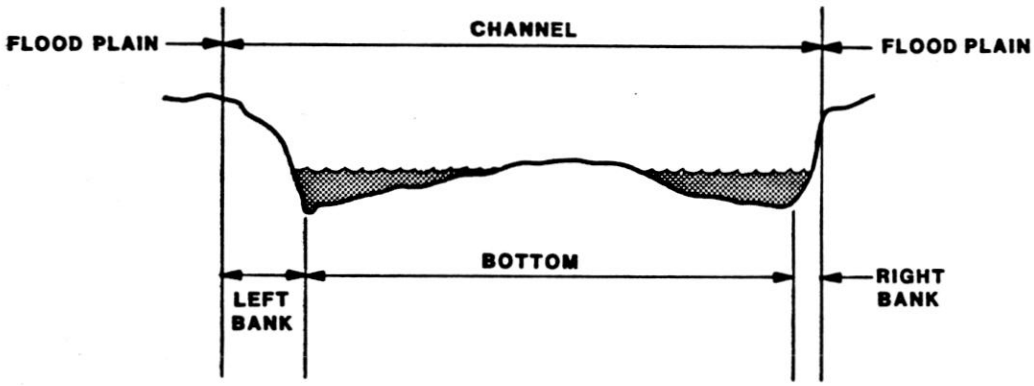


Figure 30—A well-defined stream channel with concentrated low flows and exposed bottom (downstream view).

Streambank and Channel Aggradation, Degradation, and Morphology

Streambank stability and form play a major role in determining the productivity of riparian ecosystems. Local streambank movement, through erosion and deposition, and morphology can be determined using the modified sag tape procedure developed by Ray and Megahan (1978). The streambank cross-sections can be plotted using the same horizontal and vertical scales to avoid exaggeration of bank-bottom features, or changed if banks need more detail for better analysis. This method identifies the techniques to determine both bank and channel form and movement, but the streambank can be measured separately if so desired.

The left bank is on the left side facing downstream. The cross-section profile readings should always begin at the left transect reference marker (preferably a metal stake driven into the ground) for consistency. This allows the computer to plot the left bank on the left side of the resulting graph. The readings start at the left transect stake and end at the right stake. If streambank or cross-section profiles are going to be recorded over a number of years, then the metal stakes should be driven at least 3 ft into the ground to prevent stake movement due to frost heaving. In addition, a permanent reference point that will not be affected by events that may affect the streambank, such as markers on large trees or bedrock knobs, should be established to determine whether the elevation of the top of each stake changes over time. Any movement of the stakes reduces the ability of the cross-section to accurately monitor streambank movements.

Data Collection—The data form (see appendix 3) contains space for 50 sets of cross-section measurements, with a continuation sheet for 50 additional measurements. Cross-section readings are separated by commas to form columns. Instructions for inputting data into field forms are:

Line No.—The number of the data statement to be used in the computer program. Leave this vacant until ready to input data.

Stream—Enter the name of the stream.

Location—Enter the location of the station being surveyed, with sufficient detail for it to be located later. This is only necessary when there are multiple study areas on the same stream.

Date—Enter the date. Single digit months and single digit days must be preceded by zeros. For example, May 2, 1985, is entered as 05/02/85.

Station—Enter the assigned stream code for the stream so that the data can be readily accessed by the computer.

Transect—Enter the number of the transect. Single digit transects must be preceded by a zero. For example, transect number 6 would be coded as 06.

Tension—Record the amount of tension being applied to the measuring tape, rounding to the nearest 0.5 lb.

T—Enter a code number for the type of tape being used. For example, enter a "0" for a tape of a certain weight per inch, a "1" for a tape of a different weight per inch, and so on.

M—Enter a code number for the type of water velocity meter being used. For example, enter a "0" for a certain electronic meter, a "1" for a certain cup-type meter, and so on.

Stake right—Enter the elevation of the right stake of the transect, accurate to no less than the nearest 0.01 ft, which provides an acceptable error of ±0.005 ft. Preferably measure to the nearest 0.001 ft. Both right and left stake elevations must be determined using the same level location. To reduce the time involved, position the level so that the maximum number of stake elevations can be determined from one stand. However, distance of more than 25 ft between level and rod may adversely affect accuracy. (See end of this chapter for more specifics.)

Stake left—Enter the elevation of the left stake of the transect, as with the right stake. Use the same accuracy of measurement.

Water-up and water-down—Enter the surface elevation of the water, at the center of the stream, upstream (water-up), and downstream (water-down) from the transect, rounding to the accuracy desired. Water surface elevations do not need to be taken from the same level location as the stake elevations, but once established, all water-up and water-down elevations should be taken at the same location. If the level stand must be moved, the previous water surface locations must be resurveyed from the new location before proceeding.

Distance—Enter the distance between the water-up and the water-down readings. The distance should be rounded to the nearest 0.1 ft. Take this measurement down the middle of the stream preferably using a 100-ft cloth tape. Distance measurements should be made in the middle of the stream. Using figure 31 as an example, the unitless measurement from point A to point B = 15.1, point B to point C = 20.0, point C to point D = 50.2, and point D to point E = 20.3. Adding the distances, the total distance between transect 26 and 35 = 105.6. The tape measurement should remain in the middle of the stream.

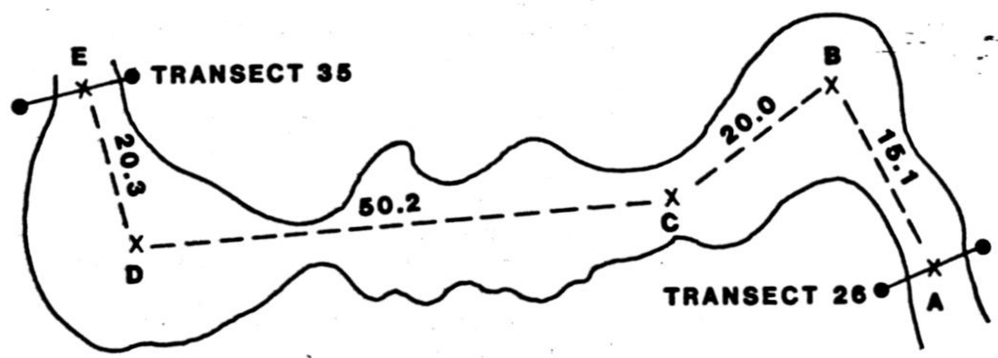


Figure 31—Measuring water-up and water-down distances.

Right bank undercut—Enter the width (distance cut into the streambank) of the right bank undercut to the nearest 0.1 ft. If more than one undercut exists, measure the dominant (usually the largest) undercut only.

Right bank height—Enter the height of the dominant right bank undercut, rounding to the nearest 0.1 ft.

Left bank undercut—Enter the width of the left bank undercut.

Left bank height—Enter the height of the left bank undercut.

Number of readings—Enter the number of sets taken across the transect. A set consists of a code number for the channel characteristic (C) (see following list), a code for the presence of water (W) (water = 1 and no water = 0), the horizontal tape distance, the distance from the ground to the tape, the depth of the water, and the water velocity. (Edge of water, can be recorded as channel characteristic = 6, water = 0 or water = 1; but do not enter a water depth with this entry.) Use space on the right side of the form to record more than one velocity reading. The channel characteristic codes are:

0 - Stake
1 - Between stake and top of streambank
2 - Top of streambank
3 - Streambank to channel bottom
4 - Edge of bottom or active channel
5 - Exposed bottom (no water)
6 - Edge of water
7 - Stream bottom.

Recording Cross-Section Survey Data—Start all measurements on the left bank. Attach the zero end of the measuring tape to a tension scale and center the tension scale handle over the end of the left transect stake. Stretch the tape across the stream to the right transect stake. After attaching the tape holder to the right stake, place the tape into the tape holder (fig. 32). Pull the tape until 10 to 20 lb of tension is obtained on the tension spring; on wide streams (>70 ft) more tension may be needed. Close the tension tape handle to hold the tape in place. Record the spring tension on the field form to the nearest 0.5 lb and check it periodically for slippage. If it slips, start again. The tape must not touch anything along its entire length, including the water, because its sag will be affected. In addition, windy conditions will affect both tape sag and tension, and should be avoided.

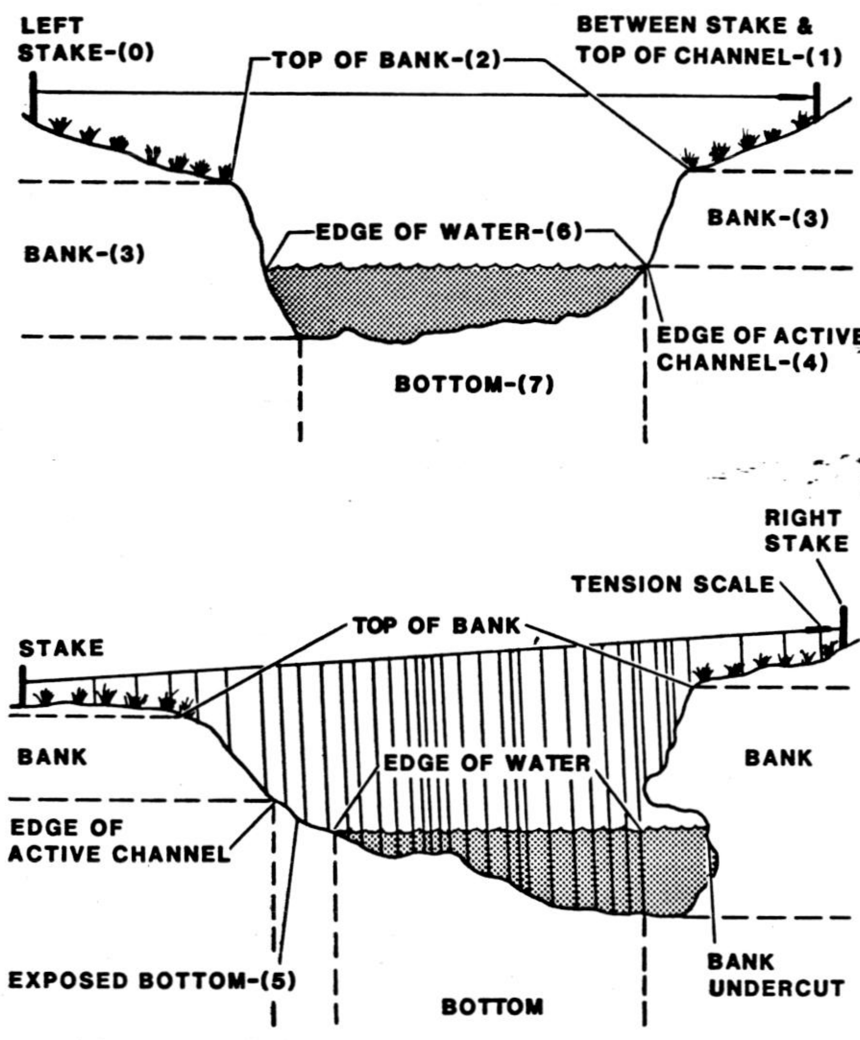


Figure 32—Example of stream channel morphological descriptions.

Measure the vertical distance between the top of the left stake and the tension scale handle where it touches the back of the stake, using a pocket tape. Record this distance on the form as a negative vertical distance in the "To Tape" column. Measure the vertical distance from the tension handle to the ground; use the hand level to position the tape at a 90° angle with the tape and pocket tape as needed. Record this positive reading as the second "To Tape" measurement on the form. Be sure to record the negative reading first, then the positive.

Proceed with the cross-section measurements making vertical measurements to the nearest 0.01 ft and all horizontal readings to the nearest 0.1 ft. Measure the horizontal distance between the stake and the zero mark on the steel tape and record this distance as a negative number in the first two "Distance Horizontal" entries on the form. This measures the length of the tension scale. Continue the survey across the entire cross-section, recording corresponding vertical and horizontal measurements and water depths. Take all vertical measurements on the downstream side of the tape. Use the hand-held rod level to make sure that each horizontal measurement is taken at a 90° angle to the water surface and tape to minimize your effect on water flow.

When proceeding across the channel, readings are taken wherever breaks in the slope of the channel surface occur, at the top of the channel sides, at the edges of any exposed bottom, and the edge of the water surface (fig. 32). Be sure to take the appropriate measurements on any islands in the stream. Record the channel characteristics for each measurement point using the channel characteristic codes listed previously.

Upon reaching the right streambank, record the right stake height above the tape holder (negative number) and below (positive number) as on the left bank; again, record the negative reading first. Use the same horizontal reading for both vertical measurements.

The bank channel characteristics to be measured are:

Channel—That portion of the cross-section containing the stream that is obviously distinct from the surrounding area due to breaks in the general slope of the land.

Edge of channel—That point at the bank-channel intercept where the break in the general slope of the land occurs.

Bank—The portion of the cross-section that restricts lateral movement of water. The bank usually has a gradient steeper than 45° and exhibits a distinct break in slope from the stream bottom. Also, an obvious change in stream bottom substrate may be a reliable delineation of the bank.

Stream bottom or active channel—The portion of the channel between the banks, where annual bedload transport occurs.

Exposed bottom—The nonwetted portion of the stream bottom. The recorder must indicate whether measurements are made in the water column (0 = no water, 1 = water). Record the obvious points of the stream channel with the appropriate characteristic code.

Elevation—Position the engineer's level so that you can shoot the maximum number of transects from the same location; this reduces cost and time. The right and left stakes of any one transect must be shot from the same place. Sink the tripod feet into the ground to stabilize the instrument and level with the built-in leveling bubble. Be sure the instrument remains level when the scope is turned in any direction. Once the instrument is set, do not bump the tripod or level.

Have someone hold the level rod on the top of the stake being surveyed. Make sure that the rod is as perfectly vertical as possible by using a hand-held rod level placed against it. Read the number corresponding to the middle cross hair and estimate the number to at least the nearest 0.01 ft, preferably to the nearest 0.001 ft. Record this number in the appropriate space on the data form and reread to verify. Be sure to read only the middle cross hair. The level can be located on either side of the stream because all that is needed is the relative difference in elevation between right and left stakes. If brush or trees are in the way, a third person could hold them back or perhaps they could be tied out of the way. Accuracy to 0.01 ft can even be obtained by some waving of the rod under these conditions. After surveying a group of stakes, determine the water-up and water-down elevations with the level rod held in the middle of the stream on the water surface. These elevations need not be taken from the same place as the stakes. The distance between the water-down and water-up on elevation recording sites needs to be measured to calculate channel gradient.

To read the level rod, note that the large red numbers are in feet, the smaller black numbers are in tenths of feet, and the black marks between the tenths are in hundredths (see figures to determine how to read hundredths). Thousandths of feet must be estimated between the hundredths marks (fig. 33).

Checklist of Hydraulic Geometry Equipment—

1. Engineer's level, tripod, level rod, and bubble rod level
2. Measuring rods (5 ft and 10 ft) marked in 0.1-ft intervals for undercut measurement
3. 100-ft cloth tape
4. 200-ft steel tape and clamp
5. Two 6-ft pocket tapes measuring to 0.01 ft
6. Tension scale (pounds)
7. Metal clipboard and field data forms
8. Folder for completed forms
9. Mechanical pencils with erasers and spare lead
10. Hip and chest waders
11. Methodology manual.

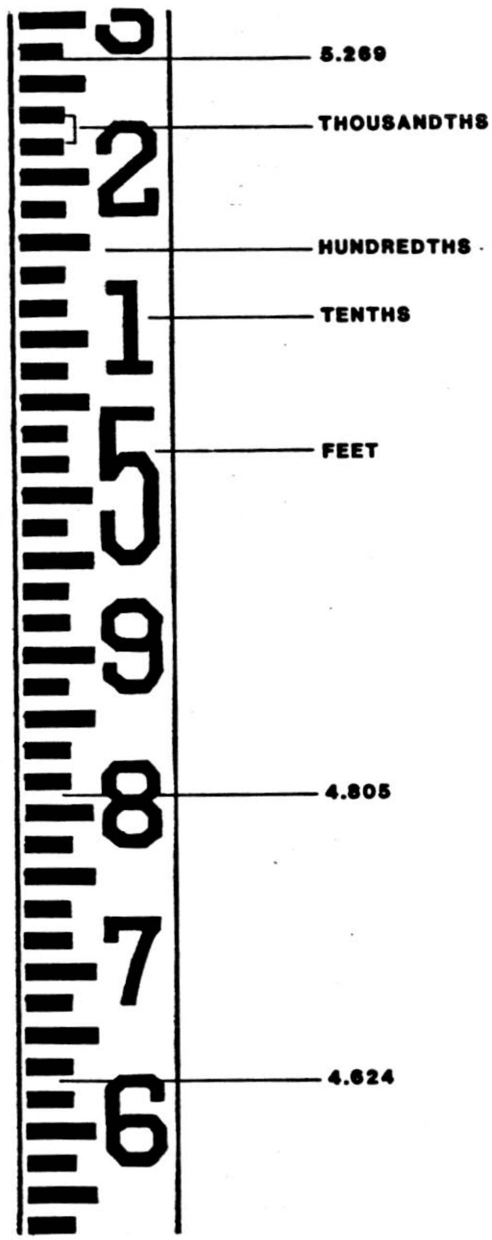


Figure 33—Example of a level rod.

Streambank Soil Alteration

Certain land uses, such as roading, logging, and livestock grazing, can start the modification of a stream by causing instability of the bank. Therefore, this streambank alteration rating may provide a warning system for changes that could eventually affect fish populations.

The streambank alteration rating reflects the changes taking place in the bank from any force (table 17). The rating is separated into five classes. Each class, except the one with no alteration, has an evaluation spread of 25 percentage points. Once the class is determined, the observer must decide the actual percentage of instability. Streambanks are evaluated on the basis of how far they have moved away from optimum conditions for the respective aquatic habitat type. Therefore, the observer must be able to visualize the streambank as it would appear under optimum conditions. Any natural or artificial alteration deviating from this condition is included in the evaluation. This visualization makes uniformity in rating an alteration difficult because it is difficult to train all observers to visualize the same optimum bank condition. Natural alteration is any change in the bank produced by natural force. Trampling by people or livestock and disturbance by bulldozers or trucks are examples of artificial methods that can alter streambank soils and form.

Natural and artificial alterations are reported individually, but together they cannot exceed 100 percent. To reduce the confidence intervals, only that part of the streambank intercepted by the channel cross-section transect line enters the evaluation. Channel cross-section transect lines have no end. The line crosses both streambanks as the channel transect line is extended. Rating the complete bank as a unit between groups of transects in our studies resulted in greater observer error.

It is commonly difficult to distinguish artificial from natural alterations. It is possible to have artificial alterations cover already existing natural alterations and vice versa. In such case only the major type of alteration on a unit area enters the rating system. If there is any doubt, the alteration is classified as natural.

The cross-sectional profile methods discussed earlier can help with the evaluation of the major alteration. However, the profiles do not determine whether changes in the streambank are caused by natural or artificial forces. Because the 95 percent confidence interval (±12.3 percent) around the mean and observer variation is quite wide, interpreting the data must be done carefully. Between the test streams studied, there was a wide spread in the precision and accuracy of measurements. Overall precision was rated fair to good, but accuracy was rated mainly poor to fair. Therefore, caution should be used in evaluating the data from this measurement.

Table 17—Streambank soil alteration rating

Rating	Description
Percent	
0	Streambanks are stable and are not being altered by water flows, animals, or other factors.
1 to 25	Streambanks are stable but are being lightly altered along the transect line. Less than 25 percent of the streambank is receiving any kind of stress, and if stress is being received, it is light. Less than 25 percent of the streambank is false,[1] broken down, or eroding.
26 to 50	Streambanks are receiving only moderate alteration along the transect line. At least 50 percent of the streambank is in a natural stable condition. Less than 50 percent of the streambank is false, broken down, or eroding. False banks are rated as altered. Alteration is rated as natural, artificial, or a combination of the two.
51 to 75	Streambanks have received major alteration along the transect line. Less than 50 percent of the streambank is in a stable condition. Over 50 percent of the streambank is false, broken down, or eroding. A false bank that may have gained some stability and cover is still rated as altered. Alteration is rated as natural, artificial, or a combination of the two.
76 to 100	Streambanks intercepted by the transect line are severely altered. Less than 25 percent of the streambank is in a stable condition. Over 75 percent of the streambank is false, broken down, or eroding. A previously damaged bank, now classified as a false bank, that has gained some stability and cover is still rated as altered. Alteration is rated as natural, artificial, or a combination of the two.

[1]False banks are those banks that have been cut back by some artificial force and are no longer immediately adjacent to the stream. They can become stabilized by vegetation, but base flows are usually too far removed from the stream to provide fish cover.

Streambank Undercut

Streambank undercut provides cover for fish and is a condition favorable to producing high fish biomass, especially in small streams. Undercut is a good indicator of how successfully streambanks are protected under alternative land uses, such as livestock grazing and road building. The undercut, if it exists, is measured with a measuring rod to the nearest 0.1 ft directly under the transect line from the farthest point of protrusion of the bank to the farthest undercut of the bank (fig. 34); water level does not influence this reading. If more than one undercut occurs under the transect, only the dominant (usually the larger) undercut is recorded.

The 95 percent confidence intervals around the means (±18.5 percent) are wide. However, year-to-year precision and accuracy are good. The major cause of the wide confidence interval is that the two points that define the undercut measurements are difficult to accurately determine. Then, too, a naturally high variation exists in size of undercuts.

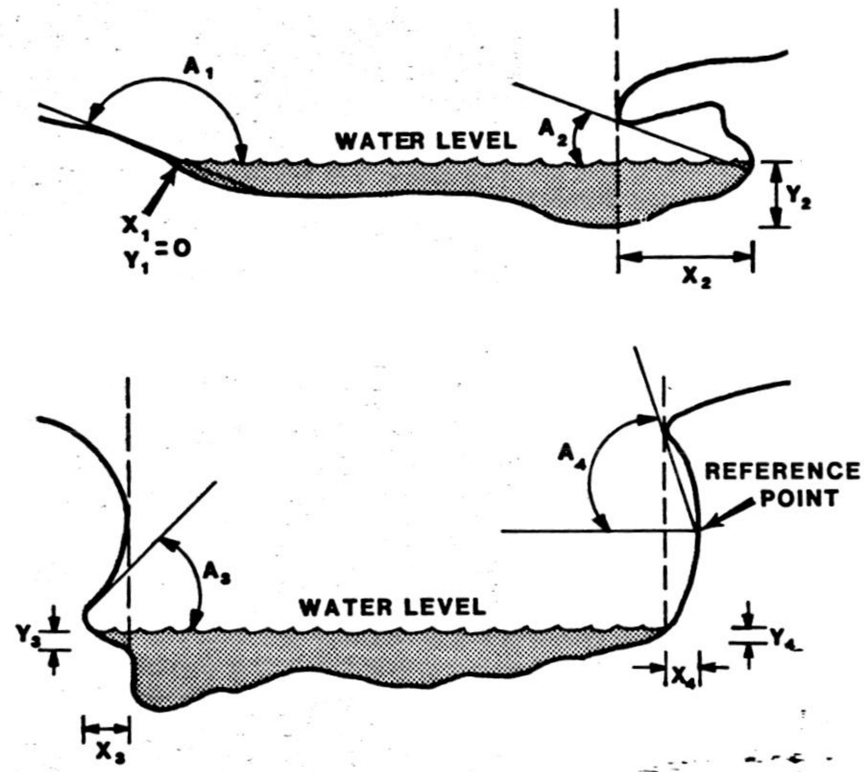


Figure 34—Hypothetical channel cross sections illustrating bank angle (A), undercut (X), and water depth (Y) measurements.

Stream Shore Water Depth

The stream shore water depth is critical for fish, especially young-of-the-year (figs. 34 and 35). Also, the following measurement is effective in evaluating riparian use activities that could modify the streambank and its riparian vegetation.

The water depth at the stream shore is measured at the shoreline or at the edge of a bank overhanging the shoreline (see fig. 34, angle A1). If the angle formed by the bank as it meets the stream bottom is over 90°, the stream shore water depth reading is always zero. If the angle is 90° or less, the water column goes under the streambank and the measurement of the stream shore water depth is greater than zero (see fig. 34, angles A2, A3, and A4). The measurement is taken to 0.1 ft, and the measurements for both shores can be totaled and averaged for an overall rating for the transect or kept separate so each bank condition can be followed.

Because of the variation in stream shore depth, the test sample had a 95 percent confidence interval about the mean of ±16.6 percent. These intervals were fairly wide because of the high variability and the difficulty in standardizing the technique. However, we did find that the precision and accuracy were good from year to year.

Figure 35—Measuring stream shore water depth.

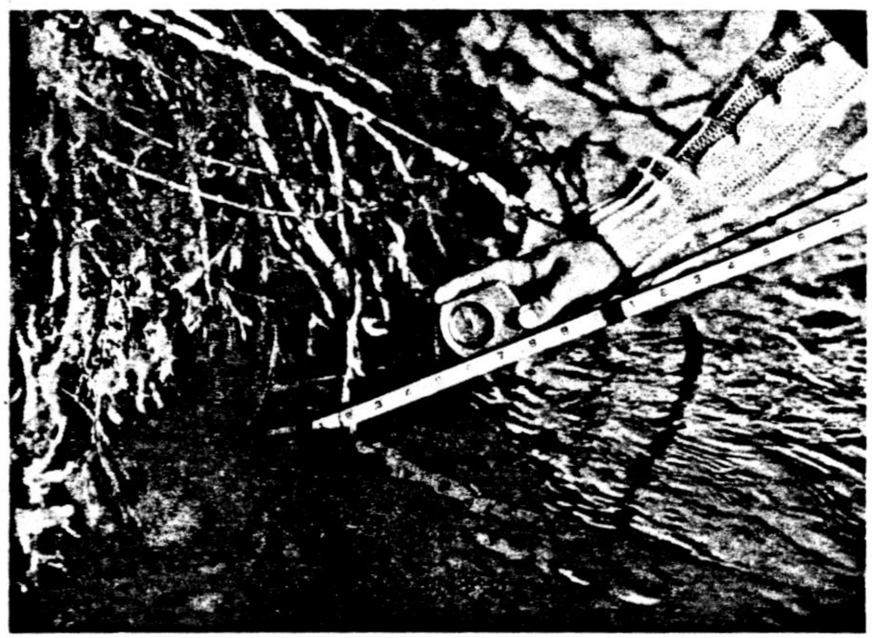


Figure 36—Using a clinometer to measure a bank angle of 45°.

Stream Channel-Bank Angle

Fish often congregate near the streambank for the cover it provides. If the bank has been cut away and moved back from the water column, valuable rearing habitat has been lost. Measuring the channel-bank angle is effective for monitoring land uses that can change the morphology and relative location of the streambank.

A clinometer is used to measure the angle formed by the downward sloping streambank as it meets the more horizontal stream bottom. When the streambank is undercut, the angle is always less than 90°. The angle is determined directly from the clinometer placed on the top of the rod as it forms the angle determined by the protruding edge of the bank to the midpoint of the undercut under the transect line (fig. 36).

Figure 37—Using a clinometer to measure a bank angle of 145°.

When the bank is not undercut, the angle is greater than 90° and is measured from the bank side by placing the clinometer on the top of the measuring rod aligned parallel to the streambank along the transect (fig. 37). The clinometer reading is subtracted from 180° to obtain the bank angle.

A streambank angle greater than 90° is easily read with precision and accuracy. An angle less than 90° is more difficult to read as multiple undercuts can complicate the bank profile, making it difficult to determine the points delineating the angle. The key is to include the midpoint of the dominant undercut in the bank profile. The 95 percent confidence intervals around the means are quite narrow (±4.4 percent), and year-to-year precision and accuracy are good.

MEASURING AND MAPPING ORGANIC DEBRIS

Organic debris originating in a riparian area plays an important role in the character and productivity of streams. The size and type of material determine the effect on channel morphology as well as its distribution in the stream. Organic debris ranges from green trees to decomposed wood or naturally occurring material to logging debris. Organic debris ranges in size from fine pieces to whole trees. The agents that put debris into streams vary from leaf drop during autumn to single-tree blowdown, windfall of several trees, or massive debris avalanches originating on steep slopes. To describe the effects of organic debris on channel morphology, the amount and type of material along the riparian area and in the stream channel should be measured with techniques that are defined and consistent within a study.

In this section we provide an array of methods to measure organic debris in streams. We present several methods that may be modified to the needs of the user. All of the methods have been used in one form or another. As with most techniques, the best method is the one that satisfies the objectives of the study.

Measuring Woody Debris in Stream Channels

One of the reasons for measuring organic debris in streams is to evaluate its effect on fish habitat. Streamside vegetation and its contribution to streams is an integral part of forest and aquatic ecosystems and must be considered in flood plain management and timber management. Among the considerations in debris management are the effects of changes in the recruitment rate of woody debris during and following logging, and methods to maintain debris loading levels that will continue to provide usable fish habitat.

The most easily observed effects of organic debris are those on stream channel morphology, where large pieces of debris are associated with a specific habitat feature such as a log dam and a plunge pool or a single log or tree forming a deflector and backwater pool.

In addition, allochthonous organic debris may function as the primary source of organic carbon in the nutrient budget of streams, particularly small woodland streams (Triska and Sedell 1975; Naiman 1982; Bilby and Likens 1980). Other management considerations include blocks to migration that must be balanced against the function of debris as in-stream habitat (Baker 1979).

Once a study reach within a stream system has been selected, the channel boundaries must be defined. Swanson and others (1984) defined the edge of bank on the basis of the mean annual flow. But this is difficult to define except by observing the edge of streamside vegetation, water marks, or an abrupt, steep bank. The purpose is to define a boundary including debris that will directly influence channel morphology and the habitat of aquatic organisms. The length of the sample area will depend on the nature of the survey, but the length should be proportional to the channel width. Keller and MacDonald (1984) used a length of 20 to 30 channel widths to define their sample area.

The effect of organic debris and the methods used to measure it depend upon the size and type of material as well as the objectives of the survey. Woody debris is measured using the metric system and may be separated into two categories: (1) large woody debris, including material greater than 1 m in length and with a diameter at one end greater than 10 cm, and (2) coarse woody debris that includes material smaller than larger woody debris, but larger than 1.0 mm in diameter. Material smaller than this is generally grouped into either fine particulate organic matter—between 0.45 mm and 1.0 mm in diameter—or dissolved organic matter—less than 0.45 mm (table 18).

Size categories may be defined in relation to the effects. For example, effects on stream channel morphology could be described by the size and orientation of individual pieces or of accumulations.

The amount of debris can be described as biomass (weight or volume), number of individual pieces, or percentage of stream area covered. For comparisons among streams, measurement of the amount of debris is usually reported in the metric system as volume (cubic meters) or weight (kilograms) per unit area (square meters). Weight or volume of debris may not be as descriptive of fish habitat as density or number of accumulations along a stretch of stream. Type of material and its location in the stream may be more important to fish habitat than are weight and volume of material. Counts of pieces of debris should be stratified to describe the type of material and its location in the stream (table 19).

In most studies of debris loading, stream-to-stream comparisons are made with biomass or weight per unit area (Keller and Talley 1979; Keller and MacDonald 1984; Triska and Cromack 1980; Bryant 1981; Swanson and others 1984). Most of these estimates were

Table 18—Categories commonly used to classify organic debris

Abbreviation	Definition
DOM	Dissolved organic material less than 0.02 inch in diameter
FPOM	Fine particulate material greater than 0.02 inch but smaller than 0.04 inch in diameter
CPOM	Coarse particulate material greater than 0.04 inch but smaller than 3.9 inches in diameter
LOD	Large organic debris material greater than 3.9 inches in diameter

Table 19—Size categories used to estimate debris volume in streams (adapted from Froehlich and others 1972)

Category	Size range (diameter)	Average diameter
	Centimeters	
Fine	less than 1	0.423
Twigs	1 - 3	1.792
Branches	3 - 10	5.049
Coarse	greater than 10 in diameter and 30 in length	

derived from counts or measurements of individual pieces along a transect line across the stream channel. Individual pieces of large organic debris (LOD) were scaled to obtain volume. Estimates of volume in cubic meters were multiplied by the estimated specific gravity of the wood in the stream (0.5) to obtain biomass in kilograms per square meter (Talley 1980).

These methods, developed by Van Wagner (1968) for measurement of forest residue and adapted by Froehlich and others (1972) and Lammel (1972) to measure woody debris in streams, stratify debris into three size categories (table 19). DeVries (1979) details the theory of line transect sampling upon which the method is based.

Pieces of debris less than or equal to 10 cm in diameter are stratified into three size classes and are counted along a line transect across the stream. Volume of debris in each size class is computed by (Van Wagner 1968):

$$V = \frac{(\pi)(\sum n_i d^2)}{8L}$$

where:

n is the number of pieces in a size class along the transect line

d is the average diameter of the size class from table 19

L is the length of the transect line.

Transects perpendicular to the stream flow were established at regular intervals along the study reach by Froehlich and others (1972) and Lamell (1972) in Oregon and Swanson and others (1984) in Alaska. In most cases 25 percent of the transect was sampled in 30-cm lengths randomly selected along the transect. The researchers counted all sticks that intersected the vertical plane under the 30-cm line in each of the three size classes. In shorter transects or where fine debris was sparse, they counted all pieces along the transect.

The volume of all pieces of debris greater than 10 cm diameter was estimated throughout the sample section. Each end (d_1 and d_2) of the piece was measured with large calipers (fig. 38). A meter stick or fiber tape was used to measure length (L). The researchers did not include the section of the piece outside of the "in-stream boundary." They computed volume (V) using the formula:

$$V = [\pi (d_1^2 + d_2^2)L]/8$$

Weight was computed by multiplying the volume by 0.5, the estimated specific gravity for softwood (Talley 1980; Swanson and others 1984). Total biomass for the section was computed by summing the weight of all pieces in the section.

Scaling debris to obtain volume and weight is time consuming. Counts of individual pieces or accumulations can provide both quantitative and qualitative descriptions of LOD in streams. In the example in table 20, the counts are made along a reach and compared as

Figure 38—Measuring debris with calipers.

number of accumulations per area or linear distance. Root wads are considered separately in this example and are separated by their location in the stream channel. Counts can be made "on the ground" by direct observation, from aerial photographs, or from scale maps. Bishop (1968) used debris counts and low-level aerial photography to describe LOD (greater than 15 cm in diameter) in Big Creek on Prince of Wales Island, southeast Alaska, over a 4-year period before and after logging. Bryant (1980) made counts of individual pieces or accumulations of debris using maps to show changes in debris loading in Maybeso Creek on Prince of Wales Island.

A more subjective system, based on percent of stream channel length affected by different size classes of debris, was developed by Silvey and others (1977) to evaluate debris loading and channel condition following fires. They used size class of debris and percent of channel length affected to derive an index of in-stream debris loading. Table 21, derived from the data sheet given by Silvey and others (1977), shows that larger material such as logs and root walls is given a greater weight than smaller material such as needles and twigs. The index is computed by multiplying the loading rating observed in each size category by the number of miles of channel surveyed and summing to obtain a total. The total can be divided by number of miles to standardize the measure. For example, if one debris jam—category IV—was observed and 10, 25, and 8 percent of 5 miles of stream were affected by debris in categories I through III, respectively, then the index shown in

Table 20—Tally sheet for large debris counts divided into size of accumulation and position in the stream

Size of accumulation	Number of accumulations across the stream		
	Less than 1/3	1/3 - 2/3	More than 2/3
Number of pieces:			
Less than 4			
5-10			
More than 10			
	Along bank	Midchannel	
Number of root wads:			
Cut			
Uncut[1]			

[1]Root wad attached to tree.

Table 21—Categories and weights used to compute the debris loading index of Silvey and others (1977)

Size category	Length of channel affected	Weighting factor (WF)	Index (miles × WF)
	Percent		
I. **Fines**: Ash, needles, twigs, and pieces less than 5 cm average diameter	0-10 11-30 30+	Low Med High	1 2 3
II. **Coarse**: Branches, limbs, and pieces 5-20 cm diameter up to 2.5 m length	0-10 11-30 30+	Low Med High	4 6 9
III. **Heavy**: Logs, trees, branches, stumps and pieces greater than 20 cm	0-10 11-30 30+	Low Med High	5 10 15
IV. **Debris "jams"** Existing or potential block	Number	High	10

Table 22—Sample data matrix for computation of debris loading indices

Size category	Length of channel affected	Weighting factor	Index
I	10 (low)	1	5
II	11-30 (med)	6	30
III	10 (low)	5	25
IV	(1)	10	50
Total		22	110

table 22 would be computed with the system shown in table 21. Then the index would be computed by multiplying the weighting factor by 5—the number of miles of stream surveyed—to obtain a total index for the stream of 110, or 22 per mile of stream. Silvey and others (1977) obtained indexes from 7.0 to 57.3 per mile for the streams they surveyed in California. A different range of values would be expected from streams in Idaho or Alaska.

Spacing and orientation of coarse debris may have a greater effect on channel morphology and aquatic habitat than does volume of debris alone. Several methods are available to evaluate these effects. To determine relative stability of pieces, the angle between the direction of flow and the most stable (anchored) end of the log may be measured. These data may be translated into an index of stability such as that suggested by Bryant (1983), or individual logs may be tagged and remeasured periodically to determine movement within the channel.

Position in the stream will largely determine the stability of large woody debris (LWD) and its use by fish as habitat. Individual logs may be grouped into categories to describe their position in the stream. Michael Murphy (personal communication) of the National Marine Fisheries Service, Auke Bay Laboratory, Auke Bay, AK, used four categories—complete bridge, collapsed bridge, ramp, and drift (fig. 39). The order is in decreasing stability and describes the association with the bank. Individual logs or accumulations of LWD may be stratified with respect to position in the stream (say, midchannel or adjacent to the bank) when LWD is related to fish habitat. The effect of a piece of debris may be recorded for the study reach. Keller and MacDonald (1984) used this technique in addition to measurements of debris volume. They compared pool-to-pool spacing (measured in channel widths), percent of channel with debris-stored sediments, percent of pool morphology influenced by debris, and debris-controlled drop in elevation of the channel.

LWD can have a significant effect on channel morphology, and in some studies it may be important to stratify pieces or accumulations by their effect on the channel. The strata are similar to those used by Keller and MacDonald (1984) and are (1) pool, (2) sediment storage, (3) flow deflection, and (4) no effect. These strata may be used to describe the potential effect on channel morphology as related to fish habitat or densities. In many cases, pieces having no effect may be classified as potential additions, such as pieces suspended above the stream that will eventually drop into the channel.

In summary, among the several methods to measure organic debris in streams are percentage area of stream affected, counts of individual pieces or accumulations, direct measurement to estimate volume or biomass, and measurement of the effect on the channel. There is also measurement of the location and orientation of individual pieces. But no one best method exists, except the one that fits the objective of the survey or study within time and budget constraints.

Obviously, a visual estimate of the percentage area of a stream affected by debris is less precise than an estimate of volume computed by the methods discussed here. It is also less time consuming. A more precise method may be combined with a "survey level" method to provide point estimates of debris loading or specific effects of debris along a stream reach. Stream mapping showing specific locations of debris and habitat types associated with debris will provide a better description of the stability and effect of large debris on channel morphology and fish habitat.

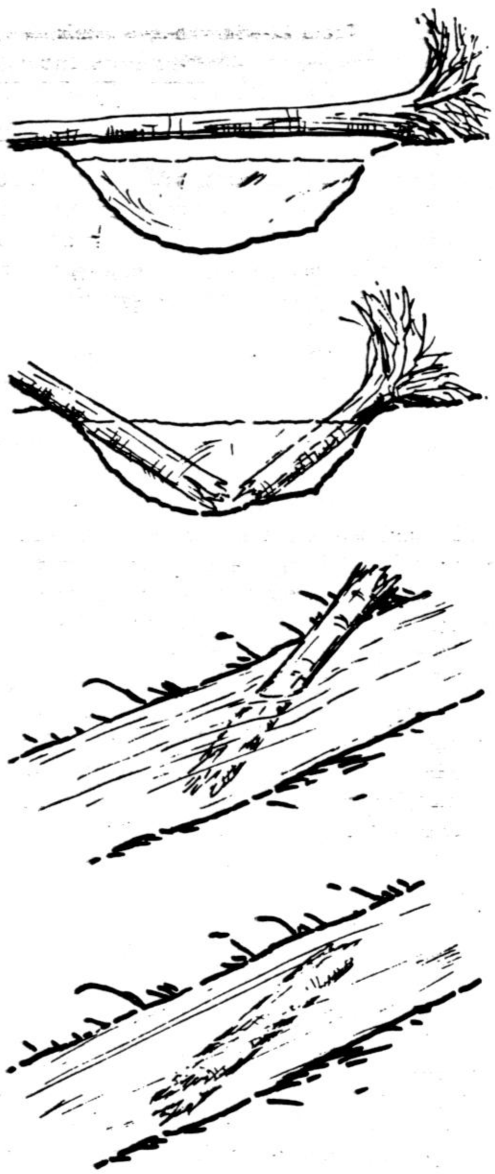


Figure 39—Four categories of large woody debris formations in streams.

Mapping Debris

Maps of stream channels can provide a useful base of data from which to evaluate effects of debris on channel morphology. Bryant (1980), Lienkaemper and Swanson (1980), and Keller and MacDonald (1984) provide examples of studies that use stream maps to identify effect of organic debris and effects of management activities on streams through changes in debris loading. In addition to the visual association between a debris formation and a specific morphological feature, maps provide a visual historic record of changes in debris location within a stream and its effect on channel morphology.

Mapping methods can vary in accuracy from a free-hand sketch of a stream reach to plane-table and aledaide measurements—time and accuracy are the constraints. A map of debris in a stream channel will identify the relative location of the piece or accumulation within the stream reach, but a known reference point must be established for the map. This can be a natural feature such as a bedrock outcrop or a large identifiable tree or boulder, or it can be a reference transect marked with stakes.

Two methods will be discussed. The first uses a fiber measuring tape, measuring rod, and compass. The second uses engineering surveying equipment. In both cases the basic principle is to establish a distance from a known point and an angle from a reference line along the stream. The former method is suitable for smaller streams generally less than 10 ft wide, whereas in a larger stream, surveying equipment increases both speed and accuracy.

Figure 40—Stream mapping with tape and rod.

Graph paper simplifies the mapping procedure when using the tape, compass, and measuring rod method.

The tape is extended in a straight line along the stream to a convenient length, determined by the course of the stream and the scale of the map (fig. 40). In the example in figure 41, a 40-ft section of stream is mapped on 10-squares-to-the-inch graph paper with one square equal to 1 ft. A compass reading is taken along the length of the tape. The center line is at 110° in figure 41. The measuring rod is set horizontal to the stream and perpendicular to the tape. Measurements to the bank are made along the tape with the measuring rod. Intervals can be varied to reflect desired detail or significant in-stream features such as large rocks, root wads, points of gravel bars, or backwater areas. Edge of bank and edge of water are recorded at each interval. Pieces of debris, logs, trees, and so forth, are identified as they intersect transect lines. Diameters, lengths, and heights from the stream surface should be recorded on the rough map or field notes.

The map in figure 41 was constructed on an acetate overlay on graph paper. Acetate can be used in wet weather and offers a distinct advantage over mapping directly on graph paper. Details on the map were filled in from field notes on the "rough" map. The scale, orientation, field personnel, and legend are included on the map.

For larger streams and rivers, surveying equipment will give the best results. A transit and stadia rod or electronic distance meter (EDM) and theodolite can accurately establish distance from a known point and angle from a given reference line along the stream section to be mapped. A tape and compass can be used but are less accurate. Because errors (such as sag in the tape) are cumulative, maps of larger areas may be extremely distorted when a tape is used.

Data may be recorded in a field notebook as shown in table 23 or on a rough sketch drawn in the field (fig. 42). A rough map, although it may be distorted, is often helpful in reconstructing the scale map. If a rough map is not constructed, then accurate notes should be taken so that points can be interpreted correctly in the office. The final map in figure 43 was reconstructed from the distance and angles measured with the EDM recorded in the data book and the rough map shown in figure 42. The rough map and the notes provide the

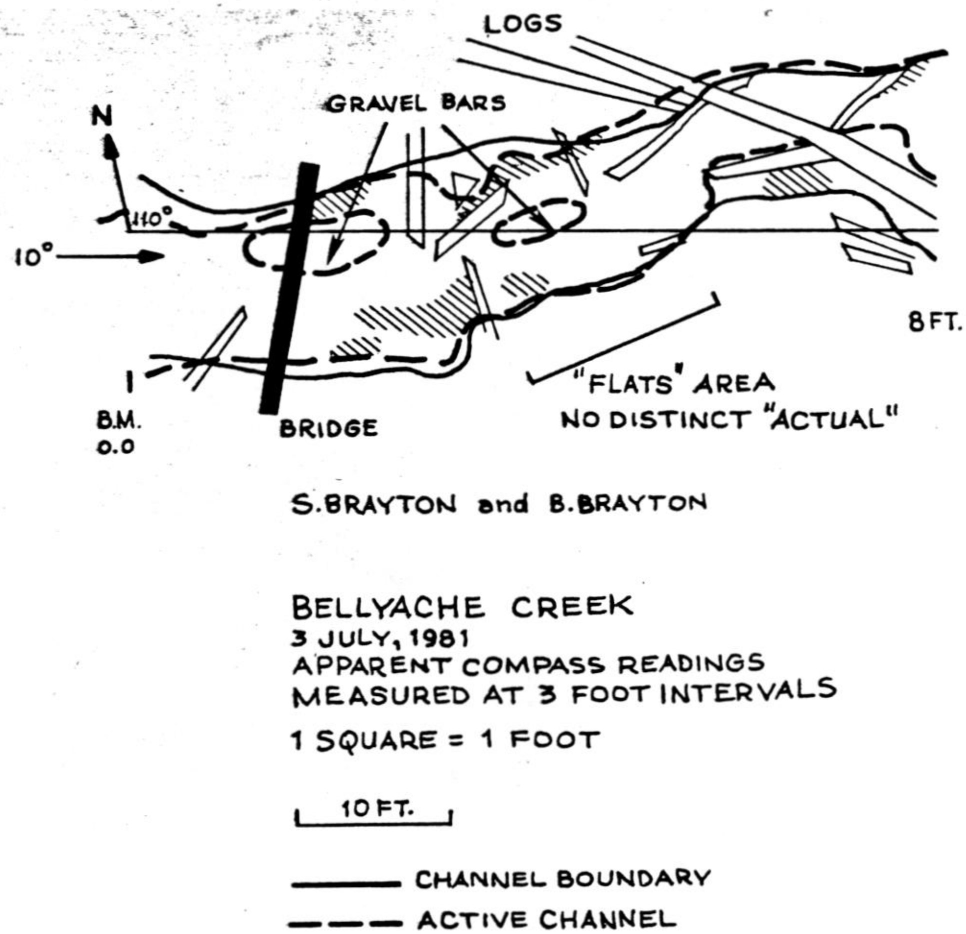


Figure 41—Map constructed using the fiber tape and measuring rod technique.

Table 23—Partial list of EDM readings used to draw figure 43

Distance	Angle	Remarks[1]
Meters	*Degrees*	
11.4	0	RB, EB, end upstream sect
15.5	44°44′	RB, EW
24.4	69°43′	LB, EB, EW, end sect 1, begin BW
22.5	81°13′	End BW
20.5	76°03′	Mouth BW, EW
19.4	86°50′	Log #1
15.7	95°02′	Log #, EW, LB
21.0	133°27′	End debris, LB
15.7	143°43′	End debris, BW, EW (alder on debris)
9.6	157°00′	Log #1, end debris
12.2	187°57′	Log #1, over water
15.3	200°57′	Mid. debris
17.5	213°10′	End debris, water behind
20.2	213°46′	Log #2 end, begin R. channel
23.5	217°29′	Submerged logs, EW
30.1	227°54′	EW, GB, log #3
33.4	221°01′	End log #3, end BW
31.8	229°30′	Mouth BW, EW, GB

[1]Abbreviations: RB = right bank, EB = edge of bank
EW = edge of water, LB = left bank
BW = backwater, GB = gravel bar.

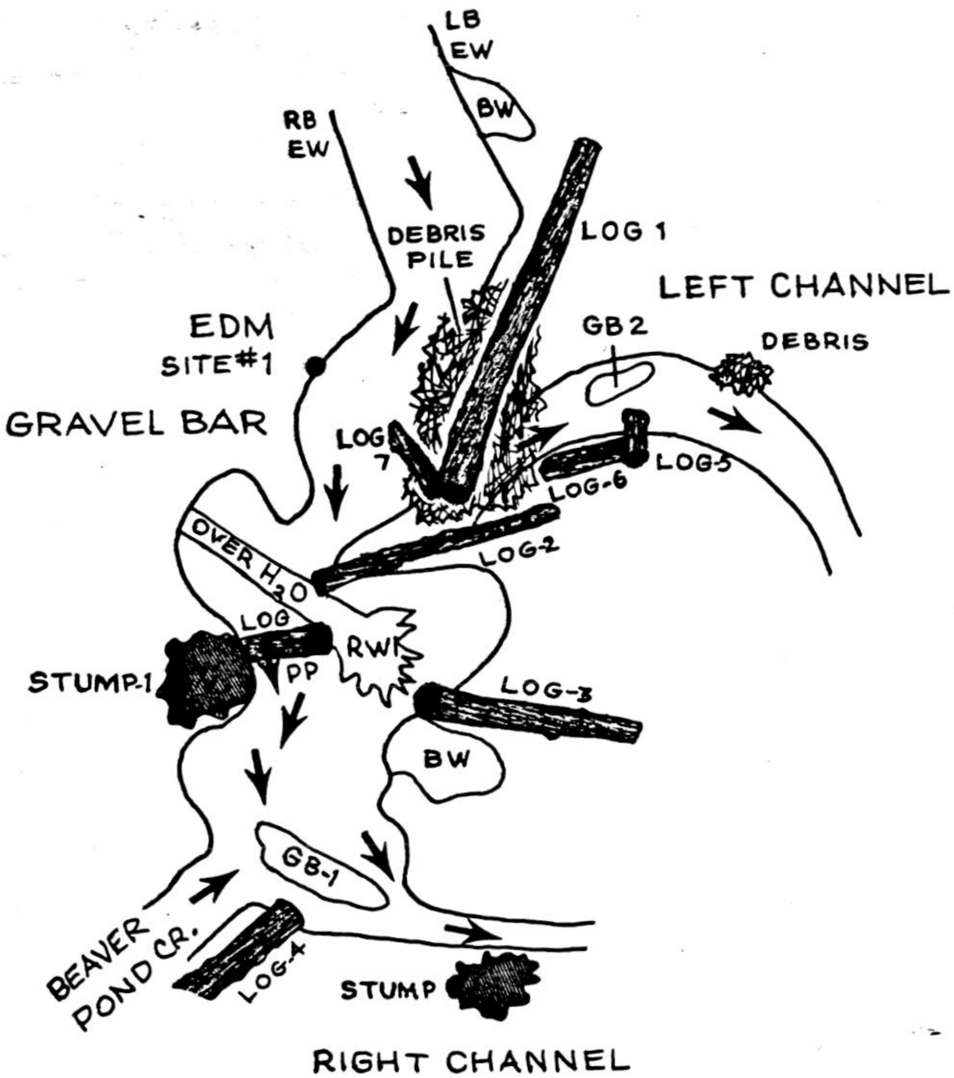


Figure 42—Sample of rough sketch and data taken during survey with an electronic distance meter (EDM).

details that are included in the final map. The differences between proportions of the rough map and the final map are significant and demonstrate the limitations of a "by eye" sketch for accurate location of points in a study area.

A less time-consuming method is to map individual pieces of debris rather than an entire reach. Individual pieces of large debris (greater than 30 cm in diameter and 2 m in length) are marked. Stanley V. Gregory of Oregon State University (personal communication) used small plastic disc tags—similar to Peterson disc tags—with individual numbers for each piece of debris. These were placed in holes of 5 to 8 cm that were bored into the side of the piece at each end and nailed to the piece. The location of each piece with respect to the bank and stream was recorded. The locations of the tags on the piece were recorded. By accurately identifying the position of the piece of debris, its relative stability in the channel can be determined as changes in position and orientation are measured over time.

Some advantages a scale map provides are (1) a graphic display of specific habitat types, (2) a measure of changes in channel morphology over time, and (3) a record of the locations of individual pieces of debris. In addition, a planimeter or digitizer can be used to derive area measurements from the map for each habitat type. For an intensive ecological study of a stream section, a detailed map of the stream and debris is indispensable (fig. 43).

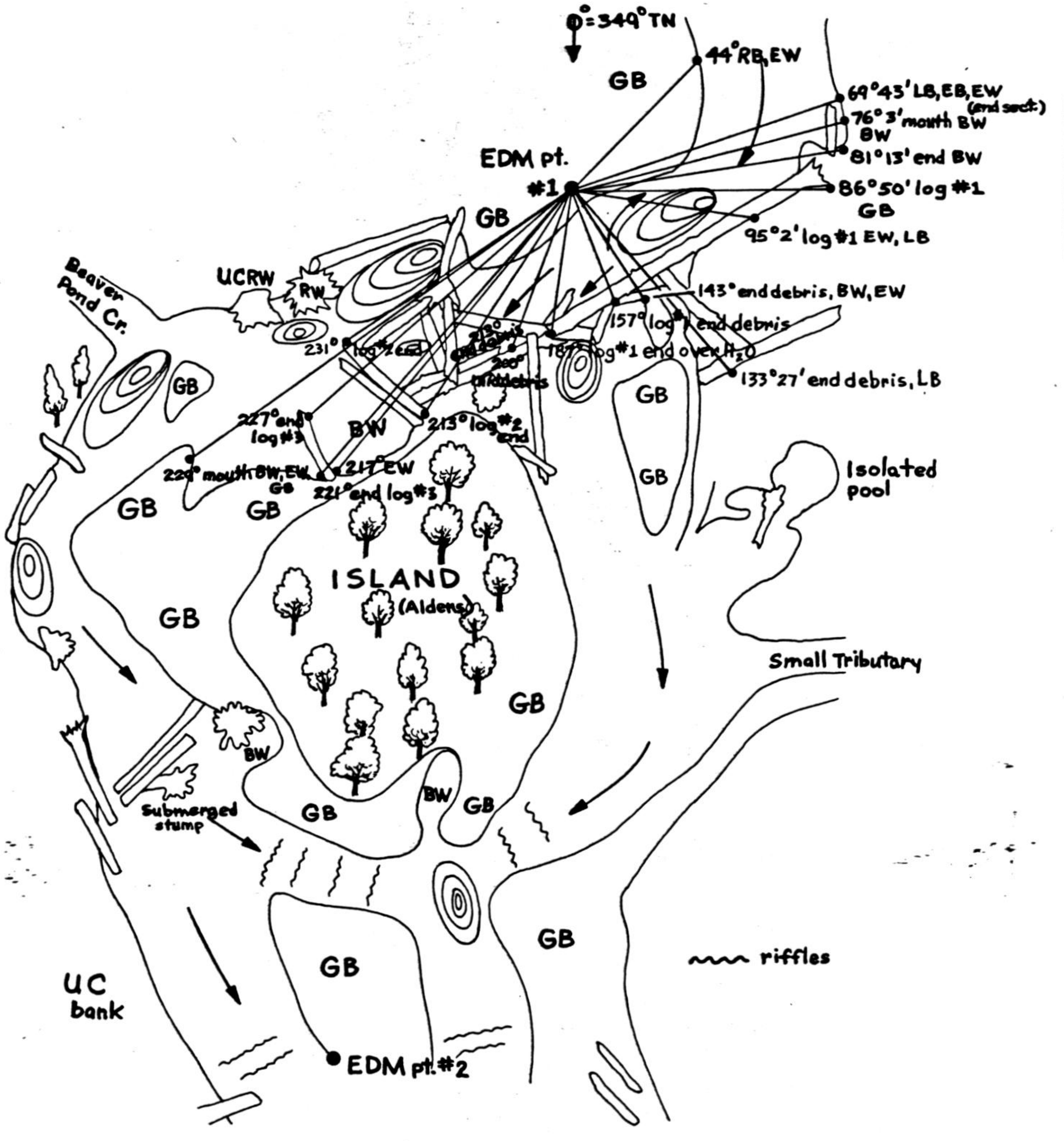


Figure 43—An example of a scale map constructed from data book entries in table 23 for Maybeso Creek.

Measuring Large Woody Debris on Stream Banks

Debris on streambanks is measured to determine the amount of material that could enter the stream channel. Measurements are made on a defined flood plain (the area outside normal flows but subject to periodic flooding). In addition, gullies, chutes, and V-notch channels leading to streams at the base of steep sideslopes may be the primary source of a large amount of organic material often in the form of debris avalanche. Measurement of woody debris in these landforms requires special consideration in methods and in the potential effect on the stream.

Measurements of woody debris along a low-gradient flood plain are made with methods similar to those used to measure debris loading in the stream channel. In the study by Swanson and others (1984) material less than 4 inches in diameter was not counted. Weight per unit area along a riparian area was estimated with the same equation given in the previous sections. A less intensive survey of LWD in a riparian area could be made by a count of individual pieces greater than 4 inches in diameter and longer than 3 ft in a defined area along the stream. Among some of the important considerations in defining potential contributions to the stream are the frequency and intensity of flooding and the size of the material. In some cases, an upper size limit could be set because the material would not be floated into the stream. In many instances, the flood plain may be a depositional area and contribute little to actual instream LWD, but the wood may be a source of nutrients or may contribute bank stability.

In measurements of this type it is important to define the flood plain area. Swanson and others (1984) used a 33-ft band on each bank for streams traversing relatively flat areas without steep banks, but the width depended on the size of the flood plain. Where the stream would not flood as great an area, as in the previous example, the width was reduced, and measurements were stopped altogether where a steep bank was encountered. Floatable debris should also be defined explicitly. Both flood plain area and floatable debris will vary with the stream system.

As already noted, steep sideslopes, gullies, and V-notches along streams are often sources of debris avalanches. The evaluation of the debris avalanche hazard is a primary consideration. Area (length and width of the gully), gradient of the slope, and the amount of debris are the primary measurements that will influence the degree of avalanche hazard. The percentage of area covered by debris can be measured by visual estimate or by counting individual pieces and by sampling the size and weight by scaling. However, in actual practice individual counts in large, steep V-notches can be an arduous task. Therefore, a relative index of sparse, moderate, or heavy loading in a V-notch will provide the most efficient method to evaluate potential avalanche sites along streams. This, combined with gradient of V-shaped area, would provide a good data base for streamside management purposes.

HISTORIC EVALUATION OF RIPARIAN HABITATS

Riparian areas constitute a small fraction of the total habitat types and ecosystems of the world, but they are some of the areas most heavily impacted by humans. Water bodies are sites of settlement and sources of water supply for people and domesticated plants and animals, and provide transportation avenues. Despite such uses and familiarity, riparian areas are one of the least understood habitats. Scientists are beginning to comprehend the importance of riparian systems, and the research effort has greatly increased in recent years, but so many changes have already occurred that few streams today still have pristine riparian areas.

While a certain amount of information may be gained by studying riparian areas as they exist at this time, a complete understanding cannot be obtained without considering their historical condition—their pristine state and the ways that humans have altered it. Because many of these alterations took place when an area was first settled, it becomes necessary to consult the historic record for information on original conditions. This chapter will examine the importance of historical research and discuss the methodology involved.

Consulting the Historical Record

Historical information regarding pristine riparian conditions can be obtained from three general sources: descriptive accounts of individual streams, records not primarily concerned with streams but including information in context with human activities, and statistical accounts compiled by State and Federal agencies.

Descriptive accounts of individual streams occur mostly in the form of State or Federal survey reports. By 1900, the U.S. Army Corps of Engineers had recorded general descriptions of most of the major waterways in the United States. Early court cases over navigable streams, riparian owner rights, and water rights sometimes contain stream descriptions. The U.S. Fish and Wildlife Service and State departments of fish and game have survey records for smaller streams, but most of this information is fairly recent (1920's to date). The majority of the earliest records of pristine stream conditions are found in records not primarily concerned with streams. These include fur trappers' and explorers' journals, pioneer diaries, letters, and memoirs. These sources require considerable sifting to obtain a few nuggets. Statistical accounts often accompanied State and Federal surveys and are frequently encountered in House and Senate documents. County, State, and Federal courthouses contain large numbers of statistical accounts.

Information can be further subdivided into primary sources, those written about events during the time they occurred, and secondary sources, those written later compiling many original accounts into a general overview. Burke (1979) notes that "the most accurate information is usually found in the original record. Primary sources, such as field notes and journals, diaries and letters, unpublished manuscripts and reports, and other archival materials allow the researcher to make judgments about the events without interpretation by anyone other than the originator of the document." Although secondary materials are presented from an author's perspective and therefore biased, they are more numerous and easier to access than primary sources and generally contain references to primary material.

A general approach to collecting historical information is to begin with general sources and become more specific in the search as the amount of information available becomes better known (Frick 1980). A good starting point is to check bibliographies and indexes for books and journal articles on the subject (see appendix 7 for a partial list). The bibliographies will suggest further reading and may indicate nonlibrary sources, such as historical museums and courthouses, for additional materials (see appendix 7). It is important during this phase of the research to maintain a working bibliography to keep track of the information gathered and to avoid duplication of effort.

Maps can be useful for tracing changes in stream courses and, in some cases, vegetation. While most of the surveying in the East was done after settlement, surveying in the West took place concomitant with or slightly before settlement, therefore giving some evidence of how pristine streams appeared. The U.S. Land Office was responsible for surveys beginning in the 1850's. The resulting records (maps and survey notes) are on file with the Bureau of Land Management, U.S. Department of the Interior. The maps themselves may be found in libraries. The U.S. Geological Survey began publishing topographic maps in the early 1900's. These are periodically updated, showing changes in stream channel configuration (fig. 44). Aerial photographs are good for documenting recent changes (1930's to present).

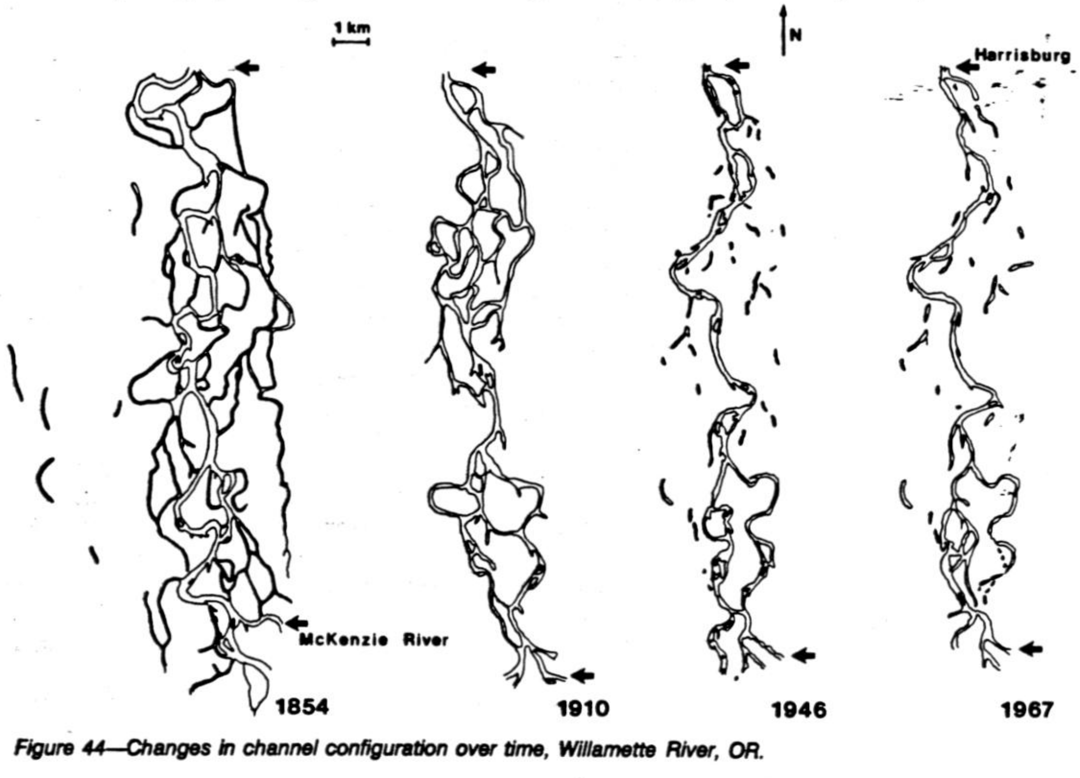


Figure 44—Changes in channel configuration over time, Willamette River, OR.

Another important source of information is early photographs. They may be of limited use in Eastern United States and Europe because most streams in those areas had been substantially altered long before the camera was invented. However, photographs of the Western United States where development was much later can be invaluable. For example, almost every historical museum in the Western United States has a photographic collection containing pictures of early logging practices, log drives, grazing, and mining activities. Photographs can show details that were incidental to the subject of the picture or details that authors of the time considered too common to note. Landscape photographs can be used in repeat photography where changes over time can be documented by repeatedly photographing an area from the same vantage point over the course of many years (Hastings and Turner 1965; Trefethen 1976; Gruell 1980).

Interpreting the Records

Just because a document is old and faded or published in 1884 does not mean that everything it says is true. There is a tendency on the part of nonhistorians to accept old documents at face value, forgetting that those early writers were as fallible and biased as the modern writers we critique so carefully today. It is therefore necessary to carefully evaluate historical documents before accepting their contents wholeheartedly (Forman and Russell 1983).

Two critiques should be used when evaluating historical material (Shafer 1980). The first, external criticism, helps to establish the authenticity of the document itself. This can be done by analyzing the contents for anachronisms, comparing the contents with other evidence outside the document, and testing the physical properties of the document itself. External criticism is important in determining the authenticity of ancient manuscripts such as the Dead Sea Scrolls and in exposing hoaxes such as the more recent Hitler diaries.

The second, internal criticism, helps to determine the credibility, meaning, and value of the document. Primary authors must observe a situation, report on it, and have a reason for doing so, and their motivation will influence how they treat their observations. An army doctor stationed in a marshy bottomland may report many cases of malaria; a land speculator encouraging people to settle the same bottomland will report that malaria is practically nonexistent. Secondary authors carry their personal philosophies and values to their work, and they affect the search for evidence and the interpretation of that evidence. Internal criticism, therefore, focuses on the author and his or her ability to observe and report, and on the intent of the composition. It also takes into consideration such factors as the amount of time that passed between the event and when it was recorded. Shafer (1980) is a good guide to external and internal criticism and their use in evaluating historical documents.

Problems in Interpretation

Most historical documents containing descriptions of riparian conditions did not have riparian areas as their primary subjects but rather contained only comments on them in passing. It is important to consider authors' reasons for writing their primary subjects, their ability to report observations, and what preconceptions and biases influenced them. Without taking these factors into consideration, it is easy for modern historical researchers to use historical material to support any conclusions they choose.

Hastings (1959) gives special attention to two of the many pitfalls in historical research that particularly apply to evaluating ecological change. He first quotes two examples of early descriptions of Arizona. The first is from an account by James H. Tevis, who came to Arizona in the 1850's. In those days, it should be remembered, grass grew very tall, belly-high to a horse. Tevis compares these conditions with those 50 years still earlier, as described to him by an Indian.

> In those days the grass grew very tall...in fact, so tall that one could see only the heads of antelopes (Tevis 1954).

The second is by Col. Green, Commandant of Camp Apache, Arizona Territory, writing in 1871:

> If you wish any further correspondence from me as to my views of Arizona, I can only tell you I have been over a great portion of it...and found it a rocky, mountainous desert, not fit even for the beasts of the field to live in (**Citizen**, April 22, 1871).

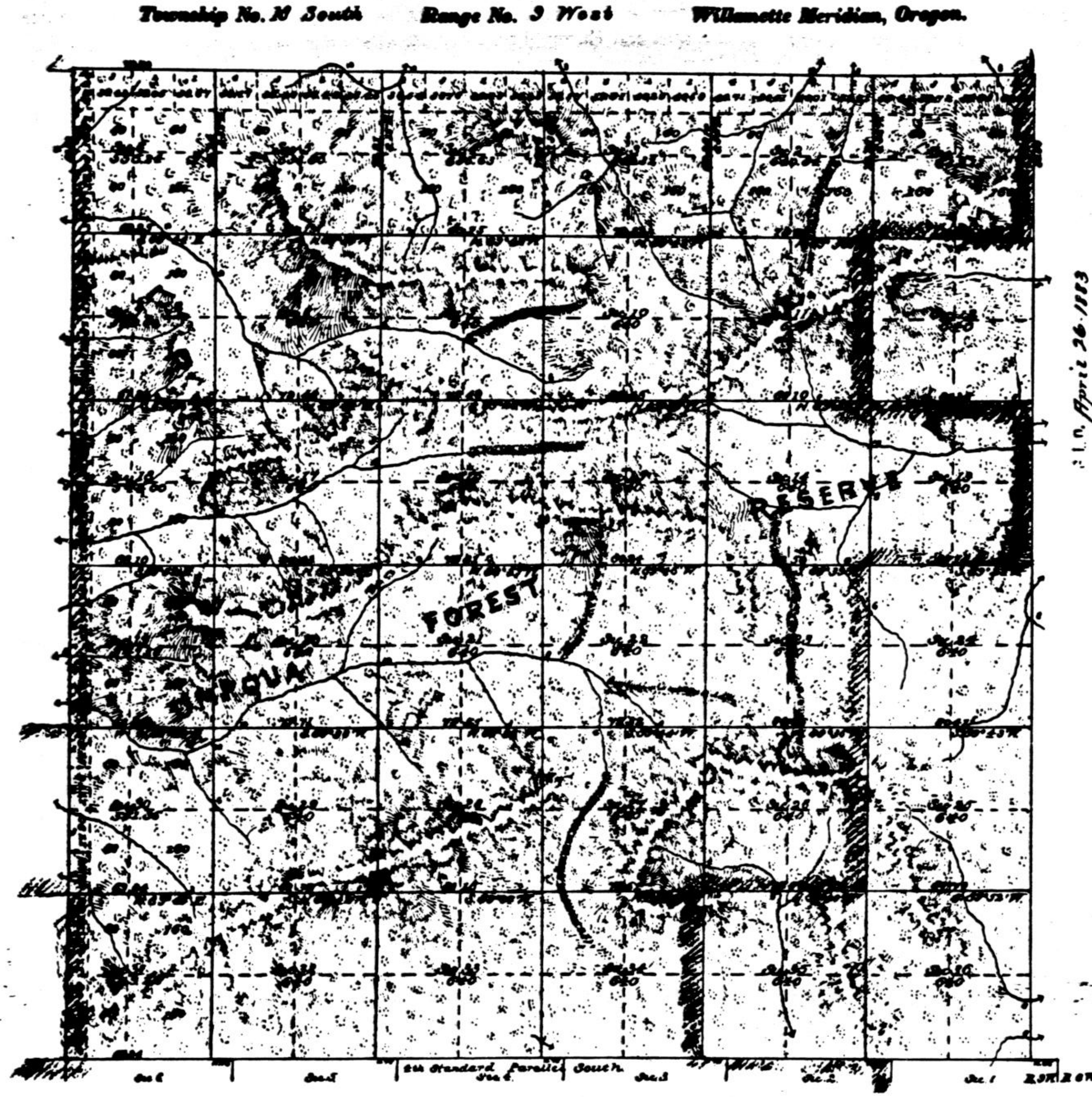


Figure 45—Survey of same section of Knowles Creek on the Oregon Coast, OR, in (A) 1882 and again in (B) 1929 showing major discrepancies between surveys. The 1929 resurvey is accurate. (Courtesy of Bureau of Land Management.)

(A)

Hastings then goes on to describe the two pitfalls:

> The first is the "good old days" fallacy. This longing after another time, another place, is implicit in much of human thinking; it operates particularly insidiously in the field of historical reminiscence. It colors the conclusions drawn from such materials unless the researcher exercises caution. To us the golden age of Arizona ecologically lay in Tevis' time. To Tevis, in turn, it lay fifty years still earlier, during the childhood of his friend the Indian Esconolea. To Esconolea's grandfather? The golden age retreats inexorable with each generation.
>
> A second pitfall is implied in the consideration that Colonel Green wrote in disparaging terms about conditions which were very good indeed according

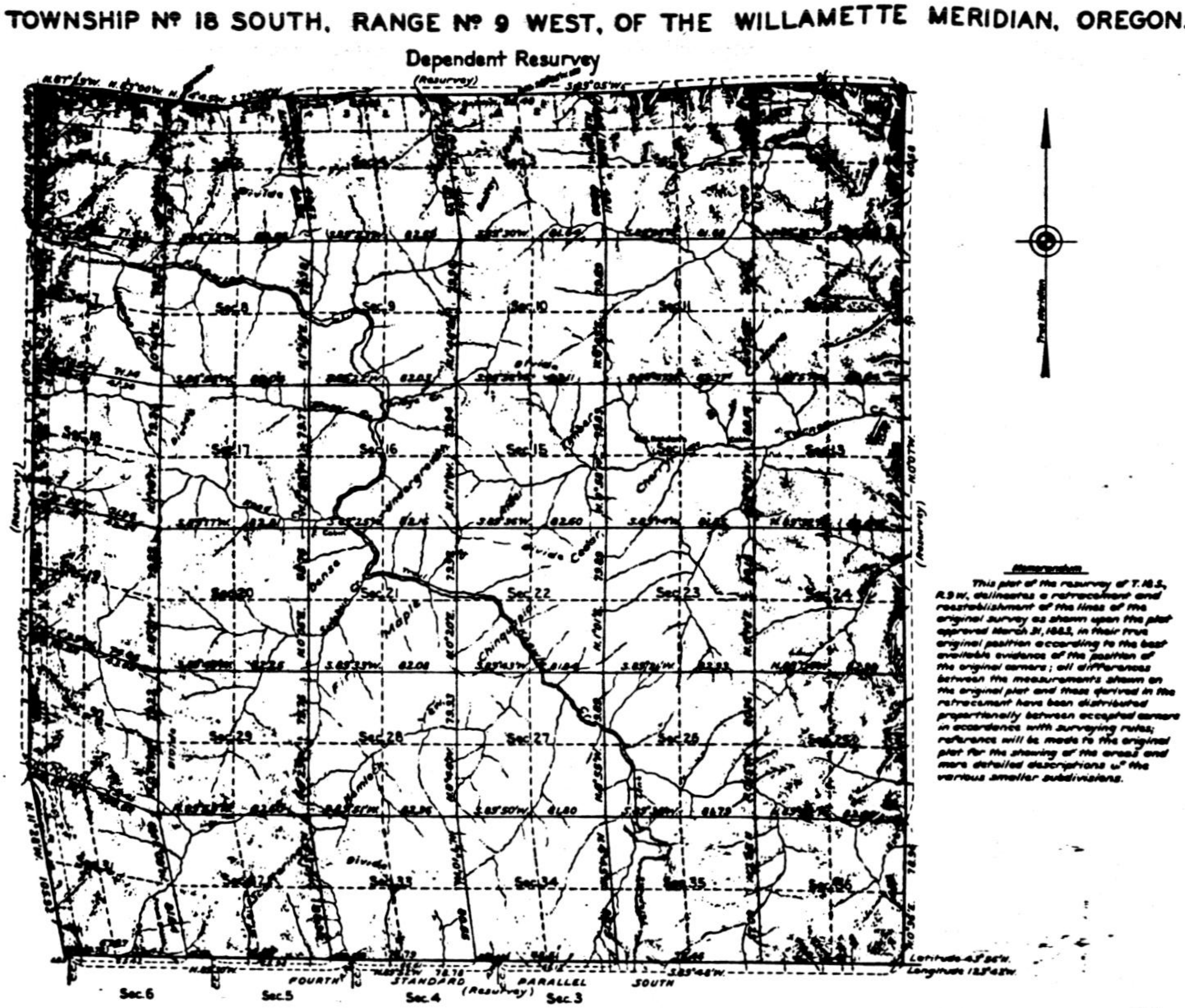


Figure 45 (Con.) **(B)**

to the Arizona legend. The legend does not necessarily err. It, after all, takes the same spatial area and compares it at two points in time. Green, on the other hand, compares two different areas in space at the same point in time. To him the Arizona of a century ago seemed uninhabitable because he tended to think of it in terms of Massachusetts, or Virginia, or Ohio. Compared to those well-watered regions of the same day, Arizona was not a "Land of Milk and Honey" at all; it was a howling, arid wilderness.

Maps present another set of problems in interpretation. Those drawn by early explorers are generally unreliable because the authors did not personally see everything they included. The surveys done by the U.S. Land Office for some areas are quite accurate and detailed, although details do not necessarily mean accuracy. For other areas, the map is so different from what exists today that there is some suspicion that the surveyor never set eyes on the territory (fig. 45). The U.S. Geological Survey topographic maps are accurate but cover a later period after most of the changes to streams and riparian areas had already taken place, and aerial photographs are still later.

Using the Historical Record

Perhaps the best way to better understand the type of information available from the historical record, and how to use it, is to examine case studies. Some human activities that have impacted streams and riparian systems include farming, grazing, mining, logging, and transportation. Different historical sources provide valuable information for these different categories.

Farming—Flood-plains are well known for their fertile soil, making them prime targets for settlement. Farmers not only cleared riparian land for crops but also used timber for homes, barns, fences, and firewood. This impact was restricted and localized by topography in some areas. In others, such as the Willamette Valley in Oregon, over 193 miles (65 percent) of the river was impacted.

While specific data on riparian clearing is unavailable, we can still trace the pattern of its demise in the Willamette Valley from various historical sources (Sedell and Froggatt 1984). The Willamette Valley was characterized by a prairie-open woodland vegetative complex maintained by fires set by Indians, with trees either on steeper slopes or in the riparian area (Towle 1974). The riparian woodland was 0.9 to 2.2 miles wide on either side of the river (Towle 1974) and was bisected by many small tributaries, channels, and sloughs that frequently overflowed (Williams 1914). Flooding was a major concern for the first settlers in the late 1840's who immigrated from the flood-prone Midwest and initially settled on lands away from the river (Bowen 1972). By 1870, Oregon's population had increased almost sevenfold over the 1850 population, 80 percent of the people lived in the Willamette Valley, and the bottomlands were rapidly settled (Dicken and Dicken 1979). With increased agricultural activity came urban centers along the river, the main transportation route of the valley. The settlers harvested easily accessible wood from the flood plain. By 1900 most of the good land in the valley was occupied; by 1930 it was not only occupied but cultivated. The net impact on the riparian woodland is seen in figure 46. A similar scenario developed along the Sacramento River in California (Sands and Howe 1977) and along the Colorado River (Ohmart and others 1977).

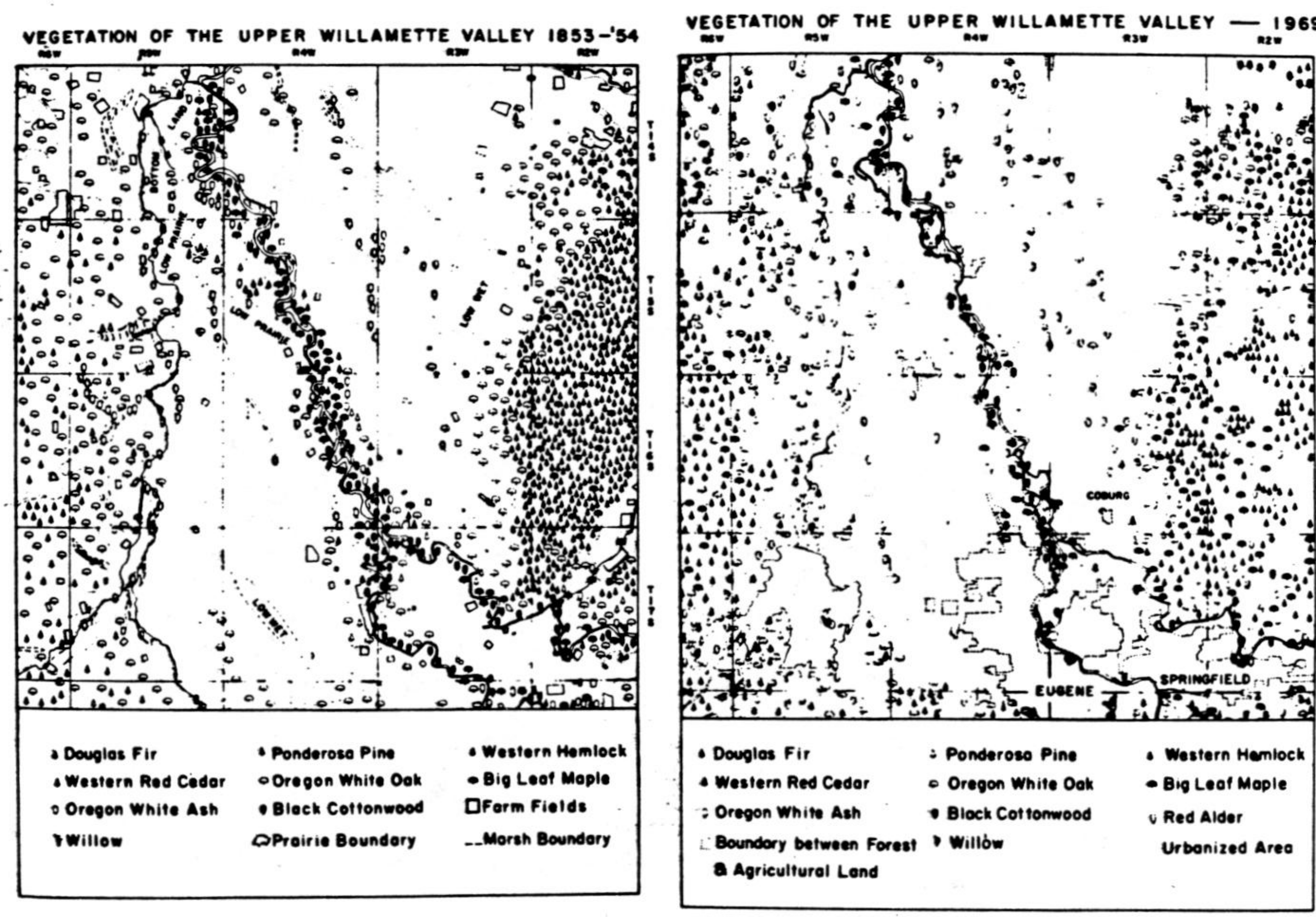


Figure 46—Vegetational changes along the Willamette River, OR (from Johannessen and others 1970).

Grazing—Livestock arrived with the first settlers but only in small numbers to serve as work animals or as a food source to the local community. Well-watered land was quickly converted to crops leaving the more arid land for "the only thing it was good for"...grazing.

The era of huge herds and massive drives was established after buffalo and Indians were no longer occupying the grasslands and before farmers had the technology to fence, irrigate, and plow the range. The free forage on the open grassland, markets in the mining, railroad, and military camps, and later the rail connection to markets in the East meant a quick profit for ranchers who rapidly filled the range with cattle and sheep. By 1879, some of the range, especially in Colorado, was being overgrazed, but the next 7 years saw large increases in the number of livestock and cattle companies, and the range became overcrowded (Frink and others 1956). Severe winters, dry summers, and low market values from 1885 to 1886 caused many cattle companies in the Great Plains to fold, and the cattle industry was reorganized into smaller herds that no longer depended solely on open rangeland for forage. Arizona's cattle population went from 5,000 head in 1870 to 35,000 in 1880 to 1,095,000 in 1890 before the drought of 1891 to 1893 reduced the herds by 50 percent (Hastings and Turner 1965). By the turn of the century, farmers were making inroads on settling and cultivating the grasslands, and livestock were no longer free to roam.

Frink and others (1956) noted that: "By preempting land near water, a man could shut others out and so have the use of great grazing areas that were in the public domain but that others could not use because they had no access to water." Later, when the cattlemen realized they could not feed livestock only from the range, the riparian wetlands were converted to hayfields (Griffiths 1902, 1903).

Grazing impacts on riparian areas have been the focus of many investigations (Platts 1981a; Kauffman and Krueger 1984). While damage continues, much of it was already done by 1900 (fig. 47).

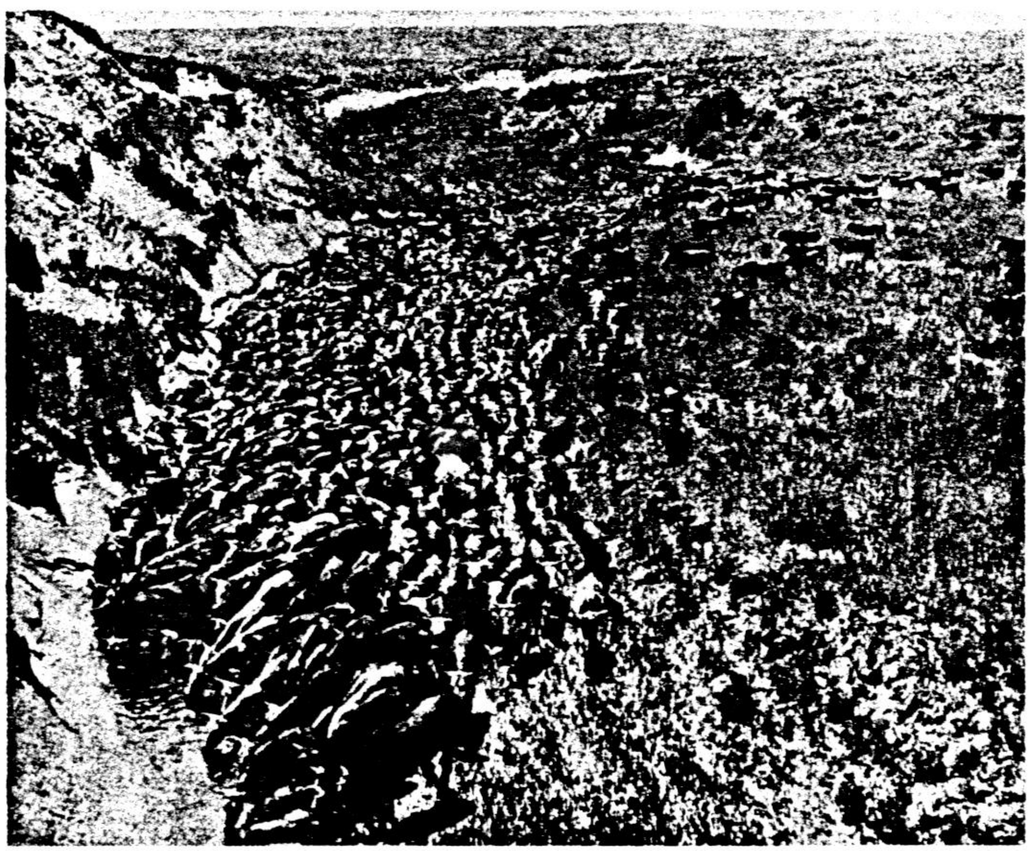


Figure 47—A Texas trail herd reaches water, 1890's (William H. Jackson photo, from State Historical Society of Colorado).

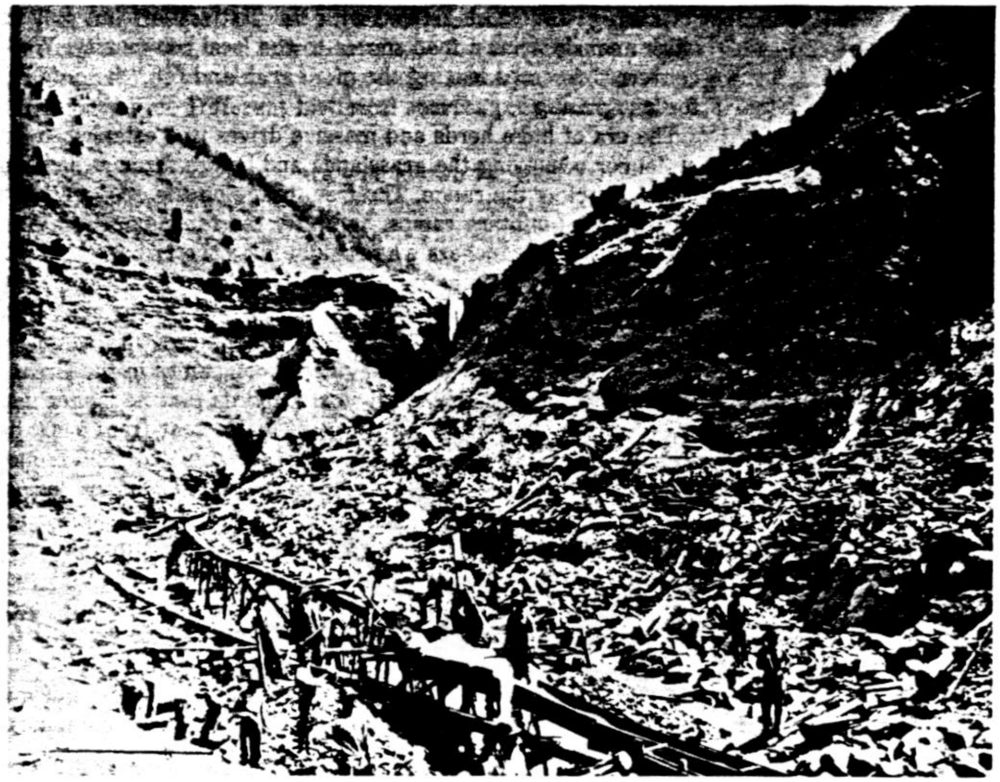
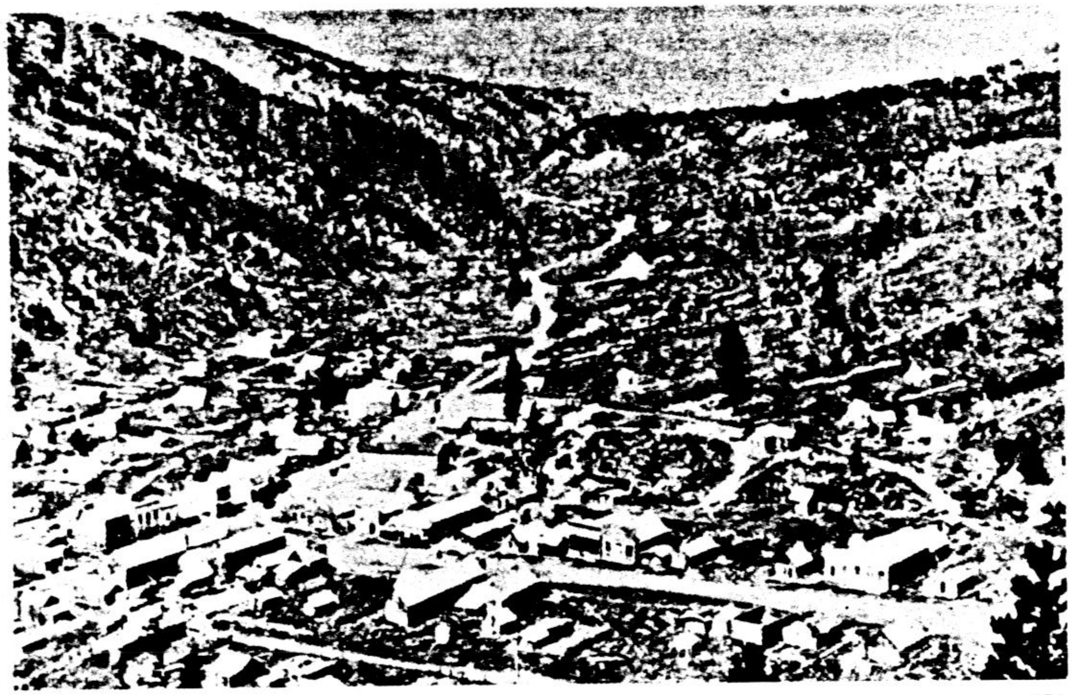


Figure 48—Placer mining in Confederate Gulch near Helena, MT, 1860's (Historical Photography Collection, University of Washington Libraries).

Mining—The first impact usually associated with mining operations is in-stream pollution from tailings. Water was often used to wash and sift ore, and whole streams could be diverted to this purpose (fig. 48). This would affect the water flow downstream causing some creeks to go intermittently or totally dry. The tailings were sources of sediment and at times toxic substances that would adversely affect in-stream flora and fauna.

In addition to their impact on streams, mining operations severely impacted riparian vegetation, particularly trees. In western Nevada from 1853 to 1914, over 64 sawmills operated on sections that are now relatively treeless. Billions of board feet of timber were driven down the Truckee, Carson, and Walker River systems for lumber, firewood, and other uses related to the development of the silver mines around Virginia City (Anonymous 1941). Many of the mining and smelting activities in Arizona, Montana, Utah, and Colorado in the late 1880's depended on stream transportation of logs. In these arid climates, where timber was not abundant, denudation occurred quickly (fig. 49).

Logging—Numerous books have described the history of the timber industry, and many articles have glorified log drives on rivers. But only one significant book—by Rector (1953)—has been published on the extent and role that water transportation played in the early days of the timber industry. A book-length manuscript by James Farnell (unpublished) was produced from research undertaken for the State Lands Division of Oregon, in which the extent of navigation was determined for each of Oregon's river basins. Each of the 23 basin studies was issued as a navigability report from the State Lands Division in Salem. These two documents record the extent, duration, and dependence on water for log transportation. The changes to stream habitats and streamside vegetation have been documented by Sedell and Luchessa (1982) and Sedell and Duval (1985).



(A)

(B)

Figure 49—Maiden Canyon in Montana's Judith Mountains. (A) In 1892: the area has been stripped of timber to provide fuel and prop supports for mining in the area (photo, W. H. Weed, U.S. Geological Survey). (B) In 1964: little of the mining town remains, and the area is largely reforested.

By the early 1880's, the best timber within 2 miles of the entire shoreline of Hood Canal, a section of Puget Sound, had been cut (Buchanan 1936). The same was true of most other readily accessible areas. Loggers constantly sought out streams along which the timber had not yet been cut. If a stream was large enough to float logs, it was soon in use. A newspaper, The West Shore, announced in 1883 that in Columbia County, OR, every "stream of any size has been cleared of obstructions, so that logs can be run down them in the high water season" (Anonymous 1883). By the end of the 1880's the same was true of almost any county along the lower Columbia, around Puget Sound, or along the "lumber coast" (Cox 1974).

From earliest days, stream improvement for log transportation encountered legal difficulties. To keep mill owners and farmers from blocking the rivers with dams and other obstructions, a stream had to be declared navigable. In Michigan, Wisconsin, and Minnesota, the courts decided that a stream that could float a sawlog was a "public highway" and that sawlogs had just as much right to be on the rivers as rafts, barges, and steamboats. Navigable streams were not to be blocked by bridges, piers, fences, or ponds. At the same time, lumbermen were not to build storage and splash dams without special legislative permission (Rector 1953).

The U.S. Government transferred ownership of the beds of the navigable waterways to a State when it entered the Union. To ascertain which riverbeds were transferable, the U.S. Supreme Court defined a navigable river:

> Those rivers must be regarded as public navigable rivers in law which are navigable in fact. And they are navigable in fact when they are used, or susceptible of being used, in their ordinary condition, as highways for commerce, over which trade and travel are or may be conducted in the customary modes of trade and travel on water. (The Daniel Ball, 1870).

All of the Western States must in general comply with this definition of navigable waters.

In Washington, any stream that was capable of successfully floating logs was a floatable stream, and the logger had a right to use its waters to float logs toward the mill or market. Even though a stream was completely incapable of such log floating during the dry season, its waters were public if natural freshets provided enough water to float logs. Thus, the logger had no right, over the objections of the riparian owner, to put in roll dams to cause backwaters or splash dams to create artificial freshets. The boom and driving companies were able to obtain the right to drive a floatable stream because they were quasi-public corporations (Bridges 1910). As such, they had the power of eminent domain and could run their splash dams by condemning the property and paying in advance to every landholder adjoining the stream.

Even though litigation frequently resulted, most streams in western Oregon and Washington were used for log drives.

Log driving is simply the process of transporting logs by floating them in loose aggregations in water with the motive power supplied by the natural or flushed streamflow (fig. 50). At first, all timber within easy access of the stream was cut and floated down the adjacent river. If timber was too far away to be profitably hauled by oxen to the mill or stream, the logger moved to another location. Gradually, loggers had to go greater distances for timber, which introduced the use of river landings, log yards, log driving, rafting, towing, and booming (Rector 1949). Still later, the more distant timber required the use of splash dams and sluiceways, expensive stream improvements, canals, tramways, trestles, log chutes and slides, trucks, and railroads for floating and driving.

As more logs were needed, artificial freshets were created by splash dams. A splash dam was a device for turning tiny streams into torrents large enough to float logs (fig. 51). A dam would be built on a stream and water stored behind it. When a large head of water had been accumulated, it would be released and would quickly sluice logs that had been dumped into the pond behind the dam—together with others collected along the watercourse below the dam—to where they could be handled by conventional means.

Streams of all sizes had to be "improved" before a log drive could begin. Principal forms of stream improvement were (Brown 1936):

> Blocking off sloughs, swamps, low meadows, and banks along wider parts of the streams by log cribbing to keep the logs and water in the main stream channel.

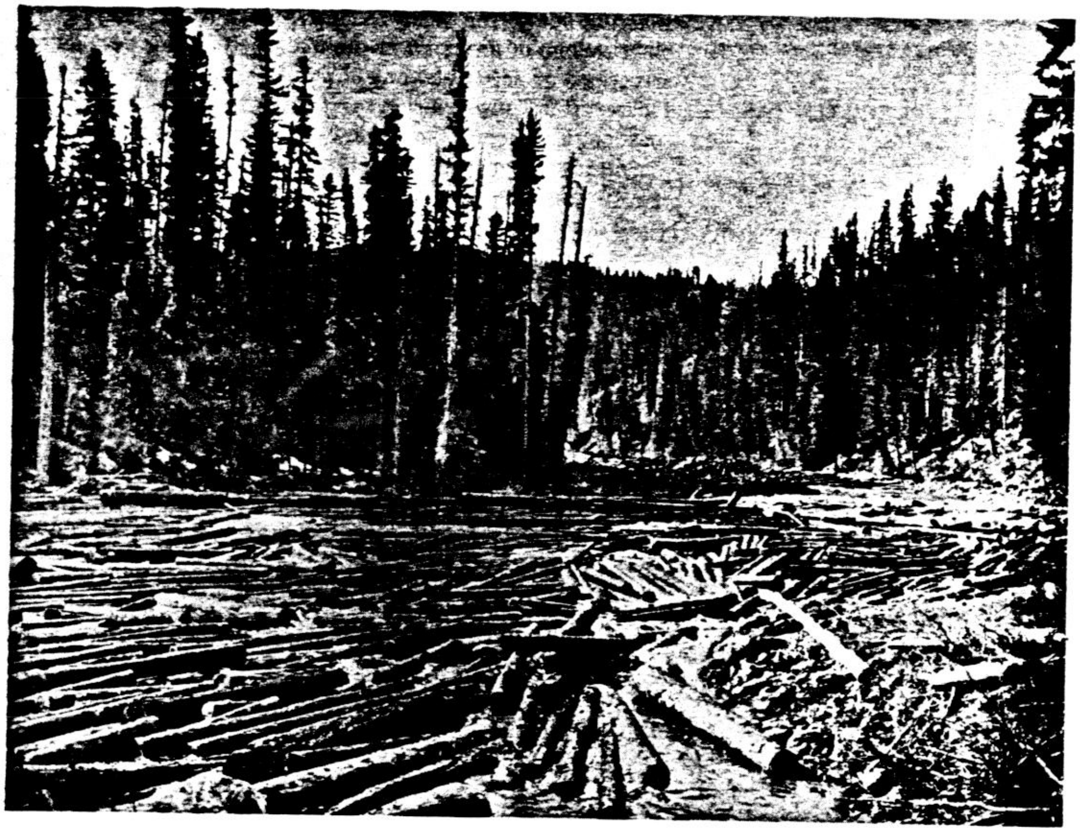


Figure 50—Log drive on the St. Joe River, ID (Eastern Washington State Historical Society).

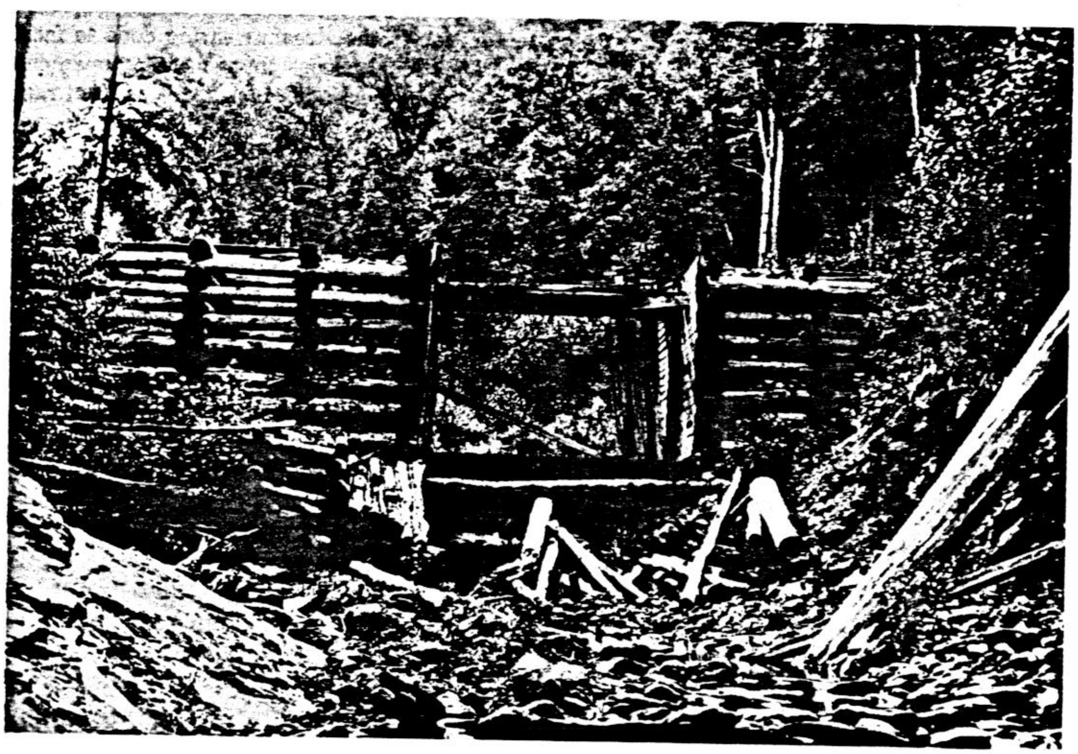


Figure 51—Splash dam on Bob Creek.

Blasting out or removing boulders, large rocks, leaning trees, sunken logs, or obstructions of any kind in the main bed during periods of low flows. Obstructions or accumulations of debris—such as floating trees, brush, and rocks—often caused serious and expensive log jams during the driving seasons. Frequently, small, low-gradient streams were substantially widened during log driving, as a result of the frequent flushing of the stream by splash dams and by the impact of the logs along the streambank.

By 1900, over 130 incorporated companies for river and stream improvement were operating in Washington. The distribution of major splash dams in western Washington and western Oregon is well documented by Sedell and Duval (1985). Over 150 major dams existed in coastal Washington rivers, and over 160 splash dams were used on coastal and Columbia River tributaries in Oregon. The splash dams shown by Sedell and Duval (1985) represent only the main dams that operated for several seasons. On many smaller tributaries, temporary dams were used seasonally, but no records were kept. Wendler and Deschamps (1955) were mainly concerned with these dams as obstacles to fish migration. Many were actually barriers, but the long-term damage was probably caused by the stream improvement before the drive and the scouring, widening, and unloading of main-channel gravels during the drive.

The rivers in the more arid parts of the United States also had to be improved before log drives could begin. Marble Creek on the St. Joe River in Idaho is one example. Blake (1971) described the numerous debris jams that had been there for many years. In an 18-mile stretch ending at Homestead Creek, over 500,000 board feet of good timber were recovered from the stream channel. An additional large amount of wood was used to fuel the steam donkey's trip up the canyon to Homestead Creek. Blake and his companions also "...pulled over and sawed any trees standing on the bank which might fall and cause a jam while the drive was on" (p. 73). Fishing was described as excellent on this stream before the drives. "Fifteen minutes after we moved through a deep hole, we could catch 6 or 8 large trout there. I have never seen trout fishing, from Canada to California, half as good as the fishing on the Marble Creek before the log drives" (p. 73). This is probably a "fish story" to some extent, but the fact remains that large trout were not there after the log drives.

Transportation—In addition to the stream clearing done to facilitate log drives, much cleaning was done for navigational purposes, maintaining open channels for boat and barge passage. Rivers were the main arteries of transportation until railroads and automobiles (highways) replaced them. In 50 years, over 800,000 snags were pulled from the lower 1,000 miles of the Mississippi River. Most of these were sycamore and cottonwood snags averaging 5.5 ft in diameter at the base, 2.3 ft at the top, and 115 ft in length (Sedell and others 1982). Over 65,000 snags and streamside trees were pulled and cut along the Willamette River from 1870 to 1950 (Sedell and Froggatt 1984). The U.S. Army Corps of Engineers has a long history, from the 1870's to the present, and some good records of "maintaining waterways free of obstructions." The Annual Reports put out by the Chief of Engineers of the U.S. Army (Secretary of War 1915) contains information on surveys done to determine the necessity of stream improvement, the various stream improvement activities performed (such as snagging, dredging, building of wing dams), and records of commerce. Stream cleaning was also done by State and local governments or private corporations, but there are fewer records of their activities.

The steamships for whom the rivers were cleaned had another impact on the riparian forest. They burned about four cords of wood per hour, 10 to 13 cords of wood per day (Williams 1980; Sedell and Froggatt 1984), and the closest available fuel grew along the stream. Along the Colorado River, fuel stations were located at 25-mile intervals, and such was the demand that the Indians became profitable woodcutters (Ohmart and others 1977). Woodcutting for the steamships was a major source of income for people in the Columbia River Gorge area (Williams 1980). The steamship era lasted for 60 years (1850 to 1910), but by 1910 the majority of the wood had already been removed from the streams and streambanks (Sedell and others 1982).

The demise of the steamships came about as the railroads came into use, and the railroads had their own impacts on riparian areas. The transcontinental railroads required large and continual supplies of railroad ties, which were not preserved with creosote in those days (fig. 52). The demand was met by logging watersheds adjacent to the railway

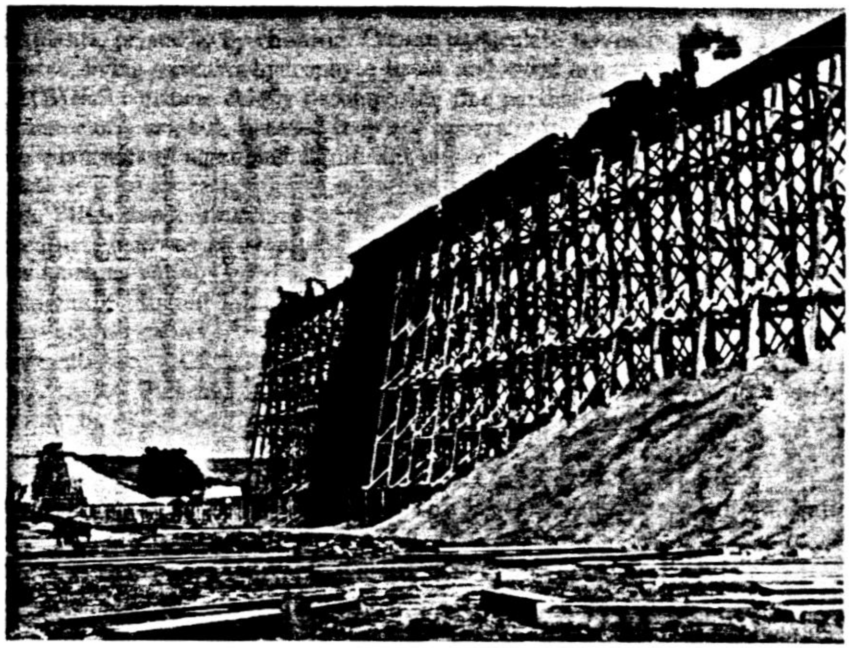


Figure 52—Construction work for large fill, Lane cut-off on the Union Pacific, 1867 (Historical Photography Collection, University of Washington Libraries).

and driving the logs down streams that intersected the line (Brown 1936). The route itself was often laid out to follow low-gradient river valleys and required removal of the riparian vegetation to accommodate it.

Implications to Riparian Research

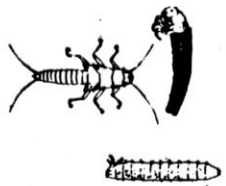
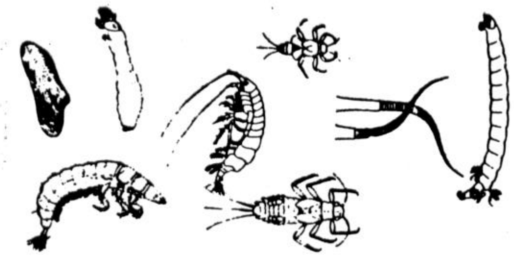
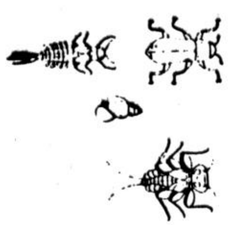
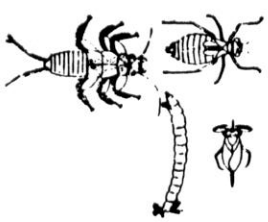
These examples demonstrate some of the substantial alterations that have occurred to riparian areas during historical times. Researchers will benefit from reviewing the historical record during their studies, even though the record may be patchy, as it will provide them with an understanding of the pristine stream condition and clarify objectives and goals of riparian enhancement and rehabilitation.

EVALUATION OF STREAM RIPARIAN AREA CONDITIONS USING BENTHIC MACROINVERTEBRATES

Historically, the composition and status of stream bottom-dwelling (benthic) invertebrates have been assessed on the basis of the taxonomic affiliation of the animals involved. Partly this individualistic, autecological approach stems from the view of the species as the basic unit of ecology, and partly it is an artifact of the historical development of knowledge in this area. In the past decade, a number of important advances in the ways that lotic ecosystems are viewed and studied have occurred (Minshall and others 1985). These have included the development of an alternative method for analyzing benthic invertebrate communities—that is, the functional feeding group approach (Cummins 1973, 1974; Cummins and Merritt 1984). This procedure permits the organization of species or higher taxa (genera, families, orders, and so forth) into ecologically meaningful groupings or guilds. The functional feeding group approach provides an assessment of the degree to which the invertebrates of a stream section/reach are dependent upon a particular food resource (table 24).

Classification of invertebrates according to feeding function is centered on morphological and behavioral mechanisms of food acquisition (Cummins 1973; Cummins and Merritt 1984). Currently, four major categories are recognized based on size, type, and general location of food ingested (table 24) (Cummins and Merritt 1984).

Table 24—A general classification system for aquatic invertebrate trophic categories (after Cummins 1973)

General category based on feeding mechanism	General particle size range of food	Subdivision based on feeding mechanisms	Subdivision based on dominant food	North American aquatic invertebrate taxa containing predominant examples
	Microns			
SHREDDERS 	>10³	Chewers and miners	Herbivores, living vascular plant tissue	Trichoptera (Phryganeidae, Leptoceridae) Lepidoptera Coleoptera (Chrysomelidae) Diptera (Chironomidae, Ephydridae)
		Chewers, miners, and gougers	Detritivores (large particle detritivores): decomposing vascular plant tissue; wood	Plecoptera (Filipalpia) Trichoptera (Limnephilidae, Lepidostomatidae) Diptera (Tipulidae, Chironomidae)
COLLECTORS 	<10³	Filter or suspension feeders	Herbivore-detritivores: living algal cells, decomposing organic matter	Pelecypoda Ephemeroptera (Siphlonuridae) Trichoptera (Philopotamidae, Psychomyiidae, Hydropsychidae, Brachycentridae) Lepidoptera Diptera (Simuliidae, Chironomidae, Culicidae)
		Sediment or deposit (surface) feeders	Detritivores (fine particle detritivores): decomposing organic matter	Oligochaeta Amphipoda Ephemeroptera (Caenidae, Ephemeridae, Ephemerellidae, Leptophlebiidae) Trichoptera (Glossosomatidae, Helicopsychidae, Molannidae, Odontoceridae, Goerinae) Lepidoptera Coleoptera (Corixidae, Elmidae, Psephenidae) Diptera (Chironomidae, Tabanidae)
SCRAPERS 	<10³	Mineral scrapers	Herbivores: algae and associated material (periphyton)	Gastropoda Ephemeroptera (Heptageniidae, Baetidae, Ephemerellidae) Trichoptera (Glossosomatidae, Helicopsychidae, Molannidae, Odontoceridae, Goerinae) Lepidoptera Coleoptera (Elmidae, Psephenidae) Diptera (Chironomidae)
		Organic scrapers	Herbivores: algae and associated material (periphyton)	Ephemeroptera (Caenidae, Leptophlebiidae, Heptageniidae, Baetidae) Hemiptera (Corixidae) Trichoptera (Leptoceridae) Diptera (Chironomidae)
PREDATORS 	>10³	Engulfers	Carnivores: whole animals (or parts)	Hirudinea Odonata Plecoptera (Setipalpia) Megaloptera Trichoptera (Rhyacophilidae, Polycentropidae, Hydropsychidae) Coleoptera (Dytiscidae, Gyrinnidae) Diptera (Ceratopogonidae, Chironomidae)
		Piercers	Carnivores: cell and tissue fluids	Turbellaria Hemiptera (Belastomatidae, Nepidae, Notonectidae, Naucoridae) Diptera (Rhagionidae)

The first category, **SHREDDERS**, feed on whole or large pieces (0.04 inch across or larger) of plants, primarily by chewing. Coarse particulate terrestrial detritus is a principal food resource; living vascular hydrophyte tissue and wood are used to a lesser extent.

COLLECTORS consume chiefly decomposing fine particulate organic matter (commonly 500 μ diameter or less), but, because they are generally indiscriminate feeders, they also ingest large quantities of algae and significant amounts of microscopic animals. It is useful to differentiate several subcategories of collectors based on location of the food and mode of acquisition. **Filter feeders** capture particles suspended in the water by means of specially constructed nets (such as *Hydropsyche*), modified mouthparts (*Simulium*), or gills (mussels). **Gatherers** (such as various mayflies) scoop, brush, or otherwise engulf deposited, loose surficial sediments. **Sediment miners** (such as tubificid worms and a number of midge larvae) burrow through deposited fine particle substrates at varying distances below the surface.

The third category, **SCRAPERS**, feed on the matrix of algae, microbes, and associated fine organic matter attached to rocks, aquatic macrophytes, or other submersed surfaces. Scrapers may be either discriminant or indiscriminant feeders but commonly ingest large amounts of algae. Modes of ingesting attached materials other than by actual scraping (such as nibbling, tearing, or cropping) are included under this heading.

The last category, **PREDATORS**, ingest living animal tissue (mainly other aquatic invertebrates) by capturing prey and ingesting whole or large parts (engulfers) or piercing the body and withdrawing fluids (piercers).

Figure 53 shows the distribution of functional feeding groups in relation to changing riparian conditions with increasing stream size. As shown, shredders are predominantly in the headwaters in association with high amounts of coarse particulate organic matter (CPOM) from the adjacent riparian area. Scrapers (grazers) predominantly occupy the shallow, more open intermediate-sized streams. Collectors are important in streams of all sizes, but they change in composition in response to particle size and makeup of the fine particulate organic matter (FPOM) and its occurrence on the stream bottom or in the water. The species composition of the predators also changes, but they remain a relatively constant proportion of the total consumers (after Vannote and others 1980).

The basic procedure for using the functional feeding group approach is simple and straightforward. Usually the invertebrates are separated, on the basis of their taxonomy, into the lowest unit practicable (preferably species or genus) and censused (see Minshall 1981). Then, the abundance or biomass values are assigned to functional feeding group categories on the basis of mouthpart morphology, food habits, feeding behavior, or all of these (see, for example, Minshall 1981, table 23). Ideally, functional feeding designations should be determined separately for each study, but frequently they are based on an examination of published results or of compilations of these results prepared by Merritt and Cummins (1984) (see table 24 for an earlier, more general version). In practice, the power of the technique is dependent on the care with which taxa are assigned to functional groups. Not only may closely related taxa (for instance, those within the same genus or family) show divergent feeding modes, but even within a single species, feeding structures and behavior may change as the invertebrate grows. In many cases, particularly in small (first to third order) headwater streams, the relative shift from autochthony to allochthony or vice versa should be reflected by changes in the ratio of shredder (sh) to scraper (sc) abundance or biomass:

sh/sc >1 = allochthonous

sh/sc <1 = autochthonous.

The idea that the functional feeding group composition of stream invertebrate communities may be a useful means of evaluating the status of riparian habitats stems from the realization that (1) trophic relationships constitute important forces in the evolution and ecology of aquatic invertebrates and (2) the trophic conditions of a stream are largely regulated by the riparian environment (Swanson and others 1982; Cummins and others 1984; Minshall and others 1985). The riparian environment controls the amount of sunlight and terrestrial plant matter reaching a stream. These factors in turn substantially determine whether the food base will be generated mainly from within the stream (autochthonous) or from without (allochthonous).

For example, provided that all other factors are equal, the more shaded a stream is, the less algae or vascular hydrophytes it will produce and the more dependent it will be on allochthonous food supplies. Unshaded streams in the United States commonly receive 1.2 to 1.8 $\times$ 10^6 kcal/m^2/yr of sunlight, whereas shaded ones may be reduced to only 10 percent or less of the total light available. Likewise, shaded deciduous forest streams commonly receive around 2,500 kcal/m^2/yr of terrestrial litter, whereas unshaded desert streams may receive less than 75 kcal/m^2/yr. Because solar, terrestrial, and other factors change as a stream becomes larger (especially wider) and more distant from its usually forested headwaters, differences in functional feeding group composition associated with stream size may be expected (Vannote and others 1980) (fig. 53). The association between predominant food type and functional feeding group composition has been found to hold in a number of relatively natural stream settings (Wiggins and Mackay 1978; Cummins and others 1981; Hawkins and Sedell 1981; Minshall 1981; Minshall and others 1983).

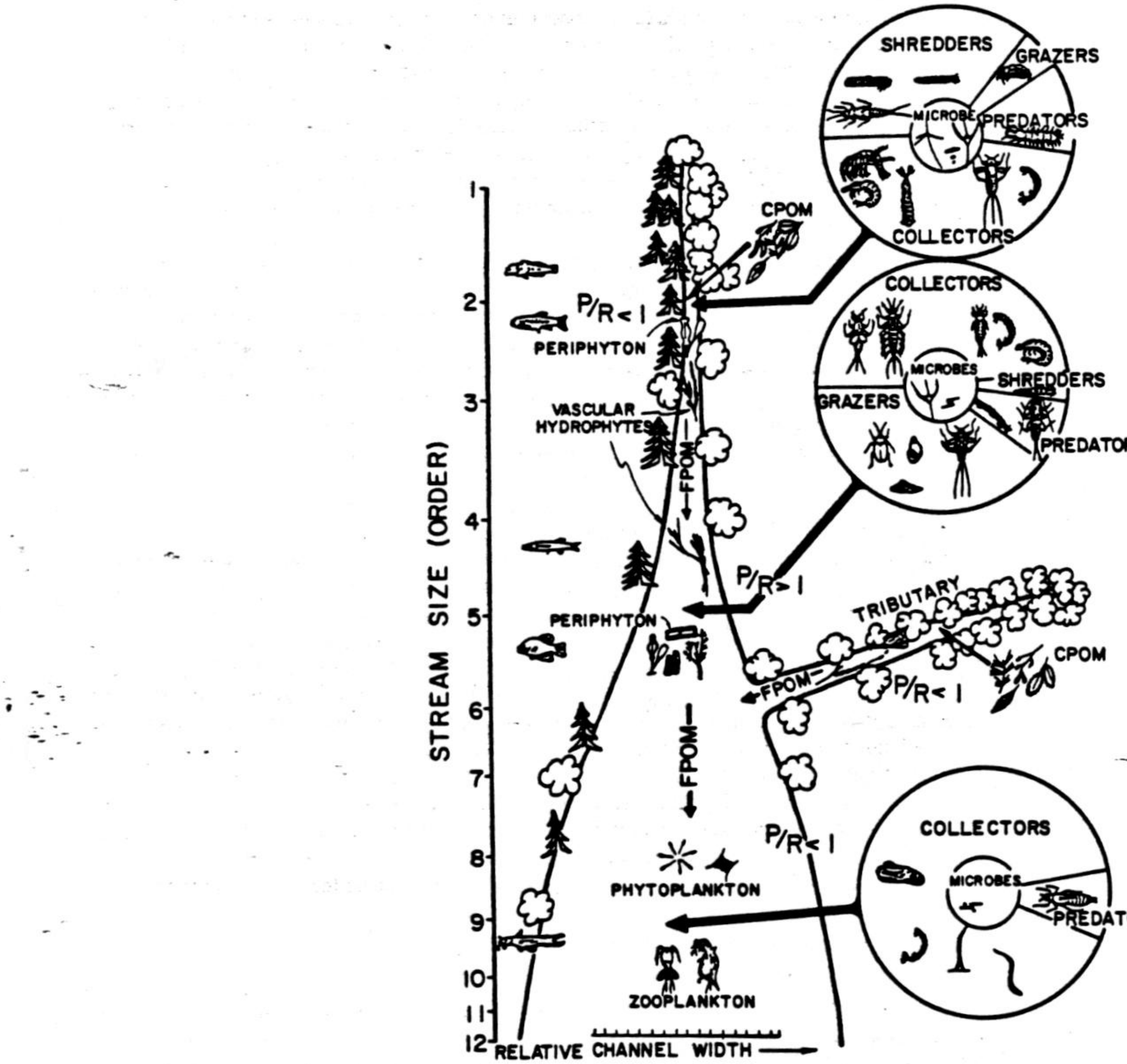


Figure 53—Distribution of functional feeding groups in relation to changing riparian conditions with increasing stream size. As shown, shredders are predominantly in the headwaters in association with high amounts of coarse particulate organic matter (CPOM) from the adjacent riparian area; scrapers (grazers) predominantly occupy the shallow, more open intermediate-sized streams. Collectors are important in streams of all sizes but change in composition in response to particle size and makeup of the fine particulate organic matter (FPOM) and its occurrence on the stream bottom or in the water. The composition of the predators also changes, but they remain a relatively constant proportion of the total consumers (after Vannote and others 1980).

Alteration of the riparian habitat generally impacts the type and density of terrestrial vegetation and the width and depth of the stream. These changes will affect the relative amounts of autochthonous and allochthonous food resources in the stream. The quality and absolute amounts of the food may also change dramatically. Consequently, the condition of the riparian habitat should be reflected in the abundance and composition of the stream invertebrate community. In general, removal of terrestrial vegetation from first to third order streams through grazing, trampling, burning, or logging can be expected to reduce the abundance and biomass of shredders and increase those of scrapers. Shifts within the collector category may also occur (such as filter feeders may increase in response to increases in the amounts of suspended organic matter), but predator levels may remain constant if only the kind and not the amount of prey is affected. Qualitative differences in the terrestrial vegetation and in the age of the stand may also affect the structure and function of the invertebrate community. For example, Vannote (1969) found that the replacement of the climax species (hickory-maple) by American beech-northern red oak in eastern deciduous forests resulted in reduced growth of shredders, especially *Tipula abdominalis*. Presumably *Tipula* is less successful now than before the change in forest type. Molles (1982) studied the caddisfly (Trichoptera) communities associated with aspen, spruce-fir, and mixed conifer forests in New Mexico. He found that the ratio of shredder to grazer biomass was higher in conifer streams (3:1) than in aspen streams (0.06:1) and attributed this to the higher retention capacity for allochthonous detritus in the conifer streams due to the greater number (five times) of logs occurring in them. In terms of forest succession, aspen stands are viewed as being younger than conifer stands.

The functional feeding group method, as applied to managed watersheds, is still in the experimental stage. There are few results available to test it. Hawkins and others (1982) studied streams in old-growth, clearcut, and second-growth forests of the Oregon Cascade Mountains. They found that shredders were no more abundant in shaded streams than in those lacking a riparian canopy. Also, the relative abundance of detritivore shredders was not always highest in shaded streams, nor was the relative abundance of scrapers always highest in unshaded streams. Similar results have been obtained in Idaho from studies of grazed and ungrazed sections of a single stream and in an assortment of burned and unburned watersheds (Minshall unpublished). Hawkins and others (1982) also found that open canopy (clearcut) streams had a much higher ratio (14:1) of collectors to scrapers than did partial (second-growth) or closed (old-growth) canopy streams (4:1). These findings are supported by studies of grazed (9:1) and ungrazed (4:1, 2:1) sections of the same stream, but results for streams in burned and unburned watersheds are variable (Minshall unpublished).

Clearer patterns could emerge from the widespread testing of the functional feeding group approach, but until that time arrives, it is best used in conjunction with more conventional approaches to community analysis—comparisons of richness, abundance, diversity, and so forth as suggested by Platts and others (1983). For instance, Newbold and others (1980) found that Euclidean distance and Shannon-Weiner diversity gave the clearest indication of logging effects of the various indices they examined.

Description of population responses should not be abandoned. Hawkins and others (1982), for example, found differences in both absolute and relative abundances of individual taxa in shaded and unshaded streams even though differences in streamside vegetation were not always evident from community level properties.

Should the functional feeding group approach prove to be a sensitive indicator of the condition of the riparian habitat, its use could greatly simplify evaluation of stream ecosystem responses to environmental change. But even if this goal is not attained, it should provide aquatic biologists and resource managers with an additional tool for measuring riparian impacts.

PLANTING OF RIPARIAN SITES

Riparian sites are an intricate part of the watershed resources of the Western United States (Thomas and others 1979). Riparian areas normally align stream courses that often traverse many plant communities, topographic sites, and climatic conditions. The entire route of a stream is interrelated and major disruptions to the stream or watershed can influence a significant portion of the course.

Livestock grazing, timber harvesting, road construction, agricultural cropping, and recreational uses have disrupted the vegetation and stability of many riparian areas (Council of Agricultural Science and Technology 1974; Leopold 1974). Once the vegetative cover of the channel is reduced, stream erosion may quickly alter the site and hinder natural or artificial restoration (Monsen 1983). Disturbances to the vegetation of other range or wildland sites are usually not so critical. The vegetation of upland sites may be seriously disrupted, yet degradation usually ceases as livestock grazing or other impacts are regulated. In contrast, disturbed riparian areas may continue to degrade after the activity stops. Water control structures may be required to alleviate erosion and allow recovery.

Controlling livestock grazing and regulating other uses of riparian sites is not always easy (Platts 1981b). Grazing adjacent upland rangelands is often dependent upon access to riparian communities. Eliminating riparian areas from livestock grazing usually impedes the effective use of associated uplands.

A more extensive revegetative plan is usually required to restore and stabilize riparian disturbances than is needed to rectify disruption to upland plant communities. Methods required for interplanting woody and herbaceous species onto unstable streambanks have not been fully developed. In addition, woody and aquatic species adapted to riparian sites are not commercially available for large-scale plantings. Research has not yet been able to determine the most appropriate techniques to propagate and plant native or introduced species that are adapted to riparian disturbances.

Factors Influencing Revegetation

The following list discusses factors that influence restoration practices.

1. Alteration of the riparian vegetation and soil may occur from on-site impacts, or as a result of poor management of other portions of the watershed (Megahan and Kidd 1972). Proper management of the entire watershed is essential prior to enactment of restoration measures of the riparian communities. Restoration of riparian sites may be conducted simultaneously with treatment of other portions of the watershed. Unless adjoining areas are reasonably stable, repair of riparian disturbance will not be effective.

2. Riparian sites usually are extremely heterogeneous, containing different plant communities, topographic conditions, parent materials, and soils within a short distance (Odum 1971). Remedial treatments must be applicable to the different conditions encountered. For example, unstable, steep banks may occur immediately adjacent to wet and boggy meadows, requiring different site preparation practices, planting techniques, and plant materials.

3. Different treatments are often required to correct separate problems—control surface erosion, eliminate bank slumping, provide shade to the stream, control weeds, and provide concealment for wildlife.

4. Riparian sites are often narrow, irregularly shaped corridors that are not accessible to conventional planting equipment. Although only small areas may require treatment, extensive erosion, sedimentation, and plant alteration may have occurred, thus requiring special equipment for restoration.

5. The dense and frequently storied assembly of many plant species is required to maintain riparian site stability. Grazing and other impacts have often reduced plant density or resulted in the removal of specific species. The loss of key species may seriously affect the persistence of other plants. To be successful, restoration may require the reestablishment of a complex array of plants. Reestablishing woody plants is often the most critical.

6. Many sites are so seriously altered that extensive restoration measures will be required to restrict further losses of soil and vegetation and reestablish a desirable plant cover.

7. Stabilization of the streambank with vegetation is often the principal concern in restoration. Revegetation may also be required to provide shade to the stream, forage for livestock, or wildlife habitat.

8. Riparian sites have often been so seriously altered that the original vegetation is no longer adapted to the disturbances. Thus attempts to restore the original complement of plants may not be practical. However, unless a grouping of plants similar to the original community can be established, aquatic and terrestrial resources may not be fully restored.

9. Noxious weeds and less desirable species have often invaded riparian disturbances. Weeds often must be removed to improve the site and allow for planting. These plants do not always provide adequate soil protection or enhance aquatic habitat. Weeds may be spread by the stream to occupy downstream disturbances and interfere with the establishment of more desirable species.

10. Site preparation is usually required to accommodate planting. Some reduction of the existing plant cover may be necessary to eliminate competition to newly seeded or planted species. However, reduction of streambank stability by plowing or similar methods of plant removal is hazardous. Thus, treatments normally include interseedings, selective, or delayed

plantings. By such procedures, small areas can be treated in sequential intervals to retain existing plant cover and encourage natural recovery.

11. Seasonal runoff and flooding influence planting dates as well as establishment and survival of new seedlings or transplants (Aldon 1970). Sites may be covered with water in the spring for a few days or weeks. Planting is frequently delayed by flooding until air temperatures and precipitation patterns are no longer conducive to seedling survival (Cluff and others 1983).

Disturbances may be seeded in the later summer or fall, yet fall-germinated seedlings may not be able to survive spring runoff. Many riparian species survive or are propagated by flooding (Kozlowski 1984). However, small seedlings usually are not as adaptive as larger plants. Seasonal runoff also disrupts and seriously damages prepared seedbeds. Transplanting large stock is often required to resist the effects of flooding and scouring.

12. Protection of young plantings is essential for plant establishment and survival. Protection from grazing may be required for a number of years to allow plants to attain a reasonable size and furnish soil protection. Transplanting large stock may be necessary to overcome the influences of grazing and flooding.

Restoration by Natural Means

Artificial revegetation is not the only means to reattain a satisfactory plant cover. Natural recovery can often occur if areas are protected from livestock grazing or other destructive effects (Meehan and Platts 1978; Vallentine 1971). If a remnant composition of desirable plants exists, natural restoration may be most practicable. Artificial revegetation normally should not be employed unless satisfactory recovery cannot be achieved by natural means within an acceptable period. Most riparian shrubs and trees are capable of resprouting and can recover from extensive use. Nonsprouting species are slower to recover and may reappear erratically. A satisfactory seed source may exist, but seedbed conditions on disturbed sites are not always conducive to seedling establishment. Although protected sites may recover slowly at first, once soil surfaces stabilize new plants often appear rapidly.

Some native herbs are difficult to propagate and plant, yet these species contribute to streambank stability. Few introduced herbaceous plants produce the root mass and streambank stability of many important native herbs. Few, if any, native *Carex* or other grasslike plants are commercially available. Where possible, these herbs should be allowed to recover naturally. Plowing or spraying should be done carefully to retain these plants. Species listed in table 25 are some of the principal understory herbs of value for streambank stabilization.

Table 25—Distribution and rooting characteristics of select native herbs for riparian sites. Information in part is from Lewis (1958). Scientific names from Welsh and others (1981).

Species	Areas[1]	Habitat	Abundance	Rooting habit	Comments
Carex aquatilis Water sedge	Asp.-SF	Wet meadows	Abundant	Caespitose, long rhizomes	Excellent streambank stability, highly palatable. Principal species for revegetation.
Carex aurea Golden sedge	Val.-SF	Marsh, wet meadows	Frequent	Caespitose, long rootstocks	Widely distributed, good ground cover.
Carex disperma Softleaved sedge	Asp.-Alp.	Swamps, meadows	Frequent	Caespitose, long rhizomes	Shady areas, solid mat, moderate vigor.
Carex douglasii Douglas sedge	PJ-Asp.	Dry meadows, alkali tolerant	Abundant	Creeping rootstocks, long clums	Adapted to compact soils, low palatability, increases under grazing.
Carex elynoides Black sedge-root	Alp.	Open, dry meadows	Common	Caespitose	Vigorous, abundant.
Carex hoodii Hood sedge	Mtn.B.-SF	Open parks, drainage ways, bottoms	Abundant	Densely caespitose	Excellent ground cover, useful forage species.
Carex lanuginosa Woolly sedge	Val.-SF	Dry to wet meadows	Abundant	Caespitose, long rootstocks	Very robust, principal species for streambank stabilization.
Carex lenticularis Kellogg sedge	Mtn.B.-SF	Wet meadows, marshes	Abundant	Caespitose, long rootstocks	Pioneer species, invades water's edge.
Carex microptera Smallwing sedge	Mtn.B.-Asp.	Meadow edges	Abundant	Densely caespitose	Good cover for streambank, palatable, spreads by seeds, widely distributed.

(con.)

Table 25—(Con.)

Species	Areas[1]	Habitat	Abundance	Rooting habit	Comments
Carex nardina Hepburn sedge	Alp.	Open meadows	Abundant	Densely caespitose	Short stature, open cover.
Carex nebrascensis Nebraska sedge	Val.-Asp.	Marshes and meadows, alkali tolerant	Common	Strongly rhizomatous	Excellent soil stabilizer, palatable, widely distributed.
Carex nigricans Black alpine sedge	SF-Alp.	Well-drained meadows	Frequent	Creeping rootstock	Good cover for wet areas.
Carex praegracilis Slim sedge	Val.-Asp.	Dry to moist, alkali bottomlands	Abundant	Long, creeping rootstocks	Large plant, dense, persistent, moderately palatable.
Carex rostrata Beaked sedge	Val.-SF	Streams, water's edge, standing water	Abundant	Culms from stout, long rhizomes	Principal species for streambank stabilization, low palatability, fluctuating water level, wide elevational range.
Carex rupestris Rock sedge	Alp.	Dry slopes and meadows	Abundant	Short rhizomes	Vigorous, spreads rapidly, limited distribution.
Carex saxatilis	LPP-SF	Water's edge	Abundant	Culms from long, creeping rootstocks	Excellent streambank cover, limited distribution.
Carex scirpoidea Downy sedge	Alp.	Dry and wet meadows	Abundant	Rhizomatous	Vigorous, spreads rapidly.
Carex simulata Analogne sedge	PP-SF	Bogs and wet meadows, calcareous soils	Frequent	Long, creeping rootstocks	Excellent cover, widely distributed.
Carex vallicola Valley sedge	Sage-Asp.	Dry slopes	Abundant	Caespitose	Spreads onto dry grass-sage sites.
Eleocharis palustris Spikerush	Val.-SF	Wet meadows and streams, alkali tolerant	Abundant	Rhizomatous	Spreads rapidly, low palatability, wide elevational range.
Juncus arcticus var. *balticus* Baltic rush	Val.-Asp.	Wet and semiwet meadows	Abundant	Rhizomatous	Principal species for stabilization. Use adapted ecotypes, spreads aggressively, persists with grazing.
Juncus drummondii Drummond rush	LPP-Alp.	Wet and dry meadows	Common	Caespitose	Spreads after disturbance, occupies infertile soil.
Juncus ensifolius Swordleaf rush	Sage-SF	Streams, wet meadows, seeps	Abundant	Strongly rhizomatous	Moderately palatable, wide elevational range.
Juncus longistylis Longstyle rush	Sage-SF	Wet meadows, streams	Common	Rhizomatous	Moderately palatable.
Juncus torreyi Torrey rush	Val.-PJ	Streams, wet meadows, seeps, alkali tolerant	Common	Strongly rhizomatous	Spreads onto disturbances.
Scirpus acutus Tule bulrush	Val.-Mtn.B.	Lake edge	Abundant	Rhizomatous	Tall, rank, dense patches, restricted to water's edge.
Scirpus maritimus Saltmarsh bulrush	Mtn.B.	Lake edge, stream bank, alkali sites	Abundant	Rhizomatous	Dense patches, spreads rapidly.

[1]Areas: Alp. = alpine, SF = spruce-fir, Asp. = aspen, LPP = lodgepole pine, PP = ponderosa pine, Mtn.B. = mountainbrush, PJ = pinyon-juniper, Sage = big sagebrush, Val. = valley.

Site Preparation and Alterations

Site disturbances must be evaluated relative to their effects on seedbed or planting conditions. Disturbances may have eliminated desirable plants, altered or removed the soil, or allowed for the invasion of weeds. Prior to treatment the entire route should be surveyed and classified by site conditions.

Physical Structures—The erection of physical structures, either temporarily or permanently, is often required to protect the seedbed or streambank from erosion (Horton 1949). Temporary structures, including logs, trees, or netting may be used during the period of plant establishment to divert or reduce stream impacts. However, during years of excessive flooding these structures might not be effective. Permanent structures are often required to stabilize erosive surfaces and prevent mass slumping. Physical structures are expensive and cannot be erected at every site. Consequently, they are usually located in the most critical areas. The reintroduction of beavers with their dam building is often an effective method of stabilizing the streambanks.

Regrading and Topsoiling—Steep banks may not be successfully planted unless the slope is reshaped. Reshaping enhances the success of both seeding and transplanting. Reshaping is usually more effective than construction of retaining or diversion structures. However, regrading is not always possible and may not be effective if serious erosion is allowed to continue. Streambanks should not be reshaped if the existing plant cover is able to stabilize the site through protective management.

Topsoiling is an effective and practical method of treating riparian sites and is important in improving the seedbed. Seedling establishment can be enhanced by slight modification of the soil surface. Topsoiling should be considered when dams, bridges, or other physical changes are made. A thin layer of topsoil can be applied over an entire site, or select but restricted spots may be covered with a thick layer. Isolated sites that are topsoiled and planted recover quickly and tend to moderate and enhance the improvement of untreated areas. Selective treatment is useful to protect erodible portions of the streambank.

Young plantings may require more than 1 year to become firmly established. An additional 2 or 3 years are needed to provide appreciable soil protection. Exposing large segments of the streambank to flooding for this period may not be advisable. Treating small segments of the stream over 2 to 5 years may be more costly but is recommended.

Reduction of Weeds and Plant Competition—New seedlings or transplants cannot be established amid an existing competitive stand of plants. However, complete elimination of the existing cover is not always required or advisable. Although improvements may ultimately result from seeding or transplanting, complete elimination of existing species to facilitate planting may be advisable only on sites where serious erosion is not expected.

Because soil stability is much more critical to riparian conditions than to upland sites, plant cover must be maintained during the planting period. If destructive erosion does not occur, undesirable plants can be completely removed by plowing, disking, spraying, and so forth. Interseeding or spot treatment is advisable for more erodible sites.

Neither seeded nor transplanted species can be established on sites supporting existing plant cover unless some means is provided to control the existing competition. Neither willow cuttings nor rooted stock can be successfully planted directly into an existing understory (Neilard and others 1981). Transplants are usually less susceptible to competition than are direct seedings. Transplanting small segments of sod or plugs of various grasses, carex, or broadleaf herbs can be accomplished without extensive site preparation. However, unrooted slips or stem cuttings of willow or other shrubs are not well suited to unprepared sites. Interplanting rooted or unrooted shrubs onto unprepared sites should be avoided. This practice is quite often employed and usually fails.

Seedbed Preparation—Construction activities such as plowing to remove weeds or regrading the streambank are treatments that do not necessarily create a favorable seedbed. These practices should not be confused with seedbed preparation. A firm soil surface and an adequate supply of soil moisture are critical to seeding and transplanting.

If site alteration treatments are used to develop a seedbed, these practices must be employed at a time and under conditions favoring a quality seedbed. Treatments should not be conducted when soil compaction would occur or if excessive drying of the seedbed would result.

Proper seedbed and planting surfaces can be achieved by allowing time for loose soils to settle, or by mechanical compaction. Highly compact or hard surfaces can be loosened by ripping, plowing, or disking. Storage of soil moisture can be accomplished by scheduling treatments to allow water to collect and infiltrate the soil.

Proper equipment should be used. Drill seeders and other conventional seeding equipment can be operated on rough irregular surfaces. Compaction wheels and furrow openers can be adjusted to create suitable surface conditions.

Barren sites are often erroneously considered appropriate areas for planting without regard to seedbed characteristics. Barren areas may be void of plant competition but may not be conducive to seeding.

Plowing and Disking—Plowing and disking are most often used to uproot and reduce dense stands of undesirable plants (Long and others 1984). Plowing is usually confined to deep soils, whereas disking is better adapted to shallow and more rocky sites. Disking is more appropriate in areas having a large accumulation of litter. Both items of equipment can be used to uproot sod-forming species. Disking or plowing may be used in conjunction with herbicides to remove the most persistent vegetation.

Plowing is usually done when soils are moist but not wet or excessively dry. Surface litter and soil structure are altered by plowing. Semiwet and wet meadows contain a high percentage of organic matter. Plowing may cause these soils to settle and crust if worked at an inappropriate time. Prior to planting plowed sites must be allowed to settle, or a firm seedbed can be created by harrowing. Planting depths cannot be properly regulated if attempts are made to seed a loosely plowed surface. Plowing can cause rapid drying of the seedbed. However, harrowing the surface to create a loose surface mulch will prevent drying.

Disking is a more versatile technique than plowing. Various size disks are available. Some are almost as effective as a moldboard plow, whereas others create much less soil disturbance. The digging depth of the disk can be adjusted to penetrate the soil to the depth desired. Small, lightweight disks can be used with a variety of tractors. These implements can be operated on small rough sites without serious damage to the machinery.

Disking is recommended for treating sites where a residual amount of vegetation is to be left in place. Disks can be adjusted to leave some vegetation on the surface or have it plowed into the soil. Seeding devices can be mounted on the disk to distribute seed directly behind or in front of the machine. Natural soil sloughing frequently occurs to cover the seed.

Herbicides for Plant Control—Herbicides can be applied to remove or control undesirable vegetation, leaving other desirable vegetation. Contamination of the stream is a concern when herbicides are used. However, recent advances with new herbicides, formulations, and application techniques have expanded the potential use of herbicides for riparian areas.

Because some species cannot be easily controlled by mechanical treatment, herbicides are particularly advantageous. More importantly, herbicides provide a rapid control method for treating poorly accessible riparian sites, an advantage because the planting season is usually short. However, use of herbicides does not always result in a suitable seedbed, and mechanical treatments may also be required to accomplish direct seedings.

Herbicides should be applied using ground sprays or hand-operated units. Both can be safely operated and large areas can be treated effectively. Hand spraying is the most efficient method of plant control when transplanting shrubs into a herbaceous understory. Glyphosate (Roundup™) can be used to eliminate most riparian species including rhizomatous grasses, grasslike plants, and broadleaf herbs. The herbicide is effective when applied at a rate of 1 pint per acre. Small spots, approximately 30 inches in diameter, are sprayed. Woody transplants can be planted immediately after the herbicide is applied although a delay of half to a full hour is recommended. An agricultural dye is added to the herbicide to mark the sprayed spots. Spot spraying and transplanting minimizes disruption to the existing vegetation. Rhizomatous plants maintain streambank stability, and sprayed spots will often collapse as the root mass dies. Entire sections of the streambank can fail or slump away if a large number of spots are closely aligned near the edge of the bank. The best recommendation is to not use herbicides close to streambanks.

For specific herbicide uses, application rates and systems, the following references are recommended: Alley and others (1978), Cords and Artz (1976), Heikes (1978), Whitson and others (1985), Jensen and others (1980), USDA Forest Service (1984), Vallentine (1980, 1983), and Welty and others (1981).

Interseeding and Interplanting—Interseeding is a means of preparing and planting the site without complete removal of the existing vegetation. Various drills, disks, scalpers, and spray units have been adapted to interplant small strips, patches, or spots while leaving most of the existing vegetative area undisturbed.

Interplanting shrubs with herbaceous plants is a practical method of reestablishing woody plants in most riparian sites. Shrubs cannot be established without first reducing the understory competition. Shrub transplants compete much more successfully than direct seedings.

Seeding Riparian Communities

Flooding dictates the planting dates. Areas not subject to flooding can be fall-planted or spring-planted depending upon climatic conditions. Areas that are flooded annually should be seeded after spring runoff. Fall plantings can be made if sites are not damaged by spring runoff.

Covering seed is essential to germination and seedling establishment. Broadcast seeding is not acceptable unless some means of seed coverage is provided. A mixture of plants is often seeded to furnish an immediate and dense ground cover. Harsh sites are difficult to seed, and adherence to proven practices must be followed. Applying excessive amounts of seed will not compensate for poor seeding techniques.

Riparian areas can be seeded with the same equipment and the same techniques used to plant upland ranges. Seeding can be accomplished using drills, cultipack seeders, interseeders, hydro-row dry-seeders, or hand planting. Aerial seeding is also appropriate, but unless helicopters are used, riparian sites are usually too small for this technique. Sites that can be planted with conventional equipment usually can be drill seeded. Unless the sites are accessible and reasonably large, seeding with tractor-drawn equipment is impractical. Smaller sites can be broadcast seeded by hand, after which the seed should be raked into the soil surface.

Plant Selection and Uses

In addition to the use of native herbs that occur within the planting sites, various introduced species can be relied upon for direct seeding and transplanting (Horton 1949; Doran 1957; Plummer and others 1968). While such species are introduced to provide immediate soil protection, they must also possess both a vegetative growth habit and root mass capable of furnishing site protection when subjected to stream erosion (Ree 1976). The new species must also allow for natural succession and the ultimate development of a desired community. Planting aggressive and competitive rhizomatous species can prevent the entry of other useful plants, unless these are included in the initial mixture.

Transplanting small plugs or large pads is a viable method of establishing herbaceous plants. Transplants can be reared or dug from wildland sites to furnish suitable materials. But because planting costs are high, only small areas are usually treated in this manner.

Species listed in tables 26 and 27 are recommended for either seeding or transplanting.

Table 26—Grasses recommended for direct seeding and transplanting riparian sites. Scientific names from Welsh and others (1981).

Species	Areas of adaptation[1]	Origin	Seeding trait	Transplant capability	Growth rate	Rooting habit	Salinity tolerance[2]	Flooding tolerance	Palatability	Spreadability
Agropyron elongatum										
Tall wheatgrass	Mtn.B.-V	Introduced	Excellent	Good	Rapid	Large clump	MT	Moderate	Fair	Good
Agropyron repens										
Quackgrass	Asp.-V	Introduced	Fair	Excellent	Slow	Rhizomatous	MT	Moderate	Good	Excellent
Agropyron smithii										
Western wheatgrass	PP-SDS	Native	Poor	Excellent	Slow	Rhizomatous	MS	Moderate	Good	Good
Agropyron trachycaulum										
Slender wheatgrass	SF-PJ	Native	Excellent	Excellent	Rapid	Rhizomatous	MS	Sensitive	Excellent	Good
Agrostis stolonifera										
Redtop	Salp.-SF	Introduced	Fair	Good	Moderate	Rhizomatous	MS	Moderate	Good	Excellent
Alopecurus pratensis										
Meadow foxtail	Alp.-Mtn.B.	Introduced	Excellent	Good	Rapid	Rhizomatous	MT	Tolerant	Good	Excellent
Bromus carinatus										
Mountain brome	Alp.-PJ	Native	Excellent	Excellent	Rapid	Rhizomatous	MT	Moderate	Good	Good
Bromus erectus										
Meadow brome	Alp.-PJ	Introduced	Excellent	Excellent	Moderate	Rhizomatous	MT	Moderate	Good	Excellent
Bromus inermis										
Smooth brome	Alp.-Mtn.B.	Introduced	Good	Excellent	Moderate	Rhizomatous	MT	Moderate	Good	Excellent
Calamagrostis canadensis										
Bluejoint reedgrass	SF-Sage	Native	Good	Excellent	Moderate	Rhizomatous	MT	Tolerant	Good	Excellent
Calamagrostis epigeois										
Chee reedgrass	Alp.-PJ	Introduced	Poor	Good	Slow	Rhizomatous	MT	Tolerant	Good	Good
Dactylis glomerata										
Orchardgrass	Alp.-Sage	Introduced	Good	Good	Rapid	Bunch	MS	Sensitive	Excellent	Fair
Deschampsia caespitosa										
Tufted hairgrass	Alp.-SF	Native	Poor	Fair	Slow	Bunch	MT	Tolerant	Fair	Poor
Distichylis spicata										
Saltgrass	V	Native	Poor	Excellent	Slow	Rhizomatous	T	Tolerant	Fair	Excellent
Elymus cinereus										
Great Basin wildrye	Mtn.B.-V	Native	Good	Good	Moderate	Large clump	T	Moderate	Good	Fair
Elymus giganteus										
Mammoth wildrye	Mtn.B.-Sage	Introduced	Fair	Good	Moderate	Rhizomatous	T	Tolerant	Good	Good
Elymus junceus										
Russian wildrye	Mtn.B.-V	Introduced	Fair	Good	Moderate	Bunch	T	Moderate	Excellent	Fair
Elymus triticoides										
Creeping wildrye	JP-V	Introduced	Good	Excellent	Moderate	Rhizomatous	T	Tolerant	Poor	Good
Festuca arundinacea										
Reed fescue (alta or tall)	Asp.-SDS	Introduced	Excellent	Excellent	Rapid	Rhizomatous	T	Tolerant	Good	Excellent
Hordeum brachyantherum										
Meadow barley	Alp.-Asp.	Native	Excellent	Excellent	Moderate	Bunch	T	Tolerant	Fair	Good
Lolium perenne										
Perennial ryegrass	SF-PP	Introduced	Excellent	Good	Rapid	Small bunch	MT	Sensitive	Good	Good
Phalaris arundinacea										
Reed canarygrass	Asp.-V	Native	Poor	Excellent	Slow	Rhizomatous	T	Tolerant	Fair	Excellent

Phleum pratense Timothy	Asp.-Mtn.B.	Introduced	Good	Good	Rapid	Bunch	MS	Moderate	Good	Good
Poa pratensis Kentucky bluegrass	Asp.-PJ	Introduced	Fair	Good	Slow	Rhizomatous	MT	Moderate	Good	Excellent
Poa secunda Sandberg bluegrass	Mtn.B.-Sage	Native	Fair	Good	Slow	Bunch	MT	Moderate	Good	Fair
Sitanion hystrix Bottlebrush squirreltail	Mtn.B.-SDS	Native	Good	Fair	Moderate	Bunch	MT	Moderate	Good	Good
Sporobolus airoides Alkali sacaton		Native	Fair	Good	Slow	Bunch	MT	Moderate	Good	Excellent

[1]Areas of adaptation—Alp. = alpine; SF = spruce-fir; Asp. = aspen; Mtn.B. = mountainbrush; PJ = pinyon-juniper; PP = ponderosa pine; Sage = big sagebrush; Salp. = subalpine; SDS = salt desert shrub; V = valley bottom.

[2]Salinity tolerance—S = sensitive; MS = moderately sensitive; MT = moderately tolerant; T = tolerant.

Table 27—Broadleaf herbs recommended for planting of riparian sites. Scientific names from Welsh and others (1981).

Species	Areas of adaptation[1]	Origin	Seeding trait	Transplant capability	Growth rate	Salinity tolerance[2]	Flooding tolerance	Palatability	Spreadability
Achillea millefolium lanulosa Western yarrow	Alp.-V	Native	Excellent	Excellent	Rapid	MS	Moderate	Poor	Excellent
Artemisia ludoviciana ludoviciana Louisiana sagewort	Alp.-Sage	Native	Excellent	Excellent	Rapid	MS	Moderate	Poor	Excellent
Aster chilensis adscendens Pacific aster	Asp.-V	Native	Poor	Excellent	Moderate	MS	Moderate	Excellent	Excellent
Bassia hyssopifolia Fivehook bassia	PJ-SDS	Native	Excellent	Good	Rapid	T	Tolerant	Good	Good
Coronilla varia Crownvetch	PJ-Mtn.B.	Introduced	Good	Excellent	Rapid	MS	Moderate	Good	Good
Epilobium angustifolium Fireweed	Asp.-Mtn.B.	Native	Excellent	Good	Rapid	S	Moderate	Fair	Excellent
Heracleum lanatum Common cowparsnip	Alp.-Mtn.B	Native	Poor	Poor	Poor	S	Sensitive	Excellent	Fair
Linum lewisii Lewis flax	Asp.-Sage	Native	Excellent	Good	Moderate	S	Sensitive	Good	Good
Medicago lupulina Black medic	Asp.-Sage	Introduced	Excellent	Good	Moderate	MT	Moderate	Good	Good
Medicago sativa Alfalfa	Asp.-Sage	Introduced	Excellent	Good	Rapid	MT	Moderate	Excellent	Fair
Melilotus officinalis Yellow sweetclover	Asp.-Sage	Introduced	Excellent	Poor	Rapid	MT	Moderate	Good	Excellent
Potentilla glandulosa glandulosa Gland cinquefoil	Asp.-PP	Native	Good	Excellent	Moderate	S	Moderate	Fair	Good
Senecio serra Butterweed groundsel	Asp.-PP	Native	Good	Excellent	Moderate	S	Moderate	Good	Good
Sidalcea oregana Oregon checkermallow	Asp.-Mtn.B.	Native	Good	Good	Moderate	S	Moderate	Fair	Good
Smilacina racemosa amplexicaulis Western Solomons-seal	Asp.-Mtn.B.	Native	Poor	Fair	Slow	S	Moderate	Excellent	Fair
Trifolium fragiferum Strawberry clover	V	Introduced	Good	Fair	Moderate	MT	Moderate	Excellent	Excellent
Trifolium hybridum Alsike clover	Asp.-Mtn.B.	Introduced	Good	Fair	Moderate	S	Moderate	Good	Good
Valeriana edulis Edible valerian	Asp.-Mtn.B.	Native	Poor	Fair	Slow	S	Moderate	Fair	Fair

[1]Areas of adaptation—Alp. = alpine; Asp. = aspen; PP = ponderosa pine; Mtn.B. = mountainbrush; PJ = pinyon-juniper; Sage = sagebrush; SDS = salt desert shrub; V = valley bottoms.
[2]Salinity tolerance—S = sensitive; MS = moderately sensitive; MT = moderately tolerant; T = tolerant.

Planting Woody Species

Woody plants are normally required to provide streambank protection and to furnish habitat and forage to wildlife and livestock (Shafer and others 1982). Destruction of the woody overstory has often resulted from prolonged grazing. Once lost, these plants are difficult and costly to restore. Because shrubs and trees are not easily and reliably seeded, transplants are most often used to assure revegetation (Plummer and others 1968).

Without the presence of a protective overstory of shrubs and trees, many herbaceous species are unable to persist and provide streambank stability.

Species of willow (*Salix*) are the most universally abundant and most widely distributed of the woody taxa of the temperate riparian communities, while other shrubs are also present and may dominate in certain regions (Anderson and others 1984). Woody species that can be easily cultured have been relied upon for site improvement (table 28). Few native shrubs have been examined for riparian plantings. Chmelar (1974), Neiland and others (1981), and McCluskey and others (1983) examined cultural treatments required to propagate species of willow. Heebner and Bergener (1983) assembled information on red alder (*Alnus rubra*), and numerous studies have reported propagation practices for growing poplars (Phipps and others 1977; Peterson and Phipps 1976; Hansen and Phipps 1983). However, on-site evaluations and adaptability studies for most species are limited.

Propagating Woody Transplants—Woody species may be planted as (1) "slips" or unrooted stem cuttings, (2) rooted cuttings, (3) nursery (Shaw 1984; McDonald and others 1983) or greenhouse grown seedlings (Owston and Stein 1977; Landis and Simonich 1984), or (4) "wildlings," which are root sections or small seedlings dug from wildland sites (Doran 1957). Willows, poplars, dogwood, and plum are examples of species easily produced from cuttings, whereas other shrubs are normally grown from seed (table 28). Rooted stock have a definite advantage over unrooted cuttings, and should be used.

Most riparian shrubs can be effectively grown as transplant stock. Container-grown transplants can be produced in a shorter time than nursery-grown stock. However, bareroot stock is cheaper, much easier to handle, and plant survival exceeds or equals container plantings.

Rooting willow cuttings as nursery grown stock is advisable. Cuttings can be collected in the fall or spring as dormant slips. Cuttings are then planted into nursery beds and grown throughout the summer. The cuttings root and grow rapidly, requiring both root and stem pruning to contain desirable size. Rooted stock can be lifted, stored, and planted in a manner similar to other bareroot materials (Dahlgreen and others 1974; McDonald and others 1983).

Culture of Willows for Transplant Stock—While willows are usually grown more easily from cuttings than from seed, some species of willow respond better to other methods of culture (Chmelar 1974). Some species have preformed root primordia that occur in the stems (Carlson 1950; Haissig 1970). These develop adventitious roots that grow quickly. Species without preformed root primordia root poorly and some not at all. Densmore and Zasada (1978) report that of five species tested, plants associated with wet or riparian sites rooted easily and nonriparian species rooted poorly. Differences apparently were due to the presence or absence of preformed root primordia (table 29). Stem cuttings taken from the riparian species developed roots that arose along the entire length of the stem. Nonriparian species rooted only at the base of the cut. Chmelar (1974) found similar differences in the origin of new roots from 107 species of willow.

Studies of approximately 20 willows common to the Intermountain region also confirm that riparian-associated plants root better than nonriparian species (table 29). Roots developed throughout the stem of both riparian and nonriparian species but tended to be confined to the base of the cut for nonriparian selections.

Species that root quickly and freely are more likely to succeed and should be planted (table 29). All others should be rooted as nursery-grown or greenhouse-grown stock prior to field planting.

Chmelar (1974) found that stem and root formation began simultaneously for most easily rooted species. Root formation was delayed as much as 15 days, or longer than the time for leaf or stem development with poorly rooted species. Similar differences were recorded with Intermountain species propagated from stem cuttings (table 29). Plants that formulate roots after leaves and stems have developed are at a serious disadvantage. Favorable conditions may not persist long enough to assure rooting and establishment if slowly rooted species are field planted. New vegetative growth may persist for 1 or 2 years before plants succumb due to an inadequate root system.

Table 28—Woody species recommended for riparian disturbances. Scientific names from Welsh and others (1981).

Species	Areas of occurrence		Adaptation to disturbed sites	Methods[2] of culture	Establishment traits			Comments
	Zones[1]	Habitat			Seedling establishment	Growth rates	Soil stability value	
Alnus tenuifolia Thinleaf alder	SF-Mtn.B.	Stream edge and well-drained soils.	Excellent	NS, CS, DS	Excellent	Rapid	Excellent	Easily established, adapted to harsh sites, grows rapidly.
Amelanchier alnifolia Saskatoon serviceberry	Asp.-Mtn.B.	Well-drained soils, seeps occasional.	Good	NS, CS	Fair	Slow	Good	Slow to establish, sensitive to understory competition.
Artemisia cana viscidula Silver sagebrush	Asp.-Sage	Well-drained and moist soils, valley bottoms.	Fair	DS, NS, CS	Good	Rapid	Fair	Well adapted to exposed moist soils able to tolerate flooding for short time.
Artemisia tridentata tridentata Basin big sagebrush	Mtn.B.-SDS	Deep, well-drained soils, occasional flooding.	Excellent	DS, NS, CS	Good	Rapid	Fair	Useful for planting extremely disturbed and well-drained soils.
Artemisia tridentata vaseyana Mountain big sagebrush	Asp.-Mtn.B.	Well-drained soils, moist sites.	Excellent	DS, NS, CS	Good	Rapid	Fair	Adapted to disturbed sites, suited to moist but not saturated soils.
Artemisia tripartita Tall threetip sagebrush	Asp.-Mtn.B.	Well-drained soils, moist sites.	Excellent	DS, NS, CS	Excellent	Rapid	Fair	Well suited to eroded exposed soils, spreads quickly.
Atriplex canescens Fourwing saltbush	Mtn.B.-V	Well-drained soils, frequent flooding and shallow water table.	Good	DS, NS	Excellent	Rapid	Good	Useful for well-drained and disturbed soils.
Atriplex gardneri Gardner saltbush	SDS-V	Semiarid deserts. Withstands seasonal flooding, and alternating wet/dry period.	Fair	DS, NS, CS	Fair	Moderate	Fair	Adapted to arid sites subjected to seasonal saturated soils.
Betula occidentalis occidentalis Water birch	SF-Mtn.B.	Stream edges.	Good	NS	Excellent	Rapid	Excellent	Establishes well by transplanting, adapted to streambanks and bogs.
Ceanothus sanguineus Redstem ceanothus	SF-PP	Moist soils, seeps, well-drained soils.	Good	DS, NS, CS	Excellent	Rapid	Excellent	Not adapted to saturated soils but useful in planting disturbed streambanks.
Chrysothamnus nauseosus consimilis Thinleaf rubber rabbitbrush	Sage-V	Well-drained soils, sites occasionally flooded.	Good	DS, NS, CS	Excellent	Moderate	Fair	Suited to heavy saturated soils.
Cornus stolonifera stolonifera Redosier dogwood	SF-Mtn.B.	Stream edges and well-drained soils.	Good	DS, NS, CS, RC	Excellent	Rapid	Excellent	Easy to grow and establish, useful for disturbed sites, requires fresh aerated water.
Crataegus douglasii Douglas hawthorn	Asp.-Sage	Stream edges and well-drained soils.	Good	NS	Fair	Slow	Good	Slow growing, but well suited to disturbed streambanks.
Elaeagnus angustifolia Russian olive	Mtn.B.-V	Stream edges, seeps, flooded sites, and well-drained soils.	Excellent	DS, NS	Excellent	Rapid	Good	Easy to establish, can become weedy.
Elaeagnus commutata Silverberry	PJ-V	Stream edges and well-drained soils.	Excellent	NS, CS	Excellent	Rapid	Good	Easily established, grows rapidly, adapted to harsh sites.
Holodiscus discolor Rockspirea	SF-Mtn.B.	Well-drained and moist soils, occasional seeps.	Good	NC, CS	Fair	Moderate	Good	Erratic establishment, but suited to disturbed sites.
Lonicera tatarica Tatarian honeysuckle	Mtn.B.-Sage	Well-drained and moist soils, occasional wet sites.	Excellent	NC, CS, DS	Excellent	Rapid	Good	Easily established, provides immediate cover, well adapted to different soil conditions.

Pachistima myrsinites Myrtle pachistima	SF-Asp.	Moist soils and seeps, requires some shade.	Fair	NS, CS	Fair	Slow	Good	Common to upland slopes, not well adapted to disturbances.
Physocarpus malvaceus Mallow ninebark	SF-Asp.	Moist and well-drained soils.	Fair	NS, CS	Fair	Moderate	Good	Requires good sites.
Populus angustifolia Narrowleaf cottonwood	Asp.-Sage	Well-drained and wet sites, edges of streams, ponds, bogs.	Good	NS, CS, RC	Good	Rapid	Good	Establishes easily, grows rapidly.
Populus fremontii fremontii Fremont cottonwood	Mtn.B.-V	Moist soils, seeps, frequently wet sites.	Good	NS, CS, RC	Good	Rapid	Good	Establishes easily, grows rapidly, furnishes good cover.
Populus tremuloides Quaking aspen	SF-Asp.	Well-drained and moist soils, occasionally occurs at edges of streams.	Fair	NS, CS, RC	Good	Rapid	Good	Considerable ecotypic differences, not well suited to highly disturbed sites, occupies wide range of moisture.
Potentilla fruticosa Bush cinquefoil	Alp.-PP	Stream edges, wet meadows.	Excellent	NS, CS	Good	Moderate	Excellent	Valuable species for riparian disturbances, establishes well and provides excellent site stability.
Prunus virginiana melanocarpa Black chokecherry	SF-PJ	Well-drained, moist soils, occasionally occurs at streams' edges.	Fair	NS, CS, RC	Good	Moderate	Good	Widely adapted, larger transplant stock establishes and grows rapidly.
Rhamnus purshiana Cascara buckthorn	SF-PP	Moist soils, frequently wet sites.	Fair	NS, CS	Fair	Moderate	Good	Limited plantings, plants perform well on disturbed sites.
Ribes aureum Golden current	Asp.-Sage	Well-drained moist sites.	Excellent	NS, CS	Excellent	Excellent	Good	Widely adapted, easily established, excellent site stability.
Rosa woodsii Woods rose	Asp.-Mtn.B.	Moist and well-drained soils, seeps and frequently streambanks.	Excellent	NS, CS, W, RC	Excellent	Moderate	Good	Widely adapted, easily established, excellent site stability, principal species for riparian disturbances.
Rubus spp.	Asp.-PP	Well-drained soils, frequently wet sites	Excellent	NS, CS, W, RC	Excellent	Moderate	Good	Well adapted to eroded sites, limited range of distribution.
Salix (see table 29)								
Sambucus racemosa pubens microbotrys Red elder	Asp.-PP	Moist sites, occasional seeps and streambanks.	Good	NS, CS	Fair	Moderate	Good	Adapted to restricted sites, establishes slowly on disturbed sites.
Sarcobatus vermiculatus Black greasewood	SDS-V	Sites with shallow water tables, occasionally flooded sites.	Good	NS, W	Fair	Slow	Good	Difficult to establish, well adapted to valley bottoms and salty soils.
Shepherdia argentea Silver buffaloberry	Mtn.B-V	Well-drained sites, edges of streams and ponds.	Good	NS	Good	Moderate	Good	Adapted to valley bottoms and saline soils.
Sorbus scopulina scopulina Green's mountain ash	SF-Asp.	Moist soils, ocassional seeps and stream bottoms.	Fair	NS, CS	Fair	Slow	Good	Not well adapted to disturbed soils, establishes slowly.
Symphoricarpos albus Common snowberry	SF-Asp.	Moist sites and well-drained soils.	Good	NS, CS, W, RC	Fair	Moderate	Excellent	Not well suited to extreme disturbed soils, once established grows well, plant large 1-0 or 2-0 stock.
Symphoricarpos occidentalis Western snowberry	SF-Mtn.B.	Moist sites, occasionally streambanks and valley bottoms.	Good	NS, CS, W, RC	Fair	Slow	Excellent	Plants not well adapted to disturbed soils, provides excellent stability and spreads well.
Symphoricarpos oreophilus Mountain snowberry	Asp.-Sage	Well-drained soils, edges of streams.	Good	NS, CS, W, RC	Fair	Slow	Excellent	Plants not well adapted to disturbed soils, provides excellent stability and spreads well.

[1]Alp. = alpine; SF = spruce-fir; Asp. = aspen; PP = ponderosa pine; Mtn.B. = mountainbrush; PJ = pinyon-juniper; Sage = big sagebrush; SDS = salt desert shrub; V = valley bottoms.
[2]DS = direct seeding; RC = rooted cuttings; NS = nursery-grown seedling; CS = container-grown seedling; W = wilding.

Table 29—Areas of occurrence of several willow species useful in riparian revegetation. Scientific names from Goodrich (1983).

Species	Areas of adaptation: Zones	Areas of adaptation: Habitat	Origin of roots	Prevalence of roots	Period required for: Root formation	Period required for: Stem formation	Comments
					- - - - - - - *Days*	- - - - - - -	
Salix amygdaloides Peachleaf willow	Aspen—big sagebrush	Stream edges, pond margins, soils saturated seasonally.	Callus cut	Moderate	10-20	10	Moderate rooting capabilities
Salix bebbiana Bebb willow	Spruce-fir—aspen	Edges of streams, occasionally well-drained soils.	Roots throughout entire length of stem	Moderate	10	10-20	Roots freely
Salix boothii	Aspen—sagebrush	Stream edges and standing water, confined to wet soils.	Roots mostly at lower one-third of stem	Abundant	10-15	10-15	Roots freely
Salix brachycarpa Barrenground willow	Subalpine—spruce-fir	Wet sites and well-drained soils.	Roots throughout entire length of stem	Abundant	15-20	15-25	Roots freely
Salix drummondiana Drummond willow	Spruce-fir—upper sagebrush	Edges of streams and ponds.	Roots throughout entire length of stem	Abundant	10	10	Roots freely
Salix exigua Sandbar willow	Spruce-fir—sagebrush	Edges of streams, wet sites, sometimes well-drained soils.	Roots throughout entire length of stem	Moderate	10-15	10	Easily rooted
Salix geyeriana Geyer willow	Subalpine—aspen—upper sagebrush	Edges of streams, frequent wet meadows.	Roots throughout entire length of stem	Few to moderate	10	10-15	Fair rooting capabilities
Salix glauca Grayleaf willow	Subalpine—spruce-fir	Wet and dry sites, widely distributed, occupies seeps and edges of snowbanks.	Roots throughout entire length of stem	Few to moderate	10	10	Requires special treatment to root
Salix lasiandra Pacific willow	Aspen—upper sagebrush	Wet soils, edges of streams and ponds.	Roots throughout entire length of stem	Abundant	10	10-15	Easily rooted
Salix lasiolepis Arroyo willow	Aspen—mountainbrush	Restricted to stream edges.	Callus and lower one-third of stem	Few to many	10	10	Erratic rooting habits
Salix lutea Shining willow	Aspen—sagebrush	Mostly along streams, may occur on sites that remain dry for short periods.	Entire stem section, most abundant at lower one-third	Moderate	10	10	Roots easily
Salix planifolia Tealeaf willow	Subalpine—aspen	Wet sites, edges of streams, wet meadows.	Roots throughout entire length of stem	Few to moderate	10	10-15	Fair rooting capabilities
Salix scouleriana Scouler willow	Spruce-fir—aspen	Well-drained soils, forest understory.	Callus cut	Moderate	10-15	10-15	Requires special treatment to root
Salix wolfii Wolf willow	Spruce-fir—aspen	Stream edges and ponds.	Roots throughout entire length of stem	Few to moderate	10-15	10-15	Erratic rooting

Snow and Vince (1984) conclude from reciprocal transplanting that dominant perennial species of salt marsh sites have a broad tolerance and are able to grow in diverse habitats. However, plants are confined to restricted areas due to dispersal limitations and the inability of propagules to establish. Seedlings are often less tolerant of environmental stress than are mature plants (Pearson and others 1966). Similar conditions apply to woody plantings. Willows and other shrubs are widely adapted to diverse sites, including seriously disrupted conditions (McCluskey and others 1983). However, young plantings are difficult to establish and only the most vigorous stock should be planted. Neiland and others (1981) conclude that planting success of unrooted cuttings of *Salix* is unpredictable and depends on site conditions and yearly climatic variables. Unrooted stem cuttings frequently fail to establish (Holloway and Zasada 1979).

Stem cuttings can be obtained from plants growing on wildland sites. Collections should be taken from stock adapted to the planting areas. Clonal differences, age of the plant, and yearly growing conditions affect the propagation capabilities of the cuttings (Doran 1957).

Cuttings should be taken in the spring or fall when plants are dormant. Densmore and Zasada (1978) found that spring collections survived nearly four times better than fall collections of the same species. Cuttings should be taken of 2- to 4-year-old wood, and stems 0.4 inch or larger in diameter survive much better than smaller dimensions. The age and size of the stem are of less importance to readily rooted willow species than to poorly rooted selections (Chmelar 1974). Larger and older wood is required to propagate poorly rooted species.

Stem cuttings should be 12 to 20 inches in length. Shorter segments may survive if planted under ideal conditions. However, Neiland and others (1981) found that cuttings with at least an 8-inch belowground length and a 7-inch aboveground portion produced twice the amount of growth the first year as did cuttings of 4 inches/3 inches. Longer stems have a greater rooting surface to extract soil moisture and a higher amount of carbohydrates.

After collection, cuttings should be bundled in groups of 50 or 100 sections and treated with a fungicide (Doran 1957) by dipping the entire stem into a prepared solution or powder. Numerous fungicides are available. Stems should be dried and then stored for future plantings.

Hormones can be used to induce rooting. Only the most difficult species require such treatment, and species with preformed root primordia should not be treated. The hormone can be applied by dipping the base of the cutting in either a powder or mixed solution. Indolebutyric acid is the most effective rooting compound because it not only increases rooting of the more difficult species but hastens rooting and lengthens the growing season (Doran 1957).

Cuttings can be stored for extended periods by enclosing the moistened bundles in plastic bags or other moist media and protecting from dehydration. The cuttings can then either be frozen and stored in coolers or maintained at temperatures slightly above freezing. Prior to planting, frozen cuttings should be chilled at 41 °F for 2 to 3 weeks to break dormancy.

Field plantings of unrooted cuttings or nursery-grown seedlings can be established in prepared beds. Planting sites should be cleared of competitive vegetation, and compact soils should be loosened to accommodate transplanting. Willows are sensitive to competition and light, and dense tall grasses reduce the survival of the transplants (Neiland and others 1981). Plant competition is much more critical to the survival of unrooted cuttings than to the survival of rooted stock. If sites are properly prepared, the majority of transplant losses occur the first year. If the understory competition is not controlled, losses can be expected for 1 to 3 years.

Understory herbs can be eliminated or reduced in density (1) by mechanical scalping or clearing of the surface soil and associated vegetation or (2) by chemical control. Transplants can be selectively placed in clearings or openings where competition is low, but interplanting into existing herblands is not achievable unless the competition can be reduced.

Clearings or scalps of 20 to 30 inches are normally required to effectively reduce competition during establishment. Mechanical scalping usually is not effective in controlling rhizomatous vegetation. Resprouting or rerooting occurs quickly and is detrimental to transplant survival.

Planting rooted or unrooted stock in areas with a high water table is not advised. Although species of willow differ in their adaptability to soil inundation, flooding can reduce growth because of an imbalance of hormones, uptake of water and nutrients, and the disruption of carbohydrate relations (Kozlowski 1984). Transplants should not be placed directly onto water-logged soils or into the stream. Better rooting occurs if transplants are placed in moist but not saturated soils.

Fertilization is often used to stimulate growth of the transplant. Fertilizers can be beneficial if growth of herbaceous plants is not stimulated (Neiland and others 1981) because increased growth of the herbs is detrimental to shrub survival. Fertilizer tablets can be used and should be placed in the planting hole or in proximity of the planted stock. Surface application should be avoided as a means of fertilizing the transplant because grasses also respond to the treatment. Increased growth of the shrub transplant can be expected for 2 to 3 years after fertilization if slow-release tablets are used.

Hansen and Phipps (1983) found that warming and soaking of poplar cuttings accelerated growth of transplants. Prerooting of willow cuttings has also improved survival and enhanced growth of field plantings. Prerooting can be accomplished by growing the willow cuttings under greenhouse conditions for a short period and then field planting the newly rooted stem. The cutting is allowed to form roots that are 0.8 to 1.2 inches in length. Once roots are formed, the cutting is hardened-off and field planted. Plants must be properly hardened or survival is significantly diminished.

Field survival of stem cuttings can be enhanced by correct planting depth. A stem cutting of approximately 20 inches in length should be planted to a depth of about 12 inches, leaving an 8-inch section exposed. Longer aboveground stems are subjected to excessive drying. If high air temperatures are expected, stems should be placed deeper in the soil. Dehydration can also be prevented by dipping or applying antitranspirants to the stems prior to planting. Film-forming antitranspirants are recommended for treating transplant stock (Kozlowski and Davis 1975). Different antitranspirant compounds are available and effective if applied at the proper rate (Davis and Kozlowski 1974).

REFERENCES

Aldon, E. F. Survival of three grass species after inundation. Research Note RM-165. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1970. 2 p.

Alley, H. P.; Gale, A. F.; Humburg, N. E. Wyoming weed control guide, 1978. Wyoming Extension Bulletin 442R. Laramie, WY: Wyoming Agricultural Extension Service; 1978. 53 p.

Anderson, B. W.; Ohmart, R. D.; Hunter, W. C. Quantifying variables for classifying desert riparian vegetation. In: Moir, W. H.; Hendzel, L., tech. coords. Workshop on southwestern habitat types: Proceedings; 1983 April 6-8; Albuquerque, NM. Albuquerque, NM: U.S. Department of Agriculture, Forest Service, Southwestern Region; 1984: 32-34.

Arizona Citizen. April 22, 1871.

Armour, C. L.; Burnham, K. P.; Platts, W. S. Field methods and statistical analyses for monitoring small salmonid streams. FWS/OBS-83/33. Washington, DC: U.S. Fish and Wildlife Service; 1983. 200 p.

Arnold, John F. Idaho batholith source book. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region; 1975. 342 p. Unpublished report.

Back, H. L.; Alder, F. E.; Gibbs, B. G. An evaluation of an electronic instrument for pasture yield estimation. Part 2. Use with double sampling for pasture yield estimation. Journal of British Grasslands Society. 24: 168-172; 1968.

Baker, C. O. The impacts of log jam removal on fish populations and stream habitat in western Oregon. Corvallis, OR: Oregon State University; 1979. 86 p. Thesis.

Baskerville, G. L. Use of logarithmic regression in the estimation of plant biomass. Canadian Journal of Forest Research. 2(1): 49-53; 1972.

Bilby, R. E.; Likens, G. E. Importance of organic debris dams in the structure and function of stream ecosystems. Ecology. 61: 1107-1113; 1980.

Bishop, D. M. Big Creek photo-study of logs and debris in the stream. Second Interim Report-1967. Juneau, AK: U.S. Department of Agriculture, Forest Service, Alaska Region; 1968. 9 p.

Blake, O. Timber down the hill. Corvallis, OR: Oregon State University Library, private collection; 1971. 85 p.

Bloom, A. L. Geomorphology: a systematic analysis of late Cenozoic landforms. Englewood Cliffs, NJ: Prentice-Hall; 1978. 510 p.

Bowen, W. A. Migration and settlement on a far western frontier: Oregon to 1850. Berkeley, CA: University of California; 1972. Ph.D. thesis.

Bridges, J. B. Definition of the law governing the use of driving streams. In: Proceedings of the Pacific logging congress, second annual session; 1910 July 21-23; Portland, OR: 1910: 50-51.

Brown, N. C. Logging-transportation: the principles and methods of log transportation in the U.S. and Canada. New York: John Wiley and Sons; 1936. 327 p.

Bryant, M. D. Evolution of large, organic debris after timber harvest: Maybeso Creek 1949-1978. General Technical Report PNW-101. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1980. 30 p.

Bryant, M. D. Organic debris in salmonid habitat in southeast Alaska: measurement and effects. In: Armantrout, N. B., ed. Acquisition and utilization of aquatic habitat inventory information: Proceedings of a symposium; 1981 October 28-30; Portland, OR. Portland, OR: Western Division American Fisheries Society; 1981: 259-265.

Bryant, M. D. The role and management of woody debris in West Coast salmonid nursery streams. North American Journal of Fisheries Management. 3: 322-330; 1983.

Buchanan, I. L. Lumbering and logging in the Puget Sound Region in territorial days. Pacific Northwest Quarterly. 27: 34-53; 1936.

Burke, C. J. Historical fires in the central western Cascades, Oregon. Corvallis, OR: Oregon State University; 1979. M.S. thesis.

Carlson, M. C. Nodal adventitious roots in willow stems of different ages. American Journal of Botany. 37: 555-561; 1950.

Carpenter, L. H.; Wallmo, D. C.; Morris, M. J. Effect of woody stems on estimating herbage weights with a capacitance meter. Journal of Range Management. 26: 151-152; 1973.

Chambers, J. L.; Brown, R. W. Methods for vegetation sampling and analysis on revegetated mixed lands. General Technical Report INT-151. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 57 p.

Chmelar, J. Propagation of willows by cuttings. New Zealand Journal of Forestry Science. 4: 185-190; 1974.

Cluff, G. J.; Evans, R. A.; Young, J. A. Desert saltgrass seed germination and seedbed ecology. Journal of Range Management. 36(4): 419-422; 1983.

Cochran, W. G. Sampling techniques. 2d ed. New York: John Wiley and Sons; 1963. 413 p.

Colwell, R. N., ed. Manual of remote sensing. Vol. II. Falls Church, VA: American Society of Photogrammetry; 1983. 1232 p.

Cords, H. P.; Artz, J. L. Rangeland, irrigated pastures, and meadows—weed control recommendations. Circular 148. Rev. Reno, NV: Nevada Agricultural Extension Service; 1976. 4 p.

Council of Agricultural Science and Technology. Livestock grazing on federal lands in the 11 western states. Journal of Range Management. 27(3): 174-181; 1974.

Cowardin, L. M.; Carter, V.; Golet, F. C.; LaRoe, E. T. Classification of wetlands and deepwater habitats of the United States. Publication FWS/OBS-79/31. Washington, DC: U.S. Department of the Interior, Fish and Wildlife Service, Office of Biological Services; 1979. 103 p.

Cox, T. R. Mills and markets: a history of the Pacific Coast lumber industry to 1900. Seattle, WA: University of Washington Press; 1974. 396 p.

Cummins, K. W. Trophic relations of aquatic insects. Annual Review of Entomology. 18: 183-206; 1973.

Cummins, K. W. Structure and function of stream ecosystems. BioScience. 24: 631-641; 1974.

Cummins, K. W.; Klug, M. J.; Ward, G. M.; Spengler, G. L.; Speaker, R. W.; Ovink, R. W.; Mahan, D. C.; Petersen, R. C. Trends in particulate organic matter fluxes, community processes, and macroinvertebrate functional groups along a Great Lakes drainage basin river continuum. Verhandlunger Internationale Vereinigung für Theoretische und Angewandte Limnologie. 21: 841-849; 1981.

Cummins, K. W.; Merritt, R. W. Ecology and distribution of aquatic insects. In: Merritt, R. W.; Cummins, K. W., eds. An introduction to the aquatic insects. 2d ed. Dubuque, IA: Kendall/Hunt Publishing; 1984: 59-65.

Cummins, K. W.; Minshall, G. W.; Sedell, J. R.; Cushing, C. E.; Petersen, R. C. Stream ecosystem theory. Verhandlungen Internationale Vereinigung für Theoretische und Angewandte Limnologie. 22; 1984.

Cuplin, P. Remote sensing streams. In: Proceedings of the international symposium on remote sensing of observation and inventory of earth resources and the endangered environment; 1978 July 2-8; Freiburg, Federal Republic of Germany. Vol. III. 2391 p. International Archives of Photogrammetry Vol. XXII-7.

Currie, P. O.; Morris, M. J.; Neal, D. L. Uses and capabilities of electronic capacitance instruments for estimating standing herbage. Part 2. Sown ranges. Journal of the British Grasslands Society. 28: 155-160; 1973.

Dahlgreen, A. K.; Ryker, R. A.; Johnson, D. L. Snow cache seedling storage: successful systems. General Technical Report INT-17. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1974. 12 p.

Davis, W. J.; Kozlowski, T. T. Short- and long-term effects of antitranspirants on water relations and photosynthesis of woody plants. Journal of the American Society for Horticultural Science. 99(4): 297-304; 1974.

Densmore, R.; Zasada, J. C. Rooting potential of Alaskan willow cuttings. Canadian Journal of Forest Research. 8: 477-479; 1978.

DeVries, P. G. Live intersect sampling theory. In: Cormack, R. M.; Patil, G. P.; Robson, O. S., eds. Sampling biological populations. Statistical Ecology Series. Vol. 5. Fairland, MD: International Co-operative Publishing House; 1979: 3-63.

Dicken, S. N.; Dicken, E. F. The making of Oregon: a study in historical geography. Vol. I. Portland, OR: Oregon Historical Society; 1979. 207 p.

Doran, W. L. Propagation of woody plants by cuttings. Experiment Station Bulletin 491. Amhurst, MA: University of Massachusetts, College of Agriculture; 1957. 99 p.

Forman, T. T.; Russell, E. W. B. Evaluation of historical data in ecology. Bulletin of the Ecological Society of America. 64: 5-7; 1983.

Frick, E. Library research guide to history. Library Research Guides, Series 4. Ann Arbor, MI: Pierian Press; 1980. 86 p.

Frink, M.; Jackson, W. T.; Spring, A. W. When grass was king. Boulder, CO: University of Colorado Press; 1956. 465 p.

Froehlich, H. A.; McGreer, D.; Sedell, J. R. Natural debris within the stream environment. US/IBP Coniferous Forest Biome, Internal Report 96. Seattle, WA: College of Forest Resources, University of Washington; 1972. 16 p.

Furnival, G. M. An index for comparing equations used in constructing volume tables. Forest Science. 7: 337-341; 1961.

Goodrich, Sherel. Utah flora: Salicaceae. Great Basin Naturalist. 43(4): 531-550; 1983.

Griffiths, D. Forage conditions on the northern border of the Great Basin. Bulletin 15. Washington, DC: U.S. Department of Agriculture, Bureau of Plant Industry; 1902. 39 p.

Griffiths, D. Forage conditions and problems in eastern Washington, eastern Oregon, northeastern California, and northwestern Nevada. Bulletin 38. Washington, DC: U.S. Department of Agriculture, Bureau of Plant Industry; 1903. 57 p.

Gruell, G. E. Fire's influence on wildlife habitat on the Bridger-Teton National Forest, Wyoming. Volume 1—Photographic record and analysis. Research Paper INT-235. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1980. 207 p.

Haissig, B. W. Preformed adventitious root initiation in brittle willows grown in a controlled environment. Canadian Journal of Botany. 4(2): 299-310; 1970.

Hansen, E. A.; Phipps, H. M. Effects of soil moisture tension and preplant treatment on early growth of hybrid *Populus* hardwood cuttings. Canadian Journal of Forest Research. 13: 458-464; 1983.

Hastings, J. R. Vegetation change and arroyo cutting in southeastern Arizona. Journal of the Arizona Academy of Science. 1: 60-67; 1959.

Hastings, J. R.; Turner, R. M. The changing mile: an ecological study of vegetation change with time in the lower mile on an arid and semiarid region. Tucson, AZ: University of Arizona Press; 1965. 317 p.

Hawkins, C. P.; Murphy, M. L.; Anderson, N. H. Effects of canopy, substrate composition, and gradient on the structure of macroinvertebrate communities in Cascade range streams of Oregon. Ecology. 63: 1840-1856; 1982.

Hawkins, C. P.; Sedell, J. R. Longitudinal and seasonal changes in functional organization of macroinvertebrate communities in four Oregon streams. Ecology. 62: 387-397; 1981.

Heebner, C. F.; Bergener, M. J. Red alder: a bibliography with abstracts. General Technical Report PNW-161. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1983. 186 p.

Heikes, P. E. Colorado weed control handbook. Fort Collins, CO: Colorado State University; 1978. Mimeographed (updated looseleaf).

Holloway, P.; Zasada, J. Vegetative propagation of 11 common Alaska woody plants. General Technical Report PNW-334. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1979. 12 p.

Horton, J. S. Trees and shrubs for erosion control on southern California mountains. Sacramento, CA: California Department of Natural Resources, Division of Forestry; 1949. 71 p.

Jensen, L. A.; Evans, J. O.; Anderson, J. L.; Hamson, A. R.; Parker, K. G. Chemical weed control guide, Utah, 1980 and 1981 addendum. Revised Circular 301. Logan, UT: Utah Agricultural Extension Service; 1981 (rev.). 113 plus 12 p.

Jensen, S. E. Soils investigation of riparian communities of East Smiths Fork and Henrys Fork Drainages, North Slope Uinta Mountains, Utah. 1981. Report to U.S. Department of Agriculture, Forest Service, Intermountain Region, Ogden, UT. 35 p.

Jensen, S. E. Evaluation of the effect of water retainment upon down drainage wetlands in the Upper Bear River drainage. 1984. Unpublished report on file at: White Horse Associates, Smithfield, UT. 50 p.

Jensen, S. E.; Tuhy, J. S. Riparian classification for the Upper Salmon/Middle Fork Salmon Rivers, Idaho. 1982. Report to U.S. Department of Agriculture, Forest Service, Intermountain Region, Ogden, UT. 195 p.

Johannessen, C. L.; Davenport, W. A.; Millet, A.; McWilliams, S. The vegetation of the Willamette Valley. Annual Association of American Geographers. 61: 286-302; 1970.

Kangus, P. Studies of succession, landscape, and phosphate mining. Gainesville, FL: University of Florida, Center for Wetlands; 1978. 23 p. Unpublished manuscript.

Kauffman, J. B.; Krueger, W. C. Livestock impacts on riparian ecosystems and streamside management implications . . . a review. Journal of Range Management. 37(5): 430-438; 1984.

Keller, E. A.; MacDonald, A. Large organic debris and anadromous fish habitat in the coastal redwood environment: the hydrologic system. Technical Completion Report, Project No. B-213-CAL and Project UCAL-WRC-W-584. Davis, CA: University of California, California Water Resources Center; 1984. 18 p.

Keller, E. A.; Talley, T. Effects of large organic material on channel form and fluvial processes. Earth Surface Processes. 4: 361-380; 1979.

Kish, L. Survey sampling. New York: John Wiley & Sons; 1965. 643 p.

Kozlowski, T. T. Plant responses to flooding of soil. BioScience. 34: 162-167; 1984.

Kozlowski, T. T.; Davis, W. J. Control of water balance in transplanted trees. Journal of Arboriculture. 1(1): 1-10; 1975.

Lammel, R. F. Natural debris and logging residue within the stream environment. Corvallis, OR: Oregon State University; 1972. 49 p. M.S. thesis.

Landis, T. D.; Simonich, E. J. Producing native plants as container seedlings. In: Murphy, P. M., compiler. The challenge of producing native plants for the Intermountain area: Proceedings; Intermountain Nurseryman's Association 1983 conference; 1983 August 8-11; Las Vegas, NV. General Technical Report INT-168. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1984: 16-25.

Langbein, W. G.; Iseri, K. T. General introduction and hydrologic definitions. Geological Survey Water Supply Paper 1541-A. Washington, DC: U.S. Department of the Interior; 1960. 29 p.

Lemmon, P. E. A new instrument for measuring forest overstory density. Journal of Forestry. 55: 667-669; 1956a.

Lemmon, P. E. A spherical densiometer for estimating forest overstory density. Forest Science. 2: 314-320; 1956b.

Leopold, S. A. Ecosystem deterioration under multiple use. In: Proceedings—wild trout management symposium. Denver, CO: U.S. Department of the Interior, Fish and Wildlife Service; 1974: 96-98.

Lewis, M. E. *Carex*—its distribution and importance in Utah. Science Bulletin Biological Series—Vol. 1, No. 11. Provo, UT: Brigham Young University; 1958. 43 p.

Lienkaemper, G. W.; Swanson, F. J. Changes in large organic debris in forested streams, western Oregon. In: Abstracts with programs, Cordilleran Section, Geological Society of America. 12(3); 1980. 116 p.

Long, S. G.; Burrell, J. K.; Laurenson, N. M.; Nyenhuis, J. H. Manual of revegetation techniques. Missoula, MT: U.S. Department of Agriculture, Forest Service, Equipment Development Center; 1984. 145 p.

Lowrance, R.; Todd, R.; Fail, J., Jr.; Hendrickson, A., Jr.; Leonard, R.; Asmussen, L. Riparian forests as nutrient filters in agricultural watersheds. BioScience. 34: 374-377; 1984.

Marshall, K.; Romesburg, H. C. CLUSTAR and CLUSTID - programs for hierarchical cluster and analysis. In: Henderson, J. A.; Davis, L. S.; Ryberg, F. M. ECOSYM: a classification and information system for wildland resource management. Logan, UT: Utah State University; 1977. 65 p.

McCluskey, C. D.; Brown, J.; Bornholdt, D.; Duff, D. A.; Winward, A. H. Willow planting for riparian habitat improvement. Technical Note 363. Denver, CO: U.S. Department of the Interior, Bureau of Land Management; 1983. 21 p.

McDonald, S. E.; Boyd, R. J.; Sears, D. E. Lifting, storage, planting practices influence growth of conifer seedlings in the Northern Rockies. Research Paper INT-300. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 12 p.

Meehan, W. R.; Platts, W. S. Livestock grazing and the aquatic environment. Journal of Soil and Water Conservation. 33(6): 274-278; 1978.

Megahan, W. F.; Kidd, W. J. Effects of logging and logging roads on erosion and sediment deposition from steep terrain. Journal of Forestry. 70(3): 136-141; 1972.

Merritt, R. W.; Cummins, K. W., eds. An introduction to the aquatic insects. 2d ed. Dubuque, IA: Kendall/Hunt Publishing Co.; 1984. 722 p.

Meyer, M.; Batson, F.; Whitmer, D. Helicopter-borne 35 mm aerial photography applications to range and riparian studies. St. Paul, MN: University of Minnesota, Remote Sensing Laboratory; 1982. 80 p.

Minshall, G. W. Structure and temporal variations of the benthic macroinvertebrate community inhabiting Mink Creek, Idaho, U.S.A., a 3rd order Rocky Mountain stream. Journal of Freshwater Ecology. 1: 13-26; 1981.

Minshall, G. W.; Cummins, K. W.; Petersen, R. C.; Cushing, C. E.; Bruns, D. A.; Sedell, J. R.; Vannote, R. L. Developments in stream ecosystem theory. Canadian Journal of Fisheries and Aquatic Sciences. 42: 1045-1055; 1985.

Minshall, G. W.; Petersen, R. C.; Cummins, K. W.; Bott, T. L.; Sedell, J. R.; Cushing, C. E.; Vannote, R. L. Interbiome comparison of stream ecosystem dynamics. Ecological Monographs. 51: 1-25; 1983.

Molles, M. C., Jr. Trichopteran communities of streams associated with aspen and conifer forests: long-term structural change. Ecology. 63: 1-6; 1982.

Monsen, S. B. Plants for revegetation of riparian sites within the Intermountain Region. In: Monsen, S. B.; Shaw, N., compilers. Managing Intermountain rangelands—improvement of range and wildlife habitats: Proceedings; 1981 September 15-17; Twin Falls, ID; 1982 June 22-24; Elko, NV. General Technical Report INT-152. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983: 83-89.

Morris, M. J.; Johnson, K. L.; Neal, D. L. Sampling shrub ranges with an electronic capacitance instrument. Journal of Range Management. 29: 78-81; 1976.

Mueller-Dombois, D.; Ellenberg, H. Aims and methods of vegetation ecology. New York: John Wiley and Sons; 1974. 547 p.

Naiman, R. J. Characteristics of sediment and organic carbon export from pristine boreal forest watersheds. Canadian Journal of Fisheries and Aquatic Sciences. 39: 1699-1718; 1982.

Neal, D. L.; Neal, J. L. Uses and capabilities of electronic capacitance instruments for estimating standing herbage. Part 1. History and development. Journal of the British Grassland Society. 28: 81-89; 1973.

Neal, D. L.; Currie, P. O.; Morris, M. J. Sampling herbaceous vegetation with an electronic capacitance instrument. Journal of Range Management. 29: 74-77; 1976.

Neiland, B. J.; Zasada, J.; Densmore, R.; Masters, M. A.; Moore, N. Investigations of techniques for large-scale reintroduction of willows in Arctic Alaska. Final report to Alyeska Pipeline Service Company. Fairbanks, AK: University of Alaska, School of Agriculture and Land Resources Management; 1981. 448 p.

Nelson, R. L.; Platts, W. S.; Graham, C. K. Relative suitabilities of linear and logarithmic regression model in electronic capacitance meter analysis of riparian vegetation. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station; [in press].

Newbold, J. D.; Erman, D. C.; Roby, K. B. Effects of logging on macroinvertebrates in streams with and without buffer strips. Canadian Journal of Fisheries and Aquatic Sciences. 37: 1076-1085; 1980.

Norton, B. E.; Tuhy, J. S.; Jensen, S. Riparian community classification for the Greys River, Wyoming. Logan, UT: Utah State University, Department of Range Science; 1981.

190 p. [Report to U.S. Department of Agriculture, Forest Service, Intermountain Region, Ogden, UT.]

Odum, E. P. Fundamentals of ecology. 3d ed. Philadelphia, PA: W. B. Saunders Company; 1971. 574 p.

Ohmart, R. D.; Deason, W. O.; Burke, C. A riparian case history: the Colorado River. In: Johnson, R. R.; Jones, D. E., tech. coords. Importance, preservation and management of riparian habitat: a symposium. General Technical Report RM-43. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1977: 35-57.

Owston, P. W.; Stein, W. I. Production and use of container seedlings in the West. In: Loucks, W. L., ed. Proceedings of meetings; August 1977. Manhattan, KS: Intermountain Nurserymen's Association; 1977: 117-125.

Pearson, G. A.; Ayers, A. D.; Ederhard, D. C. Relative salt tolerance of rice during germination and early seedling development. Soil Science. 201: 151-156; 1966.

Petersen, L. A.; Phipps, H. M. Water soaking pretreatment improves rooting and early survival of hardwood cuttings of some *Populus* clones. Tree Planters' Notes. 27(1): 12-22; 1976.

Phipps, H. M.; Belton, D. A.; Netzer, D. A. Propagating cuttings of some *Populus* clones for tree planting. Plant Propagation. 23: 8-11; 1977.

Platts, W. S. Effects of sheep grazing on a riparian-stream environment. Research Note INT-307. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1981a. 6 p.

Platts, W. S. Influence of forest and rangeland management on anadromous fish habitat in western North America. Part 7. Effects of livestock grazing. General Technical Report PNW-124. Meehan, W., tech. ed. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1981b. 25 p.

Platts, W. S.; Megahan, W. F.; Minshall, G. W. Methods for evaluating stream, riparian, and biotic conditions. General Technical Report INT-138. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 70 p.

Platts, W. S.; Nelson, R. L. The electronic capacitance meter: a tool for evaluating riparian-fishery habitat. North American Journal of Fisheries Management. 3: 219-227; 1983.

Plummer, A. P.; Christensen, D. R.; Monsen, S. B. Restoring big game range in Utah. Publication 68-3. Salt Lake City, UT: Utah Division of Fish and Game; 1968. 183 p.

Poulton, C. E.; Tisdale, E. W. A quantitative method for the description and classification of range vegetation. Journal of Range Management. 14: 13-21; 1961.

Quigley, T. M. Estimating contribution of overstory vegetation to stream surface shade. Wildlife Society Bulletin. 9(1): 22-27; 1981.

Ray, G. A.; Megahan, W. F. Measuring cross section using a sag tape: a generalized procedure. General Technical Report INT-47. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1978. 12 p.

Rector, W. G. From woods to sawmill: transportation problems in logging. Agriculture History. 23: 239-244; 1949.

Rector, W. G. Log transportation in the Lake States lumber industry 1840-1918. Glendale, CA: Arthur H. Clark Co.; 1953. 352 p.

Ree, W. O. Effect of seepage flow on reed canarygrass and its ability to protect waterways. ARS-S-154. Stillwater, OK: U.S. Department of Agriculture, Agricultural Research Service, Water Conservation Structures Laboratory; 1976. 8 p.

Reese, G. A.; Bayn, R. L.; West, N. E. Evaluation of double-sampling estimators of subalpine herbage production. Journal of Range Management. 33(4): 300-306; 1980.

Sands, A.; Howe, G. An overview of riparian forests in California: their ecology and conservation. In: Johnson, R. R.; Jones, D. E., tech. coords. Importance, preservation and management of riparian habitat: a symposium. General Technical Report RM-43. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1977: 98-115.

Scheaffer, R. L.; Mendenhall, W.; Ott, L. Elementary survey sampling. 2d ed. Boston: Duxbury Press; 1979. 278 p.

Secretary of War. Index to the reports of Chief of Engineers, U.S. Army, 1866-1912. In: House Documents: Second Session 63rd Congress, 1913-1914. Vol. 20, Part 2. Washington, DC: U.S. Government Printing Office; 1915. 350 p.

Sedell, J. R.; Duval, W. S. Water transportation and storage of logs. General Technical Report PNW-186. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest Range and Experiment Station; 1985. 68 p. [Meehan, W. R., ed.; Influence of forest and rangeland management on anadromous fish habitat in western North America; pt. 5].

Sedell, J. R.; Everest, F. H.; Swanson, F. J. Fish habitat and streamside management: past and present. In: Proceedings of the Society of American Foresters, annual meeting, 1981 September 27-30; Orlando, FL. Bethesda, MD: Society of American Foresters; 1982: 244-255.

Sedell, J. R.; Froggatt, J. L. Importance of streamside forests to large rivers: the isolation of the Willamette River, Oregon, USA from its floodplain. Verandlungen Internationale Vereinigung für Theoretische und Argewandfe Limnologie. 22: 1828, 1834; 1984.

Sedell, J. R.; Luchessa, K. J. Using the historical record as an aid to salmonid habitat enhancement. In: Armantrout, N. B., ed. Proceedings of a symposium on acquisition and utilization of aquatic habitat inventory information; 1981 October 28-30; Portland, OR. Bethesda, MD: Western Division of American Fisheries Society; 1982: 210-223.

Shafer, D. M.; Ffolliott, P. F.; Patton, D. R. Management of riparian vegetation for southwestern wildlife. Albuquerque, NM: U.S. Department of Agriculture, Forest Service, Southwest Region; 1982. 20 p.

Shafer, R. J., ed. A guide to historical method. Homewood, IL: Dorsey Press; 1980. 272 p.

Shaw, N. S. Producing bareroot seedlings of native shrubs. In: Murphy, P. M., compiler. The challenge of producing native plants for the Intermountain area: Proceedings; Intermountain Nurserymen's Association 1983 conference; 1983 August 8-11; Las Vegas, NV. General Technical Report INT-168. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1984: 6-15.

Silvey, L.; Tolle, T.; Elsea, J.; Putnam, W. A channel condition and debris loading evaluation of the Marble Cone fire area. Moscow, ID: University of Idaho, Idaho Cooperative Fishery Research Unit; 1977. 43 p.

Snow, A. A.; Vince, S. W. Plant zonation in an Alaskan salt marsh. Journal of Ecology. 72: 669-684; 1984.

Solar Pathways, Inc. Solar Pathfinder - the energy evaluator. Glenwood Springs, CO: Solar Pathways Incorporated; 1983. 20 p.

Strahler, A. N. Quantitative analysis of watershed geomorphology. Transitions of the American Geophysical Union. 38: 913-920; 1957.

Strichler, G. S. Use of the densiometer to estimate density of forest canopy on permanent sample plots. Research Note INT-180. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1959. 5 p.

Swanson, F. J.; Bryant, M. D.; Lienkaemper, G. W.; Sedell, J. R. Organic debris in small streams, Prince of Wales Island, Southeast Alaska. General Technical Report PNW-166. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1984. 12 p.

Swanson, F. J.; Gregory, S. V.; Sedell, J. R.; Campbell, A. G. Land-water interactions: the riparian zone. In: Edmonds, R. L., ed. Analysis of coniferous forest ecosystems in the western United States. US/IBP Synthesis Series 14. Stroudsburg, PA: Hutchinson Ross Publishing Company; 1982: 267-291.

Talley, T. The effects of geology and large organic debris on stream channel morphology and process for streams flowing through old growth redwood forests in northwestern California. Santa Barbara, CA: University of California; 1980. 273 p. Ph.D. thesis.

Terry, W. S.; Hunter, D. H.; Swindel, B. F. Herbage capacitance meter: an evaluation of its accuracy in Florida rangelands. Journal of Range Management. 34: 240-241; 1981.

Tevis, J. H. Arizona in the '50's. Albuquerque, NM: University of New Mexico Press; 1954. 198 p.

Theurer, F. D.; Voos, K. A.; Miller, W. J. Instream water temperature. Information Paper 16. Fort Collins, CO: U.S. Department of the Interior, Fish and Wildlife Service, IFG and Aquatic System Group; 1984. 400 p.

Thomas, J. W.; Maser, C.; Rodick, J. E. Riparian zones. In: Thomas, J. W., tech. ed. Wildlife habitats in managed forests of the Blue Mountains of Oregon and Washington. Agriculture Handbook 553. Washington, DC: U.S. Department of Agriculture, Forest Service; 1979: 40-47.

Timberman. Queen of them all was Virginia City: history of lumbering in western Nevada. Timberman. 42: 11-14, 50-62; 1941.

Towle, J. C. Woodland in the Willamette Valley: an historical geography. Eugene, OR: University of Oregon; 1974. 159 p. Ph.D. dissertation.
Trefethen, J. B. The American landscape 1776-1976, two centuries of change. Washington, DC: Wildlife Management Institute; 1976. 91 p.
Triska, F. J.; Cromack, K. The role of wood debris in forests and streams. In: Waring, R. H., ed. Forests: fresh perspectives from ecosystem analysis: Proceedings of the 40th biology colloquium. Corvallis, OR: Oregon State University Press; 1980: 171-189.
Triska, F. J.; Sedell, J. R. Accumulation and processing of fine organic debris. In: Logging debris in streams workshop: Proceedings. Corvallis, OR: Oregon State University; 1975: 35-46.
Tuhy, J. S.; Jensen, S. Riparian community classification for the upper Salmon/Middle Fork Salmon River drainages, Idaho. Report to U.S. Department of Agriculture, Forest Service, Intermountain Region, Ogden, UT; 1982. 200 p.
Tuhy, J. S.; Jensen, S. E. Riparian classification for the Greys River, Wyoming. Report to U.S. Department of Agriculture, Forest Service, Intermountain Region, Ogden, UT; 1982. 185 p.
U.S. Department of Agriculture, Forest Service. Range environmental analysis handbook. FSH 2209.21. Denver, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Region; 1973. Unnumbered pages.
U.S. Department of Agriculture, Forest Service. Range analysis handbook. FSH 2209.21. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region; 1983. Unnumbered pages.
U.S. Department of Agriculture, Forest Service. Pesticide background statements. Volume 1: herbicides. Agriculture Handbook 633. Washington, DC; 1984. Unnumbered pages.
U.S. Department of Agriculture, Soil Conservation Service. Soil taxonomy. Agriculture Handbook 436. Washington, DC; 1975. 754 p.
U.S. Department of Agriculture, Soil Conservation Service. National range handbook. Washington, DC; 1976. Unnumbered pages.
U.S. Department of Agriculture, Soil Conservation Service. Draft soil survey manual. 430-V-SSM. Washington, DC; 1981. 94 p.
U.S. Department of the Interior, Bureau of Land Management. Aerial photography specifications. Denver, CO: U.S. Department of the Interior, Bureau of Land Management, Denver Service Center; 1983. 15 p.
U.S. Supreme Court. The Daniel Ball-U.S. Case 10 Wall 557, 563. Washington, DC: U.S. Supreme Court; 1870.
Vallentine, J. F. Range development and improvements. 2d ed. Provo, UT: Brigham-Young University Press; 1980. 545 p.
Vallentine, J. F. The application and use of herbicides for range plant control. In: Monsen, S. B.; Shaw, N., compilers. Managing Intermountain rangelands—improvement of range and wildlife habitats: proceedings; 1981 September 15-17; Twin Falls, ID; 1982 June 22-24; Elko, NV. General Technical Report INT-157. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983: 39-48.
Van Wagner, C. E. The line intersect method in forest fuel sampling. Forest Science. 14(1): 20-26; 1968.
Vannote, R. L. Detrital consumers in natural systems. In: The stream ecosystem. Technical Report 7. East Lansing, MI: Michigan State University, Institute of Water Research; 1969: 20-23.
Vannote, R. L.; Minshall, G. W.; Cummins, K. W.; Sedell, J. R.; Cushing, C. E. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences. 37: 130-137; 1980.
Wellner, C. A. Estimating light intensity beneath coniferous forest canopies: simple field method. Research Note INT-250. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1979. 3 p.
Welsh, S. L.; Altwood, N. D.; Goodrich, S.; Neese, E.; Thorne, K. H.; Albe, B. Preliminary index of Utah vascular plant names. Great Basin Naturalist. 41(1): 1-108; 1981.
Welty, L. E.; Anderson, R. L.; Delaney, R. H.; Hensleigh, P. F. Glyphosate timing effects on establishment of sod-seeded legumes and grasses. Agronomy Journal. 73: 813-817; 1981.
Wendler, H. O.; Deschamps, G. Logging dams on coastal Washington streams. Washington Department of Fisheries Research Paper. 1(3): 27-38; 1955.

The West Shore. 9:128. Portland, OR; 1883.
Whitson, T. D.; William, R. D.; Parker, R.; Swan, D. G.; Dewey, S. Pacific Northwest weed control handbook. Corvallis, OR; Pullman, WA: Extension Services of Oregon State University, Washington State University, and the University of Idaho; 1985. 213 p.
Wiggins, G. B.; MacKay, R. J. Some relationships between systematics and trophic ecology of nearctic aquatic insects, with special reference to Trichoptera. Ecology. 59: 1211-1220; 1978.
Williams, C. Bridge of the Gods, mountains of fire, a return to the Columbia Gorge. White Salmon, WA: Friends of the Earth, New York and Elephant Mountain Arts; 1980. 191 p.
Williams, I. A. Drainage of farm lands in the Willamette and tributary valleys of Oregon. In: The mineral resources of Oregon. Salem, OR: Oregon Bureau of Mines and Geology. 1(4): 140-180; 1914.

APPENDIX 1: STATISTICAL TABLES

Table 30—Cumulative Normal Frequency Distribution area under the standard normal curve from 0 to Z

Z	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	0.0000	0.0040	0.0080	0.0120	0.0160	0.0199	0.0239	0.0279	0.0319	0.0359
.1	.0398	.0438	.0478	.0517	.0557	.0596	.0636	.0675	.0714	.0753
.2	.0793	.0832	.0871	.0910	.0948	.0987	.1026	.1064	.1103	.1141
.3	.1179	.1217	.1255	.1293	.1331	.1368	.1406	.1443	.1480	.1517
.4	.1554	.1591	.1628	.1664	.1700	.1736	.1772	.1808	.1844	.1879
.5	.1915	.1950	.1985	.2019	.2054	.2088	.2123	.2157	.2190	.2224
.6	.2257	.2291	.2324	.2357	.2389	.2422	.2454	.2486	.2517	.2549
.7	.2580	.2611	.2642	.2673	.2704	.2734	.2764	.2794	.2823	.2852
.8	.2881	.2910	.2939	.2967	.2995	.3023	.3051	.3078	.3106	.3133
.9	.3159	.3286	.3212	.3238	.3264	.3289	.3315	.3340	.3365	.3389
1.0	.3413	.3438	.3461	.3485	.3508	.3531	.3554	.3577	.3599	.3621
1.1	.3643	.3665	.3686	.3708	.3729	.3749	.3770	.3790	.3810	.3830
1.2	.3849	.3869	.3888	.3907	.3925	.3944	.3962	.3980	.3997	.4015
1.3	.4032	.4049	.4066	.4082	.4099	.4115	.4131	.4147	.4162	.4177
1.4	.4192	.4207	.4222	.4236	.4251	.4265	.4279	.4292	.4306	.4319
1.5	.4332	.4345	.4357	.4370	.4382	.4394	.4406	.4418	.4429	.4441
1.6	.4452	.4463	.4474	.4484	.4495	.4505	.4515	.4525	.4535	.4545
1.7	.4554	.4564	.4573	.4582	.4591	.4599	.4608	.4616	.4625	.4633
1.8	.4641	.4649	.4656	.4664	.4671	.4678	.4686	.4693	.4699	.4706
1.9	.4713	.4719	.4726	.4732	.4738	.4744	.4750	.4756	.4761	.4767
2.0	.4772	.4778	.4783	.4788	.4793	.4798	.4803	.4808	.4812	.4817
2.1	.4821	.4826	.4830	.4834	.4838	.4842	.4846	.4850	.4854	.4857
2.2	.4861	.4864	.4868	.4871	.4875	.4878	.4881	.4884	.4887	.4890
2.3	.4893	.4896	.4898	.4901	.4904	.4906	.4909	.4911	.4913	.4916
2.4	.4918	.4920	.4922	.4925	.4927	.4929	.4931	.4932	.4934	.4936
2.5	.4938	.4940	.4941	.4943	.4945	.4946	.4948	.4949	.4951	.4952
2.6	.4953	.4955	.4956	.4957	.4959	.4960	.4961	.4962	.4963	.4964
2.7	.4965	.4966	.4967	.4968	.4969	.4970	.4971	.4972	.4973	.4974
2.8	.4974	.4975	.4976	.4977	.4977	.4978	.4979	.4979	.4980	.4981
2.9	.4981	.4982	.4982	.4983	.4984	.4984	.4985	.4985	.4986	.4986
3.0	.4987	.4987	.4987	.4988	.4988	.4989	.4989	.4989	.4990	.4990
3.1	.4990	.4991	.4991	.4991	.4992	.4992	.4992	.4992	.4993	.4993
3.2	.4993	.4993	.4994	.4994	.4994	.4994	.4994	.4995	.4995	.4995
3.3	.4995	.4995	.4995	.4996	.4996	.4996	.4996	.4996	.4996	.4997
3.4	.4997	.4997	.4997	.4997	.4997	.4997	.4997	.4997	.4997	.4998
3.6	.4998	.4998	.4999	.4999	.4999	.4999	.4999	.4999	.4999	.4999
3.9	.5000									

APPENDIX 1 (Con.)

Table 31—Ordinates of the normal curve

	Second decimal place in Z									
Z	**0.00**	**0.01**	**0.02**	**0.03**	**0.04**	**0.05**	**0.06**	**0.07**	**0.08**	**0.09**
0.0	0.3989	0.3989	0.3989	0.3988	0.3986	0.3984	0.3982	0.3980	0.3977	0.3973
.1	.3970	.3965	.3961	.3956	.3951	.3945	.3939	.3932	.3925	.3918
.2	.3910	.3902	.3894	.3885	.3876	.3867	.3857	.3847	.3836	.3825
.3	.3814	.3802	.3790	.3778	.3765	.3752	.3739	.3725	.3712	.3697
.4	.3683	.3668	.3653	.3637	.3621	.3605	.3589	.3572	.3555	.3538
.5	.3521	.3503	.3485	.3467	.3448	.3429	.3410	.3391	.3372	.3352
.6	.3332	.3312	.3292	.3271	.3251	.3230	.3209	.3187	.3166	.3144
.7	.3123	.3101	.3079	.3056	.3034	.3011	.2989	.2966	.2943	.2920
.8	.2897	.2874	.2850	.2827	.2803	.2780	.2756	.2732	.2709	.2685
.9	.2661	.2637	.2613	.2589	.2565	.2541	.2516	.2492	.2468	.2444
1.0	.2420	.2396	.2371	.2347	.2323	.2299	.2275	.2251	.2227	.2203
1.1	.2179	.2155	.2131	.2107	.2083	.2059	.2036	.2012	.1989	.1965
1.2	.1942	.1919	.1895	.1872	.1849	.1826	.1804	.1781	.1758	.1736
1.3	.1714	.1691	.1669	.1647	.1626	.1604	.1582	.1561	.1539	.1518
1.4	.1497	.1476	.1456	.1435	.1415	.1394	.1374	.1354	.1334	.1315
1.5	.1295	.1276	.1257	.1238	.1219	.1200	.1182	.1163	.1145	.1127
1.6	.1109	.1092	.1074	.1057	.1040	.1023	.1006	.0989	.0973	.0957
1.7	.0940	.0925	.0909	.0893	.0878	.0863	.0848	.0833	.0818	.0804
1.8	.0790	.0775	.0761	.0748	.0734	.0721	.0707	.0694	.0681	.0669
1.9	.0656	.0644	.0632	.0620	.0608	.0596	.0584	.0573	.0562	.0551
2.0	.0540	.0529	.0519	.0508	.0498	.0488	.0478	.0468	.0459	.0449
2.1	.0440	.0431	.0422	.0413	.0404	.0396	.0387	.0379	.0371	.0363
2.2	.0355	.0347	.0339	.0332	.0325	.0317	.0310	.0303	.0297	.0290
2.3	.0283	.0277	.0270	.0264	.0258	.0252	.0246	.0241	.0235	.0229
2.4	.0224	.0219	.0213	.0208	.0203	.0198	.0194	.0189	.0184	.0180
2.5	.0175	.0171	.0167	.0163	.0158	.0154	.0151	.0147	.0143	.0139
2.6	.0136	.0132	.0129	.0126	.0122	.0119	.0116	.0113	.0110	.0107
2.7	.0104	.0101	.0099	.0096	.0093	.0091	.0088	.0086	.0084	.0081
2.8	.0079	.0077	.0075	.0073	.0071	.0069	.0067	.0065	.0063	.0061
2.9	.0060	.0058	.0056	.0055	.0053	.0051	.0050	.0048	.0047	.0046

	First decimal place in Z									
	0.0	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**
3	0.0044	0.0033	0.0024	0.0017	0.0012	0.0009	0.0006	0.0004	0.0003	0.0002
4	.0001	.0001	.0001	.0000	.0000	.0000	.0000	.0000	.0000	.0000

APPENDIX 2: ACCURACY, PRECISION, AND CONFIDENCE INTERVALS OF SELECTED VARIABLES

Table 32—Accuracy, precision, and confidence intervals for stream shore water depth

Stream	Mean depth	Confidence interval	Precision	Accuracy
	Feet	± *Percent*		
Horton Creek	0.2	19.8	Fair	Good
Gance Creek	.3	26.6	Poor	Fair
Frenchman Creek	.5	13.2	Fair	Fair
Johnson Creek	.3	16.5	Fair	Fair
South Fork Salmon River	.5	10.6	Good	Poor
Elk Creek	.3	12.9	Fair	Good

Table 33—Accuracy, precision, and confidence intervals for sun angle (arc)

Stream	Sun arc angle	Confidence interval	Precision	Accuracy
	Degrees	± *Percent*		
Horton Creek	—	—	—	—
Gance Creek	—	—	—	—
Frenchman Creek	122	1.5	Excellent	Good
Johnson Creek	148	.4	Excellent	Poor
South Fork Salmon River	109	4.0	Excellent	Excellent
Elk Creek	163	.6	Excellent	Poor

Table 34—Accuracy, precision, and confidence intervals for streambank soil alteration

Stream		Streambank alteration	Confidence interval	Precision	Accuracy
		Percent	± *Percent*		
Horton Creek	Natural	8	12	Fair	Good
	Artificial	22	8	Good	Good
Gance Creek	Natural	31	6	Good	Fair
	Artificial	13	13	Fair	Poor
Frenchman Creek	Natural	20	11	Fair	Fair
	Artificial	5	24	Poor	Poor
Johnson Creek	Natural	15	10	Fair	Fair
	Artificial	12	13	Fair	Poor
South Fork Salmon River	Natural	21	12	Fair	Poor
	Artificial	7	15	Fair	—
Elk Creek	Natural	25	7	Good	Good
	Artificial	14	10	Fair	Poor

Table 35—Accuracy, precision, and confidence intervals for streambank vegetative stability

Stream	Streambank vegetative stability	Confidence interval	Precision	Accuracy
	Units	± *Percent*		
Horton Creek	3.3	2.2	Excellent	Fair
Gance Creek	1.8	5.7	Good	Fair
Frenchman Creek	3.3	2.5	Excellent	Good
Johnson Creek	3.3	2.4	Excellent	Good
South Fork Salmon River	3.5	2.3	Excellent	Fair
Elk Creek	2.8	3.5	Excellent	Fair

Table 36—Accuracy, precision, and confidence intervals for streambank undercut

Stream	Streambank undercut	Confidence interval	Precision	Accuracy
	Degrees	± *Percent*		
Horton Creek	0.1	20.8	Poor	Good
Gance Creek	.1	30.5	Poor	Fair
Frenchman Creek	.5	15.2	Fair	Poor
Johnson Creek	.3	16.1	Fair	Poor
South Fork Salmon River	.4	14.2	Fair	Good
Elk Creek	.5	13.9	Fair	Good

Table 37—Accuracy, precision, and confidence intervals for streambank angle

Stream	Channel bank angle	Confidence interval	Precision	Accuracy
	Degrees	± *Percent*		
Horton Creek	107	3.9	Excellent	Good
Gance Creek	118	3.7	Excellent	Good
Frenchman Creek	97	4.2	Excellent	Good
Johnson Creek	97	4.8	Excellent	Poor
South Fork Salmon River	103	6.6	Good	Good
Elk Creek	103	3.2	Excellent	Good

Table 38—Accuracy, precision, and confidence intervals for streamside cover

Stream	Streamside cover	Confidence interval	Precision	Accuracy
	Units	± *Percent*		
Horton Creek	2.3	3.2	Excellent	Good
Gance Creek	2.2	5.8	Good	Poor
Frenchman Creek	2.1	3.5	Excellent	Poor
Johnson Creek	2.4	3.4	Excellent	Poor
South Fork Salmon River	2.3	4.1	Excellent	Poor
Elk Creek	2.0	4.4	Excellent	Poor

Table 39—Accuracy, precision, and confidence intervals for vegetation use (ocular)

Stream	Vegetation use	Confidence interval	Precision	Accuracy
	Percent	± *Percent*		
Horton Creek	29	5.8	Good	Excellent
Gance Creek	44	8.5	Good	Good
Frenchman Creek	11	32.5	Poor	Good
Johnson Creek	25	9.2	Good	Good
South Fork Salmon River	8	1.5	Excellent	Good
Elk Creek	31	14.7	Fair	Good

Table 40—Accuracy, precision, and confidence intervals for vegetation overhang

Stream	Vegetation overhang	Confidence interval	Precision	Accuracy
	Feet	± *Percent*		
Horton Creek	0.5	8.3	Good	Poor
Gance Creek	.1	33.1	Poor	Poor
Frenchman Creek	.6	14.0	Fair	Good
Johnson Creek	.6	13.4	Fair	Poor
South Fork Salmon River	.8	13.5	Fair	Good
Elk Creek	.5	12.0	Fair	Good

APPENDIX 3: FORMS FOR RECORDING HYDRAULIC GEOMETRY AND SOIL DATA

Line No.			
	DATA	Stream	
	DATA	Location	
	DATA	Date | Station | Xsect | Tension | T , M	
	DATA	Stake Right | Stake Left | Waterup | Waterdown	Distance
	DATA	Rt. Undercut . | Rt. Height , | Lt. Undercut , | Lt. Height | No. Rds	

Line No.		C	W	Horizontal	To Tape	Waterdepth	Velocity
	DATA	,	,	. ,	. ,	. ,	.
	DATA	,	,	. ,	. ,	. ,	.
	DATA	,	,	. ,	. ,	. ,	.
	DATA	,	,	. ,	. ,	. ,	.
	DATA	,	,	. ,	. ,	. ,	.
	DATA	,	,	. ,	. ,	. ,	.
	DATA	,	,	. ,	. ,	. ,	.
	DATA	,	,	. ,	. ,	. ,	.
	DATA	,	,	. ,	. ,	. ,	.
	DATA	,	,	. ,	. ,	. ,	.
	DATA	,	,	. ,	. ,	. ,	.
	DATA	,	,	. ,	. ,	. ,	.
	DATA	,	,	. ,	. ,	. ,	.
	DATA	,	,	. ,	. ,	. ,	.
	DATA	,	,	. ,	. ,	. ,	.

↓ ↓ ↓

	DATA	,	,	. ,	. ,	. ,	.
	DATA	,	,	. ,	. ,	. ,	.
	DATA	,	,	. ,	. ,	. ,	.
	DATA	,	,	. ,	. ,	. ,	.
	DATA	,	,	. ,	. ,	. ,	.
	DATA	,	,	. ,	. ,	. ,	.
	DATA	,	,	. ,	. ,	. ,	.
	DATA	,	,	. ,	. ,	. ,	.
	DATA	,	,	. ,	. ,	. ,	.
	DATA	,	,	. ,	. ,	. ,	.
	DATA	,	,	. ,	. ,	. ,	.
	DATA	,	,	. ,	. ,	. ,	.
	DATA	,	,	. ,	. ,	. ,	.
	DATA	,	,	. ,	. ,	. ,	.
	DATA	,	,	. ,	. ,	. ,	.

APPENDIX 3 (Con.)

Form SCS-SOILS-232C
Rev. 12-70

SOIL DESCRIPTION

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

Soil type		File No.
Area	Date	Stop No.
Classification		
Location		
N. veg. (or crop)		Climate
Parent material		
Physiography		
Relief	Drainage	Salt or alkali
Elevation	Gr. water	Stoniness
Slope	Moisture	
Aspect	Root distrib.	% Clay*
Erosion	% Coarse fragments *	% Coarser than V.F.S. *
Permeability		
Additional notes		

* Control section average

APPENDIX 3 (Con.)

Hori-zon	Depth	Color		Texture	Structure	Consistence			Reaction	Boundary			
		Dry	Moist			Dry	Moist	Wet					

APPENDIX 4: COMPUTER PROGRAM FOR HERBAGE PHYTOMASS AND UTILIZATION MEASUREMENTS

```
1000  REM
1005  REM
1010  REM
1015  REM     PROGRAM NAME: HERB-2
1020  REM
1025  REM
1030  REM     PROGRAM PREPARED BY:
1035  REM
1040  REM
1045  REM              ELIZABETH C. KENNEDY KETCHESON
1050  REM              COMPUTER PROGRAMMER ANALYST
1055  REM
1060  REM                        AND
1065  REM
1070  REM              RODGER LOREN NELSON
1075  REM              BIOLOGICAL TECHNICIAN
1080  REM
1085  REM
1090  REM
1095  REM              USDA - FOREST SERVICE
1100  REM              INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
1105  REM              FORESTRY SCIENCES LABORATORY
1110  REM              BOISE, IDAHO
1115  REM
1120  REM
1125  REM
1130  REM     THIS IS A DOUBLE-SAMPLING PHYTOMASS AND VEGETATION USE
1135  REM     AND BASIC HABITAT ANALYSIS PROGRAM FOR USE WITH AN
1140  REM     ELECTRONIC CAPACITANCE METER ON UP TO 10 PASTURES.
1145  REM     PRIMARY METER READINGS AND SECONDARY METER READINGS
1150  REM     AND VEGETATION WEIGHTS CAN BE INPUT FROM THE KEYBOARD
1155  REM     OR MASS STORAGE, AND CAN BE ACCOMPANIED BY UP TO FIVE
1160  REM     ADDITIONAL VARIABLES FOR BASIC STATISTICAL ANALYSIS
1165  REM     WITHOUT SUBJECTION TO THE DOUBLE-SAMPLING ROUTINE.
1170  REM     THE DOUBLE-SAMPLING ROUTINE CALCULATES AND PLOTS LINEAR
1175  REM     AND LOG-LINEAR REGRESSIONS AND OUTPUTS ALL NECESSARY
1180  REM     COEFFICIENTS AND CONFIDENCE STATISTICS AT THE REQUEST-
1185  REM     ED PROBABILITY LEVELS, AND CALCULATES ESTIMATED PHYTO-
1190  REM     MASS FROM THE REGRESSION RESULTS.  ADDITIONAL VARIABLES
1195  REM     ARE STATISTICALLY EVALUATED TO PROVIDE MEANS, CONFID-
1200  REM     ENCE INTERVALS, ANALYSIS OF VARIANCE, AND SITE-SPECIFIC
1205  REM     COMPARISONS OF MEANS BETWEEN ALL PASTURES.
1210  REM
1215  REM
1220  REM
1225  REM
1230  OPTION BASE 1
1235  DEG
1240  REM
1245  REM
1250  REM
1255  REM
1260  REM     THIS SECTION DIMENSIONS THE ARRAYS THAT CONTAIN THE t
1265  REM     VALUES FOR 1 THROUGH 60 DEGREES OF FREEDOM FOR THE
1270  REM     PROBABILITY LEVELS OF 90%, 95%, AND 99%.  THE VALUES
1275  REM     ARE THEN READ FROM DATA STATEMENTS INTO THE ARRAYS.
1280  REM
1285  REM
1290  REM
1295  REM
```

(con.)

```
1300  DIM T90(60),T95(60),T99(60)
1305  MAT T90=ZER
1310  MAT T95=ZER
1315  MAT T99=ZER
1320  FOR I=1 TO 60
1325      READ T90(I)
1330  NEXT I
1335  DATA 6.314,2.920,2.353,2.132,2.015,1.943,1.895,1.860,1.833,1.812
1340  DATA 1.796,1.782,1.771,1.761,1.753,1.746,1.740,1.734,1.729,1.725
1345  DATA 1.721,1.717,1.714,1.711,1.708,1.706,1.703,1.701,1.699,1.697
1350  DATA 1.696,1.694,1.693,1.691,1.690,1.689,1.688,1.686,1.685,1.684
1355  DATA 1.683,1.682,1.682,1.681,1.680,1.679,1.678,1.678,1.677,1.676
1360  DATA 1.675,1.675,1.674,1.674,1.673,1.673,1.672,1.672,1.671,1.671
1365  FOR I=1 TO 60
1370      READ T95(I)
1375  NEXT I
1380  DATA 12.706,4.303,3.182,2.776,2.571,2.447,2.365,2.306,2.262,2.228
1385  DATA 2.201,2.179,2.160,2.145,2.131,2.120,2.110,2.101,2.093,2.086
1390  DATA 2.080,2.074,2.069,2.064,2.060,2.056,2.052,2.048,2.045,2.042
1395  DATA 2.040,2.037,2.035,2.032,2.030,2.028,2.026,2.025,2.023,2.021
1400  DATA 2.020,2.018,2.017,2.015,2.014,2.013,2.012,2.010,2.009,2.008
1405  DATA 2.007,2.006,2.006,2.005,2.004,2.003,2.002,2.002,2.001,2.000
1410  FOR I=1 TO 60
1415      READ T99(I)
1420  NEXT I
1425  DATA 63.657,9.925,5.841,4.604,4.032,3.707,3.499,3.355,3.250,3.169
1430  DATA 3.106,3.055,3.012,2.977,2.947,2.921,2.898,2.878,2.861,2.845
1435  DATA 2.831,2.819,2.807,2.797,2.787,2.779,2.771,2.763,2.756,2.750
1440  DATA 2.745,2.740,2.734,2.729,2.724,2.720,2.716,2.712,2.708,2.704
1445  DATA 2.701,2.698,2.696,2.693,2.690,2.688,2.685,2.683,2.680,2.678
1450  DATA 2.676,2.674,2.673,2.671,2.669,2.667,2.665,2.664,2.662,2.660
1455  REM
1460  REM
1465  REM
1470  REM
1475  REM    THIS SECTION DIMENSIONS THE STRING AND NUMERIC ARRAYS.
1480  REM
1485  REM
1490  REM
1495  REM
1500  DIM T$[80],Vn$(50)[10],Sn$(20)[10]
1505  DIM Studysite$[40],Site$(10)[20],Grazed$(10)[20]
1510  DIM D(25,500),Sc(20)
1515  DIM Observation(10,25),Sum(10,25),Sum_squares(10,25),Mean(10,25)
1520  DIM Squared_sum(10,25),Sum_of_squares(10,25),Mean_square(10,25)
1525  DIM St_error(10,25),St_deviation(10,25),Limit(10,25)
1530  DIM Mean_sq_sum(25),Mean_sq_between(25),Mean_sq_within(25),Sum_of_sums(25)
,Sum_sq_within(25)
1535  DIM Total_obs(25),Df_between(25),Df_within(25),Df_total(25),F_value(25)
1540  DIM Pool_mean_sq(10,10,25),Pool_st_error(10,10,25),Site_spec_t(10,10,25)
1545  DIM Ln_cross_plt_wt(10),Ln_eng_plt_wt(10),Ln_met_plt_wt(10)
1550  DIM Lin_var_yhat(10),Lin_err_yhat(10),Lin_lim_yhat(10)
1555  DIM Lin_lim_pct(10),Lin_eng_phytom(10),Lin_met_phytom(10)
1560  DIM Dif_lin_eng_phy(10,10),Dif_lin_met_phy(10,10),Dif_lin_phy_pct(10,10)
1565  DIM Mx_dif_leng_phy(10,10),Mx_dif_lnmt_phy(10,10),Mx_dif_leng_pct(10,10)
1570  DIM Mn_dif_leng_phy(10,10),Mn_dif_lnmt_phy(10,10),Mn_dif_leng_pct(10,10)
1575  DIM Log_observation(10,25),Log_sum(10,25),Log_sum_squares(10,25),Log_mean(
10,25)
1580  DIM Log_squared_sum(10,25),Log_sum_of_sqs(10,25),Log_mean_square(10,25)
1585  DIM Lg_cross_plt_wt(10),Lg_eng_plt_wt(10),Lg_met_plt_wt(10)
1590  DIM Lg_av_var_yhat(10),Log_lim_yhat(10)
1595  DIM Tr_log_err_yhat(10),Tr_log_var_yhat(10),Eng_tr_err_yhat(10)
1600  DIM Log_lim_pct(10),Log_eng_phytom(10),Log_met_phytom(10)
```

(con.)

APPENDIX 4 (Con.)

```
1605  DIM Dif_log_eng_phy(10,10),Dif_log_met_phy(10,10),Dif_log_phy_pct(10,10)
1610  DIM Mx_dif_long_phy(10,10),Mx_dif_lgmt_phy(10,10),Mx_dif_long_pct(10,10)
1615  DIM Mn_dif_long_phy(10,10),Mn_dif_lgmt_phy(10,10),Mn_dif_long_pct(10,10)
1620  DIM Trlowlimlgyhat(10),Truplimlgyhat(10)
1625  DIM Trenlwlimlgyhat(10),Trenuplimlgyhat(10)
1630  REM
1635  REM
1640  REM
1645  REM
1650  REM     THIS SECTION INITIALIZES EACH OF THE ELEMENTS IN THE
1655  REM     NUMERIC ARRAYS TO EQUAL ZERO.
1660  REM
1665  REM
1670  REM
1675  REM
1680  MAT D=ZER
1685  MAT Sc=ZER
1690  MAT Observation=ZER
1695  MAT Sum=ZER
1700  MAT Sum_squares=ZER
1705  MAT Mean=ZER
1710  MAT Squared_sum=ZER
1715  MAT Sum_of_squares=ZER
1720  MAT Mean_square=ZER
1725  MAT St_error=ZER
1730  MAT St_deviation=ZER
1735  MAT Limit=ZER
1740  MAT Mean_sq_sum=ZER
1745  MAT Mean_sq_between=ZER
1750  MAT Sum_sq_within=ZER
1755  MAT Mean_sq_within=ZER
1760  MAT Sum_of_sums=ZER
1765  MAT Total_obs=ZER
1770  MAT Df_between=ZER
1775  MAT Df_within=ZER
1780  MAT Df_total=ZER
1785  MAT F_value=ZER
1790  MAT Pool_mean_sq=ZER
1795  MAT Pool_st_error=ZER
1800  MAT Site_spec_t=ZER
1805  MAT Ln_cross_plt_wt=ZER
1810  MAT Ln_eng_plt_wt=ZER
1815  MAT Ln_met_plt_wt=ZER
1820  MAT Lin_var_yhat=ZER
1825  MAT Lin_err_yhat=ZER
1830  MAT Lin_lim_yhat=ZER
1835  MAT Lin_lim_pct=ZER
1840  MAT Lin_eng_phytom=ZER
1845  MAT Lin_met_phytom=ZER
1850  MAT Dif_lin_eng_phy=ZER
1855  MAT Dif_lin_met_phy=ZER
1860  MAT Dif_lin_phy_pct=ZER
1865  MAT Mx_dif_leng_phy=ZER
1870  MAT Mx_dif_lnmt_phy=ZER
1875  MAT Mx_dif_leng_pct=ZER
1880  MAT Mn_dif_leng_phy=ZER
1885  MAT Mn_dif_lnmt_phy=ZER
1890  MAT Mn_dif_leng_pct=ZER
1895  MAT Log_observation=ZER
1900  MAT Log_sum=ZER
1905  MAT Log_sum_squares=ZER
1910  MAT Log_mean=ZER
1915  MAT Log_squared_sum=ZER
```

(con.)

```
1920   MAT Log_sum_of_sqs=ZER
1925   MAT Log_mean_square=ZER
1930   MAT Lg_cross_plt_wt=ZER
1935   MAT Lg_eng_plt_wt=ZER
1940   MAT Lg_met_plt_wt=ZER
1945   MAT Lg_av_var_yhat=ZER
1950   MAT Log_lim_yhat=ZER
1955   MAT Tr_log_err_yhat=ZER
1960   MAT Tr_log_var_yhat=ZER
1965   MAT Eng_tr_err_yhat=ZER
1970   MAT Log_lim_pct=ZER
1975   MAT Log_eng_phytom=ZER
1980   MAT Log_met_phytom=ZER
1985   MAT Dif_log_eng_phy=ZER
1990   MAT Dif_log_met_phy=ZER
1995   MAT Dif_log_phy_pct=ZER
2000   MAT Mx_dif_long_phy=ZER
2005   MAT Mx_dif_lgmt_phy=ZER
2010   MAT Mx_dif_long_pct=ZER
2015   MAT Mn_dif_long_phy=ZER
2020   MAT Mn_dif_lgmt_phy=ZER
2025   MAT Mn_dif_long_pct=ZER
2030   MAT Trlowlimlgyhat=ZER
2035   MAT Truplimlgyhat=ZER
2040   MAT Trenlwlimlgyhat=ZER
2045   MAT Trenuplimlgyhat=ZER
2050   REM
2055   REM
2060   REM
2065   REM
2070   REM     THIS SECTION INITIALIZES EACH OF THE UNDIMENSIONED
2075   REM     VARIABLES TO EQUAL ZERO.
2080   REM
2085   REM
2090   REM
2095   REM
2100   LET Lin_sum_of_xy=Linear_n=Lin_df_total=Lin_df_resid=Lin_df_regress=0
2105   LET Lin_sum_cross=Lin_sum_sq_res=Lin_mean_sq_res=Lin_error_est=0
2110   LET Lin_furnival_i=Linear_b=Lin_error_b=Linear_a=Linear_r_sq=0
2115   LET Linear_r=Lin_covar=Lin_mean_sq_reg=Lin_f_value=0
2120   LET Log_sum_of_xy=Logarithmic_n=Log_df_total=Log_df_resid=Log_df_regress=0
2125   LET Log_sum_cross=Log_sum_sq_res=Log_mean_sq_res=Log_error_est=0
2130   LET Log_furnival_i=Logarithmic_b=Log_error_b=Logarithmic_a=Logrithmic_r_sq
=0
2135   LET Logarithmic_r=Log_covar=Log_mean_sq_reg=Log_f_value=0
2140   REM
2145   REM
2150   REM
2155   REM
2160   REM     THIS SECTION ALLOWS THE OPERATOR TO INPUT THE
2165   REM     NAME OF THE DATA FILE TO BE SUMMARIZED.
2170   REM
2175   REM
2180   REM
2185   REM
2190   PRINTER IS 16
2195   PRINT PAGE
2200   PRINT "
       "
2205   PRINT "      YOU WILL BE ASKED TO INPUT THE NAME OF THE DATA FILE THAT YOU
 WANT         "
2210   PRINT "      TO RUN THROUGH THIS PROGRAM, FOLLOWED BY A COLON (:), FOLLOWE
D BY         "
```

(con.)

APPENDIX 4 (Con.)

```
2215  PRINT "      THE NUMBER  OF THE MASS STORAGE DEVICE WHERE THE FILE IS STOR
ED (i.e.    "
2220  PRINT "      T14, T15, OR F8).  PRESS THE CONT KEY AFTER YOU HAVE TYPED IN
 THE        "
2225  PRINT "      FILE NAME.
            "
2230  PRINT "
            "
2235  LINPUT "PLEASE ENTER THE FILE NAME AND THE MASS STORAGE DEVICE.",File$
2240  ASSIGN #1 TO File$
2245  READ #1,1;T$,No,Nv,Vn$(*),Ns,Sn$(*),Sc(*)
2250  REDIM D(Nv,No)
2255  READ #1,2
2260  READ #1;D(*)
2265  REM
2270  REM
2275  REM
2280  REM
2285  REM    THIS SECTION DETERMINES THE YEAR OF THE SURVEY AND THE
2290  REM    STUDY SITE FROM THE NAME OF THE DATA FILE.
2295  REM
2300  REM
2305  REM
2310  REM
2315  LET Year=VAL(File$[4,5])+1900
2320  LET Site=VAL(File$[1,3])
2325  IF Site=501 THEN Studysite$="LOWER RED RIVER"
2330  IF Site=601 THEN Studysite$="LOWER BIG CREEK, UTAH"
2335  IF Site=602 THEN Studysite$="UPPER BIG CREEK, UTAH"
2340  IF Site=611 THEN Studysite$="OTTER CREEK, UTAH"
2345  IF Site=701 THEN Studysite$="CHIMNEY CREEK, NEVADA"
2350  IF Site=711 THEN Studysite$="TABOR CREEK, NEVADA"
2355  IF Site=801 THEN Studysite$="UPPER FRENCHMAN CREEK"
2360  IF Site=802 THEN Studysite$="LOWER FRENCHMAN CREEK"
2365  IF Site=871 THEN Studysite$="ELK CREEK"
2370  IF Site=881 THEN Studysite$="UPPER BEAR VALLEY CREEK"
2375  IF Site=882 THEN Studysite$="LOWER BEAR VALLEY CREEK"
2380  IF Site=901 THEN Studysite$="HORTON/POLE CREEK"
2385  IF Site=951 THEN Studysite$="GANCE CREEK, NEVADA"
2390  IF Site=971 THEN Studysite$="JOHNSON CREEK"
2395  IF Site=991 THEN Studysite$="UPPER STOLLE"
2400  IF Site=992 THEN Studysite$="STOLLE GUARD"
2405  IF Site=993 THEN Studysite$="STOLLE COUGAR"
2410  IF Site=994 THEN Studysite$="LOWER STOLLE"
2415  REM
2420  REM
2425  REM
2430  REM
2435  REM    THIS SECTION DETERMINES WHICH OF THE SITES WERE SAMPLED
2440  REM    AND WHICH OF THOSE SITES WERE GRAZED AND UNGRAZED.
2445  REM
2450  REM
2455  REM
2460  REM
2465  FOR S=1 TO Ns-1
2470      IF Sn$(S)[5,5]="1" THEN Site$(S)="STUDY SITE 1"
2475      IF Sn$(S)[5,5]="2" THEN Site$(S)="STUDY SITE 2"
2480      IF Sn$(S)[5,5]="3" THEN Site$(S)="STUDY SITE 3"
2485      IF Sn$(S)[5,5]="4" THEN Site$(S)="STUDY SITE 4"
2490  NEXT S
2495  FOR S=1 TO Ns-1
2500      IF Sn$(S)[7,10]="UNGR" THEN Grazed$(S)="UNGRAZED"
2505      IF Sn$(S)[7,10]="GRCA" THEN Grazed$(S)="GRAZED-CATTLE"
```

(con.)

```
2510        IF Sn$(S)[7,10]="GRSH" THEN Grazed$(S)="GRAZED-SHEEP"
2515   NEXT S
2520   LET Site$(Ns)="CALIBRATION DATA"
2525   REM
2530   REM
2535   REM
2540   REM
2545   REM     THIS SECTION ALLOWS THE OPERATOR TO SELECT THE CONFIDENCE
2550   REM     LEVEL TO BE USED IN THE STATISTICAL ANALYSES.
2555   REM
2560   REM
2565   REM
2570   REM
2575   PRINTER IS 16
2580   PRINT PAGE
2585   PRINT "
           "
2590   PRINT "      YOU WILL BE ASKED TO INPUT THE CONFIDENCE LEVEL ( 90, 95, 99
) YOU      "
2595   PRINT "      WANT TO USE IN THE STATISTICAL ANALYSIS.  PRESS THE CONT KEY
AFTER      "
2600   PRINT "      YOU HAVE TYPED IN THE CONFIDENCE LEVEL.
           "
2605   PRINT "
           "
2610   INPUT "PLEASE ENTER THE CONFIDENCE LEVEL ( 90, 95, 99 ).",Level
2615   REM
2620   REM
2625   REM
2630   REM
2635   REM     THIS SECTION CALCULATES THE BASIC STATISTICS ( THE SUMS, THE
2640   REM     MEANS, THE SUM OF THE SQUARES, THE MEAN OF THE SQUARES ) FOR
2645   REM     EACH OF THE VARIABLES FOR THE PRIMARY DATA.
2650   REM
2655   REM
2660   REM
2665   REM
2670   FOR S=1 TO Ns-1
2675        FOR I=2 TO Nv
2680             FOR J=Sc(S) TO Sc(S+1)-1
2685                  IF D(I,J)=-9999999.99999 THEN 2725
2690                  LET Observation(S,I)=Observation(S,I)+1
2695                  LET Sum(S,I)=Sum(S,I)+D(I,J)
2700                  LET Sum_squares(S,I)=Sum_squares(S,I)+D(I,J)^2
2705                  IF D(I,J)=0 THEN 2725
2710                  LET Log_observation(S,I)=Log_observation(S,I)+1
2715                  LET Log_sum(S,I)=Log_sum(S,I)+LOG(D(I,J))
2720                  LET Log_sum_squares(S,I)=Log_sum_squares(S,I)+LOG(D(I,J))^2
2725             NEXT J
2730             IF Observation(S,I)<=1 THEN 2780
2735             LET Mean(S,I)=Sum(S,I)/Observation(S,I)
2740             LET Squared_sum(S,I)=Sum(S,I)^2
2745             LET Sum_of_squares(S,I)=Sum_squares(S,I)-Squared_sum(S,I)/Observat
ion(S,I)
2750             LET Mean_square(S,I)=Sum_of_squares(S,I)/(Observation(S,I)-1)
2755             LET St_error(S,I)=(Mean_square(S,I)/Observation(S,I))^.5
2760             LET St_deviation(S,I)=Mean_square(S,I)^.5
2765             IF Level=90 THEN LET Limit(S,I)=St_error(S,I)*T90(Observation(S,I)
-1)
2770             IF Level=95 THEN LET Limit(S,I)=St_error(S,I)*T95(Observation(S,I)
-1)
2775             IF Level=99 THEN LET Limit(S,I)=St_error(S,I)*T99(Observation(S,I)
-1)
```

(con.)

APPENDIX 4 (Con.)

```
2780            IF Log_observation(S,I)<=1 THEN 2805
2785            LET Log_mean(S,I)=Log_sum(S,I)/Log_observation(S,I)
2790            LET Log_squared_sum(S,I)=Log_sum(S,I)^2
2795            LET Log_sum_of_sqs(S,I)=Log_sum_squares(S,I)-Log_squared_sum(S,I)/
Log_observation(S,I)
2800            LET Log_mean_square(S,I)=Log_sum_of_sqs(S,I)/(Log_observation(S,I)
-1)
2805        NEXT I
2810    NEXT S
2815    REM
2820    REM
2825    REM
2830    REM
2835    REM    THIS SECTION CALCULATES THE BASIC STATISTICS ( THE SUMS, THE
2840    REM    MEANS, THE SUM OF THE SQUARES, THE MEAN OF THE SQUARES ) FOR
2845    REM    EACH OF THE VARIABLES FOR THE SECONDARY DATA.
2850    REM
2855    REM
2860    REM
2865    REM
2870    FOR I=2 TO Nv
2875        FOR J=Sc(Ns) TO No
2880            IF D(I,J)=-9999999.99999 THEN 2900
2885            LET Observation(Ns,I)=Observation(Ns,I)+1
2890            LET Sum(Ns,I)=Sum(Ns,I)+D(I,J)
2895            LET Sum_squares(Ns,I)=Sum_squares(Ns,I)+D(I,J)^2
2900            IF (D(I,J)=0) OR (D(I,J)=-9999999.99999) THEN 2920
2905            LET Log_observation(Ns,I)=Log_observation(Ns,I)+1
2910            LET Log_sum(Ns,I)=Log_sum(Ns,I)+LOG(D(I,J))
2915            LET Log_sum_squares(Ns,I)=Log_sum_squares(Ns,I)+LOG(D(I,J))^2
2920        NEXT J
2925        IF Observation(Ns,I)<=1 THEN 2975
2930        LET Mean(Ns,I)=Sum(Ns,I)/Observation(Ns,I)
2935        LET Squared_sum(Ns,I)=Sum(Ns,I)^2
2940        LET Sum_of_squares(Ns,I)=Sum_squares(Ns,I)-Squared_sum(Ns,I)/Observati
on(Ns,I)
2945        LET Mean_square(Ns,I)=Sum_of_squares(Ns,I)/(Observation(Ns,I)-1)
2950        LET St_error(Ns,I)=(Mean_square(Ns,I)/Observation(Ns,I))^.5
2955        LET St_deviation(Ns,I)=Mean_square(Ns,I)^.5
2960        IF Level=90 THEN LET Limit(Ns,I)=St_error(Ns,I)*T90(Observation(Ns,I)-
1)
2965        IF Level=95 THEN LET Limit(Ns,I)=St_error(Ns,I)*T95(Observation(Ns,I)-
1)
2970        IF Level=99 THEN LET Limit(Ns,I)=St_error(Ns,I)*T99(Observation(Ns,I)-
1)
2975        IF Log_observation(Ns,I)<=1 THEN 3000
2980        LET Log_mean(Ns,I)=Log_sum(Ns,I)/Log_observation(Ns,I)
2985        LET Log_squared_sum(Ns,I)=Log_sum(Ns,I)^2
2990        LET Log_sum_of_sqs(Ns,I)=Log_sum_squares(Ns,I)-Log_squared_sum(Ns,I)/L
og_observation(Ns,I)
2995        LET Log_mean_square(Ns,I)=Log_sum_of_sqs(Ns,I)/(Log_observation(Ns,I)-
1)
3000    NEXT I
3005    REM
3010    REM
3015    REM
3020    REM
3025    REM    THIS SECTION DOES THE ANALYSIS OF VARIANCE BETWEEN SITES
3030    REM    FOR EACH OF THE VARIABLES.
3035    REM
3040    REM
3045    REM
3050    REM
```

(con.)

```
3055  FOR I=2 TO Nv
3060      LET Df_between(I)=Ns-2
3065      FOR S=1 TO Ns-1
3070          LET Total_obs(I)=Total_obs(I)+Observation(S,I)
3075          IF Observation(Ns,I)=0 THEN 3085
3080          LET Mean_sq_sum(I)=Mean_sq_sum(I)+Squared_sum(S,I)/Observation(Ns,
I)
3085          LET Sum_sq_within(I)=Sum_sq_within(I)+Sum_squares(S,I)
3090          LET Sum_of_sums(I)=Sum_of_sums(I)+Sum(S,I)
3095      NEXT S
3100      IF Total_obs(I)<=2 THEN 3135
3105      LET Df_total(I)=Total_obs(I)-1
3110      LET Df_within(I)=Df_total(I)-Df_between(I)
3115      LET Sum_of_sums(I)=Sum_of_sums(I)^2/(Sc(Ns)-1)
3120      LET Mean_sq_between(I)=(Mean_sq_sum(I)-Sum_of_sums(I))/Df_between(I)
3125      LET Mean_sq_within(I)=Sum_sq_within(I)/Df_within(I)
3130      LET F_value(I)=Mean_sq_between(I)/Mean_sq_within(I)
3135  NEXT I
3140  REM
3145  REM
3150  REM
3155  REM
3160  REM    THIS SECTION DOES THE SITE SPECIFIC COMPARISONS ( THE
3165  REM    T-VALUES ) FOR EACH OF THE VARIABLES.
3170  REM
3175  REM
3180  REM
3185  REM
3190  FOR I=2 TO Nv
3195      FOR S=1 TO Ns-2
3200          FOR S1=S+1 TO Ns-1
3205              LET Pool_mean_sq(S,S1,I)=(Sum_of_squares(S,I)+Sum_of_squares(S
1,I))/(Observation(S,I)-1+(Observations(S1,I)-1))
3210              IF Observation(S,I)<>Observation(S1,I) THEN 3230
3215              IF Observation(S,I)=0 THEN 3245
3220              LET Pool_st_error(S,S1,I)=(2*Pool_mean_sq(S,S1,I)/Observation(
S,I))^.5
3225              GOTO 3240
3230              IF (Observation(S,I)=0) OR (Observation(S1,I)=0) THEN 3245
3235              LET Pool_st_error(S,S1,I)=(Pool_mean_sq(S,S1,I)*((Observation(
S,I)+Observation(S1,I))/(Observation(S,I)*Observation(S1,I))))^.5
3240              LET Site_spec_t(S,S1,I)=(Mean(S,I)-Mean(S1,I))/Pool_st_error(S
,S1,I)
3245          NEXT S1
3250      NEXT S
3255  NEXT I
3260  REM
3265  REM
3270  REM
3275  REM
3280  REM    THIS SECTION ALLOWS THE OPERATOR TO SELECT THE EXPLANATORY
3285  REM    VARIABLE (X) AND THE RESPONSE VARIABLE (Y).
3290  REM
3295  REM
3300  REM
3305  REM
3310  PRINTER IS 16
3315  PRINT PAGE
3320  PRINT "
"
3325  PRINT "     YOU WILL BE ASKED-TO INPUT THE NUMBER OF THE EXPLANATORY VARI
ABLE (X)   "
3330  PRINT "     AND THE RESPONSE VARIABLE (Y).  PRESS THE CONT KEY AFTER YOU
```

(con.)

APPENDIX 4 (Con.)

```
HAVE EN-    "
3335  PRINT "      TERED THE NUMBERS OF THE VARIABLES.
      "
3340  PRINT "
      "
3345  INPUT "PLEASE ENTER THE NUMBER OF THE EXPLANATORY VARIABLE (X)",X
3350  INPUT "PLEASE ENTER THE NUMBER OF THE RESPONSE VARIABLE (Y)",Y
3355  REM
3360  REM
3365  REM
3370  REM
3375  REM    THIS SECTION CALCULATES THE STATISTICS ( SUM OF X*Y, SUM OF
3380  REM    THE CROSSPRODUCTS, SUM OF THE SQUARES FOR THE REGRESSION,
3385  REM    MEAN OF THE SQUARES FOR THE REGRESSION, AND THE STANDARD
3390  REM    ERROR OF ESTIMATE ) FOR THE LINEAR REGRESSION AND FOR THE
3395  REM    LOGARITHMIC REGRESSION FOR THE SELECTED VARIABLES.
3400  REM
3405  REM
3410  REM
3415  REM
3420  FOR J=Sc(Ns) TO No
3425      LET Lin_sum_of_xy=Lin_sum_of_xy+D(X,J)*D(Y,J)
3430      IF (D(X,J)=0) OR (D(Y,J)=0) THEN 3440
3435      LET Log_sum_of_xy=Log_sum_of_xy+LOG(D(X,J))*LOG(D(Y,J))
3440  NEXT J
3445  LET Linear_n=Observation(Ns,X)
3450  LET Lin_df_total=Linear_n-1
3455  LET Lin_df_resid=Lin_df_total-1
3460  LET Lin_df_regress=1
3465  LET Lin_sum_cross=Lin_sum_of_xy-Sum(Ns,X)*Sum(Ns,Y)/Linear_n
3470  LET Lin_sum_sq_res=Sum_of_squares(Ns,Y)-Lin_sum_cross^2/Sum_of_squares(Ns,
X)
3475  LET Lin_mean_sq_res=Lin_sum_sq_res/Lin_df_resid
3480  LET Lin_error_est=Lin_mean_sq_res^.5
3485  LET Lin_furnival_i=Lin_error_est
3490  LET Linear_b=Lin_sum_cross/Sum_of_squares(Ns,X)
3495  LET Lin_error_b=(Lin_mean_sq_res/Sum_of_squares(Ns,X))^.5
3500  LET Linear_a=Mean(Ns,Y)-Linear_b*Mean(Ns,X)
3505  LET Linear_r_sq=Lin_sum_cross^2/Sum_of_squares(Ns,X)/Sum_of_squares(Ns,Y)
3510  LET Linear_r=Linear_r_sq^.5
3515  LET Lin_covar=Lin_sum_cross/Lin_df_total
3520  LET Lin_mean_sq_reg=Lin_sum_cross^2/Sum_of_squares(Ns,X)/Lin_df_regress
3525  LET Lin_f_value=Lin_mean_sq_reg/Lin_mean_sq_res
3530  LET Logarithmic_n=Log_observation(Ns,X)
3535  LET Log_df_total=Logarithmic_n-1
3540  LET Log_df_resid=Log_df_total-1
3545  LET Log_df_regress=1
3550  LET Log_sum_cross=Log_sum_of_xy-Log_sum(Ns,X)*Log_sum(Ns,Y)/Logarithmic_n
3555  LET Log_sum_sq_res=Log_sum_of_sqs(Ns,Y)-Log_sum_cross^2/Log_sum_of_sqs(Ns,
X)
3560  LET Log_mean_sq_res=Log_sum_sq_res/Log_df_resid
3565  LET Log_error_est=Log_mean_sq_res^.5
3570  LET Log_furnival_i=Log_error_est*EXP(Log_mean(Ns,Y))
3575  LET Logarithmic_b=Log_sum_cross/Log_sum_of_sqs(Ns,X)
3580  LET Log_error_b=(Log_mean_sq_res/Log_sum_of_sqs(Ns,X))^.5
3585  LET Logarithmic_a=Log_mean(Ns,Y)-Logarithmic_b*Log_mean(Ns,X)
3590  LET Logrithmic_r_sq=Log_sum_cross^2/Log_sum_of_sqs(Ns,X)/Log_sum_of_sqs(Ns
,Y)
3595  LET Logarithmic_r=Logrithmic_r_sq^.5
3600  LET Log_covar=Log_sum_cross/Log_df_total
3605  LET Log_mean_sq_reg=Log_sum_cross^2/Log_sum_of_sqs(Ns,X)/Log_df_regress
3610  LET Log_f_value=Log_mean_sq_reg/Log_mean_sq_res
3615  REM
```

(con.)

```
3620  REM
3625  REM
3630  REM
3635  REM    THIS SECTION PRINTS OUT THE GENERAL DATA FOR THE STUDY SITE.
3640  REM
3645  REM
3650  REM
3655  REM
3660  PRINTER IS 0
3665  PRINT USING 3670
3670  IMAGE 80("*")
3675  PRINT USING "K,25X,K,26X,K";"*","STREAMSIDE HERBAGE ANALYSIS","*"
3680  PRINT USING "K,20X,K,20X,K";"*","DOUBLE SAMPLING WITH CAPACITANCE METER","
*"
3685  PRINT USING 3670
3690  PRINT LIN(2)
3695  PRINT USING "K,X,K";"STUDY AREA:",Studysite$
3700  PRINT USING "K,X,4D";"YEAR OF SURVEY:",Year
3705  PRINT
3710  PRINT USING "K,X,2D";"NO. SITES EVALUATED:",Ns-1
3715  FOR S=1 TO Ns-1
3720      PRINT USING "5X,K,2X,K";Site$(S),Grazed$(S)
3725  NEXT S
3730  PRINT
3735  PRINT USING "K,X,K";"STARTING TEMP:","_______________"
3740  PRINT USING "K,4X,K";"RESET TEMP:","_______________"
3745  PRINT USING "K,4X,K";"RESET TEMP:","_______________"
3750  PRINT USING "K,3X,K";"FINISH TEMP:","_______________"
3755  PRINT
3760  PRINT USING "K,X,K";"DATA COLLECTION DATE:","_______________"
3765  PRINT USING "K,4X,K";"DATA COLLECTED BY:","_______________"
3770  PRINT USING "K,4X,K";"DATA EVALUATED BY:","_______________"
3775  PRINT LIN(2)
3780  REM
3785  REM
3790  REM
3795  REM
3800  REM    THIS SECTION PRINTS OUT THE RAW DATA FOR THE SECONDARY DATA SET.
3805  REM
3810  REM
3815  REM
3820  REM
3825  PRINT USING 3830;"RAW DATA LISTING"
3830  IMAGE  31("-"),X,K,X,31("-")
3835  PRINT LIN(1)
3840  PRINT USING "32X,K";"SECONDARY SAMPLE"
3845  PRINT LIN(1)
3850  PRINT USING "10X,K,7X,K,8X,K,6X,K";"GREEN WEIGHT","COMPOSITION","COVERAGE"
,"DISTANCE TO STREAM"
3855  PRINT USING 3860
3860  IMAGE 7X,18("-"),2X,16("-"),2X,15("-"),2X,18("-")
3865  PRINT USING "K,5X,K,8X,K,5X,K,2X,K,2X,K,2X,K,6X,K,8X,K";"METER","GM","OZ",
"% SHRUB","% GRASS","% COVER","% EXP","FT","M"
3870  PRINT USING 3875
3875  IMAGE 5("-"),2X,8("-"),2X,8("-"),2X,7("-"),2X,7("-"),2X,7("-"),2X,6("-"),2
X,8("-"),2X,8("-")
3880  FOR J=Sc(Ns) TO No
3885      IF D(8,J)=-9999999.99999 THEN 3905
3890      PRINT USING 3895;D(2,J),D(7,J),.03527*D(7,J),D(3,J),D(4,J),D(6,J),D(5,
J),D(8,J),.3048*D(8,J)
3895      IMAGE 1X,3D,4X,4D.D,4X,3D.2D,5X,3D,6X,3D,6X,3D,5X,3D,5X,M3D.D,3X,M3D.2
D
3900      GOTO 3915
```

(con.)

APPENDIX 4 (Con.)

```
3905        PRINT USING 3910;D(2,J),D(7,J),.03527*D(7,J),D(3,J),D(4,J),D(6,J),D(5,
J),"----","----"
3910        IMAGE 1X,3D,4X,4D.D,4X,3D.2D,5X,3D,6X,3D,6X,3D,5X,3D,7X,K,6X,K
3915    NEXT J
3920    PRINT
3925    PRINT USING "19X,K";"** NOTE:  '----' INDICATES MISSING DATA **"
3930    PRINT LIN(2)
3935    REM
3940    REM
3945    REM
3950    REM
3955    REM    THIS SECTION PRINTS OUT THE RAW DATA FOR THE PRIMARY DATA SET.
3960    REM
3965    REM
3970    REM
3975    REM
3980    PRINT USING "32X,K";"PRIMARY SAMPLES"
3985    PRINT LIN(1)
3990    FOR S=1 TO Ns-1
3995        IF Grazed$(S)="UNGRAZED" THEN PRINT USING "29X,K,2X,K";Site$(S),Grazed
$(S)
4000        IF Grazed$(S)="GRAZED-CATTLE" THEN PRINT USING "27X,K,2X,K";Site$(S),G
razed$(S)
4005        IF Grazed$(S)="GRAZED-SHEEP" THEN PRINT USING "27X,K,2X,K";Site$(S),Gr
azed$(S)
4010        IF Grazed$(S)="UNGRAZED" THEN PRINT USING 4025
4015        IF Grazed$(S)="GRAZED-CATTLE" THEN PRINT USING 4030
4020        IF Grazed$(S)="GRAZED-SHEEP" THEN PRINT USING 4035
4025        IMAGE 29X,22("-")
4030        IMAGE 27X,27("-")
4035        IMAGE 27X,26("-")
4040        PRINT
4045        PRINT USING "17X,K,12X,K,10X,K";"COMPOSITION","COVERAGE","DISTANCE TO
STREAM"
4050        PRINT USING 4055
4055        IMAGE 14X,18("-"),4X,17("-"),4X,20("-")
4060        PRINT USING "4X,K,5X,K,2X,K,4X,K,2X,K,7X,K,10X,K";"METER","%  SHRUB","
%  GRASS","%  COVER","%  EXPD","FT","M"
4065        PRINT USING 4070
4070        IMAGE 3X,7("-"),4X,8("-"),2X,8("-"),4X,8("-"),2X,7("-"),4X,9("-"),3X,8
("-")
4075        FOR J=Sc(S) TO Sc(S+1)-1
4080            IF D(8,J)=-9999999.99999 THEN 4100
4085            PRINT USING 4090;D(2,J),D(3,J),D(4,J),D(6,J),D(5,J),D(8,J),.3048*D
(8,J)
4090            IMAGE 5X,3D,9X,3D,7X,3D,8X,3D,7X,3D,7X,M3D.D,5X,M3D.2D
4095            GOTO 4110
4100            PRINT USING 4105;D(2,J),D(3,J),D(4,J),D(6,J),D(5,J),"----","----"
4105            IMAGE 5X,3D,9X,3D,7X,3D,8X,3D,7X,3D,9X,K,8X,K
4110        NEXT J
4115        PRINT
4120        PRINT USING "19X,K";"** NOTE:  '----' INDICATES MISSING DATA **"
4125        PRINT LIN(2)
4130    NEXT S
4135    REM
4140    REM
4145    REM
4150    REM
4155    REM    THIS SECTION PRINTS OUT THE BASIC STATISTICS AND THE ANALYSES
4160    REM    OF VARIANCE FOR THE PRIMARY AND SECONDARY DATA.
4165    REM
4170    REM
4175    REM
```

(con.)

APPENDIX 4 (Con.)

```
4180   REM
4185   PRINT USING 3670
4190   PRINT USING "K,27X,K,28X,K";"*","BASIC DATA MANIPULATION","*"
4195   PRINT USING 3670
4200   PRINT LIN(2)
4205   PRINT USING 4210;"SUMMARY STATISTICS"
4210   IMAGE 30("-"),X,K,X,30("-")
4215   PRINT LIN(1)
4220   FOR I=2 TO Nv
4225        IF I=2 THEN PRINT USING "11X,K,26X,K";"METER READING","ANALYSIS OF VAR
IANCE"
4230        IF I=3 THEN PRINT USING "14X,K,29X,K";"% SHRUB","ANALYSIS OF VARIANCE"
4235        IF I=4 THEN PRINT USING "14X,K,29X,K";"% GRASS","ANALYSIS OF VARIANCE"
4240        IF I=5 THEN PRINT USING "13X,K,28X,K";"% EXPOSED","ANALYSIS OF VARIANC
E"
4245        IF I=6 THEN PRINT USING "14X,K,29X,K";"% COVER","ANALYSIS OF VARIANCE"
4250        IF I=7 THEN PRINT USING "12X,K,27X,K";"CLIP WEIGHT","ANALYSIS OF VARIA
NCE"
4255        IF I=8 THEN PRINT USING "9X,K,24X,K";"DISTANCE TO STREAM","ANALYSIS OF
 VARIANCE"
4260        PRINT USING 4265
4265        IMAGE 37("-"),3X,40("-")
4270        PRINT USING "33X,2D,K,4X,K,9X,K,3X,K,2X,K";Level,"%","SOURCE","DF","ME
AN SQUARE","F-VALUE"
4275        PRINT USING 4280;"SITE","MEAN","VAR","SE","LIMITS"
4280        IMAGE K,2X,K,5X,K,6X,K,5X,K,3X,13("-"),2X,3("-"),2X,11("-"),2X,7("-")
4285        IF Total_obs(I)>2 THEN PRINT USING 4295;"BETWEEN SITES",Df_between(I),
Mean_sq_between(I),F_value(I)
4290        IF Total_obs(I)<=2 THEN PRINT USING 4300;"BETWEEN SITES"
4295        IMAGE 4("-"),2X,5("-"),2X,7("-"),2X,7("-"),2X,6("-"),3X,K,2X,3D,2X,7D.
3D,2X,4D.2D
4300        IMAGE 4("-"),2X,5("-"),2X,7("-"),2X,7("-"),2X,6("-"),3X,K
4305        FOR S=1 TO Ns-1
4310            IF Total_obs(I)<=2 THEN 4355
4315            IF S=1 THEN PRINT USING 4320;S,Mean(S,I),Mean_square(S,I),St_error
(S,I),Limit(S,I),"WITHIN SITES",Df_within(I),Mean_sq_within(I)
4320            IMAGE 1X,2D,3X,3D.1D,2X,5D.1D,2X,3D.3D,2X,3D.2D,3X,K,3X,3D,2X,7D.3
D
4325            IF S=2 THEN PRINT USING 4330;S,Mean(S,I),Mean_square(S,I),St_error
(S,I),Limit(S,I),"TOTAL",Df_total(I)
4330            IMAGE 1X,2D,3X,3D.1D,2X,5D.1D,2X,3D.3D,2X,3D.2D,3X,K,10X,3D
4335            IF S>2 THEN PRINT USING 4340;S,Mean(S,I),Mean_square(S,I),St_error
(S,I),Limit(S,I)
4340            IMAGE 1X,2D,3X,3D.1D,2X,5D.1D,2X,3D.3D,2X,3D.2D
4345        NEXT S
4350        IF Total_obs(I)>2 THEN 4365
4355        PRINT USING "40X,K";"WITHIN SITES"
4360        PRINT USING "1X,K,4X,K";"NO SITE-SPECIFIC DATA THIS VARIABLE","TOTAL"
4365        PRINT USING 4370
4370        IMAGE 4("-"),2X,5("-"),2X,7("-"),2X,7("-"),2X,6("-")
4375        PRINT USING 4380;"CAL",Mean(Ns,I),Mean_square(Ns,I),St_error(Ns,I),Lim
it(Ns,I),"CALIBRATION ANOVA IN REGRESSION ANALYSIS"
4380        IMAGE K,3X,3D.1D,2X,5D.1D,2X,3D.3D,2X,3D.2D,3X,K
4385        PRINT LIN(1)
4390   NEXT I
4395   REM
4400   REM
4405   REM
4410   REM
4415   REM    THIS SECTION PRINTS OUT THE SITE SPECIFIC COMPARISONS FOR EACH
4420   REM    OF THE VARIABLES IN THE PRIMARY DATA SET.
4425   REM
4430   REM
```

(con.)

APPENDIX 4 (Con.)

```
4435   REM
4440   REM
4445   PRINT LIN(2)
4450   PRINT USING 4455;"SITE SPECIFIC COMPARISONS (T-VALUES) BY VARIABLE"
4455   IMAGE 15("-"),X,K,X,15("-")
4460   PRINT LIN(1)
4465   FOR I=1 TO 2
4470        PRINT USING "46X,K";"VARIABLE"
4475        PRINT USING 4480
4480        IMAGE 25X,45("-")
4485        IF I=1 THEN PRINT USING "32X,K,17X,K";"METER","COMPOSITION"
4490        IF I=2 THEN PRINT USING "31X,K,17X,K";"COVERAGE","TO STREAM"
4495        PRINT USING 4500
4500        IMAGE 25X,20("-"),5X,20("-")
4505        PRINT USING 4510;"STUDY SITES","CALC-T","T(",Level,"%)","DF","CALC-T",
"T(",Level,"%)","DF"
4510        IMAGE 9X,K,5X,K,2X,K,2D,K,3X,K,6X,K,2X,K,2D,K,3X,K
4515        PRINT USING 4520
4520        IMAGE 9X,11("-"),5X,6("-"),2X,6("-"),2X,4("-"),5X,6("-"),2X,6("-"),2X,
4("-")
4525        FOR S=1 TO Ns-2
4530             FOR S1=S+1 TO Ns-1
4535                  LET V1=V2=V3=V4=0
4540                  IF I=2 THEN 4570
4545                  LET V1=ABS(Site_spec_t(S,S1,2))
4550                  LET V2=Observation(S,2)+Observation(S1,2)-2
4555                  LET V3=ABS(Site_spec_t(S,S1,3))
4560                  LET V4=Observation(S,3)+Observation(S1,3)-2
4565                  GOTO 4590
4570                  LET V1=ABS(Site_spec_t(S,S1,5))
4575                  LET V2=Observation(S,5)+Observation(S1,5)-2
4580                  LET V3=ABS(Site_spec_t(S,S1,8))
4585                  LET V4=Observation(S,8)+Observation(S1,8)-2
4590                  IF (V4>0) AND (Level=90) THEN PRINT USING 4620;S," vs",S1,V1,T
90(V2),V2,V3,T90(V4),V4
4595                  IF (V4<=0) AND (Level=90) THEN PRINT USING 4625;S," vs",S1,V1,
T90(V2),V2
4600                  IF (V4>0) AND (Level=95) THEN PRINT USING 4620;S," vs",S1,V1,T
95(V2),V2,V3,T95(V4),V4
4605                  IF (V4<=0) AND (Level=95) THEN PRINT USING 4625;S," vs",S1,V1,
T95(V2),V2
4610                  IF (V4>0) AND (Level=99) THEN PRINT USING 4620;S," vs",S1,V1,T
99(V2),V2,V3,T99(V4),V4
4615                  IF (V4<=0) AND (Level=99) THEN PRINT USING 4625;S," vs",S1,V1,
T99(V2),V2
4620                  IMAGE 11X,2D,K,2D,7X,2D.3D,2X,2D.3D,2X,4D,5X,2D.3D,2X,2D.3D,2X
,4D
4625                  IMAGE 11X,2D,K,2D,7X,2D.3D,2X,2D.3D,2X,4D,6X,"----",4X,"----",
4X,"--"
4630             NEXT S1
4635        NEXT S
4640        PRINT LIN(1)
4645   NEXT I
4650   PRINT USING "19X,K";"** NOTE:  '----' INDICATES MISSING DATA **"
4655   PRINT LIN(2)
4660   REM
4665   REM
4670   REM
4675   REM
4680   REM     THIS SECTION PRINTS OUT THE SUMMARY STATISTICS AND THE ANALYSIS
4685   REM     OF VARIANCE FOR THE LINEAR REGRESSION MODEL.
4690   REM
4695   REM
```

(con.)

```
4700  REM
4705  REM
4710  PRINT USING 3670
4715  PRINT USING "K,25X,K,26X,K";"*","SECONDARY DATA MANIPULATION","*"
4720  PRINT USING "K,18X,K,18X,K";"*","LINEAR AND LOGARITHMIC REGRESSION ANALYSE
S","*"
4725  PRINT USING 3670
4730  PRINT LIN(2)
4735  PRINT USING 4740;"LINEAR REGRESSION MODEL: Y = A+BX"
4740  IMAGE 21("-"),X,K,X,24("-")
4745  PRINT LIN(1)
4750  PRINT USING 4755;"SUMMARY STATISTICS","ANALYSIS OF VARIANCE"
4755  IMAGE 8("-"),X,K,X,8("-"),8X,7("-"),X,K,X,7("-")
4760  PRINT LIN(1)
4765  PRINT USING "2X,K,7X,K,9X,K,9X,K,12X,K,4X,K,3X,K,3X,K";"N","B","Sb","A","S
OURCE","DF","MEAN SQUARE","F-VALUE"
4770  PRINT USING 4775
4775  IMAGE X,3("-"),3X,7("-"),3X,8("-"),3X,8("-"),8X,8("-"),2X,3("-"),2X,12("-"
),2X,7("-")
4780  PRINT USING 4785;Linear_n,Linear_b,Lin_error_b,Linear_a,"REGRESS.",Lin_df_
regress,Lin_mean_sq_reg,Lin_f_value
4785  IMAGE X,3D,3X,2D.4D,3X,3D.4D,3X,3D.4D,8X,K,2X,3D,2X,7D.4D,2X,4D.2D
4790  PRINT USING "44X,K,2X,3D,2X,7D.4D";"RESIDUAL",Lin_df_resid,Lin_mean_sq_res
4795  PRINT USING "2X,K,7X,K,7X,K,6X,K,10X,K,5X,3D";"R","RSQ","Syx","COVAR","TOT
AL",Lin_df_total
4800  PRINT USING 4805
4805  IMAGE 6("-"),3X,6("-"),3X,7("-"),3X,8("-")
4810  PRINT USING "1D.4D,3X,1D.4D,3X,2D.4D,3X,5D.2D,8X,K,X,3D.4D";Linear_r,Linea
r_r_sq,Lin_error_est,Lin_covar,"FURNIVAL'S INDEX =",Lin_furnival_i
4815  PRINT LIN(3)
4820  REM
4825  REM
4830  REM
4835  REM
4840  REM    THIS SECTION PRINTS OUT THE SUMMARY STATISTICS AND THE ANALYSIS
4845  REM    OF VARIANCE FOR THE LOGARITHMIC REGRESSION MODEL.
4850  REM
4855  REM
4860  REM
4865  REM
4870  PRINT USING 4875;"LOGARITHMIC REGRESSION MODEL:  LNY = A+BLNX"
4875  IMAGE 17("-"),X,K,X,18("-")
4880  PRINT LIN(1)
4885  PRINT USING 4755;"SUMMARY STATISTICS","ANALYSIS OF VARIANCE"
4890  PRINT LIN(1)
4895  PRINT USING "2X,K,7X,K,9X,K,9X,K,12X,K,4X,K,3X,K,3X,K";"N","B","Sb","A","S
OURCE","DF","MEAN SQUARE","F-VALUE"
4900  PRINT USING 4775
4905  PRINT USING 4785;Logarithmic_n,Logarithmic_b,Log_error_b,Logarithmic_a,"RE
GRESS.",Log_df_regress,Log_mean_sq_reg,Log_f_value
4910  PRINT USING "44X,K,2X,3D,2X,7D.4D";"RESIDUAL",Log_df_resid,Log_mean_sq_res
4915  PRINT USING "2X,K,7X,K,7X,K,6X,K,10X,K,5X,3D";"R","RSQ","Syx","COVAR","TOT
AL",Log_df_total
4920  PRINT USING 4805
4925  PRINT USING "1D.4D,3X,1D.4D,3X,2D.4D,3X,5D.2D,8X,K,X,3D.4D";Logarithmic_r,
Logrithmic_r_sq,Log_error_est,Log_covar,"FURNIVAL'S INDEX =",Log_furnival_i
4930  PRINT
4935  PRINT USING 3670
4940  PRINT LIN(4)
4945  GOTO 5120
4950  REM
4955  REM
4960  REM
```

(con.)

APPENDIX 4 (Con.)

```
4965  REM
4970  REM     THIS SECTION IS A SUBROUTINE THAT ALLOWS THE OPERATOR TO SET UP
4975  REM     THE 9872B GRAPHICS PLOTTER FOR PLOTTING THE SECONDARY DATA AND
4980  REM     REGRESSION LINES.
4985  REM
4990  REM
4995  REM
5000  REM
5005 P:       ! PLOTTER SUBROUTINE
5010          PRINTER IS 16
5015          PRINT PAGE,"
                        "
5020          PRINT "      IT IS NOW TIME TO SET UP THE PLOTTER.  PLEASE FOLLOW T
HESE STEPS:       "
5025          PRINT "         1. PRESS THE CHART LOAD KEY ON THE PLOTTER.
                 "
5030          PRINT "         2. PUT THE PAPER ON THE PLOTTER WITH THE LOWER LEFT
 HAND CORNER      "
5035          PRINT "                 OF THE PAPER SNUG IN THE LOWER LEFT HAND CO
RNER OF THE       "
5040          PRINT "                 PLOTTER.  SMOOTH OUT ANY WRINKLES IN THE PA
PER.              "
5045          PRINT "         3. PRESS THE CHART HOLD KEY ON THE PLOTTER.
                 "
5050          PRINT "         4. PRESS THE P1 KEY ON THE PLOTTER.
                 "
5055          PRINT "         5. LOCATE THE PEN AT THE DESIRED LOWER LEFT HAND CO
RNER USING        "
5060          PRINT "                 THE DIRECTIONAL ARROW KEYS, THE PEN DOWN KE
Y, AND THE        "
5065          PRINT "                 PEN UP KEY.
                 "
5070          PRINT "         6. PRESS THE ENTER KEY ON THE PLOTTER.
                 "
5075          PRINT "         7. LOCATE THE PEN AT THE DESIRED UPPER RIGHT HAND C
ORNER USING       "
5080          PRINT "                 THE DIRECTIONAL ARROW KEYS, THE PEN DOWN KE
Y, AND THE        "
5085          PRINT "                 PEN UP KEY.
5090          PRINT "         8. PRESS THE ENTER KEY ON THE PLOTTER.
                 "
5095          PRINT "         9. WAIT NOW WHILE THE GRAPHS ARE PLOTTED.
                 "
5100          PRINT "
                 "
5105          PLOTTER IS 7,5,"9872A"
5110          LIMIT
5115          RETURN
5120  REM
5125  REM
5130  REM
5135  REM
5140  REM     THIS SECTION ALLOWS THE OPERATOR TO CHOOSE THE TYPE OF GRAPH
5145  REM     TO BE PLOTTED.
5150  REM
5155  REM
5160  REM
5165  REM
5170  PRINTER IS 16
5175  PRINT PAGE
5180  PRINT "
           "
```

(con.)

```
5185  PRINT "       YOU HAVE A CHOICE OF THE TYPE OF GRAPH YOU WOULD LIKE DRAWN
:           "
5190  PRINT "                 1. AN ARITHMETIC PLOT
            "
5195  PRINT "                 2. A LOGARITHMIC PLOT
            "
5200  PRINT "                 3. NO PLOTS
            "
5205  PRINT "
            "
5210  INPUT "PLEASE ENTER THE NUMBER OF THE TYPE OF PLOT (1 OR 2 OR 3).",Plottyp
e
5215  IF (Plottype<1) OR (Plottype>3) THEN 5170
5220  IF Plottype=3 THEN 6270
5225  REM
5230  REM
5235  REM
5240  REM
5245  REM    THIS SECTION ALLOWS THE OPERATOR TO CHOOSE THE DEVICE ON WHICH
5250  REM    THE GRAPHS ARE TO BE PLOTTED ( THE CRT OR THE 9872B PLOTTER ).
5255  REM
5260  REM
5265  REM
5270  REM
5275  PRINT PAGE
5280  PRINT "
            "
5285  PRINT "     YOU WILL BE ASKED TO ENTER THE NUMBER OF THE DEVICE THAT YOU
WANT        "
5290  PRINT "     THE GRAPHS PLOTTED ON.  PLEASE ENTER A 1 IF YOU WANT THE GRAP
HS          "
5295  PRINT "     PLOTTED ON THE CRT OR A 2 IF YOU WANT THE GRAPHS PLOTTED ON T
HE          "
5300  PRINT "     9872B GRAPHICS PLOTTER.  PRESS THE CONT KEY AFTER YOU ENTER T
HE          "
5305  PRINT "     DEVICE NUMBER.
            "
5310  PRINT "
            "
5315  INPUT "PLEASE ENTER THE PLOTTER DEVICE NUMBER (1 OR 2).",Device
5320  IF Device=1 THEN 5380
5325  IF Device=2 THEN GOSUB P
5330  GOTO 5435
5335  REM
5340  REM
5345  REM
5350  REM
5355  REM    THIS SECTION SETS UP THE GRAPH.
5360  REM
5365  REM
5370  REM
5375  REM
5380  PLOTTER IS 13,"GRAPHICS"
5385  GRAPHICS
5390  REM
5395  REM
5400  REM
5405  REM
5410  REM    THIS SECTION DETERMINES THE X-SCALE.
5415  REM
5420  REM
5425  REM
5430  REM
```

(con.)

```
5435  LET Xmin=0
5440  LET Maximum_x=0
5445  FOR J=Sc(Ns) TO No
5450      IF D(X,J)<Maximum_x THEN 5460
5455      LET Maximum_x=D(X,J)
5460  NEXT J
5465  IF (Maximum_x>0) AND (Maximum_x<=25) THEN Xmax=25
5470  IF (Maximum_x>25) AND (Maximum_x<=50) THEN Xmax=50
5475  IF (Maximum_x>50) AND (Maximum_x<=100) THEN Xmax=100
5480  IF (Maximum_x>100) AND (Maximum_x<=250) THEN Xmax=250
5485  IF (Maximum_x>250) AND (Maximum_x<=500) THEN Xmax=500
5490  LET Xtic=Xmax/10
5495  REM
5500  REM
5505  REM
5510  REM
5515  REM     THIS SECTION DETERMINES THE Y-SCALE.
5520  REM
5525  REM
5530  REM
5535  REM
5540  LET Ymin=0
5545  LET Maximum_y=0
5550  FOR J=Sc(Ns) TO No
5555      IF D(Y,J)<Maximum_y THEN 5565
5560      LET Maximum_y=D(Y,J)
5565  NEXT J
5570  IF (Maximum_y>0) AND (Maximum_y<=25) THEN Ymax=25
5575  IF (Maximum_y>25) AND (Maximum_y<=50) THEN Ymax=50
5580  IF (Maximum_y>50) AND (Maximum_y<=100) THEN Ymax=100
5585  IF (Maximum_y>100) AND (Maximum_y<=250) THEN Ymax=250
5590  IF (Maximum_y>250) AND (Maximum_y<=500) THEN Ymax=500
5595  IF (Maximum_y>500) AND (Maximum_y<=1000) THEN Ymax=1000
5600  LET Ytic=Ymax/10
5605  IF Device=1 THEN SCALE -1.5*Xtic,10.5*Xtic,-1.5*Ytic,11.5*Ytic
5610  IF Device=2 THEN SCALE -1.5*Xtic,10.5*Xtic,-1.5*Ytic,11.5*Ytic
5615  CLIP Xmin,Xmax,Ymin,Ymax
5620  AXES 10*Xtic,10*Ytic,Xmin,Ymin
5625  UNCLIP
5630  REM
5635  REM
5640  REM
5645  REM
5650  REM     THIS SECTION DRAWS AND LABELS THE X AND Y AXES.
5655  REM
5660  REM
5665  REM
5670  REM
5675  PEN 1
5680  FOR Z=0 TO 10
5685      MOVE Z*Xtic,0
5690      DRAW Z*Xtic,-.1*Ytic
5695  NEXT Z
5700  FOR Z=0 TO 10
5705      MOVE 0,Z*Ytic
5710      DRAW -.1*Xtic,Z*Ytic
5715  NEXT Z
5720  IF Device=1 THEN CSIZE 2.5,.5
5725  IF Device=2 THEN CSIZE 2,.5
5730  LDIR 0
5735  LORG 4
5740  FOR Z=0 TO 10
5745      MOVE Z*Xtic,-.5*Ytic
```

(con.)

```
5750        IF Xmax=25 THEN LABEL USING "2D.D";Z*Xtic
5755        IF Xmax=50 THEN LABEL USING "2D";Z*Xtic
5760        IF (Xmax=100) OR (Xmax=250) OR (Xmax=500) THEN LABEL USING "3D";Z*Xtic
5765    NEXT Z
5770    LORG 2
5775    FOR Z=0 TO 10
5780        MOVE -.5*Xtic,Z*Ytic
5785        IF Ymax=25 THEN LABEL USING "2D.D";Z*Ytic
5790        IF Ymax=50 THEN LABEL USING "2D";Z*Ytic
5795        IF (Ymax=100) OR (Ymax=250) OR (Ymax=500) THEN LABEL USING "3D";Z*Ytic
5800        IF Ymax=1000 THEN LABEL USING "4D";Z*Ytic
5805    NEXT Z
5810    IF Device=1 THEN CSIZE 3,.5
5815    IF Device=2 THEN CSIZE 2.5,.5
5820    LORG 4
5825    MOVE .5*Xmax,-1.4*Ytic
5830    LABEL USING "K";"METER READING"
5835    LDIR 90
5840    LORG 6
5845    MOVE -1.4*Xtic,.5*Ymax
5850    LABEL USING "K";"GREEN (CLIP) WEIGHT (GM)"
5855    REM
5860    REM
5865    REM
5870    REM
5875    REM     THIS SECTION WRITES THE TITLE AND THE DESCRIPTIVE IN-
5880    REM     FORMATION FOR THE PLOT ON THE TOP OF THE PLOT.
5885    REM
5890    REM
5895    REM
5900    REM
5905    PEN 1
5910    IF Device=1 THEN CSIZE 3.5,.5
5915    IF Device=2 THEN CSIZE 3,.5
5920    LDIR 0
5925    LORG 6
5930    MOVE .5*Xmax,11*Ytic
5935    LABEL USING "K";T$
5940    IF Plottype=1 THEN LABEL USING "K,M2D.2D,K,2D.2D,K";"Yhat = ",Linear_a," +
",Linear_b,"*X"
5945    IF Plottype=2 THEN LABEL USING "K,M2D.2D,K,2D.2D,K";"LnYhat = ",Logarithmi
c_a," + ",Logarithmic_b,"*LnX"
5950    REM
5955    REM
5960    REM
5965    REM
5970    REM     THIS SECTION PLOTS THE POINTS.
5975    REM
5980    REM
5985    REM
5990    REM
5995    IF Device=1 THEN CSIZE 2.5,.5
6000    IF Device=2 THEN CSIZE 2,.5
6005    LORG 5
6010    FOR J=Sc(Ns) TO No
6015        MOVE D(X,J),D(Y,J)
6020        LABEL USING "K";"+"
6025    NEXT J
6030    PENUP
6035    REM
6040    REM
6045    REM
6050    REM
6055    REM     THIS SECTION PLOTS THE LINEAR REGRESSION LINE.
```

(con.)

```
 REM
5 REM
0 REM
5 REM
0 MOVE Xmin,Ymin
5 IF Plottype=2 THEN 6130
90 IF Xmax<=100 THEN Step=.1
95 IF Xmax>100 THEN Step=1
00 FOR J=0 TO Xmax STEP Step
05     Yhat=Linear_a+Linear_b*J
10     IF Yhat>Ymax THEN 6125
115    DRAW J,Yhat
120 NEXT J
125 GOTO 6215
130 REM
135 REM
140 REM
6145 REM
6150 REM    THIS SECTION PLOTS THE LOGARITHMIC REGRESSION LINE.
6155 REM
6160 REM
6165 REM
6170 REM
6175 IF Xmax<=100 THEN Step=.1
6180 IF Xmax>100 THEN Step=1
6185 FOR J=.0000000001 TO Xmax STEP Step
6190     LET Lg_var_yhat_plt=(Log_error_est*(1/Logarithmic_n+(LOG(J)-Log_mean(N
s,X))^2/Log_sum_of_sqs(Ns,X))^.5)^2
6195     LET Yhat=EXP(Logarithmic_a+Logarithmic_b*LOG(J)+Lg_var_yhat_plt/2)
6200     IF Yhat>Ymax THEN 6215
6205     DRAW J,Yhat
6210 NEXT J
6215 PEN 0
6220 IF Device=1 THEN DUMP GRAPHICS
6225 IF Device=1 THEN GCLEAR
6230 IF Device=1 THEN PRINTER IS 0
6235 IF Device=1 THEN PRINT LIN(4)
6240 PRINTER IS 16
6245 PRINT PAGE
6250 LINPUT "DO YOU WANT A DIFFERENT TYPE OF PLOT ? (Y OR N)",A$
6255 IF A$="Y" THEN 5170
6260 IF A$="N" THEN 6270
6265 GOTO 6245
6270 REM
6275 REM
6280 REM
6285 REM
6290 REM    THIS SECTION CALCULATES THE STANDING PHYTOMASS ESTIMATES
6295 REM    FOR ALL SITES IN BOTH ENGLISH AND METRIC UNITS FOR BOTH
6300 REM    THE LINEAR AND LOGARITHMIC REGRESSION MODELS.
6305 REM
6310 REM
6315 REM
6320 REM
6325 FOR S=1 TO Ns-1
6330     LET Ln_cross_plt_wt(S)=Linear_a+Linear_b*Mean(S,X)
6335     LET Ln_eng_plt_wt(S)=Ln_cross_plt_wt(S)*.03527
6340     LET Ln_met_plt_wt(S)=Ln_cross_plt_wt(S)/.929368
6345     LET Eng_ln_err_est=Lin_error_est*.03527
6350     LET Lin_var_yhat(S)=Eng_ln_err_est^2*(1/Linear_n+(Mean(S,X)-Mean(Ns,X)
)^2/Sum_of_squares(Ns,X))+(Mean_square(Ns,X)-Eng_ln_err_est^2)/Observation(S,X)
6355     LET Lin_err_yhat(S)=Lin_var_yhat(S)^.5
```

(con.)

```
6360      IF Level=90 THEN LET Lin_lim_yhat(S)=Lin_err_yhat(S)*T90(Observation(S
,X)-1)
6365      IF Level=95 THEN LET Lin_lim_yhat(S)=Lin_err_yhat(S)*T95(Observation(S
,X)-1)
6370      IF Level=99 THEN LET Lin_lim_yhat(S)=Lin_err_yhat(S)*T99(Observation(S
,X)-1)
6375      LET Lin_lim_pct(S)=(Mean(S,X)+Lin_lim_yhat(S)-(Mean(S,X)-Lin_lim_yhat(
S)))/Mean(S,X)*100
6380      LET Lin_eng_phytom(S)=Ln_cross_plt_wt(S)*48
6385      LET Lin_met_phytom(S)=Lin_eng_phytom(S)*1.1208
6390      LET A=Log_error_est^2*(1/Logarithmic_n+(Log_mean(S,X)-Log_mean(Ns,X))^
2/Log_sum_of_sqs(Ns,X))
6395      LET B=(Log_mean_square(Ns,X)-Log_error_est^2)/Log_observation(S,X)
6400      LET C=Logarithmic_a+Logarithmic_b*Log_mean(S,X)
6405      LET Lg_av_var_yhat(S)=A+B
6410      LET Log_av_err_yhat(S)=Lg_av_var_yhat(S)^.5
6415      LET Lg_cross_plt_wt(S)=EXP(Logarithmic_a+Logarithmic_b*Log_mean(S,X)+A
/2)
6420      LET Lg_eng_plt_wt(S)=Lg_cross_plt_wt(S)*.03527
6425      LET Lg_met_plt_wt(S)=Lg_cross_plt_wt(S)/.929368
6430      IF Level=90 THEN LET Log_lim_yhat(S)=Log_av_err_yhat(S)*T90(Log_observ
ation(S,X)-1)
6435      IF Level=95 THEN LET Log_lim_yhat(S)=Log_av_err_yhat(S)*T95(Log_observ
ation(S,X)-1)
6440      IF Level=99 THEN LET Log_lim_yhat(S)=Log_av_err_yhat(S)*T99(Log_observ
ation(S,X)-1)
6445      LET Lowlimlg_yhat(S)=Log_mean(S,X)-Log_lim_yhat(S)
6450      LET Uplimlg_yhat(S)=Log_mean(S,X)+Log_lim_yhat(S)
6455      LET Trlowlimlgyhat(S)=EXP(Lowlimlg_yhat(S)+Log_av_err_yhat(S)/2)
6460      LET Truplimlgyhat(S)=EXP(Uplimlg_yhat(S)+Log_av_err_yhat(S)/2)
6465      LET Log_lim_pct(S)=(Truplimlgyhat(S)-Trlowlimlgyhat(S))/Lg_cross_plt_w
t(S)*100
6470      LET Trenlwlimlgyhat(S)=Trlowlimlgyhat(S)*.03527
6475      LET Trenuplimlgyhat(S)=Truplimlgyhat(S)*.03527
6480      LET Log_eng_phytom(S)=Lg_cross_plt_wt(S)*48
6485      LET Log_met_phytom(S)=Log_eng_phytom(S)*1.1208
6490   NEXT S
6495   REM
6500   REM
6505   REM
6510   REM
6515   REM     THIS SECTION CALCULATES THE STANDING PHYTOMASS DIFFERENTIALS
6520   REM     FOR ALL SITES IN BOTH ENGLISH AND METRIC UNITS FOR BOTH THE
6525   REM     LINEAR AND LOGARITHMIC REGRESSION MODELS.
6530   REM
6535   REM
6540   REM
6545   REM
6550   FOR S=1 TO Ns-1
6555      FOR S1=1 TO Ns-1
6560         LET Dif_lin_eng_phy(S,S1)=Lin_eng_phytom(S)-Lin_eng_phytom(S1)
5565         LET Dif_lin_met_phy(S,S1)=Lin_met_phytom(S)-Lin_met_phytom(S1)
;570         LET Dif_lin_phy_pct(S,S1)=Dif_lin_eng_phy(S,S1)/Lin_eng_phytom(S)*
 00
 575         LET Mx_dif_leng_phy(S,S1)=Lin_eng_phytom(S)+Lin_lim_yhat(S)*48-(Li
_eng_phytom(S1)-Lin_lim_yhat(S1)*48)
;80          LET Mx_dif_lnmt_phy(S,S1)=Lin_met_phytom(S)+Lin_lim_yhat(S)*57.696
'Lin_met_phytom(S1)-Lin_lim_yhat(S1)*57.696)
 85          LET Mx_dif_leng_pct(S,S1)=Mx_dif_leng_phy(S,S1)/(Lin_eng_phytom(S)
in_lim_yhat(S))*100
 90          LET Mn_dif_leng_phy(S,S1)=Lin_eng_phytom(S)-Lin_lim_yhat(S)*48-(Li
ng_phytom(S1)+Lin_lim_yhat(S1)*48)
```

(con.)

```
6595          LET Mn_dif_lnmt_phy(S,S1)=Lin_met_phytom(S)-Lin_lim_yhat(S)*57.696
-(Lin_met_phytom(S1)+Lin_lim_yhat(S1)*57.696)
6600          LET Mn_dif_leng_pct(S,S1)=Mn_dif_leng_phy(S,S1)/(Lin_eng_phytom(S)
-Lin_lim_yhat(S))*100
6605          LET Dif_log_eng_phy(S,S1)=Log_eng_phytom(S)-Log_eng_phytom(S1)
6610          LET Dif_log_met_phy(S,S1)=Log_met_phytom(S)-Log_met_phytom(S1)
6615          LET Dif_log_phy_pct(S,S1)=Dif_log_eng_phy(S,S1)/Log_eng_phytom(S)*
100
6620          LET Mx_dif_long_phy(S,S1)=Log_eng_phytom(S)+Log_lim_yhat(S)*48-(Lo
g_eng_phytom(S1)-Log_lim_yhat(S1)*48)
6625          LET Mx_dif_lgmt_phy(S,S1)=Log_met_phytom(S)+Log_lim_yhat(S)*57.696
-(Log_met_phytom(S1)-Log_lim_yhat(S1)*57.696)
6630          LET Mx_dif_long_pct(S,S1)=Mx_dif_long_phy(S,S1)/(Log_eng_phytom(S)
+Log_lim_yhat(S))*100
6635          LET Mn_dif_long_phy(S,S1)=Log_eng_phytom(S)-Log_lim_yhat(S)*48-(Lo
g_eng_phytom(S1)+Log_lim_yhat(S1)*48)
6640          LET Mn_dif_lgmt_phy(S,S1)=Log_met_phytom(S)-Log_lim_yhat(S)*57.696
-(Log_met_phytom(S1)+Log_lim_yhat(S1)*57.696)
6645          LET Mn_dif_long_pct(S,S1)=Mn_dif_long_phy(S,S1)/(Log_eng_phytom(S)
-Log_lim_yhat(S))*100
6650       NEXT S1
6655    NEXT S
6660    REM
6665    REM
6670    REM
6675    REM
6680    REM     THIS SECTION PRINTS OUT THE STANDING PHYTOMASS ESTIMATES
6685    REM     AND DIFFERENTIALS BY SITE FOR THE LINEAR REGRESSION MODEL.
6690    REM
6695    REM
6700    REM
6705    REM
6710    PRINTER IS 0
6715    PRINT USING 3670
6720    PRINT USING "K,20X,K,21X,K";"*","STANDING HERBAGE PHYTOMASS ESTIMATION","*
"
6725    PRINT USING "K,24X,K,24X,K";"*","YIELD AND DIFFERENTIAL BY SITE","*"
6730    PRINT USING 3670
6735    PRINT LIN(2)
6740    PRINT USING 6745;"LINEAR REGRESSION MODEL"
6745    IMAGE 27("-"),X,K,X,28("-")
6750    PRINT LIN(1)
6755    PRINT USING "30X,K";"ESTIMATED PHYTOMASS"
6760    PRINT USING 6765
6765    IMAGE 30X,19("-")
6770    PRINT
6775    PRINT USING "14X,K,34X,K";"PER SAMPLE PLOT","TOTAL YIELD"
6780    PRINT USING 6785;Level,"%  CONF INT"
6785    IMAGE 10X,23("-"),5X,2D,K,5X,24("-")
6790    PRINT USING "1X,K,6X,K,4X,K,5X,K,7X,K,8X,K";"SITE","OZ/2FTSQ","GM/0.19MSQ"
,"(AS % OF EST)","LB/AC","KG/HA"
6795    PRINT USING 6800
6800    IMAGE 1X,4("-"),5X,10("-"),3X,10("-"),5X,13("-"),5X,10("-"),3X,10("-")
6805    FOR S=1 TO Ns-1
6810       PRINT USING 6815;S,Ln_eng_plt_wt(S),Ln_met_plt_wt(S),Lin_lim_pct(S),Li
n_eng_phytom(S),Lin_met_phytom(S)
6815       IMAGE 2X,2D,8X,3D.2D,7X,3D.2D,11X,3D.2D,9X,5D.2D,5X,5D.2D
6820    NEXT S
6825    PRINT LIN(2)
6830    PRINT USING "30X,K";"YIELD DIFFERENTIALS"
6835    PRINT USING 6765
6840    PRINT
6845    PRINT USING "21X,K,17X,K,16X,K";"MEAN","MAXIMUM","MINIMUM"
```

(con.)

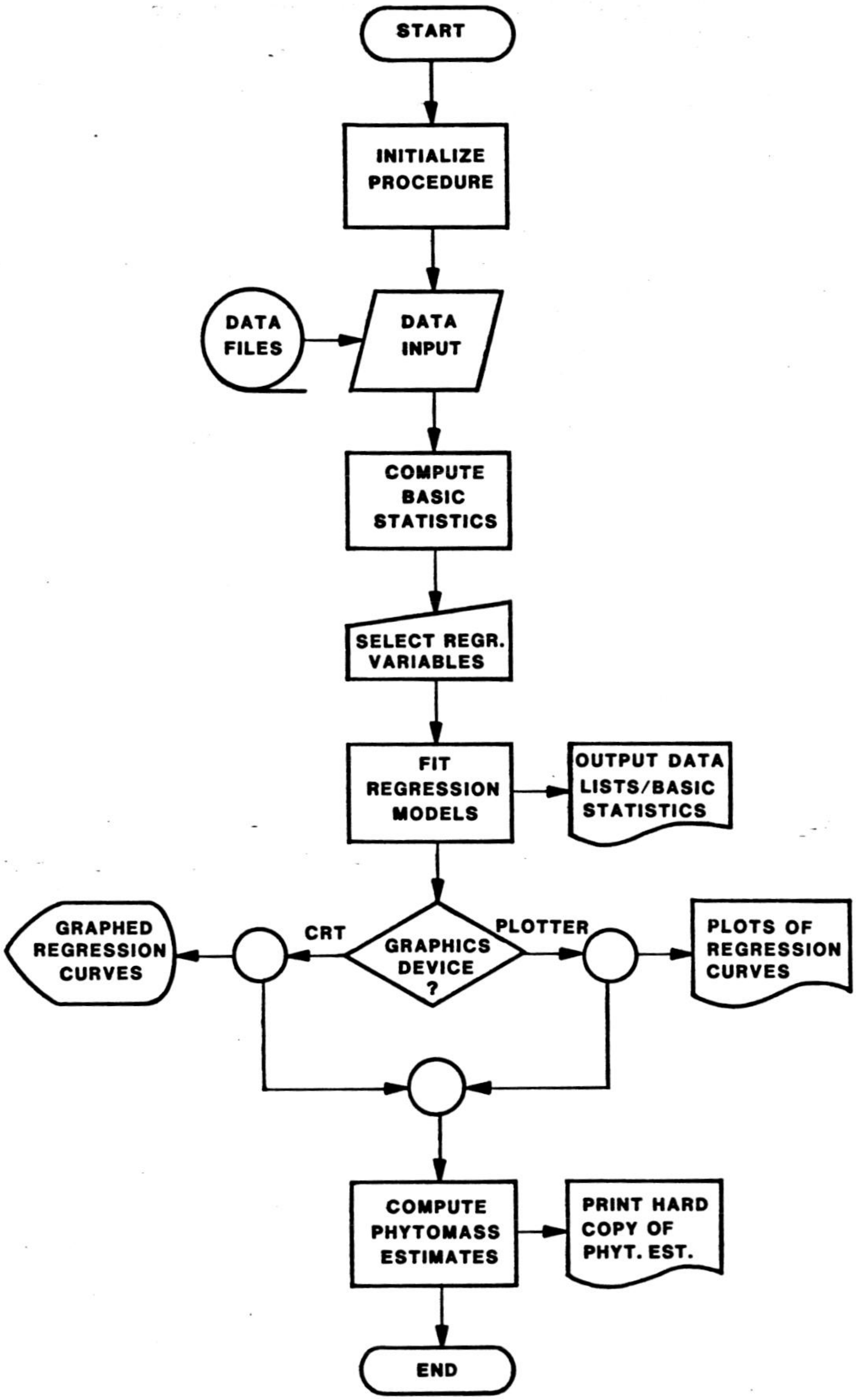
```
6850  PRINT USING 6855
6855  IMAGE 12X,21("-"),2X,21("-"),2X,21("-")
6860  PRINT USING "2X,K,6X,K,4X,K,4X,K,4X,K,4X,K,4X,K,4X,K,4X,K,4X,K";"SITES","L
B/AC","KG/HA","%","LB/AC","KG/HA","%","LB/AC","KG/HA","%"
6865  PRINT USING 6870
6870  IMAGE 1X,7("-"),4X,7("-"),2X,7("-"),2X,3("-"),2X,7("-"),2X,7("-"),2X,3("-"
),2X,7("-"),2X,7("-"),2X,3("-")
6875  FOR S=1 TO Ns-1
6880       FOR S1=1 TO Ns-1
6885            LET D1=D2=D3=M1=M2=M3=M4=M5=M6=0
6890            IF S=S1 THEN 6955
6895            IF Dif_lin_eng_phy(S,S1)<0 THEN 6955
6900            LET D1=Dif_lin_eng_phy(S,S1)
6905            LET D2=Dif_lin_met_phy(S,S1)
6910            LET D3=Dif_lin_phy_pct(S,S1)
6915            LET M1=Mx_dif_leng_phy(S,S1)
6920            LET M2=Mx_dif_lnmt_phy(S,S1)
6925            LET M3=Mx_dif_leng_pct(S,S1)
6930            LET M4=Mn_dif_leng_phy(S,S1)
6935            LET M5=Mn_dif_lnmt_phy(S,S1)
6940            LET M6=Mn_dif_leng_pct(S,S1)
6945            PRINT USING 6950;S," -",S1,D1,D2,D3,M1,M2,M3,M4,M5,M6
6950            IMAGE 1X,2D,K,2D,5X,7D,2X,7D,2X,3D,2X,7D,2X,7D,2X,3D,2X,M6D,2X,M6D
,2X,3D
6955       NEXT S1
6960  NEXT S
6965  PRINT LIN(1)
6970  PRINT USING "15X,K";"NOTE:  A NEGATIVE SIGN INDICATES THAT THE SITE WITH"
6975  PRINT USING "15X,K";"       THE LESSER PHYTOMASS ESTIMATE HAS AN UPPER "
6980  PRINT USING "15X,K";"       LIMIT LARGER THAN THE ESTIMATED YIELD OF THE"
6985  PRINT USING "15X,K";"       SITE TO WHICH IT WAS COMPARED."
6990  PRINT LIN(2)
6995  REM
7000  REM
7005  REM
7010  REM
7015  REM     THIS SECTION PRINTS OUT THE STANDING PHYTOMASS ESTIMATES AND
7020  REM     DIFFERENTIALS BY SITE FOR THE LOGARITHMIC REGRESSION MODEL.
7025  REM
7030  REM
7035  REM
7040  REM
7045  PRINT USING 7050;"LOGARITHMIC REGRESSION MODEL"
7050  IMAGE 25("-"),X,K,X,25("-")
7055  PRINT LIN(1)
7060  PRINT USING "30X,K";"ESTIMATED PHYTOMASS"
7065  PRINT USING 6765
7070  PRINT
7075  PRINT USING "14X,K,34X,K";"PER SAMPLE PLOT","TOTAL YIELD"
7080  PRINT USING 6785;Level,"%  CONF INT"
7085  PRINT USING "1X,K,6X,K,4X,K,5X,K,7X,K,8X,K";"SITE","OZ/2FTSQ","GM/0.19MSQ"
,"(AS % OF EST)","LB/AC","KG/HA"
7090  PRINT USING 6800
7095  FOR S=1 TO Ns-1
7100       PRINT USING 6815;S,Lg_eng_plt_wt(S),Lg_met_plt_wt(S),Log_lim_pct(S),Lo
g_eng_phytom(S),Log_met_phytom(S)
7105  NEXT S
7110  PRINT LIN(2)
7115  PRINT USING "30X,K";"YIELD DIFFERENTIALS"
7120  PRINT USING 6765
7125  PRINT
7130  PRINT USING "21X,K,17X,K,16X,K";"MEAN","MAXIMUM","MINIMUM"
7135  PRINT USING 6855
```

(con.)

APPENDIX 4 (Con.)

```
7140  PRINT USING "2X,K,6X,K,4X,K,4X,K,4X,K,4X,K,4X,K,4X,K,4X,K,4X,K";"SITES","L
B/AC","KG/HA","%","LB/AC","KG/HA","%","LB/AC","KG/HA","%"
7145  PRINT USING 6870
7150  FOR S=1 TO Ns-1
7155      FOR S1=1 TO Ns-1
7160          LET D1=D2=D3=M1=M2=M3=M4=M5=M6=0
7165          IF S=S1 THEN 7225
7170          IF Dif_log_eng_phy(S,S1)<0 THEN 7225
7175          LET D1=Dif_log_eng_phy(S,S1)
7180          LET D2=Dif_log_met_phy(S,S1)
7185          LET D3=Dif_log_phy_pct(S,S1)
7190          LET M1=Mx_dif_long_phy(S,S1)
7195          LET M2=Mx_dif_lgmt_phy(S,S1)
7200          LET M3=Mx_dif_long_pct(S,S1)
7205          LET M4=Mn_dif_long_phy(S,S1)
7210          LET M5=Mn_dif_lgmt_phy(S,S1)
7215          LET M6=Mn_dif_long_pct(S,S1)
7220          PRINT USING 6950;S," -",S1,D1,D2,D3,M1,M2,M3,M4,M5,M6
7225      NEXT S1
7230  NEXT S
7235  PRINT LIN(1)
7240  PRINT USING "15X,K";"NOTE:  A NEGATIVE SIGN INDICATES THAT THE SITE WITH"
7245  PRINT USING "15X,K";"       THE LESSER PHYTOMASS ESTIMATE HAS AN UPPER "
7250  PRINT USING "15X,K";"       LIMIT LARGER THAN THE ESTIMATED YIELD OF THE"
7255  PRINT USING "15X,K";"       SITE TO WHICH IT WAS COMPARED."
7260  PRINT LIN(2)
7265  PRINT USING 3670
7270  PRINT LIN(4)
7275  END
```

APPENDIX 5: FLOW CHART FOR HERB-2



APPENDIX 6: REQUIREMENTS, EXAMPLE, AND COMPUTER PROGRAM FOR CALCULATING STREAM SURFACE SHADING FROM TOPOGRAPHIC AND VEGETATIVE FEATURES

Requirements:

1. HP-41C
2. Quad memory module
3. Printer
4. Card reader
5. Math Pac (only if using the entire temperature model) The source code is available on magnetic cards from:

   USDI-USF&WS-WELUT

   Instream Flow and Aquatic Systems Group

   Drake Creekside Bldg. 1

   2627 Redwing Road

   Fort Collins, CO 80526
6. The solar shade model requires 7 magnetic cards and is available at the above address.

HP-41C Shade Input/Output Example:

```
     XEQ "SHADE"

TRACE:Y/N?
N
                         RUN
ANGLES:D/R?
D                        RUN
TIME PER:M/D?
M                        RUN

LAT:D.M=?
                 42.30   RUN
AR:D.M=?
                 30.20   RUN
B:M=?
                  10.0   RUN
aTE:D.M=?
                 25.00   RUN
VCE:M=?
                   6.0   RUN
VHE:M=?
                   9.0   RUN
VOE:M=?
                   1.5   RUN
VDE:D=?
                   0.8   RUN
aTW:D.M=?
                 25.00   RUN
VCW:M=?
                    -0
                     0   RUN
VHW:M=?
VOW:M=?
                     0
                     0   RUN
VDW:D=?
                         RUN

MONTH:NO.=?
                 5.009   RUN
INC:DAY=?
                     2   RUN
```

```
MONTH NO. 5
FROM: DAY=121
THRU: DAY=151

aS = 53.29 D.M.
ST = 0.0911 D
SW = 0.3034 D
Sh = 0.3945 D

MONTH NO. 6
FROM: DAY=152
THRU: DAY=181

aS= 55.37 D.M.
ST = 0.0838 D
SV = 0.2937 D
SH = 0.3774 D

MONTH NO. 7
FROM: DAY=182
THRU: DAY=212

aS = 54.38 D.M.
ST = 0.0872 D
SV = 0.2984 D
SH = 0.3856 D

MONTH NO. 8
FROM: DAY=213
THUR: DAY=243


aS = 50.11 D.M.
ST = 0.1019 D
SV = 0.3161 D
SH = 0.4180 D

MONTH NO. 9
FROM: DAY=244
THRU: DAY=273

aS = 42.36 D.M.
ST = 0.1281 D
SV = 0.3430 D
SH = 0.4711 D
```

HP-41C Source Code Listing for the Solar Shade Model: (Con.)

```
01♦LBL "SHADE"
02 CLRG
03 CF 29
04 RAD
05 FIX 0
06 "TRACE:Y/N?"
07 AVIEW
08 CF 02
09 AON
10 STOP
11 ASTO X
12 AOFF
13 "Y"
14 ASTO Y
15 X=Y?
16 SF 02
17 "ANGLES:D/R?"
18 AVIEW
19 CF 00
20 AON
21 STOP
22 ASTO X
23 AOFF
24 "R"
25 ASTO Y
26 X=Y?
27 SF 00
28 "TIME PER:M/D?"
29 AVIEW
30 SF 08
31 AON
32 STOP
33 ASTO X
34 AOFF
35 "D"
36 ASTO Y
37 X=Y?
38 CF 08
39 ADV
40 ":R=?"
41 ASTO 00
42 ":D.M=?"
43 ASTO 01
44 ":M=?"
45 ASTO 02
46 "LAT"
47 FS? 00
48 ARCL 00
49 FC? 00
50 ARCL 01
51 PROMPT
52 FS? 00
53 GTO 00
54 HR
55 D-R
56♦LBL 00
57 STO 12
58 SIN
59 STO 33
60 RCL 12
61 COS
62 STO 34
63 "AR"
64 FS? 00
65 ARCL 00
66 FC? 00
67 ARCL 01
68 PROMPT
69 FS? 00
70 GTO 00
71 HR
72 D-R
73♦LBL 00
74 STO 13
75 "B"
76 ARCL 02
77 PROMPT
78 STO 14
79 "aTE"
80 FS? 00
81 ARCL 00
82 FC? 00
83 ARCL 01
84 PROMPT
85 FS? 00
86 GTO 00
87 HR
88 D-R
89♦LBL 00
90 STO 15
91 TAN
92 STO 42
93 "VCE"
94 ARCL 02
95 PROMPT
96 STO 16
97 "VHE"
98 ARCL 02
99 PROMPT
100 STO 17
101 "VOE"
102 ARCL 02
103 PROMPT
104 STO 18
105 "VDE:D=?"
106 PROMPT
107 STO 19
108 "aTW"
109 FS? 00
110 ARCL 00
111 FC? 00
112 ARCL 01
113 PROMPT
114 FS? 00
115 GTO 00
116 HR
117 D-R
118♦LBL 00
119 STO 21
120 TAN
121 STO 43
122 "VCW"
123 ARCL 02
124 PROMPT
125 STO 22
126 "VHW"
127 ARCL 02
128 PROMPT
129 STO 23
130 "VOW"
131 ARCL 02
132 PROMPT
133 STO 24
134 "VDW:D=?"
135 PROMPT
136 STO 25
137♦LBL 99
138 ADV
139 ADV
140 FC? 08
141 GTO 00
142 1.031
143 STO 00
144 32.059
145 STO 01
146 60.090
147 STO 02
148 91.120
149 STO 03
150 121.151
```

(con.)

HP-41C Source Code Listing for the Solar Shade Model: (Con.)

```
STO 04
152.181
STO 05
182.212
STO 06
213.243
STO 07
244.273
STO 08
274.304
STO 09
305.334
STO 10
335.365
STO 11
"MONTH:NO.=?"
PROMPT
STO 29
.011
STO 30
"INC:DAY=?"
PROMPT
1 E5
/
♦LBL 01
ST+ IND 30
ISG 30
GTO 01
GTO 03
♦LBL 00
12
"TIME PER.:NO.=?"
PROMPT
X>Y?
X<>Y
1 E3
/
1
+
STO 29
STO 30
♦LBL 02
ADV
FIX 0
RCL 30
INT
"TIME PER. NO. "
ARCL X
AVIEW
"DAYS"
ARCL X
"├:JUL.=?"
1
-
PROMPT
STO IND Y
ISG 30
GTO 02
♦LBL 03
ADV
ADV
FIX 0
0
STO 26
STO 27
STO 28
STO 56
RCL 29
INT
FS? 08
"MONTH NO. "
FC? 08
"TIME PER. NO. "
ARCL X
AVIEW
1
-
RCL IND X
STO 30
♦LBL 04
SF 01
CF 09
1
ST+ 56
RCL 30
INT
FIX 0
"DAY= "
ARCL X
FC? 02
CF 21
ADV
AVIEW
SF 21
FIX 6
XEQ D
XEQ E
XEQ F
XEQ G
STO 55
CHS
STO 54
RCL 53
RCL 37
*
RCL 53
SIN
RCL 38
*
+
2
*
STO 40
♦LBL 00
RCL 15
X≠0?
GTO 05
RCL 21
X=0?
GTO 06
♦LBL 05
CF 03
RCL 39
RCL 13
ABS
X<=Y?
SF 03
FC? 03
XEQ A
FS? 03
XEQ B
FS? 09
GTO 14
XEQ C
CF 04
RCL 50
X<0?
SF 04
XEQ H
FS? 01
STO 54
FC? 01
STO 55
FS?C 01
GTO 05
♦LBL 06
1
RCL 55
RCL 54
-
```

(con.)

HP-41C Source Code Listing for the Solar Shade Model: (Con.)

```
301 RCL 37
302 *
303 RCL 55
304 SIN
305 RCL 54
306 SIN
307 -
308 RCL 38
309 *
310 +
311 RCL 40
312 /
313 -
314 ST+ 27
315 FC? 02
316 GTO 00
317 ADV
318 "ST= "
319 ARCL X
320 AVIEW
321•LBL 00
322 SF 01
323 SF 04
324 SF 09
325 SF 10
326 .016
327 STO 31
328 0
329 STO 20
330 RCL 44
331 STO 46
332 RCL 55
333 RCL 54
334 -
335 16
336 /
337 STO 41
338 X=0?
339 GTO 08
340 0
341 STO 46
342•LBL 07
343 FC?C 10
344 SF 10
345 16
346 RCL 31
347 INT
348 X=Y?
349 SF 09
350 RCL 41
351 *
352 RCL 54
353 +
354 STO 48
355 X>0?
356 CF 04
357 COS
358 RCL 38
359 *
360 RCL 37
361 +
362 ASIN
363 1 E-9
364 X<=Y?
365 X<>Y
366 STO 49
367 COS
368 STO 52
369 RCL 49
370 ST+ 46
371 FS? 10
372 ST+ 46
373 SIN
374 STO 51
375 RCL 33
376 *
377 RCL 35
378 -
379 RCL 34
380 /
381 RCL 52
382 /
383 ACOS
384 FS? 04
385 CHS
386 STO 50
387 RCL 13
388 X<=Y?
389 CF 01
390 -
391 SIN
392 ABS
393 RCL 52
394 *
395 RCL 51
396 /
397 FS? 01
398 RCL 17
399 FC? 01
400 RCL 23
401 *
402 FS? 01
403 RCL 16
404 FC? 01
405 RCL 22
406 2
407 /
408 FS? 01
409 RCL 18
410 FC? 01
411 RCL 24
412 -
413 +
414 RCL 14
415 X>Y?
416 X<>Y
417 0
418 X<=Y?
419 X<>Y
420 RCL 51
421 *
422 FS? 01
423 RCL 19
424 FC? 01
425 RCL 25
426 *
427 ST+ 20
428 FS? 10
429 ST+ 20
430 FC?C 09
431 GTO 00
432 2
433 /
434 ST- 20
435 RCL 49
436 2
437 /
438 ST- 46
439•LBL 00
440 ISG 31
441 GTO 07
442 1.5
443 ST/ 41
444 RCL 20
445 RCL 41
446 *
447 RCL 14
448 RCL 40
449 *
450 /
```

(con.)

HP-41C Source Code Listing for the Solar Shade Model: (Con.)

```
ST+ 28
STO 47
◆LBL 08
FC? 02
GTO 00
"SV= "
ARCL X
AVIEW
◆LBL 00
RCL 44
RCL 46
X=Y?
GTO 00
RCL 41
*
RCL 55
RCL 54
-
/
STO 46
-
RCL 47
*
RCL 46
+
◆LBL 00
ST+ 26
FC? 02
GTO 00
"aL= "
ARCL X
AVIEW
ADV
◆LBL 00
ISG 30
GTO 04
RCL 56
ST/ 20
ST/ 26
ST/ 27
ST/ 28
RCL 29
1
-
RCL IND X
FIX 0
"FROM: DAY= "
ARCL X
AVIEW
STO Y
FRC
1000
*
X=0?
RCL Y
"THRU: DAY= "
ARCL X
AVIEW
ADV
FIX 2
RCL 26
R-D
HMS
"aS = "
ARCL X
"⊢ D.M"
AVIEW
FIX 4
RCL 27
"ST = "
ARCL X
"⊢ D"
AVIEW
RCL 28
"SV = "
ARCL X
"⊢ D"
AVIEW
+
"SH = "
ARCL X
"⊢ D"
AVIEW
◆LBL 14
ISG 29
GTO 03
ADV
BEEP
GTO 99
◆LBL D
172
X<>Y
-
PI
*
182.5
/
COS
.40928
*
STO 32
FC? 02
GTO 00
"DECL= "
ARCL X
AVIEW
◆LBL 00
SIN
STO 35
RCL 33
*
STO 37
RCL 32
COS
STO 36
RCL 34
*
STO 38
RTN
◆LBL E
RCL 37
RCL 38
+
ASIN
STO 44
FC? 02
RTN
"aSX= "
ARCL X
AVIEW
RTN
◆LBL F
0
STO 50
CF 05
FS? 02
SF 05
FS? 05
CF 02
XEQ b
STO 45
FS? 05
SF 02
FC? 02
RTN
"aT0= "
ARCL X
AVIEW
RTN
◆LBL G
```

(con.)

HP-41C Source Code Listing for the Solar Shade Model: (Con.)

```
1
RCL 35
RCL 34
/
CHS
X>Y?
X<>Y
-1
X<=Y?
X<>Y
ACOS
STO 39
FC? 02
GTO 00
"AZ0= "
ARCL X
AVIEW
◆LBL 00
RCL 37
RCL 38
/
CHS
ACOS
STO 53
FC? 02
RTN
"HRS0= "
ARCL X
AVIEW
RTN
◆LBL A
RCL 44
RCL 45
X<=Y?
GTO 00
0
STO 46
STO 47
RTN
◆LBL 00
FC? 01
GTO 00
RCL 39
CHS
STO 46
0
STO 47
RTN
◆LBL 00
0
STO 46
RCL 39
STO 47
RTN
◆LBL B
FC? 01
GTO 09
CF 09
RCL 44
RCL 45
X<=Y?
GTO 00
RCL 39
PI
RCL 13
X>0?
-
X<=0?
+
ABS
X>Y?
GTO 00
SF 09
"DOUBLE SUNSHINE"
"├ PERIOD"
AVIEW
"EXECUTION STOPP"
"├ED THIS"
AVIEW
"TIME PERIOD"
AVIEW
RTN
◆LBL 00
RCL 39
CHS
STO 46
RCL 13
STO 47
X<=0?
RTN
◆LBL 00
RCL 44
RCL 45
X>Y?
GTO 00
0
STO 47
RTN
◆LBL 00
0
STO 46
RTN
◆LBL 09
RCL 39
STO 47
RCL 13
STO 46
X>0?
RTN
◆LBL 00
RCL 44
RCL 45
X>Y?
GTO 00
0
STO 46
RTN
◆LBL 00
0
STO 47
RTN
◆LBL C
FS? 02
ADV
RCL 46
RCL 47
+
2
/
STO 50
CF 07
FS? 02
SF 07
FS? 07
CF 02
XEQ b
STO 49
.020
STO 31
◆LBL 10
XEQ a
XEQ b
CF 05
RCL 49
X>Y?
SF 05
RCL 50
FC? 01
GTO 11
FS? 05
```

(con.)

```
STO 47
FC? 05
STO 46
GTO 12
◆LBL 11
FS? 05
STO 46
FC? 05
STO 47
◆LBL 12
RCL 46
RCL 47
+
2
/
STO 50
-
ABS
1 E-6
X>Y?
GTO 00
ISG 31
GTO 10
◆LBL 00
XEQ b
STO 49
FS? 07
SF 02
FC? 02
RTN
FS? 01
"aLSR= "
FC? 01
"aLSS= "
ARCL 49
AVIEW
FS? 01
"AZSR= "
FC? 01
"AZSS= "
ARCL 50
AVIEW
RTN
◆LBL a
RCL 50
COS
RCL 34
*
STO 41
◆LBL 13
RCL 49
SIN
RCL 33
*
RCL 49
COS
RCL 41
*
-
RCL 35
-
STO 48
RCL 33
RCL 49
COS
*
RCL 41
RCL 49
SIN
*
+
/
ST- 49
ABS
1 E-6
X<=Y?
GTO 13
RCL 48
ABS
X>Y?
GTO 13
RCL 49
FC? 02
RTN
"aLS= "
ARCL X
AVIEW
RTN
◆LBL b
RCL 50
RCL 13
CF 06
X<=Y?
SF 06
-
SIN
ABS
FC? 06
RCL 42
FS? 06
RCL 43
*
ATAN
FC? 02
RTN
"aLT= "
ARCL X
AVIEW
RTN
◆LBL H
RCL 49
SIN
RCL 37
-
RCL 38
/
1
X>Y?
X<>Y
ACOS
FS? 04
CHS
FC? 02
RTN
FS? 01
"HRSR= "
FC? 01
"HRSS= "
ARCL X
AVIEW
RTN
END
```

APPENDIX 7: BIBLIOGRAPHIES, SOURCE MATERIALS, AND REPOSITORIES FOR INFORMATION ON HISTORICAL RIPARIAN CONDITIONS

Partial List of General Bibliographies and Indices

American Historical Association. Guide to historical literature. Rev. ed. Howe, G. F.; [and others], eds. New York: Macmillan; 1961. 997 p.

America: history and life. Santa Barbara, CA: ABC-Clio; 1964. 137 p.

Beers, H. P. Bibliographies in American history: guide to materials for research. Rev. ed. New York: Wilson; 1942. 502 p.

Cassara, E. History of the United States of America: a guide to information sources. Detroit: Gale Research; 1977. 459 p.

Catalogue of the public documents of the United States, 1893-1940. Washington, DC: U.S. Government Printing Office; 1896-1945. 25 vols.

Checklist of United States public documents, 1789-1909. 3d ed. Washington, DC: U.S. Government Printing Office; 1911. 1707 p.

Coulter, E. M.; Gerstenfeld, M. Historical bibliographies: a systematic and annotated guide. Berkeley, CA: University of California; 1935. 41 p.

Crouch, M.; Raum, H., compilers. Directory of state and local history periodicals. Chicago: American Library Association; 1977. 125 p.

Davis, R. C. North American forest history: a guide to archives and manuscripts in the United States and Canada. Forest History Society. Santa Barbara, CA: ABC-Clio; 1977. 376 p.

Directory of historical societies and agencies in the United States and Canada. McDonald, D., compiler and ed. 11th ed. Nashville, TN: American Association for State and Local History; 1978. 474 p.

Fahl, R. J. North American forest and conservation history: a bibliography. Forest History Society. Santa Barbara, CA: ABC-Clio; 1977. 408 p.

Faye, H. Picture sources: an introductory list. New York: Special Libraries Association; 1959. 115 p.

Gerould, W. G., ed. American newspapers, 1821-1936: a union list of files available in the United States and Canada. New York: H. W. Wilson; 1937. 807 p.

Guide to the American Historical Review, 1895-1945. Scott, F. D.; Teigler, E., compilers. Washington, DC: American Historical Association, 1945. 41 p.

Hamer, P. M. A guide to archives and manuscripts in the United States. New Haven, CT: Yale University Press for the National Historical Publications Committee; 1961. 775 p.

Harvard guide to American history. Rev. ed. Freidel, Frank, ed. Cambridge, MA: Belknap Press; 1974. 2 vols.

Historical abstracts, 1450 to present: bibliography of the world's periodical literature. Santa Barbara, CA: ABC-Clio; 1955. 652 p.

Nineteenth century readers' guide to periodical literature, 1890-1899. New York: H. W. Wilson; 1944. 2 vols plus supplement 1900-1922.

Numerical lists and schedule of volume. Washington, DC: U.S. Government Printing Office; 1942 to date.

Monthly catalog of United States government publications, 1895 to present. Washington, DC: U.S. Government Printing Office; 1895. Monthly.

Poole's index to periodical literature, 6 vols. Vol. 1, Boston: Osgood, 1882; vols 2-6, Boston: Houghton, 1888-1908.

Readers' guide to periodical literature. New York: H. W. Wilson; 1905.

Schmeckebier, L. F.; Eastin, R. B. Government publications and their use. 2d rev. ed. Washington, DC: The Brookings Institution; 1969. 510 p.

Sheehy, E. P. A guide to reference books. 9th ed. Chicago: American Library Association; 1976. 1033 p.

Shumway, G. L. Oral history in the United States: a directory. New York: Oral History Association; 1971. 120 p.

U.S. Bureau of the Budget. Statistical services of the United States government. Rev. ed. Washington, DC: U.S. Government Printing Office; 1968. 156 p.

U.S. Bureau of the Census. Historical statistics of the United States, colonial times to 1970. Bicentennial Edition. Washington, DC: U.S. Government Printing Office; 1975. 2 vols.

U.S. Library of Congress. The national union catalog of manuscript collections, 1959/61. Hamden, CT: Shoe String; 1962. 1253 p.

Vanderbilt, P. Guide to the special collections of prints and photographs in the Library of Congress. Washington, DC: U.S. Government Printing Office; 1955. 200 p.

Partial List of Pacific Northwest References

Drazon, Joseph G. The Pacific Northwest: an index to people and places in books. Metuchen, NJ: Scarecrow Press; 1979. 164 p.

Haskell, D. C. The United States exploring expedition 1838-1844 and its publications 1844-1874. Washington, DC: U.S. Government Printing Office; 1942. 188 p.

Hitt, J. M. A reference list of public documents, 1854-1918, found in the files of the (Washington) State Library. 1920. 41 p.

Judson, K. B. Subject index to the history of the Pacific Northwest and of Alaska as found in the United States government documents, congressional series, in the American State papers, and in other documents, 1789-1881. Olympia, WA: FM Lamborn, Public Printer; 1913. 341 p.

Moore, R. E.; Purcell, N. H., eds. Pacific Northwest Americana, 1949-1974: a supplement to Charles W. Smith's third edition 1950. 1st ed. Portland, OR: Binford and Mort; 1981. 365 p.

Oliphant, J. O. On the cattle ranges of the Oregon Country. Seattle, WA: University of Washington Press; 1968. 372 p.

Oregon Historical Records Survey. Guide to the manuscript collections of the Oregon Historical Society. Portland, OR; 1940. 133 p.

Oregon Historical Society. A bibliography of Pacific Northwest history. Portland, OR; 1958. 27 p.

Rockwood, E. R. Oregon state documents: a checklist, 1843-1925. Portland, OR: Oregon Historical Society; 1947. 283 p.

Smith, C. W. Pacific Northwest Americana: a checklist of books and pamphlets relating to the history of the Pacific Northwest. 2d ed. New York; 1921. 3d ed. revised and extended by I. Mayhew. Portland, OR: Binford and Mort; 1950. 381 p.

Smith, C. W. Special collections in libraries of the Pacific Northwest. Seattle, WA: University of Washington Press; 1927. 20 p.

Smith, C. W. A union list of manuscripts in libraries of the Pacific Northwest, compiled by Charles W. Smith. Seattle, WA: University of Washington Press; 1931. 57 p.

Wagner, H. R. The plains and the Rockies: a bibliography of original narratives of travel and adventure 1800-1865. Revised and extended by Charles L. Camp. San Francisco, CA; 1937. 71 p.

Winther, O. O. A classified bibliography of the periodical literature of the Trans-Mississippi West. Westport, CT: Greenwood Press; 1972. 71 p.

Partial List of Source Material

- Journals
- Letters
- Diaries
- Unpublished manuscripts
- Mechanic liens
- Court cases
- Newspaper accounts
- Cadastral survey notes
- Personal interviews
- Photograph collections
- County commissioner records
- Booming plats

Partial List of Repositories

- Libraries: university, city, local
- Historical Society museums
- County museums
- Archives: university, State, Federal
- U.S. Army Corps of Engineers
- U.S. Department of the Interior, Bureau of Land Management
- U.S. Fish and Wildlife Service
- U.S. Department of Agriculture, Forest Service
- Courthouses: county, State, Federal

APPENDIX 8: RIPARIAN TYPES OF THE UPPER SALMON/MIDDLE FORK SALMON RIVER DRAINAGES, IDAHO

Abbreviation	Type
	Tree-dominated Types
ABLA/CACA h.t.	*Abies lasiocarpa/Calamagrostis canadensis* h.t.
ABLA/STAM h.t.	*Abies lasiocarpa/Streptopus amplexifolius* h.t.
PIEN/EQAR h.t.	*Picea englemannii/Equisetum arvense* h.t.
PICO/VAOC c.t.	*Pinus contorta/Vaccinium occidentale* c.t.
POTRI	*Populus trichocarpa* (incidental communities)
	Shrub-dominated Types
ALIN-COST c.t.	*Alnus incana-Cornus stolonifera* c.t.
ALSI-MEFE	*Alnus sinuata-Menziesia ferruginea* (incidental communities)
ARCA	*Artemisia cana* (incidental communities)
POFR/DAIN c.t.	*Potentilla fruticosa/Danthonia intermedia* c.t.
SALIX/CARO c.t.	*Salix* spp./*Carex rostrata* c.t.
SACO/CASC c.t.	*Salix commutata/Carex scopulorum* c.t.
SADR/CACA c.t.	*Salix drummondiana/Calamagrostis canadensis* c.t.
SAEX	*Salix exigua* (incidental communities)
SAGE/CACA c.t.	*Salix geyeriana/Calamagrostis canadensis* c.t.
SAMY/POPR c.t.	*Salix myrtillifolia/Poa pratensis* c.t.
SAWO/CAMI c.t.	*Salix wolfii/Carex microptera* c.t.
SAWO/SWPE c.t.	*Salix wolfii/Swertia perennis* c.t.
	Herb-dominated Types
AGSC-bar c.t.	*Agrostis scabra*-streambar c.t.
ASIN-FEID c.t.	*Aster integrifolius-Festuca idahoensis* c.t.
CARO c.t.	*Carex rostrata* c.t.
CASI	*Carex simulata* (incidental communities)
DECE c.t.	*Deschampsia caespitosa* c.t.
ELPA c.t.	*Eleocharis pauciflora* c.t.
JUBA c.t.	*Juncus balticus* c.t.
MIPE	*Mitella pentandra* (incidental communities)
POPR c.t.	*Poa pratensis* c.t.

APPENDIX 9: RIPARIAN COMMUNITY TYPES OF EASTERN IDAHO AND WESTERN WYOMING

Abbreviation	Community type
Tree-dominated Community Types	
PICEA/EQAR c.t.	*Picea/Equisetum arvense* c.t.
PICEA/COST c.t.	*Picea/Cornus stolonifera* c.t.
PICEA/CACA c.t.	*Picea/Calamagrostis canadensis* c.t.
PICEA/GATR c.t.	*Picea/Galium triflorum* c.t.
POAN/COST c.t.	*Populus angustifolia/Cornus stolonifera* c.t.
POAN/POPR c.t.	*Populus angustifolia/Poa pratensis* c.t.
Mixed Shrub-dominated Community Types	
ALIN/RIHU c.t.	*Alnus incana/Ribes hudsonianum* c.t.
COST/HELA c.t.	*Cornus stolonifera/Heracleum lanatum* c.t.
COST/GATR c.t.	*Cornus stolonifera/Galium triflorum* c.t.
RHAL c.t.	*Rhamnus alnifolia* c.t.
POFR/DECE c.t.	*Potentilla fruticosa/Deschampsia caespitosa* c.t.
POFR/FEID c.t.	*Potentilla fruticosa/Festuca idahoensis* c.t.
POFR/POPR c.t.	*Potentilla fruticosa/Poa pratensis* c.t.
ARCA/FEID c.t.	*Artemisia cana/Festuca idahoensis* c.t.
ARCA/POPR c.t.	*Artemisia cana/Poa pratensis* c.t.
***Salix geyeriana*-dominated Community Types**	
SAGE/POPA c.t.	*Salix geyeriana/Poa palustris* c.t.
SAGE/CARO c.t.	*Salix geyeriana/Carex rostrata* c.t.
SAGE/CACA c.t.	*Salix geyeriana/Calamagrostis canadensis* c.t.
SAGE/mesic forb c.t.	*Salix geyeriana*/mesic forb c.t.
SAGE/POPR c.t.	*Salix geyeriana/Poa pratensis* c.t.
***Salix boothii*-dominated Community Types**	
SABO/CARO c.t.	*Salix boothii/Carex rostrata* c.t.
SABO/CANE c.t.	*Salix boothii/Carex nebraskensis* c.t.
SABO/CACA c.t.	*Salix boothii/Calamagrostis canadensis* c.t.
SABO/EQAR c.t.	*Salix boothii/Equisetum arvense* c.t.
SABO/POPA c.t.	*Salix boothii/Poa palustris* c.t.
SABO/SMST c.t.	*Salix boothii/Smilacina stellata* c.t.
SABO/POPR c.t.	*Salix boothii/Poa pratensis* c.t.
***Salix wolfii*-dominated Community Types**	
SAWO/CAAQ c.t.	*Salix wolfii/Carex aquatilis* c.t.
SAWO/CARO c.t.	*Salix wolfii/Carex rostrata* c.t.
SAWO/CACA c.t.	*Salix wolfii/Calamagrostis canadensis* c.t.
SAWO/CANE c.t.	*Salix wolfii/Carex nebraskensis* c.t.
SAWO/DECE c.t.	*Salix wolfii/Deschampsia caespitosa* c.t.
SAWO/POPA c.t.	*Salix wolfii/Poa palustris* c.t.
SAWO/mesic forb c.t.	*Salix wolfii*/mesic forb c.t.
Other *Salix*-dominated Community Types	
SAEX/EQAR c.t.	*Salix exigua/Equisetum arvense* c.t.
SAEX/POPR c.t.	*Salix exigua/Poa pratensis* c.t.
SALU c.t.	*Salix lucida* c.t.
SAPL c.t.	*Salix planifolia* c.t.
SAEA c.t.	*Salix eastwoodii* c.t.

(con.)

APPENDIX 9 (Con.)

Abbreviation	Community type
	Graminoid-dominated Community Types
CAMI c.t.	*Carex microptera* c.t.
CASI c.t.	*Carex simulata* c.t.
CARO c.t.	*Carex rostrata* c.t.
CAAQ c.t.	*Carex aquatilis* c.t.
CANE c.t.	*Carex nebraskensis* c.t.
CAREX c.t.	Miscellaneous *Carex* c.t.'s
DECE c.t.	*Deschampsia caespitosa* c.t.
POPA c.t.	*Poa palustris* c.t.
POPR c.t.	*Poa pratensis* c.t.
	Forb-dominated Community Types
VACA c.t.	*Veratrum californicum* c.t.
MECI c.t.	*Mertensia ciliata* c.t.
MFM c.t.	Mesic forb meadow c.t.
	Wetlands
	No c.t.'s differentiated

APPENDIX 10: POOL QUALITY RATING TABLES

Since the appearance of our earlier stream evaluation methodology manual (Platts and others 1983), some refinements have been made in techniques. The chief of these has been modification of the pool quality rating tables to reflect stream size based on stream order (Langbein and Iseri 1960; Strahler 1957). In situations where stream order is not clearly applicable, such as streams that are predominantly spring-fed, order can be assigned on the basis of size using other streams of known order in the area for reference. This appendix contains three pool quality rating tables for streams of orders 1 and 2, 3 through 5, and 6 or greater, respectively.

Table 41—Rating pool quality in streams of order 1 and 2

	Description	Pool rating
1A	Maximum pool diameter is within 10 percent of the average stream width of the study site . . . . . Go to 2A, 2B	
1B	Maximum pool diameter exceeds the average stream width of the study site by 10 percent or more . . . . . Go to 3A, 3B, 3C	
1C	Maximum pool diameter is less than the average stream width of the study site by 10 percent or more . . . . . Go to 4A, 4B, 4C	
2A	Maximum pool depth is less than 1 foot . . . . . Go to 5A, 5B	
2B	Maximum pool depth is greater than or equal to 1 foot . . . . . Go to 3A, 3B, 3C	
3A	Maximum pool depth is greater than or equal to 2 feet, regardless of cover conditions, or depth is greater than or equal to 1 foot with abundant fish cover[1]	Rate 5
3B	Maximum pool depth is less than 1 foot with intermediate to abundant cover, or is between 1 and 2 feet and lacks abundant cover	Rate 4
3C	Maximum pool depth is less than 1 foot and fish cover is rated as exposed	Rate 3
4A	Maximum pool depth is greater than or equal to 1 foot with intermediate[2] or better cover . . .	Rate 3
4B	Maximum pool depth is less than 1 foot but fish cover is intermediate or better, or depth is greater than or equal to 1 foot with exposed cover conditions	Rate 2
4C	Maximum pool depth is less than 1 foot and pool cover is rated as exposed[3]	Rate 1
5A	Pool with intermediate to abundant cover	Rate 3
5B	Pool with exposed cover conditions	Rate 2

[1]If cover is abundant, the pool has excellent instream cover and most of the perimeter of the pool has a fish cover.
[2]If cover is intermediate, the pool has moderate instream cover and one-half of the pool perimeter has fish cover.
[3]If cover is exposed, the pool has poor instream cover and less than one-fourth of the pool perimeter has any fish cover.

Table 42—Rating pool quality in streams of order 3 through 5

	Description	Pool rating
1A	Maximum pool diameter is within 10 percent of the average stream width of the study site	Go to 2A, 2B
1B	Maximum pool diameter exceeds the average stream width of the study site by 10 percent or more	Go to 3A, 3B, 3C
1C	Maximum pool diameter is less than the average stream width of the study site by 10 percent or more	Go to 4A, 4B, 4C
2A	Maximum pool depth is less than 2 feet	Go to 5A, 5B
2B	Maximum pool depth is greater than or equal to 2 feet	Go to 3A, 3B, 3C
3A	Maximum pool depth is greater than or equal to 3 feet, regardless of cover conditions, or depth is greater than or equal to 2 feet with abundant fish cover[1]	Rate 5
3B	Maximum pool depth is less than 3 feet with intermediate to abundant cover, or is between 2 and 3 feet and lacks abundant cover	Rate 4
3C	Maximum pool depth is less than 2 feet and fish cover is rated as exposed	Rate 3
4A	Maximum pool depth is greater than or equal to 2 feet with intermediate[2] or better cover	Rate 3
4B	Maximum pool depth is less than 2 feet but fish cover is intermediate or better, or depth is greater than or equal to 2 feet with exposed cover conditions	Rate 2
4C	Maximum pool depth is less than 2 feet and pool cover is rated as exposed[3]	Rate 1
5A	Pool with intermediate to abundant cover	Rate 3
5B	Pool with exposed cover conditions	Rate 2

[1]If cover is abundant, the pool has excellent instream cover and most of the perimeter of the pool has a fish cover.
[2]If cover is intermediate, the pool has moderate instream cover and one-half of the pool perimeter has fish cover.
[3]If cover is exposed, the pool has poor instream cover and less than one-fourth of the pool perimeter has any fish cover.

Table 43—Rating pool quality in streams of order 6 or greater

	Description	Pool rating
1A	Maximum pool diameter is within 10 percent of the average stream width of the study site	Go to 2A, 2B
1B	Maximum pool diameter exceeds the average stream width of the study site by 10 percent or more	Go to 3A, 3B, 3C
1C	Maximum pool diameter is less than the average stream width of the study site by 10 percent or more	Go to 4A, 4B, 4C
2A	Maximum pool depth is less than 4 feet	Go to 5A, 5B
2B	Maximum pool depth is greater than or equal to 4 feet	Go to 3A, 3B, 3C
3A	Maximum pool depth is greater than or equal to 6 feet, regardless of cover conditions, is over 4 feet with abundant fish cover[1]	Rate 5
3B	Maximum pool depth is less than 6 feet with intermediate to abundant cover between 4 and 6 feet and lacks abundant fish cover	Rate 4
3C	Maximum pool depth is less than 4 feet and fish cover is rated as exposed	Rate 3
4A	Maximum pool depth is greater than or equal to 4 feet with intermediate[2] or better cover	Rate 3
4B	Maximum pool depth is less than 4 feet but fish cover is intermediate or better, or depth is greater than or equal to 4 feet with exposed cover conditions	Rate 2
4C	Maximum pool depth is less than 4 feet and pool cover is rated as exposed[3]	Rate 1
5A	Pool with intermediate to abundant cover	Rate 3
5B	Pool with exposed cover conditions	Rate 2

[1]If cover is abundant, the pool has excellent instream cover and most of the perimeter of the pool has a fish cover.
[2]If cover is intermediate, the pool has moderate instream cover and one-half of the pool perimeter has fish cover.
[3]If cover is exposed, the pool has poor instream cover and less than one-fourth of the pool perimeter has any fish cover.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1987—773-039/41,036 REGION NO. 8

Platts, William S.; Armour, Carl; Booth, Gordon D.; Bryant, Mason; Bufford, Judith L.; Cuplin, Paul; Jensen, Sherman; Lienkaemper, George W.; Minshall, G. Wayne; Monsen, Stephen B.; Nelson, Rodger L.; Sedell, James R.; Tuhy, Joel S. Methods for evaluating riparian habitats with applications to management. General Technical Report INT-221. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station; 1987. 177 p.

This report develops a standard way of measuring and evaluating riparian conditions. These methods will be helpful to those persons documenting, monitoring, predicting, or evaluating riparian, stream, or range conditions, and how this relates to their biotic resources, especially those conditions needed to relate to impacts from land uses.

KEYWORDS: methods, range, riparian, aquatic habitat, fish, streams, inventory, macroinvertebrates

PESTICIDE PRECAUTIONARY STATEMENT

This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

CAUTION: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife—if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

INTERMOUNTAIN RESEARCH STATION

The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

The Intermountain Research Station territory includes Montana, Idaho, Utah, Nevada, and western Wyoming. Eighty-five percent of the lands in the Station area, about 231 million acres, are classified as forest or rangeland. They include grasslands, deserts, shrublands, alpine areas, and forests. They provide fiber for forest industries, minerals and fossil fuels for energy and industrial development, water for domestic and industrial consumption, forage for livestock and wildlife, and recreation opportunities for millions of visitors.

Several Station units conduct research in additional western States, or have missions that are national or international in scope.

Station laboratories are located in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Ogden, Utah

Provo, Utah (in cooperation with Brigham Young University)

Reno, Nevada (in cooperation with the University of Nevada)