U.S. Department of the Interior
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Hydrologic Classification and Estimation of Basin and Hydrologic Characteristics of Subbasins in Central Idaho

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By Stephen W. Lipscomb

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1604

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1998

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
CHARLES G. GROAT, Director

For sale by:
U.S. Geological Survey
Information Services
Box 25286
Denver Federal Center
Denver, CO 80225

Library of Congress Cataloging-in-Publications Data

Lipscomb, Stephen W.
Hydrologic classification and estimation of basin and hydrologic characteristics of subbasins in central Idaho / by Stephen W. Lipscomb.
p. cm. -- (U.S. Geological Survey professional paper : 1604)
"Prepared in cooperation with the U.S. Bureau of Indian Affairs."
Includes bibliographical references.
Supt. of Docs. no.: I19.16: 1604
ISBN 0-607-90403-8 (alk. paper)
1. Hydrology--Idaho--Clearwater River Watershed. I. United States. Bureau of Indian Affairs. II. Title. III. Series.
QE75.P9 no. 1604
[GB705.I2]
557.3 s--dc21
[551.48'09796'85] 98-38923
CIP

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Format: American International Standard Code for Information Interchange (ASCII)
Operating system used: DOS
Filenames: Table09 (80 characters wide; 71 K)
Table10 (132 characters wide; 127 K)
Table11 (80 characters wide; 5 K)
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Multiply	By	To obtain
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
inch (in.)	25.4	millimeter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer

Degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) by the equation:

$$°C = 5/9\ (°F - 32)$$

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

Hydrologic Classification and Estimation of Basin and Hydrologic Characteristics of Subbasins in Central Idaho

By Stephen W. Lipscomb

Abstract

Hydrologic data for streams and associated subbasins within the Salmon and Clearwater River Basins were analyzed to support instream flow claims made by the Bureau of Indian Affairs on behalf of the Nez Perce Indian Tribe. These claims are part of the adjudication of the Snake River Basin by the State of Idaho.

Each of the hundreds of streams in the Salmon and Clearwater River Basins has unique hydrologic characteristics that are determined in part by the physiography, topography, geology, land cover, and other features of the stream's contributing watershed. These features, to a large extent, determine the hydrologic response of a particular watershed or subbasin to climatological inputs.

Hydrologic classification of streams into homogeneous, or similar, groups requires pertinent information about each stream and its associated subbasin. Historically, obtaining these data required planimetering areas from topographic, geologic, climatologic, and land-cover maps for each subbasin. This approach was labor intensive and, as a result, generally limited the scope of study to small areas. Sources of data for regional studies often were limited to small-scale maps lacking in detail and accuracy. Recently, many of these tasks have been automated by the use of computer techniques, which have resulted in significant time savings and increased data resolution.

Software developed by the U.S. Geological Survey's Earth Resources Observation System Data Center was used to delineate 1,050 subbasins in the study area. One-degree digital elevation models were used as a data source. The delineated subbasins provided the foundation for developing a geographic information system (GIS) data base with variables, including area, elevation, precipitation, geology, land cover, channel gradient, basin slope, and other attributes that describe the physical characteristics of each subbasin.

A selected group of the variables was used in a two-step statistical classification procedure, which consisted of principal components analysis and cluster analysis. The resulting classification grouped 1,050 subbasins into 34 hydrologically homogeneous classes that were designed to be used as the basis for a data-collection network for quantifying instream flows. A validation of the classification scheme indicated that the procedure was successful in grouping the subbasins.

Estimates of mean annual and mean monthly discharge were required for quantifying the instream flow claims. These estimates were derived from regional regression equations previously developed for the State of Idaho and are provided in this report. Mean annual and mean monthly discharges for a selected group of streamflow-gaging stations within the study area also were calculated.

As the project was nearing completion, the Bureau of Indian Affairs requested that the study area be expanded to include 70 subbasins within the Weiser, Payette, and Snake River Basins. A GIS data base was developed and estimates of mean annual and mean monthly discharges were made for these basins. The data base and estimates of discharge for the Weiser, Payette, and Snake River Basins were derived by using the same methods as were used for the Salmon and Clearwater River Basins.

INTRODUCTION

Background

The State of Idaho has initiated an adjudication of all water rights in the Snake River Basin, including the Salmon and Clearwater River Basins. To protect its interests, the Federal Government is attempting to establish and quantify the State appropriative and Federal reserved water rights held by the United States on its own behalf and as trustee for affected Indian tribes, including the Nez Perce Tribe.

Much of the area included in historical treaties between the Nez Perce Tribe and the United States lies within the Snake River Basin. Although some of the tribal water rights claims for parts of the Snake River Basin have been settled, the claims in the Salmon and Clearwater River Basins have yet to be resolved.

The focus of the tribal claims is the quantification of water rights necessary to maintain or restore productive fish habitat. Hundreds of streams within the Salmon and Clearwater River Basins either are, or historically have been, capable of providing habitat for large populations of resident and anadromous fish species. The Bureau of Indian Affairs (BIA), acting as trustee for the tribe, has made water rights claims designed to protect these fish species by ensuring adequate instream flows.

In 1988, the BIA entered into a cooperative agreement with the U.S. Geological Survey (USGS) to provide hydrologic data and analysis in support of the instream flow studies. This report describes methods used to classify subbasins and make estimates of mean annual and mean monthly discharges for subbasins within the study area. Another study was done concurrently with this study. The objective of the concurrent study was to estimate flow-duration values for subbasins within the study area. Results and methods used are described in a companion report (Kjelstrom, 1998).

Purpose and Scope

The objectives of the study were to (1) identify all subbasins with drainage areas of 10 mi^2 or greater within the Salmon and Clearwater River Basins; (2) classify the identified subbasins into hydrologically homogeneous groups; and (3) provide the BIA with estimates of mean annual and mean monthly discharge for each of the subbasins. Classification of subbasins was required for the design of the data-collection program needed to provide hydrologic inputs for fish habitat models. The estimated streamflow statistics provide boundary conditions for these models.

A data base of basin characteristics was developed for 1,050 subbasins in the Salmon and Clearwater River Basins. The data base included physiographic, climatologic, geologic, and land-cover data, as well as numerous other variables related to, or influencing, the hydrologic characteristics of each subbasin. The subbasins were classified into homogeneous groups by using principal components and cluster analyses. Estimates of mean annual and mean monthly discharges were made for each subbasin.

This report describes methods used to develop the data base of basin characteristics, classify subbasins, and estimate streamflow parameters. The report also includes results of the subbasin classification and streamflow parameter estimates, as well as mean annual and mean monthly discharges for a selected group of sites where streamflow-gaging stations have been operated.

As the study was nearing completion, the BIA requested delineation of additional subbasins within the Weiser, Payette, and Snake River Basins, construction of a hydrologic data base, and estimation of mean annual and mean monthly discharges for these subbasins in a fashion similar to that done for the Salmon and Clearwater River Basins. Results of this work are provided at the end of this report.

DESCRIPTION OF STUDY AREA

The Salmon and Clearwater River Basins (fig. 1) contain large, pristine wilderness areas. Within the two basins are parts of seven national forests, one national historical park, one national recreation area, four wilderness areas, and five designated wild and scenic rivers. The four wilderness areas have a combined area of more than 6,000 mi^2, or about 25 percent of the study area. Access to these areas is restricted to foot or pack animal, and road access to much of the remainder of the Salmon and Clearwater River Basins is limited or nonexistent.

The headwaters of the Salmon River are in the Sawtooth Range of central Idaho. The river is 425 mi long and drains an area of about 14,025 mi^2. Principal

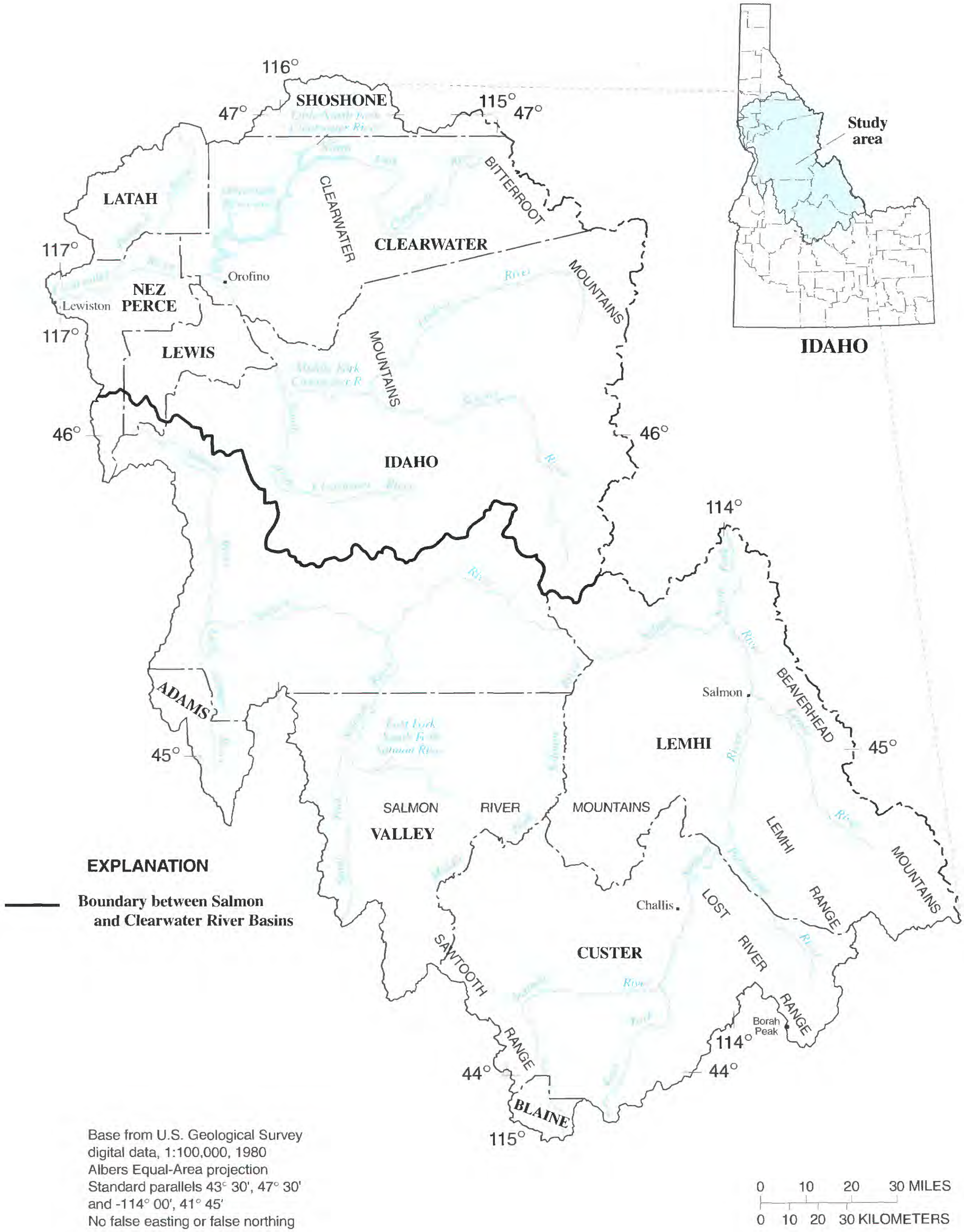

Figure 1. Location of study area, central Idaho.

tributaries are the East Fork Salmon, Pahsimeroi, Lemhi, North Fork Salmon, Middle Fork Salmon, South Fork Salmon, and Little Salmon Rivers. The mean annual discharge of the Salmon River at the USGS streamflow-gaging station nearest the mouth is 11,300 ft^3/s. The drainage area of the basin upstream from this gaging station is 13,550 mi^2 or 97 percent of the entire basin area.

The headwaters of the Clearwater River are in the Bitterroot Mountains near the Idaho-Montana State line; the river drains an area of about 9,440 mi^2. Principal tributaries are the North Fork, South Fork, and Middle Fork Clearwater Rivers and the Lochsa and Selway Rivers, whose confluence forms the Middle Fork Clearwater River. The mean annual discharge of the Clearwater River at the USGS streamflow-gaging station nearest the mouth is 15,300 ft^3/s. The drainage area of the basin upstream from this gaging station is 9,350 mi^2 or 99 percent of the entire basin area.

Physiography and Topography

The Salmon and Clearwater River Basins are part of the Northern Rocky Mountains physiographic province. The principal mountain ranges within the basins are the Clearwater and Bitterroot Mountains to the north, the Salmon River Mountains and Sawtooth Range to the south, and the Beaverhead Mountains to the southeast (fig. 1). The Lemhi and Lost River Ranges to the southeast are not as areally extensive. The Sawtooth Range in the southern Salmon River Basin includes some of the most scenic and rugged alpine peaks in the continental United States.

The study area includes the highest and lowest points in Idaho. Borah Peak (fig. 1), at the headwaters of the Pahsimeroi River, rises 12,662 ft above sea level, whereas Lewiston, at the confluence of the Clearwater and Snake Rivers, is at an elevation of 739 ft. Total relief in the study area is more than 2 mi.

Much of the Salmon River Basin is characterized by channels deeply incised in bedrock and bordered by steep terrain that, at elevations less than 8,000 feet, is heavily forested. The two major exceptions are the Lemhi and Pahsimeroi River Basins in the eastern part of the Salmon River Basin. Both of these basins have broad, alluvial valleys bounded by steep mountains. Mean elevation of the Salmon River Basin is 6,620 ft.

The Clearwater River Basin consists of two fairly distinct topographic regions. The eastern mountainous region is similar in many respects to the Salmon River Basin except that it has areas of lower elevation and less steep terrain. The western region is characterized by gently rolling plateaus that slope westward. Mean elevation of the Clearwater River Basin is 4,320 ft.

Climate

Although located more than 300 mi from the Pacific Ocean, the mountains in central Idaho are strongly influenced by maritime air masses moving eastward from the coast. This weather pattern is predominant during the winter when storms originating in the north Pacific move regularly through the area. Moisture-laden airmasses are uplifted by the orographic influence of various mountain ranges and produce greater amounts of precipitation at higher elevations (Thomas, 1963) (fig. 2).

In the Salmon and Clearwater River Basins, precipitation extremes are common. High-elevation valleys along the Idaho side of the Bitterroot Mountains receive between 60 and 70 in. of precipitation annually, whereas the National Weather Service's (NWS) weather station at Challis on the Salmon River recorded a mean annual precipitation of 7.9 in. during the period from 1917 to 1989.

Mean annual air temperature ranges from about 35°F in the Sawtooth Range of the southern Salmon River Basin to more than 50°F in valleys of the Clearwater and Little Salmon River Basins. Minimum temperatures less than -50°F are common in the mountains and maximum temperatures greater than 105°F are common in the lowlands.

Geology

The study area is underlain by four major rock types—metamorphic and sedimentary rocks, granite, volcanic rocks, and alluvium (fig. 3). The oldest are metamorphic rocks (argillite, quartzite, gneiss, and schist), which are part of the Precambrian Belt Series. Sedimentary rocks (limestone, sandstone, and shale) of Paleozoic age are present in the southeastern part of the study area (King and Beikman, 1974).

The most prominent geologic feature, not only of the study area but also of the entire State, is the Mesozoic-age Idaho batholith. This body of granitic rock, which composes the central mountains, is one of the

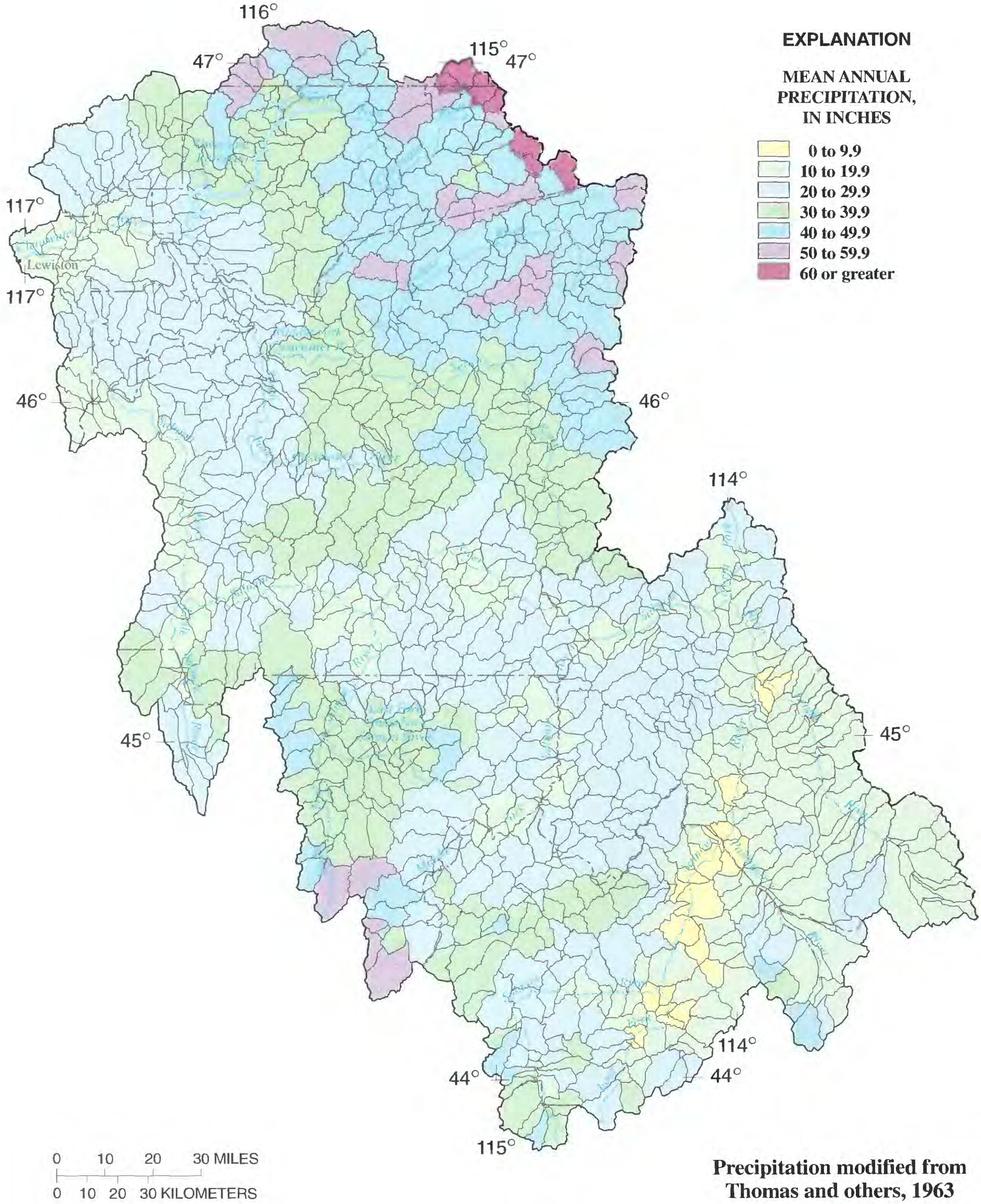

Figure 2. Mean annual precipitation calculated for each subbasin, central Idaho. (Data based on period of record from 1930 to 1957)

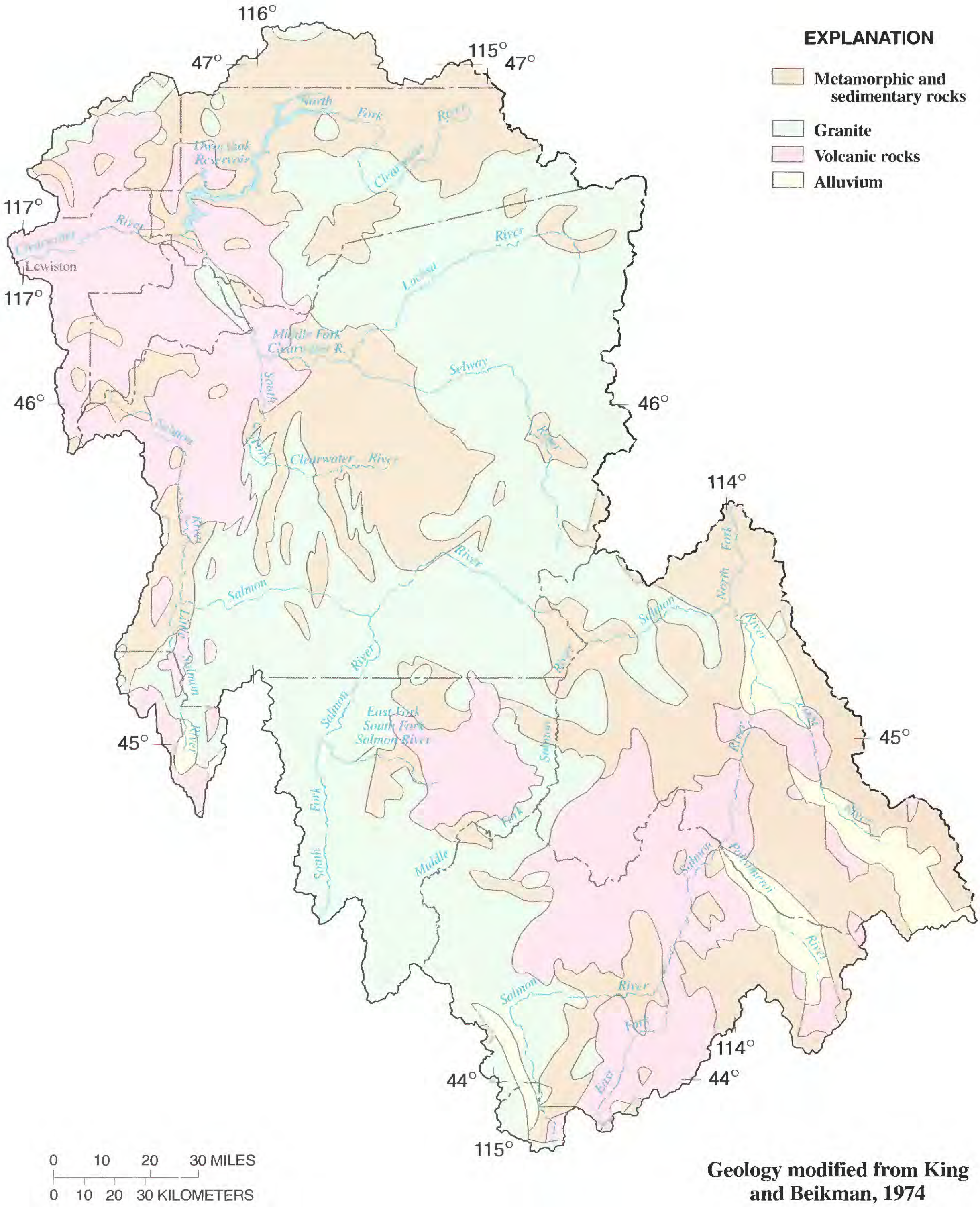

Figure 3. Generalized geology, central Idaho.

largest of its type in the world. The batholith underlies an area nearly 250 mi long and 80 to 100 mi wide.

Two volcanic units of Cenozoic age underlie the study area. Challis Volcanics (rhyolite to andesite) are present east of the Idaho batholith, and basalts of the Columbia River Basalt Group are present west of the batholith. Alluvium of Cenozoic age is present primarily in the intermontane valleys of the Lemhi and Pahsimeroi River Basins.

Land Cover

Forests of pine and fir predominate in the Salmon and Clearwater River Basins, covering 66 and 78 percent of the basins, respectively (fig. 4). In the Salmon and Clearwater River Basins, the only arable lands, where irrigation is practicable, are narrow strips located along the major rivers. An exception is the western part of the Clearwater River Basin where rolling terrain and sufficient summer precipitation permit dryland farming. Broad valleys of the Lemhi and Pahsimeroi Rivers and the upper Salmon River Basin also contain a significant amount of irrigated agricultural acreage. The amount of land used for agricultural purposes in the Salmon and Clearwater River Basins is 3 and 12 percent of the total area, respectively.

Rangeland composes 30 and 10 percent of the Salmon and Clearwater River Basins, respectively. Vegetation types include sagebrush in the dry eastern parts of the Salmon River Basin and various grasses dispersed throughout other parts. The grasses are an important source of food for the State's livestock production. Vegetation in less accessible, high-elevation areas is important because it provides erosion control and wildlife forage. Areas of bare rock, water, and tundra are scattered throughout the study area but are not extensive.

DATA-BASE DEVELOPMENT

Each of the hundreds of streams in the Salmon and Clearwater River Basins has unique hydrologic characteristics that are determined in part by the physiography, topography, geology, land cover, and other features of the stream's contributing watershed. These features, to a large extent, determine the hydrologic response of a particular watershed or subbasin to climatological inputs.

Hydrologic classification of streams into homogeneous, or similar, groups requires pertinent information about each stream and its associated subbasin. Historically, obtaining these data required planimetering areas from topographic, geologic, climatologic, and land-cover maps for each subbasin. This approach was labor intensive and, as a result, generally limited the scope of study to small areas. Sources of data for regional studies often were limited to small-scale maps lacking in detail and accuracy. Recently, many of these tasks have been automated by the use of computer techniques, which have resulted in significant time savings and increased data resolution.

Geographic Information Systems

Data used in hydrologic studies typically fall into two categories, temporal and spatial. Temporal data vary with time, whereas spatial data vary with distance or location. An example of temporal data is a series of stage readings recorded at a regular time interval at a streamflow-gaging station. An example of spatial data is a map showing the location of streamflow-gaging stations in the Salmon and Clearwater River Basins.

By their nature, spatial data lend themselves well to graphical representation in the form of maps. The desired information is coded onto base maps, as illustrated by the mean subbasin elevation map of the Salmon and Clearwater River Basins (fig. 5). From the base map, which includes various boundaries and geographical references such as latitude and longitude, location and orientation can be ascertained. Patterns or colors can be used to show such things as range in elevation or relative percentage of area in a given elevation band.

Spatial analysis has been simplified by the development of specialized computer software. These software systems, commonly referred to as geographic information systems (GIS), are capable of organizing and managing large quantities of spatial data and have utilities for editing, graphical representation, and analysis of the data.

Two basic types of GIS software are those having raster and those having vector processing capabilities. Raster processors analyze digital spatial data that are organized into a grid of cells, such as Landsat images. Vector processors analyze data that are organized by points, lines, and polygons. Examples are the digitized version of a geology map that shows areas (polygons)

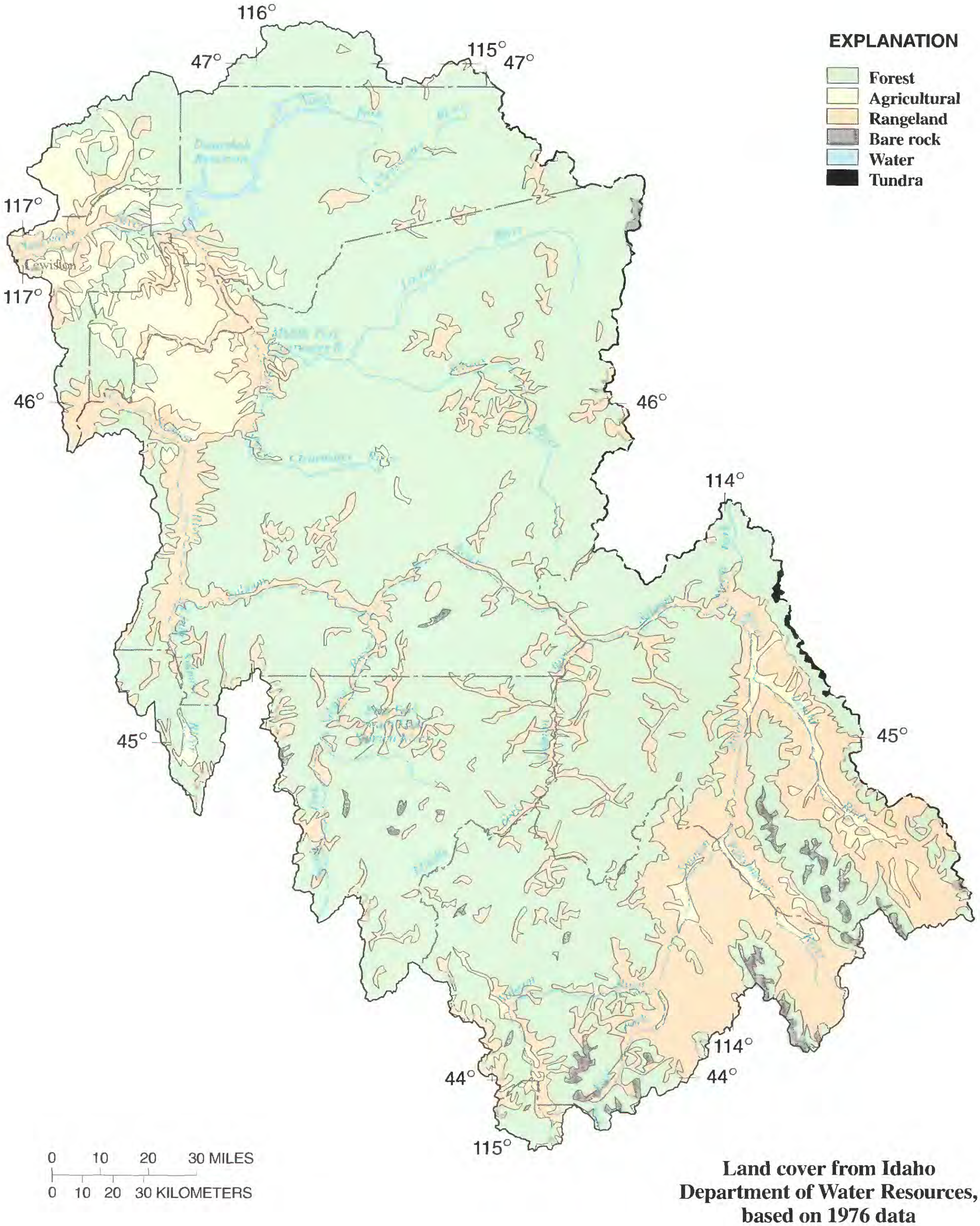

Figure 4. Land cover, central Idaho.

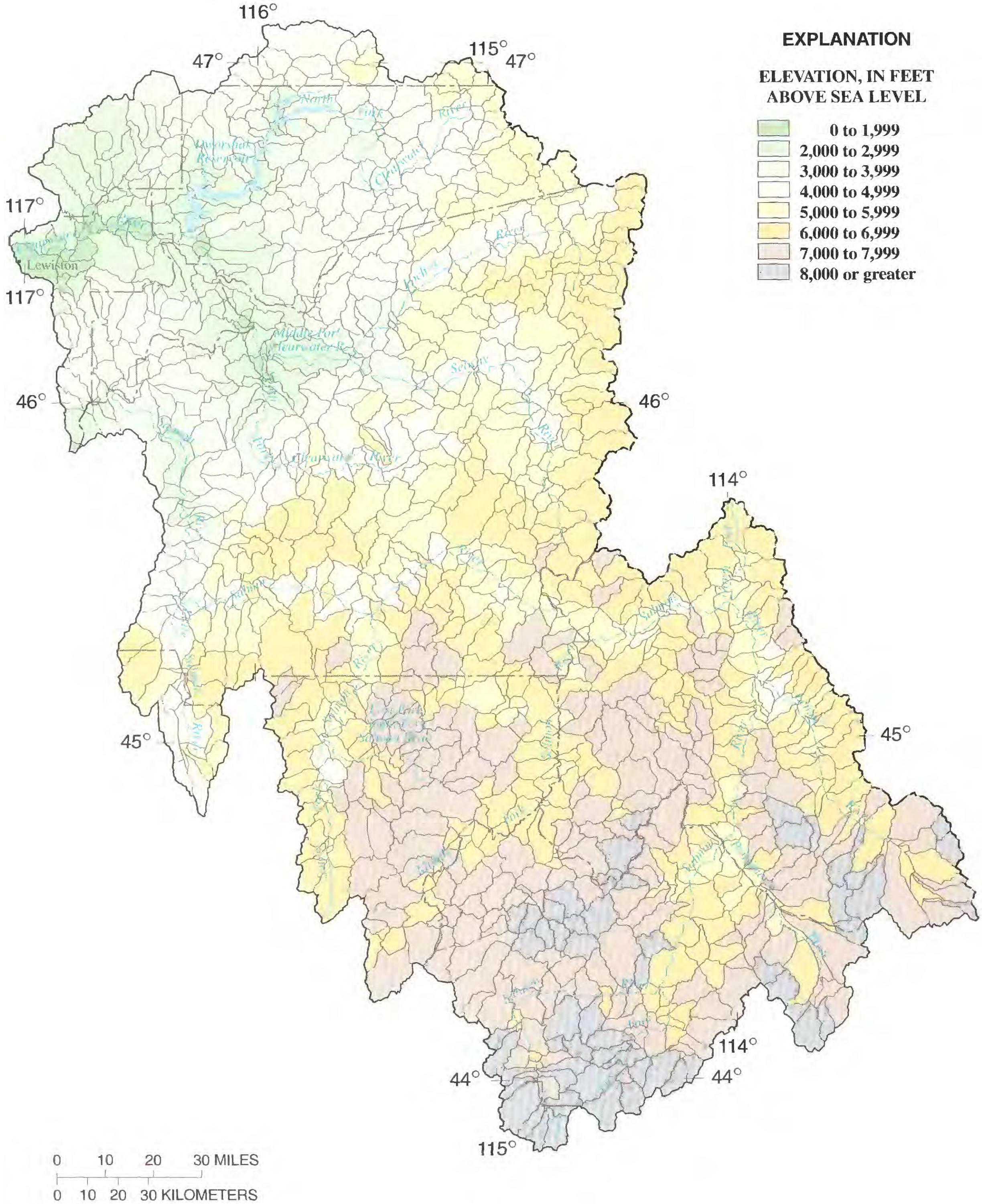

Figure 5. Mean subbasin elevation, central Idaho.

of similar rock type, or a precipitation map that shows lines of equal precipitation.

Because of the regional extent of the Salmon and Clearwater River Basins (23,465 mi^2) and a study objective of determining hydrologic characteristics for streams with drainage areas as small as 10 mi^2, this study was well suited to the use of GIS.

Basin Delineation

The physical characteristics of streams and streamflows are determined to a large extent by the physical characteristics of the contributing drainage basin. Streams in steep, mountainous areas typically have straight, chutelike channels and steep gradients, whereas streams in flat, lowland areas tend to have meandering channels and flatter gradients. Likewise, streams underlain by bedrock are constrained within the bounds of a fixed channel that changes little in position over many years, whereas streams underlain by alluvial materials can migrate across wide flood plains in only a few years. Because of the interrelation between a stream and its drainage basin, data bases constructed for this study include information about both.

A primary objective of this study was to provide hydrologic information for streams in the Salmon and Clearwater River Basins in support of instream flow studies designed by the BIA for the protection of fish habitat. Drainage basins of at least 10 mi^2 in areal extent served as the fundamental unit for subsequent analyses. Delineation of all subbasins as small as 10 mi^2 in an area of more than 23,000 mi^2 was a task well suited to automation and the use of a computer.

Specialized application software was developed by the USGS at the Earth Resources Observation System (EROS) Data Center, Sioux Falls, S.D., to delineate drainage basin boundaries by using digital elevation models (DEM's) as a data source (Jenson and Domingue, 1988). DEM's consist of computerized files of regularly spaced elevation data. Two types of DEM's are available, 7.5 minute and 1 degree. A 7.5-minute DEM covers the same area as a 7.5-minute (1:24,000-scale) topographic map, whereas a 1-degree DEM covers a 1- by 1-degree block equivalent to the area covered by two 1:100,000-scale topographic maps. Elevations in a 7.5-minute DEM correspond to a regularly spaced grid of ground-surface elevations at 30-meter intervals; elevations in a 1-degree DEM are regularly spaced at 3 arc-second intervals.

The software was designed to read raw data from the DEM files, condition the data by filling depressions, create flow direction and flow accumulation data sets, and define drainage basin boundaries, stream networks, and overland flowpaths. Two options are available for the delineation of drainage basin boundaries. The first allows the user to select specific sites upstream from which the basin boundaries are delineated. The second automatically delineates all subbasins within a given area according to a user-specified threshold size.

Subbasins in the Salmon and Clearwater River Basins were delineated using 1-degree DEM's. Fifteen 1-degree DEM's were required to provide complete coverage of the study area. The individual DEM's were mosaicked, or joined, to produce a single data file used in the analysis. Because the data array in a single 1-degree DEM is 1,201 rows by 1,201 columns of elevation values, the mosaicked data file contained nearly 22 million elevations.

The automatic delineation option was used with a specified threshold value equivalent to about 10 mi^2. Results were converted to a vector format polygon coverage for further analysis by using ARC/INFO, a vector-based GIS. A secondary arc (line) coverage of the stream network corresponding to the basins also was generated. The 1,050 subbasin polygons delineated within the Salmon and Clearwater River Basins served as the fundamental units for subsequent hydrologic analysis (pl. 1).

Automated basin delineation programs are particularly well suited for areas with high relief and well-defined basin boundaries as exist over most of the Salmon and Clearwater River Basins. A few subbasins tributary to the main stem of the Clearwater River and subbasins in the upper reaches of the Lemhi and Pahsimeroi River Basins contain areas of relatively low relief. The computer-delineated subbasin boundaries in these areas required additional editing due partly to the resolution of *xyz* coordinates of the 1-degree DEM's. The *xy*, or horizontal, coordinates of the DEM's are spaced 3 arc-seconds apart in both the north-south and east-west directions. Therefore, the spacing of elevation data in the DEM is approximately 55 meters (about 180 ft) at study area latitudes. The *z*, or elevation, coordinate is recorded to the nearest meter with an error range of approximately 30 meters (about 98 ft) at a 90-percent confidence interval. Consequently, where relief is low, the basin delineation algorithms resolve basin boundaries less accurately. In such instances, a straight line is generated through the flat region until

Table 1. Definitions of subbasin attributes derived for the Salmon and Clearwater River Basins, central Idaho, calculated by using a geographic information system

Attribute name	Definition
BASIN.NUM	Unique number for subbasin identification.
HUC	U.S. Geological Survey hydrologic unit code number.
REGION	Region code for mean annual discharge computation, derived by using U.S. Geological Survey regional regression equations.
STNID	U.S. Geological Survey downstream order number for streamflow-gaging station located within subbasin.
ORDER	Strahler (1957) stream order index.
TO	Downstream subbasin linkage.
LAT	Latitude of subbasin centroid.
LONG	Longitude of subbasin centroid.
SQMAREA	Subbasin drainage area, in square miles.
CUMAREA	Cumulative contributing drainage area, in square miles.
EMEAN	Mean subbasin elevation, in meters above sea level.
CUMEMEAN	Mean elevation of contributing drainage area, in meters above sea level.
EMIN	Minimum subbasin elevation, in meters above sea level.
EMAX	Maximum subbasin elevation, in meters above sea level.
PRECIP	Mean annual subbasin precipitation, in inches.
CUMPRECIP	Mean annual precipitation for contributing drainage area, in inches.
GEO1	Percentage of subbasin area consisting of granitic rocks.
GEO2	Percentage of subbasin area consisting of basaltic and other volcanic rocks.
GEO3	Percentage of subbasin area consisting of alluvium.
GEO4	Percentage of subbasin area consisting of metamorphic and sedimentary rocks.
CUMGEO1–4	Percentage of contributing drainage area consisting of each of the four rock types.
STR1	Percentage of subbasin area consisting of agricultural land.
STR2	Percentage of subbasin area consisting of rangeland.
STR3	Percentage of subbasin area consisting of forest land.
STR4	Percentage of subbasin area consisting of riparian land.
STR5	Percentage of subbasin area consisting of bare rock.
STR6	Percentage of subbasin area consisting of water bodies.
STR7	Percentage of subbasin area consisting of tundra.
STR8	Percentage of subbasin area consisting of urban areas.
CUMSTR1–8	Percentage of contributing drainage area consisting of each of the eight land-cover types.
SMEAN	Mean subbasin slope, in percent (average of all grid-cell slopes from DEM).
CHSLOPE	Mean channel slope, in percent.
ASPECT	Percentage of subbasin area within eight 45° ranges of azimuth (NW, N, NE, E, SE, S, SW, W).
NFACE	Combined percentage of subbasin area with north-facing aspect (NW, N, and NE).
SFACE	Combined percentage of subbasin area with south-facing aspect (SW, S, and SE).
CUMNFACE	Percentage of north-facing aspect for contributing drainage area.
SHAPE	Subbasin shape function (ratio of the area to the perimeter squared, A/P^2).
QAFINAL	Estimated mean annual discharge for contributing drainage area, in cubic feet per second.
UNITQA	Unit mean annual discharge (QAFINAL/CUMAREA), in cubic feet per second per square mile.
QJAN–QDEC	Estimated mean monthly discharge, in cubic feet per second, for contributing drainage area.
QPJAN–QPDEC	Estimated mean monthly discharge as a percentage of mean annual discharge for contributing drainage area.

sufficient relief is encountered to define the basin boundary correctly. Extensive areas of low relief can result in erroneous boundary delineation. Only a small percentage of the subbasins were affected by this data limitation and required manual editing. A digital line graph of the Salmon and Clearwater stream network and 1:100,000-scale topographic maps were used to check overall accuracy of the subbasin boundaries and to facilitate basin boundary adjustment where required.

Basin Characteristics

The basin characteristics data base was constructed by assigning physiographic, climatologic, geologic, land cover, and other attributes that influence the hydrologic response of each of the delineated subbasins. Most of the information was derived either from the DEM's or from coverages that contain information related to specific themes such as geology or land-cover type (figs. 3 and 4). The derivation was accomplished by using the GIS intersect function, wherein the coverage containing subbasin polygons was intersected with each of the thematic coverages, or the DEM. The percentage of subbasin areas composed of a specific basin characteristic was calculated. The information subsequently was transferred to the data base associated with the subbasin coverage (pl. 1).

The data base contains many attributes that describe characteristic features of the small local subbasins. These attributes were denoted as "local" attributes. In many cases, counterparts of the local attributes were calculated to describe the same feature for the entire contributing watershed upstream from a specific subbasin. These attributes were denoted as "cumulative" attributes. A computer program was written to automate their derivation by using downstream linkage information resident in the data base. A listing of the attributes and a brief definition of each are given in table 1.

Data Sources

PHYSIOGRAPHY AND TOPOGRAPHY

Much information, in addition to the subbasin boundaries, was calculated from individual grid elevations from the 1-degree DEM's by using the raster processing capabilities of the EROS Data Center. Extracted information included values for minimum, maximum, and mean elevation and slope for each of the subbasins and the percentage of the subbasin's area within specified bands of elevation and slope. Subbasin aspect, in percentage of subbasin area within specified azimuth ranges, also was calculated.

Elevation data are referenced in the horizontal plane by using the geographic (latitude/longitude) coordinate system of the 1972 World Geodetic System datum. Elevations are in meters referenced to sea level (U.S. Geological Survey, 1987). The DEM's were produced by the Defense Mapping Agency and distributed by the USGS after being reformatted. The primary source of elevation data is 1:250,000-scale topographic maps; secondary sources are 1:100,000- and 1:24,000-scale topographic maps.

PRECIPITATION

Mean annual precipitation values for subbasins of the Salmon and Clearwater River Basins were obtained from an isohyetal map of the Snake River Basin (Thomas and others, 1963). This map is a modification of the original produced by the U.S. Weather Bureau and the U.S. Army Corps of Engineers that was based on precipitation records from 1930 to 1957.

An initial attempt to scan a mylar copy of the precipitation map was unsuccessful because of the amount of followup editing required. The lines of equal precipitation were instead digitized and converted to an arc coverage.

GEOLOGY

Geology of the study area (fig. 3) was obtained from a digitized geology map of Idaho that was clipped from a 1:2,500,000-scale geology map of the United States (King and Beikman, 1974). A more detailed geology map would have been desirable but was unavailable in a digital format. Because of the areal extent of this study and the need to reduce the classification variables to a manageable number, the geology map that was used was determined to be adequate.

LAND COVER

A coverage of Idaho land cover was obtained from the Idaho Department of Water Resources. They generated the coverage from 1976 Landsat images of the State. These images, in turn, were classified statistically into eight land-cover categories: forest, agricultural, rangeland, riparian, bare rock, water, tundra, and urban (Mike Sissel, Idaho Department of Water Resources, oral commun., 1988). The Salmon and Clearwater River Basins consist almost entirely of three land-cover categories: forest, agricultural, and rangeland (fig. 4).

OTHER DATA SOURCES

Other attributes were added manually to the data base or were calculated internally on the basis of existing attributes. Examples of manually derived attributes include stream name, stream order, and channel slope. Channel slope was derived for streams associated with each subbasin by EA Engineering, who were under contract with the BIA. The channel slope values were derived by digitizing the stream length between contours on 7.5-minute topographic maps and dividing the length by the change in elevation. Examples of internally calculated attributes include subbasin shape and subbasin area in square miles.

HYDROLOGIC CLASSIFICATION OF SUBBASINS

A primary objective of the study was classification of subbasins into hydrologically homogeneous groups. The classification was designed to serve as the basis for a data-collection program needed to provide input for fish habitat models.

Statistical Methods

The completed basin characteristics data base consisted of 1,050 subbasins along with associated stream names and descriptive variables. Multivariate analysis of a selected group of these variables was used to classify the subbasins into hydrologically homogeneous groups. Selection of variables determined to have the most influence on the hydrologic response of the subbasins was based on previous studies, multivariate regression analysis, and professional judgment. Previous studies used to aid in the selection of variables were those of Strahler (1957), Emmett (1975), Hedman and Osterkamp (1982), Quillian and Harenberg (1982), and Horn (1988). The 14 variables included in the analysis were area (CUMAREA), mean elevation (CUMEMEAN), mean annual precipitation (CUMPRECIP), geology types (CUMGEO1–4), three land-cover types (CUMSTR1–3), mean basin slope (SMEAN), channel slope (CHSLOPE), north-facing aspect (CUMNFACE), and shape (SHAPE).

The statistical classification of subbasins consisted of two primary analytical steps—principal components analysis, followed by cluster analysis. The steps are illustrated by the flowchart in figure 6. A similar procedure has been used to classify sites for land-use planning (Radloff and Betters, 1978; Omi and others, 1979), plant and animal communities (Poole, 1971), and drainage basins (Mather and Doornkamp, 1970).

Principal Components Analysis

Principal components (PC) analysis is a basic form of the more general category of statistical procedures known as factor analysis. PC analysis is used to examine correlations between descriptive variables and to reduce the dimensions of a raw data set by eliminating redundant information. PC analysis was employed to consolidate descriptive information within the 14 (variables)-by-1,050 (subbasins) data matrix into a reduced number of new composite variables or components. The desired result of this reduction was to streamline the subsequent cluster analysis and thus improve subbasin classification.

The derivation of principal components is accomplished by extracting m (mutually orthogonal) eigenvectors and eigenvalues from a data set of m variables. The m eigenvectors define the principal axes of the data matrix; the associated eigenvalues define the magnitude. The eigenvalues are a measure of the variance explained by each of the eigenvectors, or principal axes. Of the m principal axes, the first contains the largest percentage of the total variance in the original data (see table 2), followed by the second, third, and so on. Each original observation is converted to a principal component score by projecting it onto the principal axes. The projected score is calculated according to the appropriate component loadings defined by the eigenvectors (Davis, 1986). A subset of the m principal components is retained with the objective of capturing the maximum information (variance) in the original data with as few components as possible. The component scores for the retained principal components, rather than the original data, are employed in the subsequent cluster analysis.

Because of the sensitivity of PC analysis to a given variable's units of measurement, the data were standardized by computing the components from the

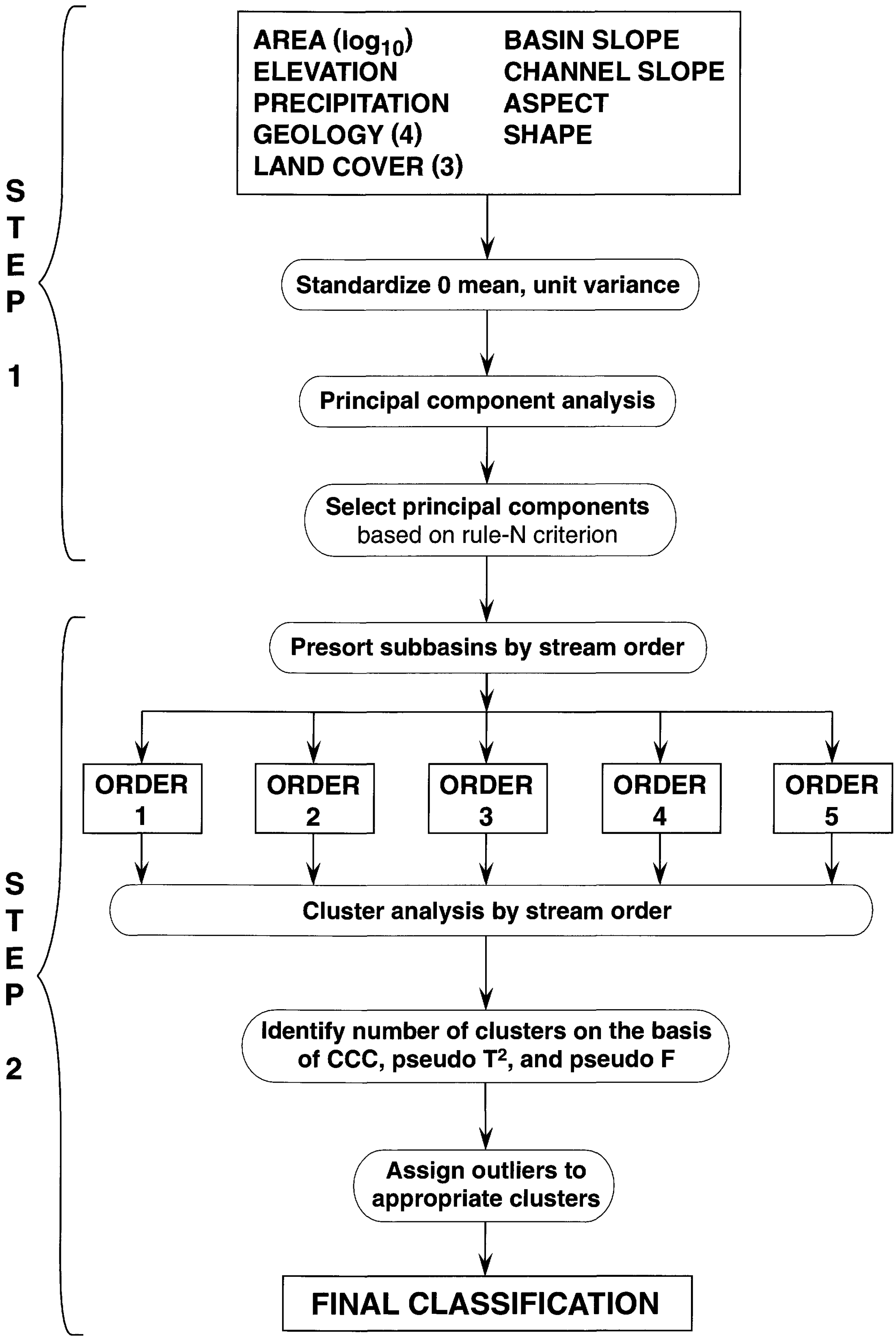

Figure 6. Two-step statistical procedure used to classify subbasins, central Idaho. (CCC, cubic clustering criterion)

correlation matrix of the data. Without this approach, a variable with units measured in centimeters, for example, would have 100 times the influence as would the same variable measured in meters.

Derivation of appropriate principal components from the 14 variables can be approached in several ways. In this study, two approaches were taken and a comparison made of their individual strengths and weaknesses.

The first approach involved performing the PC analysis on all 14 variables and selecting the "most appropriate" number of components to be retained for the subsequent cluster analysis. The second approach involved grouping variables into categories of "like characteristics," such as the four geology variables or the three land-cover variables. PC analysis then was performed on these subsets of the original data, and a selected number of components was retained for clustering from each group. Both approaches required a criterion for selecting the optimum number of components to be retained.

COMPONENTS SELECTION CRITERION

The rule-N criterion was proposed for determining which components to retain from each PC analysis (Preisendorfer and others, 1981). This criterion is designed to determine at what level the eigenvalues (variance) from a PC analysis of actual data are distinguishable from those derived from an analysis of a random data matrix of the same size.

Table 2. Selection of principal components by using the rule-N criterion from analysis of all 14 variables for subbasins in central Idaho

[PC, principal component; underlined ratio indicates the level of retained components]

PC	Eigenvalues Real data (*x*)	Eigenvalues Random data (*y*)	Ratio (*x/y*)	Percent variance explained
1	3.80	1.20	3.17	27.16
2	2.08	1.13	1.84	14.86
3	1.64	1.10	1.49	11.68
4	1.53	1.07	1.43	10.96
5	1.26	1.06	<u>1.19</u>	9.01
6	.84	1.02	.82	5.96
7	.81	1.02	.79	5.80
8	.58	.98	.59	4.12
9	.48	.96	.50	3.47
10	.41	.95	.43	2.91
11	.38	.92	.41	2.71
12	.18	.90	.20	1.29
13	.01	.85	.01	.07
14	.001	.83	.001	.01

Table 3. Selection of principal components by using the rule-N criterion from analysis of four geology variables for subbasins in central Idaho

[PC, principal component; underlined ratio indicates the level of retained components]

PC	Eigenvalues Real data (*x*)	Eigenvalues Random data (*y*)	Ratio (*x/y*)	Percent variance explained
1	1.67	1.07	1.56	41.78
2	1.34	1.00	1.34	33.57
3	.98	.97	<u>1.01</u>	24.63
4	.001	.96	.001	.02

To apply rule-N, PC analysis is performed on the correlation matrix of the real data and then on the random data set. The ratio of the eigenvalues from the real data analysis to those from the random data analysis is calculated, and the components are retained where this ratio exceeds 1.0.

Results from various PC analyses, including both grouped and ungrouped variables, are summarized in tables 2–5. The ratio of real to random eigenvalues underlined in each table indicates the level of principal components that would be retained by using the rule-N criterion. The last column gives the percentage of the total variance explained by each of the components. The cumulative percentage of variance explained by the retained components is calculated by totaling these values.

The results of PC analysis on all 14 variables are summarized in table 2. Application of the rule-N criterion led to the retention of 5 of the 14 components because the ratio of real to random eigenvalues for the fifth component is 1.19, whereas the ratio for the sixth component is 0.82. The variance explained by these five components equals 73.7 percent and is calculated by summing the values of the first five principal components in the "Percent variance explained" column. The remaining variance is attributed to random noise in the data according to the rule-N criterion.

The second approach involved performing PC analysis separately on groups of the original 14 variables. Some subjectivity is required to determine the group to which each variable belongs. A reasonable approach, and the one that was used for this analysis, was to place the four geology variables into one group, the three land-cover variables into a second group, and the remaining seven variables into a third group.

Table 4. Selection of principal components by using the rule-N criterion from analysis of three land-cover variables for subbasins in central Idaho

[PC, principal component; underlined ratio indicates the level of retained components]

PC	Eigenvalues		Ratio	Percent variance
	Real data (*x*)	Random data (*y*)	(*x/y*)	explained
1	1.96	1.06	1.85	65.37
2	1.03	.97	1.06	34.23
3	.01	.97	.01	.40

This alternative leads to three separate PC analyses, one for each of the groups. The results from these analyses are summarized in tables 3–5. About 100 percent of the variance of the four geology variables can be explained by the first three principal components of the data, as determined by the rule-N criterion (table 3). Similarly, PC analysis of the land-cover group results in the selection of two components that explain 99.6 percent of the variance in this group (table 4). Finally, PC analysis of group three, composed of the remaining variables, results in the selection of three components that explain 67.3 percent of the group's variance (table 5).

The total variance explained by the eight selected components is calculated by using the following equation:

$$\frac{[0.673\ (7) + 1.00\ (4) + 0.996\ (3)]}{14} = 0.836, \text{ or } 83.6 \text{ percent.}$$

The percent variance explained within the three groups thus is weighted according to the number of original variables within the group.

A comparison of the two approaches indicates that the PC analysis of ungrouped variables results in the selection of five components that explain 73.7 percent of the total variance, whereas the analysis of grouped variables results in the selection of eight components that explain 83.6 percent of the total variance. Hence, the first alternative has the advantage of fewer components (five), whereas the second alternative explains 9.9 percent more variance but requires eight components to do so. Another look at the results of the first alternative (table 2) reveals that retaining eight of its components would result in the explanation of 89.6 percent of the total variance.

Another factor to consider in comparing the two approaches is the way in which the components are distributed among the variables. The first approach has the advantage of equal distribution, whereas the second approach allocates its retained components within groups of similar variables. This allocation results in three geology components, two land-cover components, and three components to describe the six remaining variables. The result of this allocation is an undue weighting of the geology and land-cover information within the eight retained components, which would have significant influence on the subsequent cluster analysis.

Another problem with the second approach is that it limits the possible interrelations that might be detected by the PC analysis. For example, a strong correlation might be possible between the forested area variable and the precipitation variable that would go undetected if the grouped approach were used. The relation is not lost, because cluster analysis would be performed on components retained from each group. However, the advantage of explaining the variance of these two variables with a single component, thereby further streamlining the clustering problem, is lost.

These results indicate that a single PC analysis of all variables is the better approach, followed by a selection of components on the basis of rule-N. Application of this approach resulted in the retention of five principal components (table 2). The original data then were converted to principal component scores by projecting each observation onto the five component axes. At this point, the 1,050 subbasins no longer are described by 14 variables; rather, each subbasin now is described by scores on the five principal components axes. Thus, the clustering problem has been distilled from a 1,050-by-14 matrix to a 1,050-by-5 matrix and most of the significant information has been retained.

Table 5. Selection of principal components by using the rule-N criterion from analysis of area, elevation, precipitation, basin slope, channel slope, aspect, and basin shape for subbasins in central Idaho

[PC, principal component; underlined ratio indicates the level of retained components]

PC	Eigenvalues		Ratio	Percent variance
	Real data (*x*)	Random data (*y*)	(*x/y*)	explained
1	1.74	1.08	1.61	24.79
2	1.65	1.06	1.56	23.51
3	1.33	1.02	1.09	19.00
4	.86	1.00	.86	12.34
5	.72	.97	.74	10.32
6	.48	.95	.51	6.81
7	.23	.93	.25	3.22

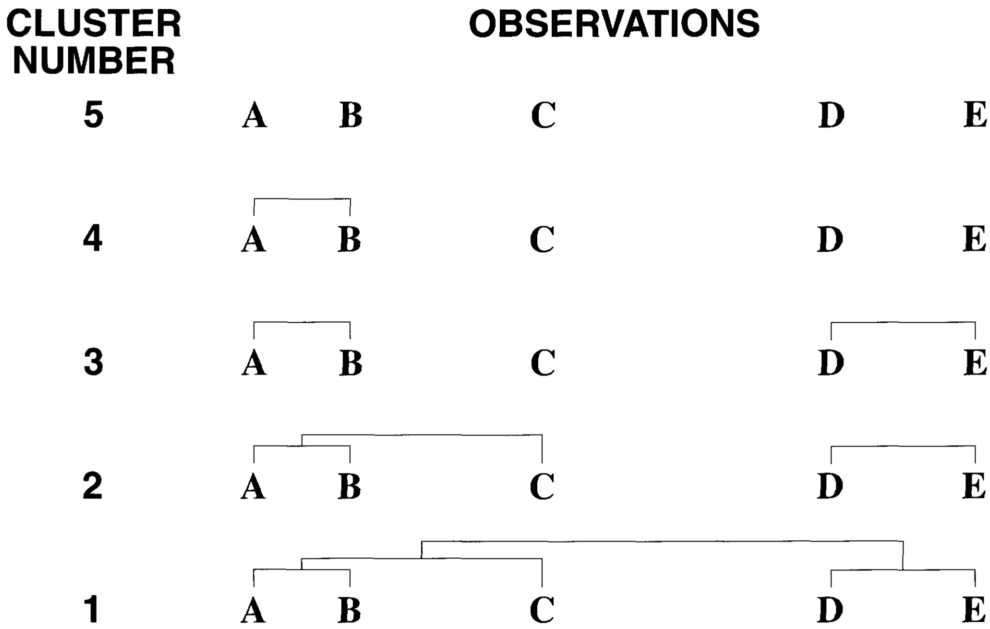

Figure 7. Steps in a simple clustering problem.

Cluster Analysis

Cluster analysis was developed as a means of classifying objects into homogeneous groups on the basis of some measure or set of measures describing the objects. Cluster analysis was advanced by taxonomists endeavoring to develop objective ways to classify living organisms. Several approaches have been taken to accomplish these and similar goals; the one applied in this study was the "hierarchical clustering" type (Hartigan, 1975; Davis, 1986).

Hierarchical clustering begins by a search of the entire data set for the two most similar observations, which then are grouped into a cluster. After the initial grouping, the procedure iterates, looking for the next closest pair. The initial cluster then is represented as a single unit for comparison with the other observations, and the procedure continues until all the observations have been grouped into a single cluster (fig. 7). A complete history of cluster membership is maintained as the observations are assigned sequentially to groups with similar characteristics. This history of cluster membership is referenced following the analysis to aid in determining the optimum level of clustering.

Several methods can be used to determine similarity between observations, including the correlation coefficient r and m-dimensional Euclidean (squared) distance between points, where m is equal to the number of variables describing each observation. Other variations in hierarchical clustering algorithms center around the choice of what is used as a measurement point for each newly formed cluster. The centroid method (Sokal and Michener, 1958) was selected because of its robustness to outliers. In the centroid method, distance is calculated as the Euclidean distance between each cluster's centroid. As new members are added to a cluster, the centroid location is recalculated and used to define that cluster's location in space for the next iteration.

Cluster analysis is the primary step in assigning membership of each subbasin to a characteristic group or stratum. Before the analysis could be undertaken, some subjective decisions were necessary. As in the PC analysis, alternative approaches exist. One approach is to perform the cluster analysis on all observations. This approach has the advantage of providing the broadest basis for linking any two or more subbasins. In other words, no restrictions are imposed on the analysis by assuming some prior knowledge of the data. Conversely, if some knowledge is available and its imposition would result in an improved analysis of the data, further examination is warranted.

A second approach involves presorting the subbasins by stream order prior to the cluster analysis. Stream order is defined as the hierarchical position of a stream within the overall stream network. First-order streams are unbranched headwater streams with no tributaries, second-order streams have tributaries of second or lower order only, third-order streams have tributaries of third or lower order, and so on. This pattern begins at the headwaters of every basin with first-order streams and continues until the primary stream reaches tidewater. Stream order is sensitive to map scale; consequently, a first-order stream identified on a 1:100,000-scale map might be given a third-order designation on a 1:24,000-scale map. For the purpose of this study, first-order streams were defined indirectly by the imposition of the 10-mi^2 minimum drainage area during the basin delineation analysis. This level of stream order designation would approximately coincide with the designations derived from a 1:250,000-scale topographic map.

PRESORTING BY STREAM ORDER

Presorting by stream order assumes that stream order is a reasonable initial index for grouping the subbasins. Therefore, first-order streams should be grouped only with other first-order streams, second-order with second-order, and so on for all stream orders. Presorting subbasins on the basis of stream order is a primary sorting criterion in other classification schemes (Horton, 1945; Strahler, 1957) and correlates well with many other elements of watershed hydrology (Emmett, 1975; Platts, 1979). In this report, stream order and subbasin order are used interchangeably because both terms have the same connotation.

Presorting subbasins within the Salmon and Clearwater River Basins by stream order resulted in the definition of 541 first-order, 219 second-order, 123 third-order, 98 fourth-order, and 69 fifth-order subbasins. A separate cluster analysis was performed on each of these groups.

CLUSTERING PROCEDURES

Prior to clustering, scores computed from the PC analysis were standardized to a mean of zero and unit variance to eliminate undue weighting of variables because of arbitrary units of measurement.

As described earlier, the clustering procedure iterates through the data set, grouping observations into clusters until each observation has been placed into a single final group. The history of each of these groups is stored in memory so that any level of grouping, from 1,050 clusters to 1 cluster, can be recalled. Often, illustration of that history in the form of a tree diagram is useful. The tree diagram then can be used to determine the optimum level of clustering for a given set of data. The large size of the Salmon and Clearwater data set did not lend itself well to that type of graphical analysis or presentation, so other more suitable means were investigated.

Although the centroid clustering method used in this analysis was less sensitive to outliers than other methods were, subbasins with low estimated probability densities were eliminated from the analysis because of their potential for causing cluster distortion (SAS Institute, Inc., 1985). Thus, 5 percent of the outliers were omitted from each of the five data sets prior to clustering.

CLUSTER SELECTION CRITERIA

The determination of optimum cluster number often is difficult, especially if there is no prior knowledge as to expected numbers. Various techniques have been suggested to enable the detection of the optimum number of clusters. These techniques include the cophenetic correlation coefficient (Davis, 1986) and the cubic clustering criterion (Sarle, 1983; SAS Institute, Inc., 1985). The latter technique was used in this analysis because it is well documented and is included with the statistical package used to perform the cluster analysis.

The cubic clustering criterion (CCC) can be used as a tool for selecting the optimum cluster number when algorithms that minimize the within-cluster sum of squares are used. Pseudo T^2 (PST^2) and pseudo F (PSF) statistics are used to corroborate the findings of the CCC (SAS Institute, Inc., 1985). The CCC, PST^2, and PSF values are plotted against the number of clusters (NCL). An optimum grouping of observations is indicated by a well-defined peak (steep leading and trailing limb) on the CCC plot. These peaks can be corroborated by a corresponding peak on the PSF plot and a sharp drop on the PST^2 plot at the same level (NCL) as the CCC plot. Suboptimum groupings often are indicated by nondistinctive or less well-defined peaks.

CCC plots are shown in figures 8–12 (back of report), along with their associated combined PST^2 and PSF plots. The CCC versus NCL plot for first-order subbasins (fig. 8) indicates peaks at 7, 10, 14, 17, and 21 clusters; peaks at 27 and 29 clusters are less well defined on their trailing end. The combined plot of PST^2 and PSF for first-order subbasins shows strong corroboration of peaks at 7, 10, and 17; CCC peaks at

14 and 21 clusters are poorly corroborated by the PSF plot.

The CCC versus NCL plot for second-order subbasins (fig. 9) gives a clear indication of optimum clusters at the 6, 9, and 14 level, and the PST^2 and PSF plots show strong corroboration at each of these cluster levels.

The plot that shows CCC as a function of NCL for third-order subbasins (fig. 10) indicates peaks at 6, 10, and 16 clusters; however, the PST^2 and PSF plots indicate that 5 clusters are optimum. The rising limb of the level 6 peak on the CCC plot is not well defined, which indicates a nondistinctive cluster at the 5/6 level. The peaks at 10 and 16 clusters are poorly corroborated by the PST^2 and PSF plots. In this instance, 6 clusters were selected, even though some overlap might be possible between the two nondistinctive clusters.

The plot that shows CCC as a function of NCL for fourth-order subbasins (fig. 11) indicates a well-defined peak at 4 clusters and less well-defined peaks at 7, 11, and 13 clusters. The choice of 4 clusters is better established upon inspection of the PST^2 and PSF plots.

The plot that shows CCC as a function of NCL for fifth-order subbasins (fig. 12) has a well-defined peak at 2 clusters and less well-defined peaks at 5 and possibly 10 clusters. The peak at 2 clusters is strongly corroborated by the PST^2 and PSF plots.

The preceding evaluation of cluster selection criteria resulted in the selection of potential cluster numbers by stream order as shown in table 6. When all three selection criteria gave evidence of good clusters at more than one level (for example, orders 1 and 2), the largest number of clusters (underlined in table 6) was selected to provide a more detailed classification. By using these criteria, 43 potential clusters or classes initially were identified to describe all the subbasins in the study area.

Table 6. Potential and final number of subbasin clusters by stream order, central Idaho

[Underlined number indicates number of clusters selected]

Stream order	Potential cluster numbers	Final cluster numbers (after refinements)
1	7, 10, <u>17</u>	12
2	6, 9, <u>14</u>	10
3	5, <u>6</u>	6
4	<u>4</u>	4
5	<u>2</u>	2

CLUSTER REFINEMENT

About 5 percent (68) of the outlier subbasins with low estimated probability densities were eliminated from the cluster analysis to avoid distortion. These basins were assigned class membership using a "nearest neighbor" approach. In this approach, plots of subbasin clusters were used as a means for determining appropriate class membership of unassigned basins on the basis of proximity, orientation, and other factors. Subbasins grouped into classes with fewer than five members were arbitrarily reassigned to larger classes on the basis of their cluster history to reduce the number of less significant classes. The reassignment resulted in a reduction of first-order classes from 17 to 12 and a reduction of second-order classes from 14 to 10. The final classification consisted of a total of 34 classes, as shown in table 6. Final grouping of the subbasins by stream order into hydrologically homogeneous classes is shown in figures 13–17.

Validation of Hydrologic Classification

To evaluate the effectiveness of the classification scheme, clusters were validated by visually inspecting their spatial distribution and by comparing the hydrologic similarity of gaging stations within clusters on the basis of mean monthly discharges.

SPATIAL DISTRIBUTION OF CLUSTERS

The reasonableness of the first- and second-order subbasin classification is difficult to ascertain by visual inspection alone because these two groups contain the largest number of subbasins and classes. On plots of class assignment, the tendency for neighboring subbasins to be grouped together and the regional nature of the resulting classes were used to draw some conclusions. Neighboring first-order subbasins tend to be grouped together into a single class rather than dispersed into multiple classes. This grouping indicates that cluster analysis is a way to "recognize" fundamental similarities among neighboring subbasins by using basin characteristics, such as mean elevation, mean annual precipitation, geology, and land-cover type.

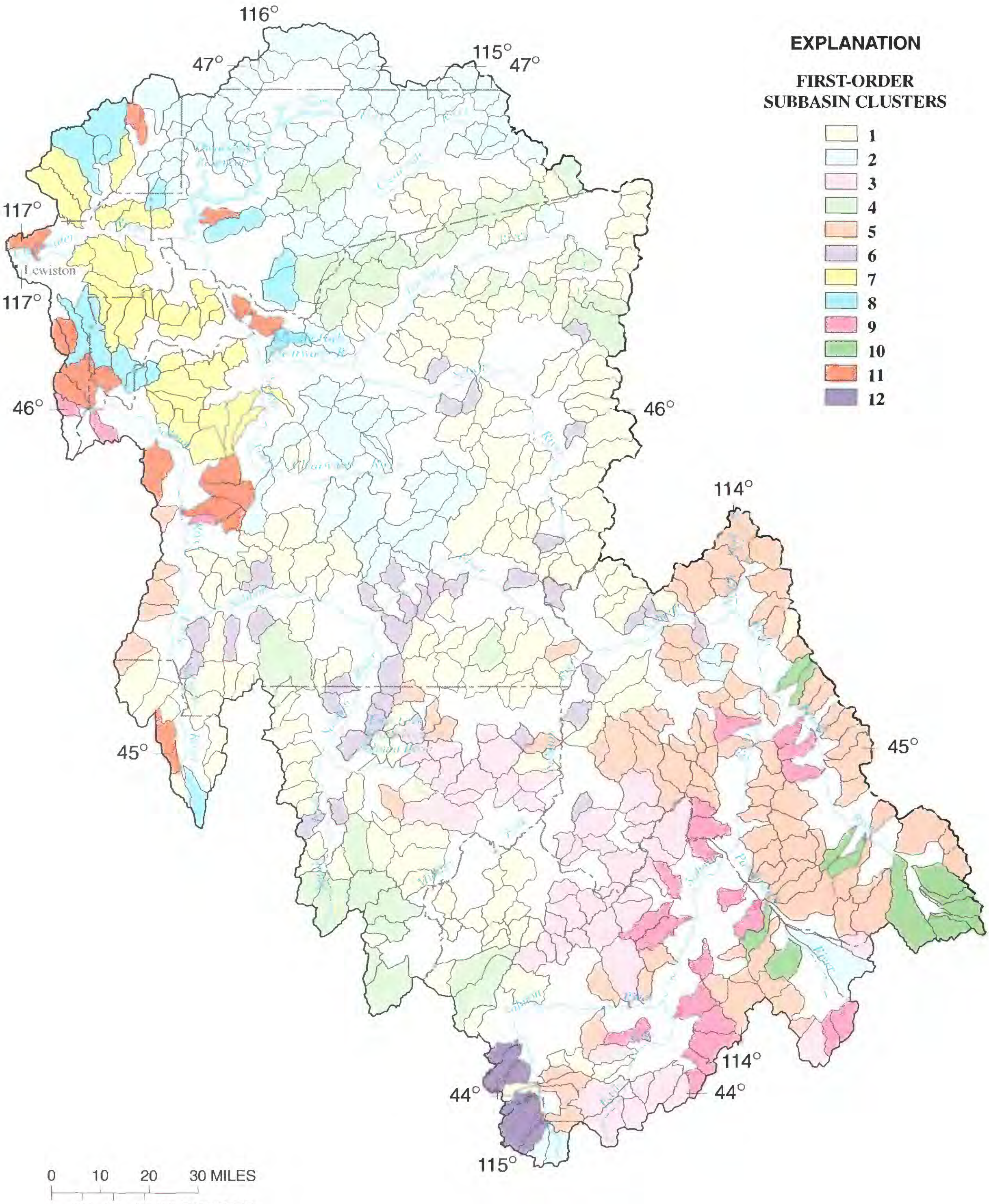

Figure 13. Final classification of first-order subbasins, central Idaho.

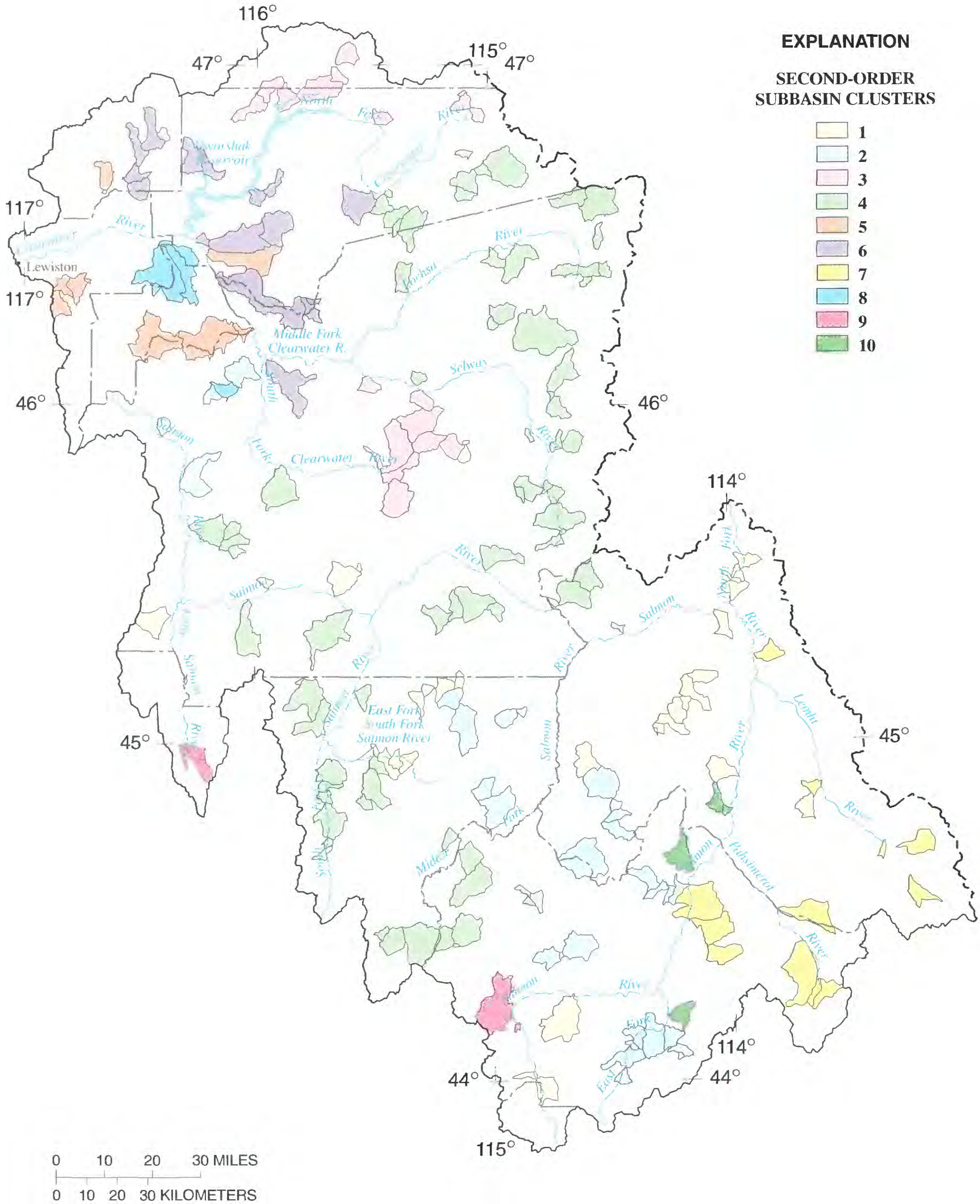

Figure 14. Final classification of second-order subbasins, central Idaho.

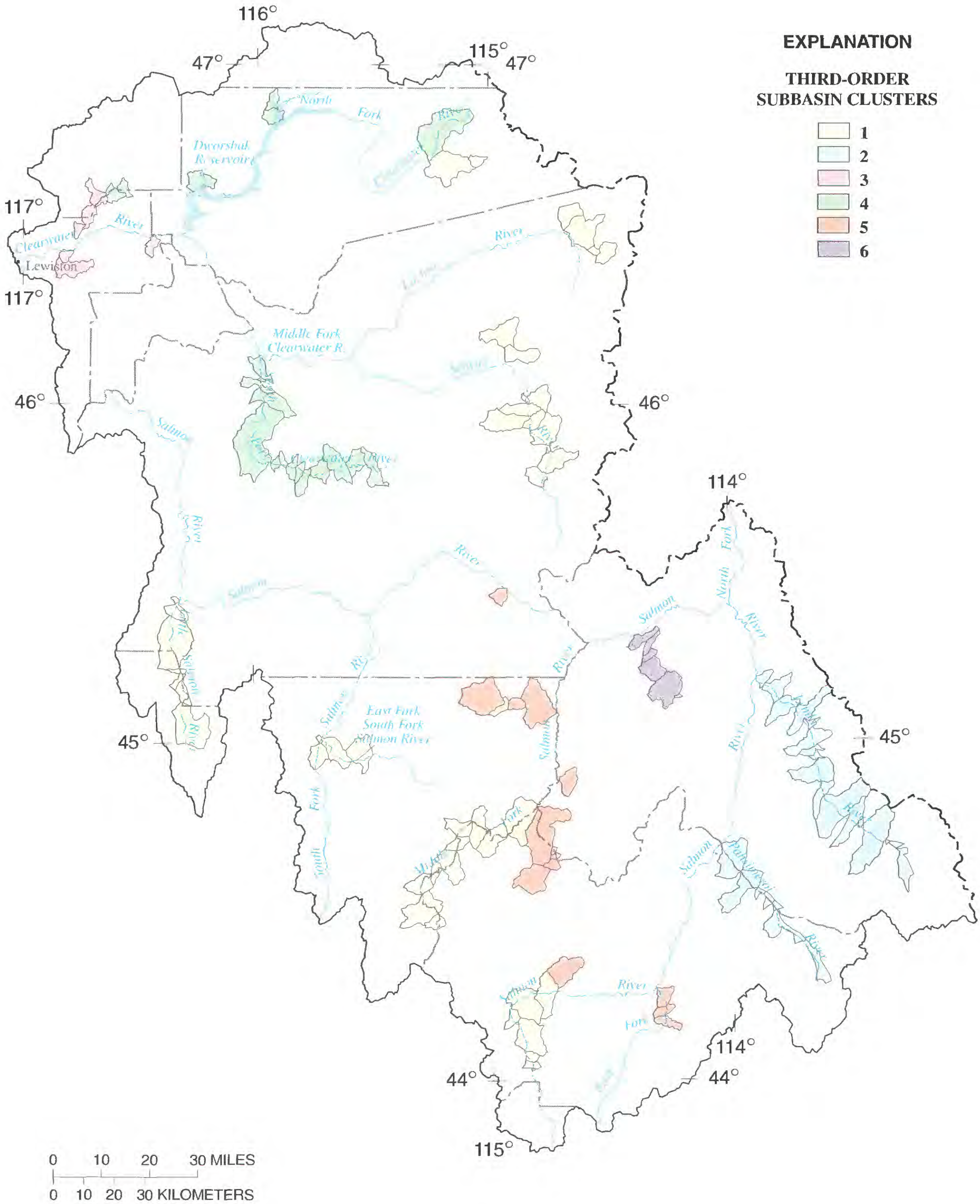

Figure 15. Final classification of third-order subbasins, central Idaho.

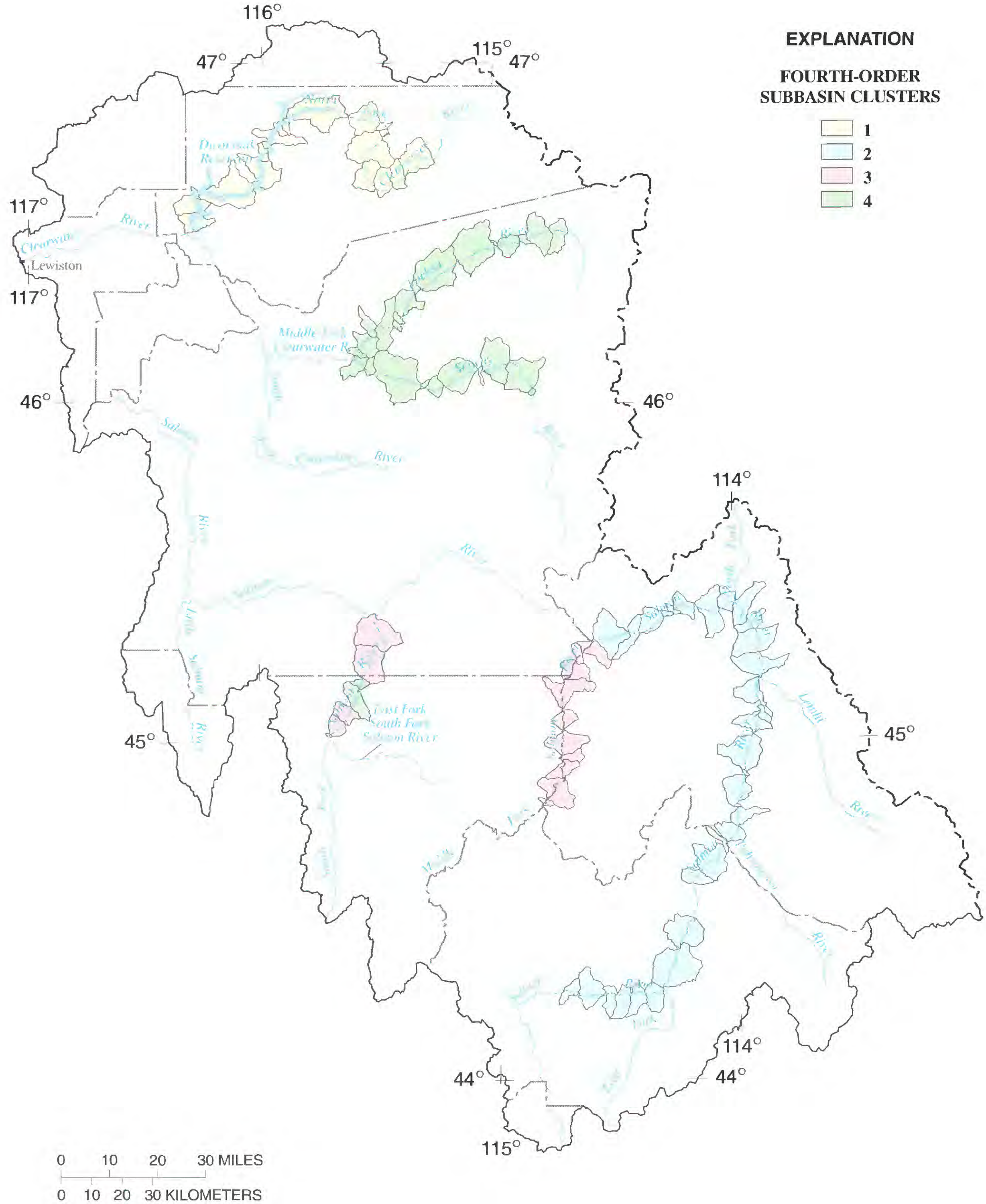

Figure 16. Final classification of fourth-order subbasins, central Idaho.

Figure 17. Final classification of fifth-order subbasins, central Idaho.

Furthermore, small clumps of neighboring subbasins are grouped with other similar clumps in a loosely regional manner, which indicates that the analysis also is capable of recognizing broader, more regional similarities and differences between the subbasins.

Plots of third-, fourth-, and fifth-order subbasins indicate a well-defined classification according to main-stem river reaches. The grouping of subbasins along complete main-stem reaches is an indication of the ability of cluster analysis to recognize similarities among adjacent reaches of the same stream. An example is the classification of fifth-order subbasins (fig. 17). Cluster analysis correctly distinguished main-stem reaches of the Clearwater and Salmon Rivers by placing them into appropriate groups.

In some cases, primarily third- and fourth-order subbasins, main-stem stream segments from different river systems were placed in the same class, or cross classified. For example, third-order subbasins of the Lemhi and Pahsimeroi Rivers (fig. 15) were grouped together, which indicates similarities. The Lemhi and Pahsimeroi River Basins are similar and are unique to the study area. Both have broad, alluvial valleys and trellis stream patterns in contrast to the deep, V-shaped valleys and dendritic stream patterns characteristic of many of the other basins. Another example of cross classification of main-stem reaches is illustrated in figure 16, where a fourth-order subbasin of the South Fork Salmon River was placed in the same class as subbasins of the Lochsa and Selway Rivers in the Clearwater River Basin. The South Fork Salmon, Lochsa, and Selway River Basins have similar characteristics of mean elevation, annual precipitation, and land-cover type.

Another way to illustrate the spatial distribution of clusters is to plot the five component scores of each subbasin according to their class membership and observe how well the clusters group. Five-dimensional data are difficult to plot and even more difficult to interpret. Therefore, scores on only the first three components were plotted because they represent a large percentage of the total variance in the data (figs. 18–22, back of report). Because of the number of first- and second-order subbasins, distinguishing between clusters for these two groups was difficult. The quasi-three-dimensional plots of third-, fourth-, and fifth-order subbasins, however, provide a clearer picture of the shape and compactness of the individual clusters, as well as their spatial relations. In most instances, where clusters overlap, rotation of the *xy* and *z* axes provides a different perspective, one that better illustrates the distinction between clusters. Because the plots include only three of the five total components, inclusion of the remaining components would further discretize neighboring clusters.

Table 7. Streamflow-gaging stations in central Idaho for which mean annual and mean monthly discharges were calculated

[Locations of gaging stations shown in figure 23; No., number]

Gaging station No.	Gaging station name
13295500	Salmon River below Valley Creek, at Stanley
13296000	Yankee Fork Salmon River near Clayton
13296500	Salmon River below Yankee Fork, near Clayton
13297330	Thompson Creek near Clayton
13297355	Squaw Creek below Bruno Creek, near Clayton
13297450	Little Boulder Creek near Clayton
13297597	Herd Creek below Trail Gulch, near Clayton
13298500	Salmon River near Challis
13302000	Pahsimeroi River near May
13302005	Pahsimeroi River at Ellis
13302500	Salmon River at Salmon
13305000	Lemhi River near Lemhi
13305500	Lemhi River at Salmon
13306000	North Fork Salmon River at North Fork
13307000	Salmon River near Shoup
13308500	Middle Fork Salmon River near Cape Horn
13309000	Bear Valley Creek near Cape Horn
13309220	Middle Fork Salmon River at Middle Fork Lodge, near Yellow Pine
13310500	South Fork Salmon River near Knox
13310700	South Fork Salmon River near Krassel Ranger Station
13311500	East Fork South Fork Salmon River near Stibnite
13312000	East Fork South Fork Salmon River near Yellow Pine
13313000	Johnson Creek at Yellow Pine
13313500	Secesh River near Burgdorf
13314000	South Fork Salmon River near Warren
13315000	Salmon River near French Creek
13315500	Mud Creek near Tamarack
13316500	Little Salmon River at Riggins
13316800	North Fork Skookumchuck Creek near White Bird
13317000	Salmon River at White Bird
13317500	Deer Creek near Winchester
13336500	Selway River near Lowell
13336900	Fish Creek near Lowell
13337000	Lochsa River near Lowell
13337500	South Fork Clearwater River near Elk City
13338500	South Fork Clearwater River at Stites
13339500	Lolo Creek near Greer
13340000	Clearwater River at Orofino
13340500	North Fork Clearwater River at Bungalow Ranger Station
13340600	North Fork Clearwater River near Canyon Ranger Station
13340615	Beaver Creek near Canyon Ranger Station
13341000	North Fork Clearwater River at Ahsahka
13341050	Clearwater River near Peck
13341400	East Fork Potlatch River near Bovill
13341500	Potlatch River at Kendrick
13342450	Lapwai Creek near Lapwai
13342500	Clearwater River at Spalding

Table 8. Mean annual and mean monthly discharges calculated for selected streamflow-gaging stations within the Salmon and Clearwater River Basins, central Idaho

[No., number; ft³/s, cubic feet per second]

Gaging station No.	Mean annual discharge (ft³/s)	Mean monthly discharge (ft³/s)											
		Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
13295500	664	379	380	339	315	306	312	631	1,610	1,970	967	415	341
13296000	197	65	60	53	46	44	55	207	745	770	217	92	69
13296500	999	509	498	446	412	405	423	932	2,620	3,270	1,430	607	495
13297330	18	5.1	5.3	4.8	4.5	4.5	7.7	26	63	62	19	7.0	5.3
13297355	35	11	12	11	9.8	9.5	14	42	119	128	35	13	11
13297450	23	10	8.5	6.9	6.2	5.8	5.9	8.4	37	88	65	22	12
13297597	53	24	23	21	20	18	18	26	106	205	97	44	31
13298500	1,490	791	736	659	616	619	626	1,280	3,690	4,970	2,260	982	774
13302000	212	247	281	264	244	246	255	215	133	182	160	156	189
13302005	260	319	339	316	293	301	307	230	155	221	162	162	216
13302500	1,970	1,280	1,310	1,150	1,080	1,090	1,130	1,660	4,020	5,800	2,760	1,250	1,110
13305000	278	262	279	238	232	238	260	270	331	559	296	150	175
13305500	246	232	268	219	205	218	253	293	302	577	208	71	121
13306000	91	39	41	38	35	35	46	130	308	263	78	38	34
13307000	3,040	1,970	2,010	1,810	1,710	1,730	1,780	2,470	6,310	9,200	4,020	1,770	1,640
13308500	241	101	91	87	75	70	71	172	797	916	291	130	103
13309000	290	119	116	105	95	90	97	276	1,060	940	281	129	109
13309220	1,520	616	647	566	556	505	570	1,260	4,010	5,220	2,030	852	660
13310500	145	56	49	50	43	42	52	195	541	494	133	52	41
13310700	576	163	211	217	241	223	288	633	1,750	2,010	617	201	162
13311500	50	19	17	17	15	14	17	49	171	185	54	26	21
13312000	137	54	49	51	43	40	48	166	447	493	152	74	57
13313000	347	99	102	94	88	84	94	309	1,280	1,420	383	121	90
13313500	188	75	72	57	49	45	46	164	721	720	246	78	59
13314000	1,600	490	561	607	498	490	716	2,540	5,910	5,550	1,730	593	449
13315000	10,600	4,400	4,490	4,040	3,680	3,790	4,380	10,600	32,800	35,800	13,400	5,290	4,080
13315500	19	2.5	3.8	8.2	4.7	5.3	15	98	74	13	3.6	2.0	1.8
13316500	805	253	299	321	323	392	651	1,320	2,370	2,470	729	258	228
13316800	18	3.8	5.4	6.4	7.6	11	11	37	72	45	7.5	2.4	2.3
13317000	11,300	4,850	4,950	4,530	4,180	4,420	5,440	11,700	32,100	39,000	13,800	5,430	4,480
13317500	12	1.0	1.7	2.8	1.6	1.7	7.1	54	45	17	4.6	1.1	.7
13336500	3,760	975	1,250	1,400	1,250	1,460	2,170	6,060	13,500	12,100	3,130	912	763
13336900	254	74	119	151	113	149	179	608	969	496	100	44	45
13337000	2,860	757	1,060	1,230	1,110	1,230	1,780	4,900	10,300	8,490	2,170	665	571
13337500	274	70	90	97	99	109	176	662	1,140	585	146	57	53
13338500	1,070	292	354	463	556	633	994	2,070	3,420	2,660	821	289	262
13339500	312	79	138	154	179	401	630	871	813	487	142	59	72
13340000	8,800	2,150	2,990	3,760	4,100	4,700	7,620	15,700	29,100	25,100	6,580	2,060	1,840
13340500	2,840	992	1,280	1,480	1,270	1,520	1,700	5,010	10,000	7,100	2,030	892	761
13340600	3,490	1,030	1,490	1,750	1,830	2,140	3,120	5,940	11,100	8,850	2,680	1,160	976
13340615	99	46	70	47	57	85	171	277	193	105	55	45	43
13341000	5,710	1,850	2,910	3,710	3,140	3,520	5,110	12,200	17,900	11,500	3,540	1,560	1,350
13341050	15,500	4,470	7,110	9,640	10,200	10,900	14,900	22,000	38,700	36,200	11,600	4,980	6,930
13341400	62	16	29	45	66	92	105	206	114	39	13	8.5	11
13341500	427	42	151	347	472	824	1,180	1,380	551	140	37	16	18
13342450	81	17	24	61	72	124	208	223	136	54	17	8.2	12
13342500	15,300	4,400	6,960	8,820	8,580	10,000	14,600	28,200	46,400	36,600	10,700	4,090	4,500

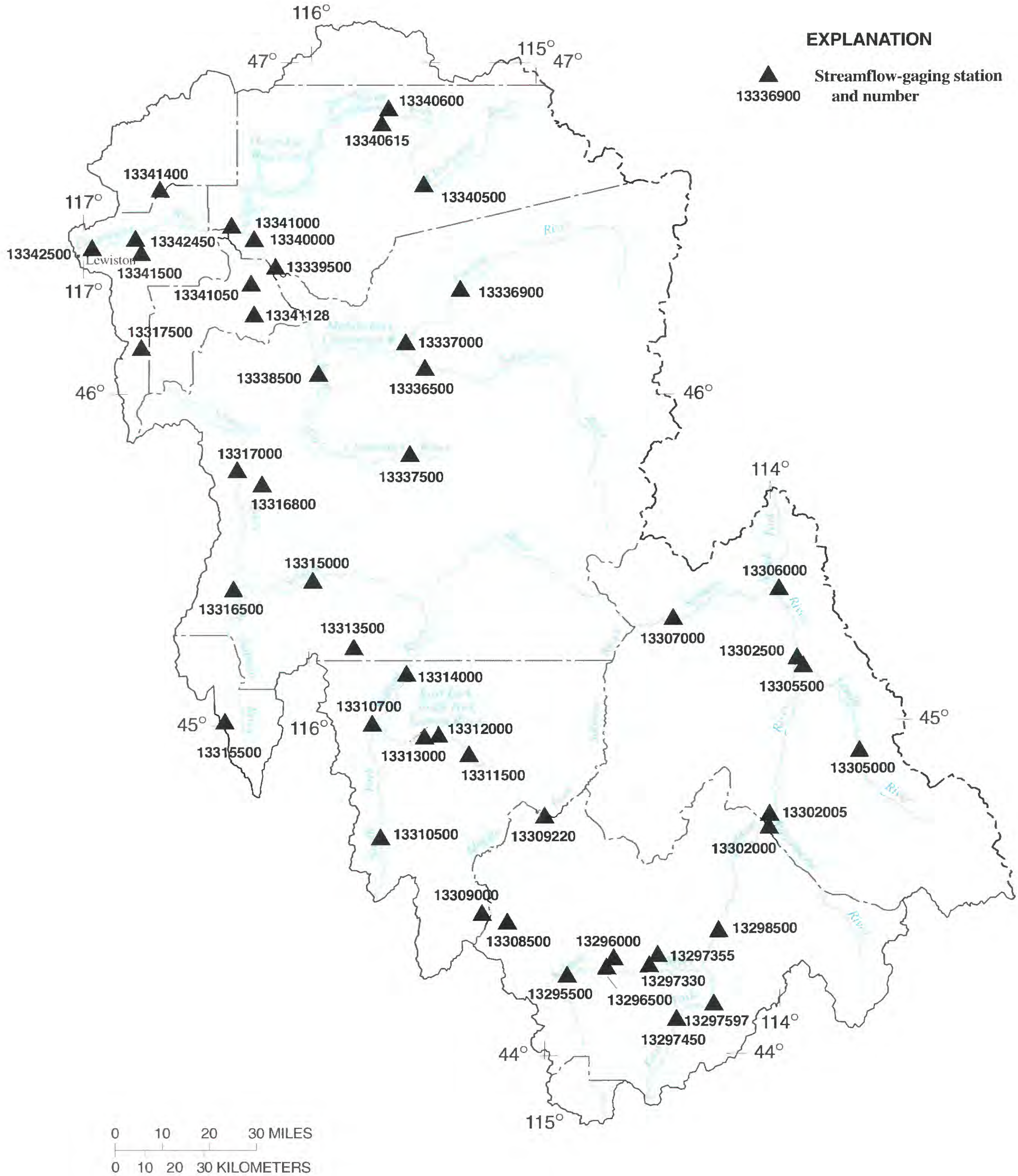

Figure 23. Location of streamflow-gaging stations used for cluster comparisons, central Idaho.

COMPARISON OF MEAN MONTHLY DISCHARGES

Records from current and discontinued streamflow-gaging stations in the study area (fig. 23) were analyzed to compare hydrologic characteristics for sites within and between clusters. Only stations that had a minimum of 10 years' record and that were not affected by significant diversions or regulations upstream were chosen. Streamflow-gaging stations were fairly well distributed throughout the study area; however, not all classes of subbasins contained a station. Those that did were evaluated to further validate the classification approach.

Mean annual and mean monthly discharges were calculated for the selected streamflow-gaging stations (tables 7 and 8). A comparison of stations within each class was made by constructing histograms of mean monthly discharge for periods of record. Mean monthly discharges were normalized by calculating them as a percentage of the mean annual discharge for each month (figs. 24–28, back of report). The histograms provide a means for comparing mean monthly discharge magnitude and timing between and within various classes.

A good example of between-class differences is illustrated by comparing the histograms of class 1–2 with class 1–4 (fig. 24). The first number in the descriptor refers to subbasin order and the second identifies cluster membership. Class 1–2 (subbasin order 1, cluster 2) contains the East Fork Potlatch River near Bovill (station 13341400) and Beaver Creek near Canyon Ranger Station (station 13340615). Both streams are within the west-central part of the Clearwater River Basin. This area is characterized by elevations less than 4,000 ft that are subject to rain on snow from January through March. Streamflow generally peaks during April as a result of snowmelt runoff. The two stations in class 1–4, in contrast, are characteristic of basins at higher elevations. Mean elevations of the South Fork Salmon River near Knox (station 13310500) and the Secesh River near Burgdorf (station 13313500) are nearly 3,000 ft higher than mean elevations of the two stations in class 1–2. These stations represent basins where base-flow conditions prevail from October through March, when much of the annual precipitation for the area is in the form of snow. Temperatures remain low enough at these elevations to keep the snowpack intact until the latter part of April; then rapid snowmelt produces peak streamflow in May and June.

Another example of between-class differences is shown by comparing monthly flow histograms of class 3–1 with 3–2 (fig. 26). The four stations within class 3–1, all of which lie within the central and western Salmon River Basin, exhibit a pattern of runoff magnitude and timing similar to that of many streams in central Idaho. Base-flow conditions prevail from October through March, followed by the snowmelt-runoff period, which typically peaks in June and July, followed by a return to base-flow conditions in August and September. The stations in class 3–2 exhibit a sharply contrasting pattern. These four stations, two in the Lemhi River Basin and two in the Pahsimeroi River Basin, have a relatively uniform base-flow period that prevails almost year-round with little variation, except during the summer months when water is diverted for irrigation. The unconsolidated alluvial material that underlies both basins (fig. 3) dampens snowmelt-runoff peaks and elevates discharge magnitude during base-flow periods. Geology of the Lemhi and Pahsimeroi River Basins is unique in the study area (fig. 3), as is the hydrology illustrated by the histograms for class 3–2 stations in figure 26.

Within each subbasin order except the fifth, subbasins in the eastern Clearwater River Basin are cross classified with those in the western part of the Salmon River Basin. An example mentioned earlier is illustrated in the fourth-order classification (fig. 16), where a reach of the South Fork Salmon River is cross classified with main-stem reaches of the Lochsa and Selway Rivers. These three river systems have many physical similarities. Mean monthly flow histograms for streamflow-gaging stations in these reaches (fig. 27) further corroborate basin similarities. A comparison of mean monthly flows for the three streamflow-gaging stations within class 4–4 is shown in figure 27. The Lochsa River near Lowell, the Selway River near Lowell, and the South Fork Salmon River near Warren (stations 13337000, 13336500, and 13314000, respectively) exhibit nearly identical hydrologic characteristics in terms of the timing and magnitude of mean monthly discharge.

These examples provide further evidence that PC and cluster analyses were successful in distinguishing between dissimilar hydrologic features and in grouping subbasins with similar features.

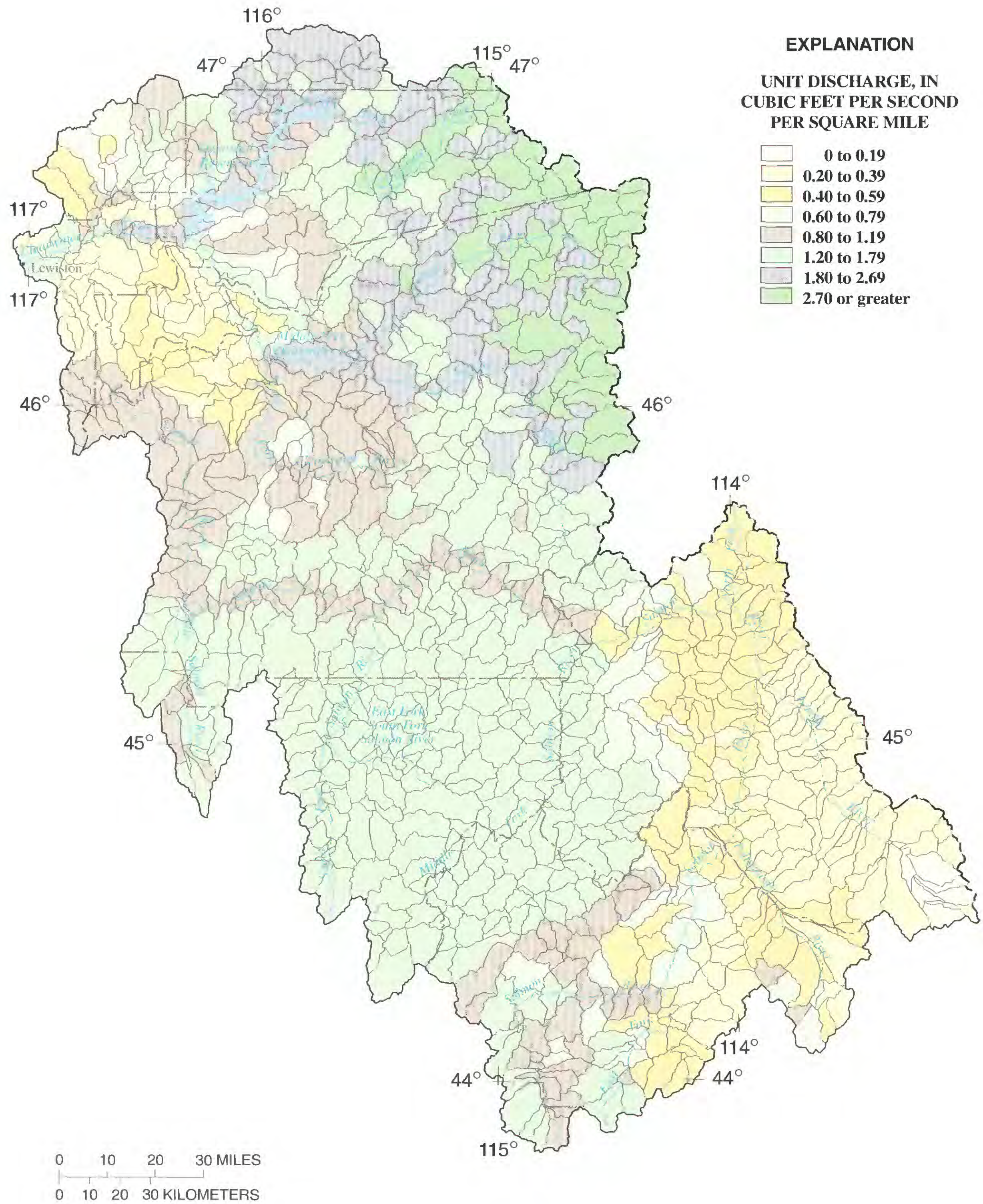

Figure 29. Unit mean annual discharge calculated for each subbasin, central Idaho.

Estimation of Streamflow Parameters

A secondary objective of the study was to provide the BIA with estimates of mean annual and mean monthly discharges for each of the subbasins within the study area. This information was needed to provide boundary conditions for fish habitat modeling and to provide a check on the reasonableness of instream flow determinations. Mean annual and mean monthly discharge estimates were derived using methods described in this report.

MEAN ANNUAL DISCHARGE

Estimates of mean annual discharge (*Qa*) for each of the subbasins were calculated (table 9, on diskette, back of report) by using regionalized regression equations developed by the USGS for Idaho (Quillian and Harenberg, 1982). These equations were derived from multivariate regression analysis of known basin characteristics for basins having streamflow-gaging stations within designated regions. The required input to these equations varied from region to region but included area, mean basin elevation, mean annual precipitation, percentage of forested area, and longitude of the basin outlet. Input data for the Salmon and Clearwater River subbasins were obtained from the GIS data base. Standard error of estimates for the equations used in this study ranged from 26 to 54 percent. The subbasin numbers were an artifact of the basin delineation procedures and are not sequential; hence, the largest subbasin number is 1,082 rather than 1,050. A determination of regions was made for each of the subbasins, and the appropriate equation was used to estimate mean annual discharge.

A comparison between actual and estimated unit mean annual discharge (*Qa*/area) was made for all subbasins with streamflow-gaging stations, and the percent error associated with the estimated value was calculated. Only streamflow-gaging stations that were not affected by significant regulations or diversions upstream and that included at least 75 percent of the total subbasin area were used for comparisons.

In some cases, a regional adjustment to the estimated *Qa* was made on the basis of the percent error. The adjustment was made when the differences between actual and calculated unit *Qa*'s for several gaging stations in an area tended to be either all negative or all positive and about the same magnitude. In most cases, the adjustment was made by increasing or decreasing the estimated *Qa* values within the area by a constant percentage. The exception to this was subbasins in the eastern part of the Salmon River Basin. Initial estimates of *Qa* in that area were made using the equation for region nine; however, a comparison of results of the actual *Qa* values for gaging stations indicated that this equation typically underestimated the *Qa*'s by 50 percent or more. When the estimates for these subbasins were recalculated using the equation for adjacent region five, most differences between estimated and actual *Qa*'s were reduced to within 5 percent. Therefore, the equation for region five was used to compute estimates for *Qa*'s for subbasins in the eastern part of the Salmon River Basin.

Following the regional adjustments, some local adjustments were made on the basis of the unit *Qa* values calculated for streamflow-gaging stations. The unit *Qa* values for the gaging stations were compared with unit *Qa* values for all the subbasins estimated on the basis of the regression equations and the regional adjustments. Adjustments were made to estimated unit *Qa*'s on the basis of actual values at the gaging station or stations in the vicinity. Adjustments were made in a way that produced a smooth transition from one gaging station to the next and a generally increasing unit runoff with increasing mean elevation and precipitation.

A description of regional and local adjustments and the extent to which they were applied is included in table 9. The distribution of final unit *Qa* values for the entire study area is illustrated in figure 29.

MEAN MONTHLY DISCHARGE

Estimates of mean monthly discharges for subbasins were calculated by apportioning the estimated mean annual discharges into monthly increments. A characteristic, or index, streamflow-gaging station was selected for each subbasin, and the actual ratio of mean monthly discharge to mean annual discharge was used as a basis for apportioning the estimated *Qa*'s. The selection of index streamflow-gaging stations was based on similarities in locale, area, elevation, and precipitation. The index gaging station and estimate of mean monthly discharge for each of the subbasins in the Salmon and Clearwater River Basins are given in table 10 (on diskette, back of report).

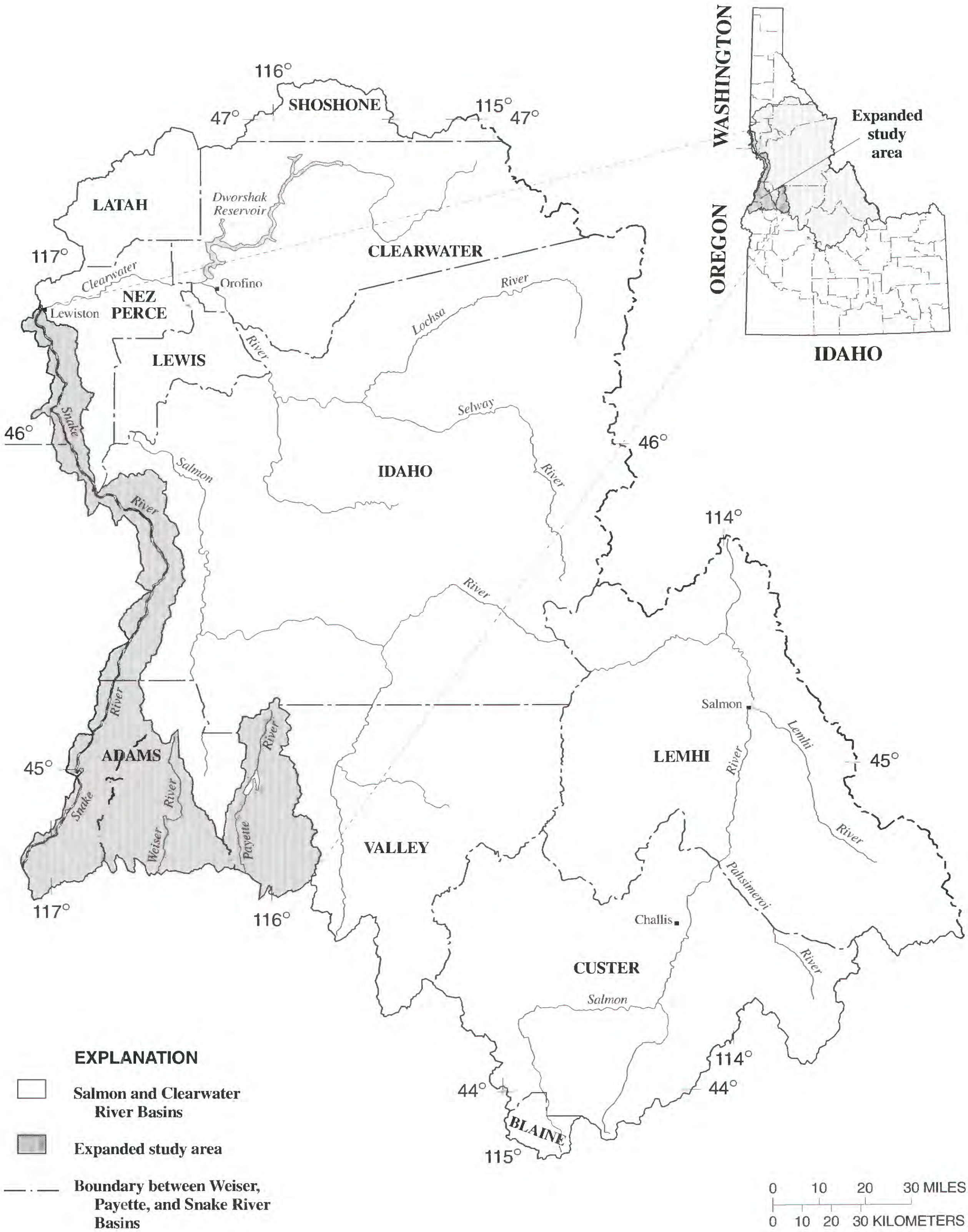

Figure 30. Location of expanded study area, including parts of the Weiser, Payette, and Snake River Basins, west-central Idaho.

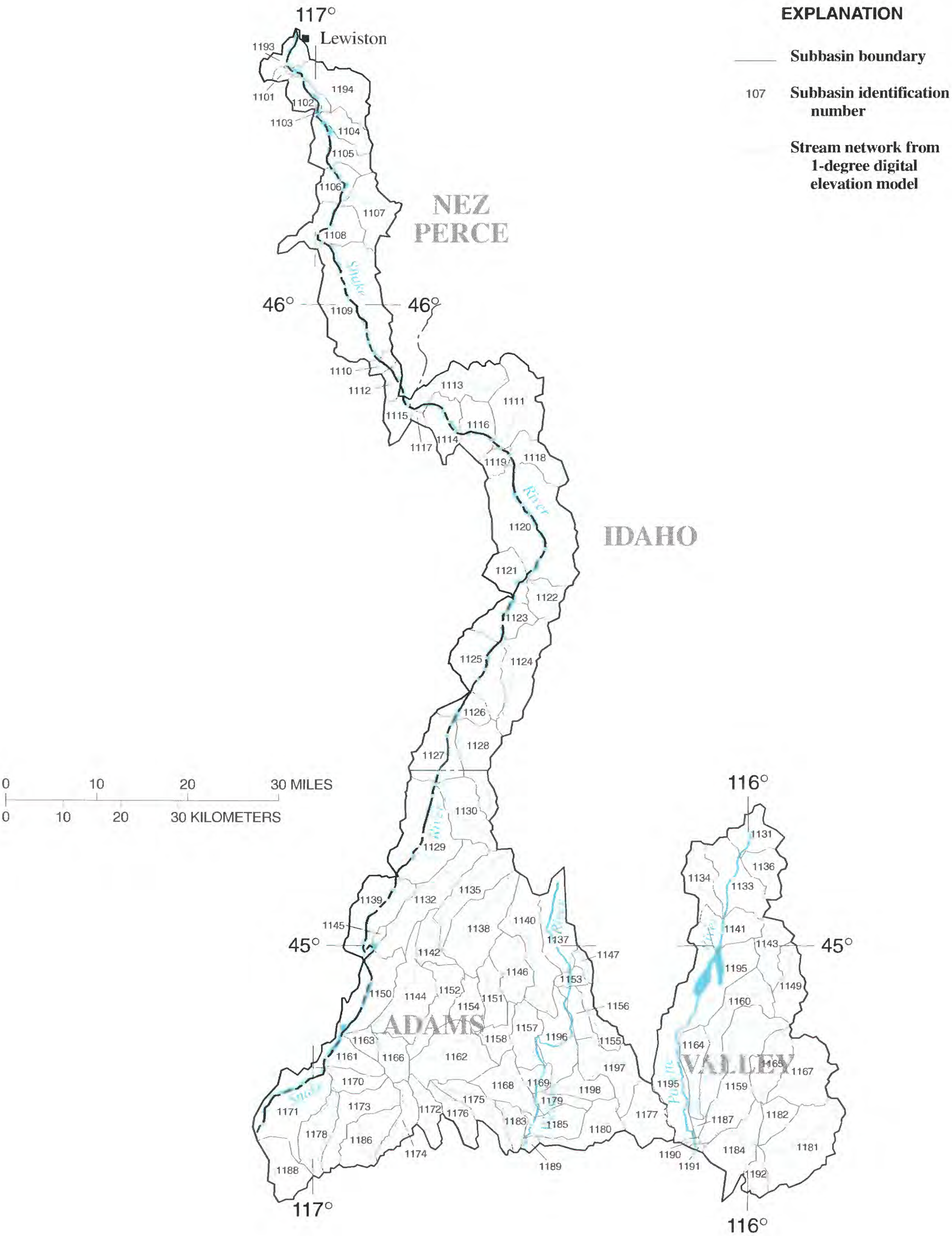

Figure 31. Subbasins and corresponding stream network delineated from 1-degree digital elevation models within the expanded study area, west-central Idaho.

STUDY OF WEISER, PAYETTE, AND SNAKE RIVER SUBBASINS

In January 1991, as the study of the Salmon and Clearwater River Basins was nearing completion, the BIA requested that the scope of the study be expanded to include a selected group of subbasins within the Weiser, Payette, and Snake River Basins north of latitude 44°40'. These subbasins cover an area of 2,290 mi^2, or roughly one-tenth the area of the original study. The expanded study area is adjacent to and west of the Salmon and Clearwater River Basins (fig. 30).

Objectives of the expanded study were identical to those for the Salmon and Clearwater River Basins study, with the exception that subbasin classification was not to be done. The objectives were to identify and delineate subbasins and develop a GIS data base similar to the Salmon and Clearwater Rivers data base for use in estimating mean annual and mean monthly discharges for the subbasins. The approaches used to meet these objectives were identical to those used for the original study area.

Within the expanded study area, 70 subbasins were identified by using the basin delineation software (fig. 31). These subbasins included 47 first-order, 17 second-order, and 6 third-order streams. The study area included only Idaho tributaries to the Snake River and did not include main-stem Snake River segments. Main-stem segments are shown in figure 31 only to provide continuity among the other subbasins. Estimates of mean annual and mean monthly discharge were calculated by using the appropriate regional regression equations developed by Quillian and Harenberg (1982) and were adjusted by using a similar approach described for the Salmon and Clearwater Rivers study area. Results from these analyses are given in tables 11 and 12 (on diskette, back of report).

SUMMARY

Adjudication of water rights by the State of Idaho within the Snake River Basin prompted various Federal agencies to establish and quantify State appropriative and Federal reserved water rights. The Bureau of Indian Affairs (BIA), acting on behalf of the Nez Perce Tribe, entered into a cooperative agreement with the U.S. Geological Survey (USGS) in 1988 to provide hydrologic data and analysis for streams within the Salmon and Clearwater River Basins. Results of the study are needed to support future water rights claims made by the BIA.

Study objectives included delineation of subbasins within the Salmon and Clearwater River Basins, development of a data base of subbasin characteristics for use in the classification of the subbasins into homogeneous groups, and estimation of mean annual and mean monthly discharges for the identified subbasins.

Specialized software developed by the Earth Resources Observation System Data Center was used to delineate more than 1,000 subbasins within the study area. One-degree digital elevation models were used as a data source. The software performed well in areas with high relief and well-defined drainage basin boundaries; little or no additional editing was required. Subbasins within areas of flatter terrain required additional editing; however, editing was limited to a small percentage of the total study area.

The identified subbasins were used as the foundation for a geographic information system data base that included more than 30 variables that describe physical characteristics of each subbasin. The sources of data used to derive the variables included 1-degree digital elevation models and various thematic layers.

A selected group of the variables was used in a two-step statistical classification procedure, which consisted of principal components analysis and cluster analysis. The resulting classification grouped 1,050 subbasins into 34 hydrologically homogeneous classes, which were to be used as a basis for the design of a data-collection network for quantifying instream flows. To evaluate the effectiveness of the classification scheme, clusters were validated by visually inspecting their spatial distribution and by comparing the hydrologic similarity of gaging stations within clusters on the basis of mean monthly discharge.

Validation indicated that the method of classification was successful in grouping subbasins with similar hydrologic characteristics. Similar procedures could be used in the analysis of existing data-collection networks and as an optimization tool for the design of new sampling programs. By identifying stream reaches, aquifers, and basins with similar characteristics, data-collection efforts could be optimally distributed to provide maximum return on resources expended.

Estimates of mean annual and mean monthly discharges were made for each of the subbasins. These statistics were calculated by using regionalized regres-

sion equations previously developed by the USGS for Idaho.

The study area was ultimately expanded to include parts of the Weiser, Payette, and Snake River Basins. In these basins, 70 subbasins were delineated, a hydrologic data base was created, and estimates of mean annual and mean monthly discharges were made using methods similar to those used for the Salmon and Clearwater River Basins.

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Figures 8–12, 18–22, and 24–28

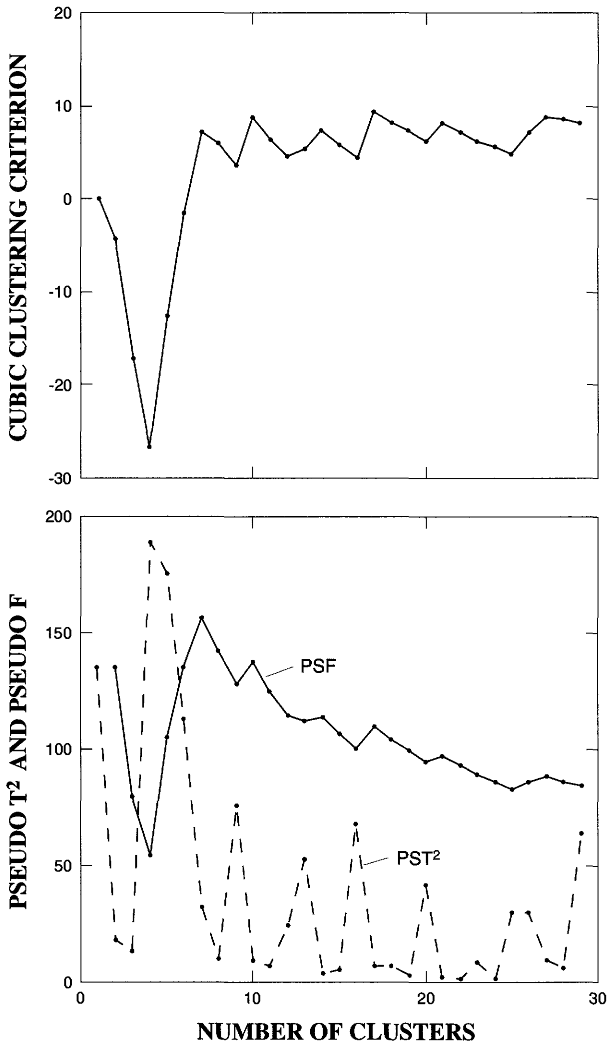

Figure 8. Relations among the cubic clustering criterion (CCC), pseudo T^2 (PST^2), pseudo F (PSF), and number of clusters (NCL) for first-order subbasins, central Idaho.

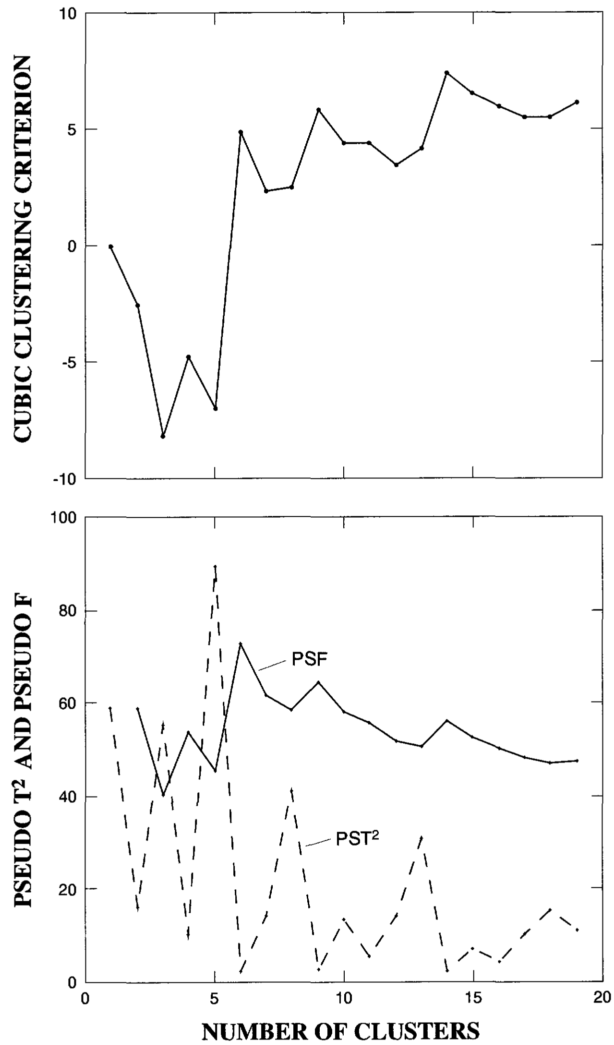

Figure 9. Relations among the cubic clustering criterion (CCC), pseudo T^2 (PST^2), pseudo F (PSF), and number of clusters (NCL) for second-order subbasins, central Idaho.

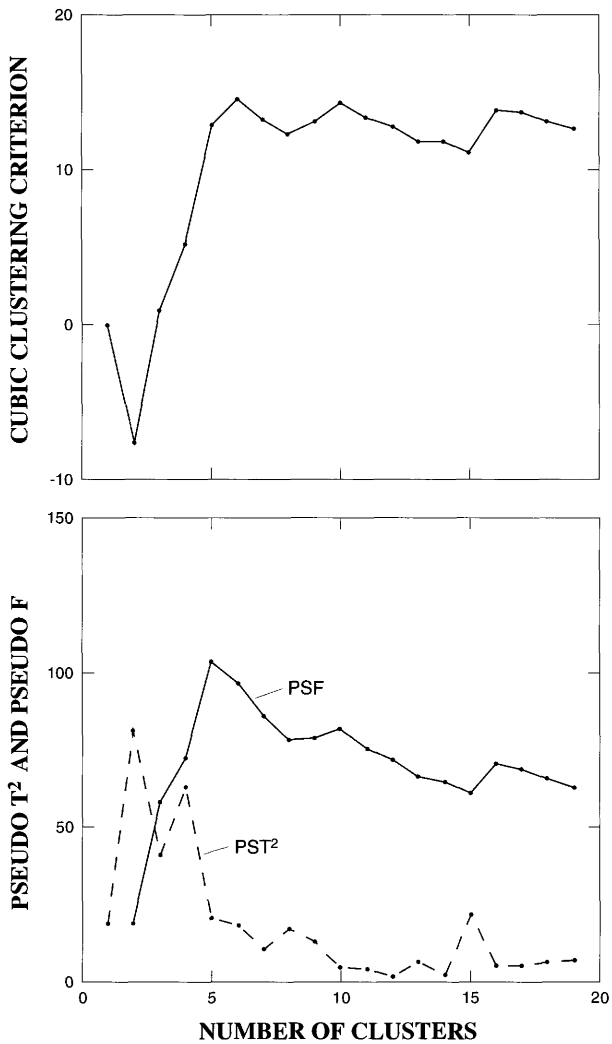

Figure 10. Relations among the cubic clustering criterion (CCC), pseudo T^2 (PST^2), pseudo F (PSF), and number of clusters (NCL) for third-order subbasins, central Idaho.

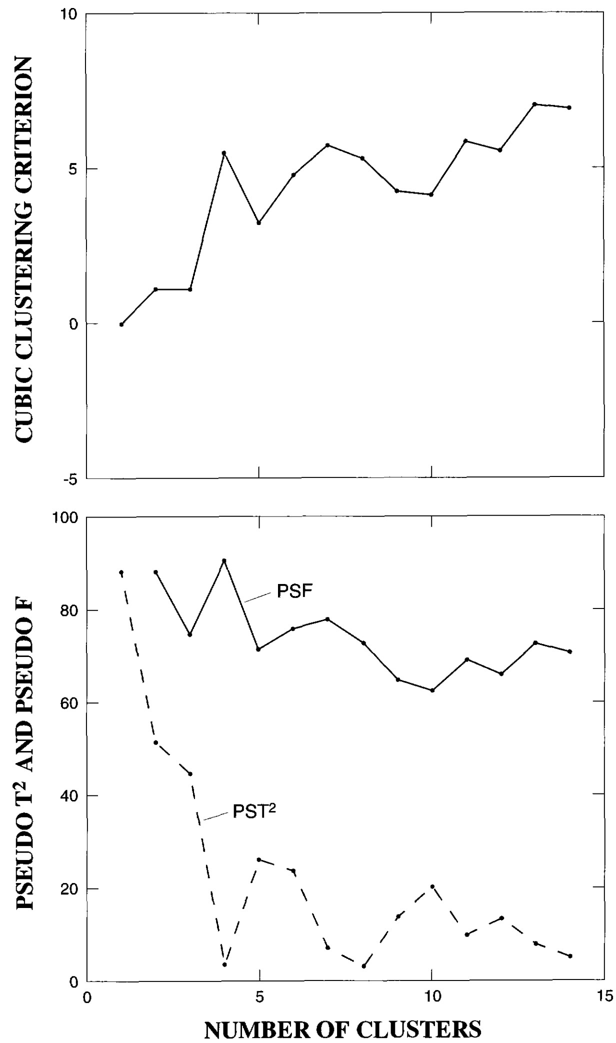

Figure 11. Relations among the cubic clustering criterion (CCC), pseudo T^2 (PST^2), pseudo F (PSF), and number of clusters (NCL) for fourth-order subbasins, central Idaho.

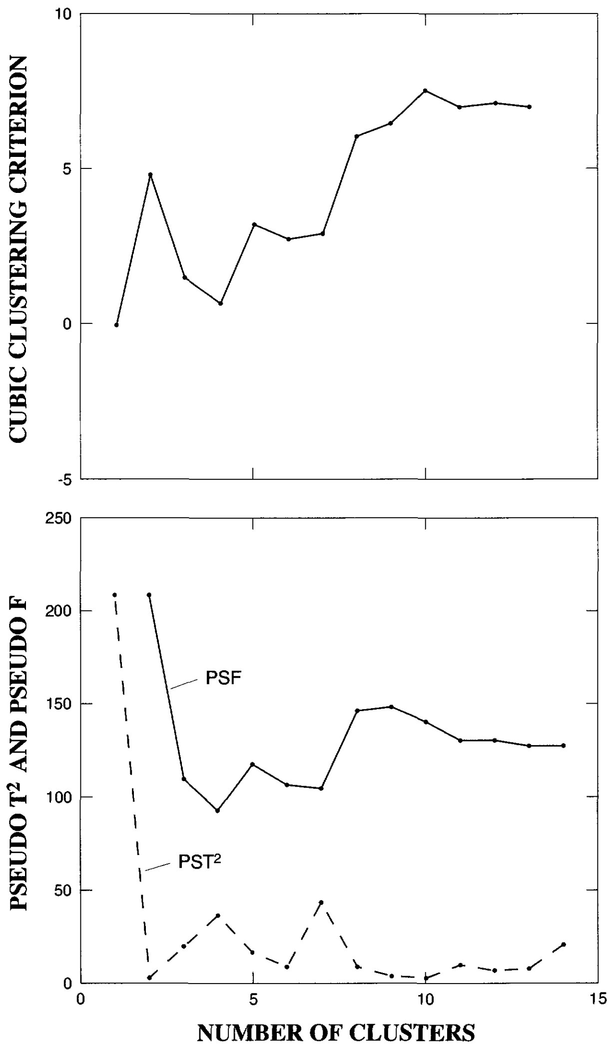

Figure 12. Relations among the cubic clustering criterion (CCC), pseudo T^2 (PST^2), pseudo F (PSF), and number of clusters (NCL) for fifth-order subbasins, central Idaho.

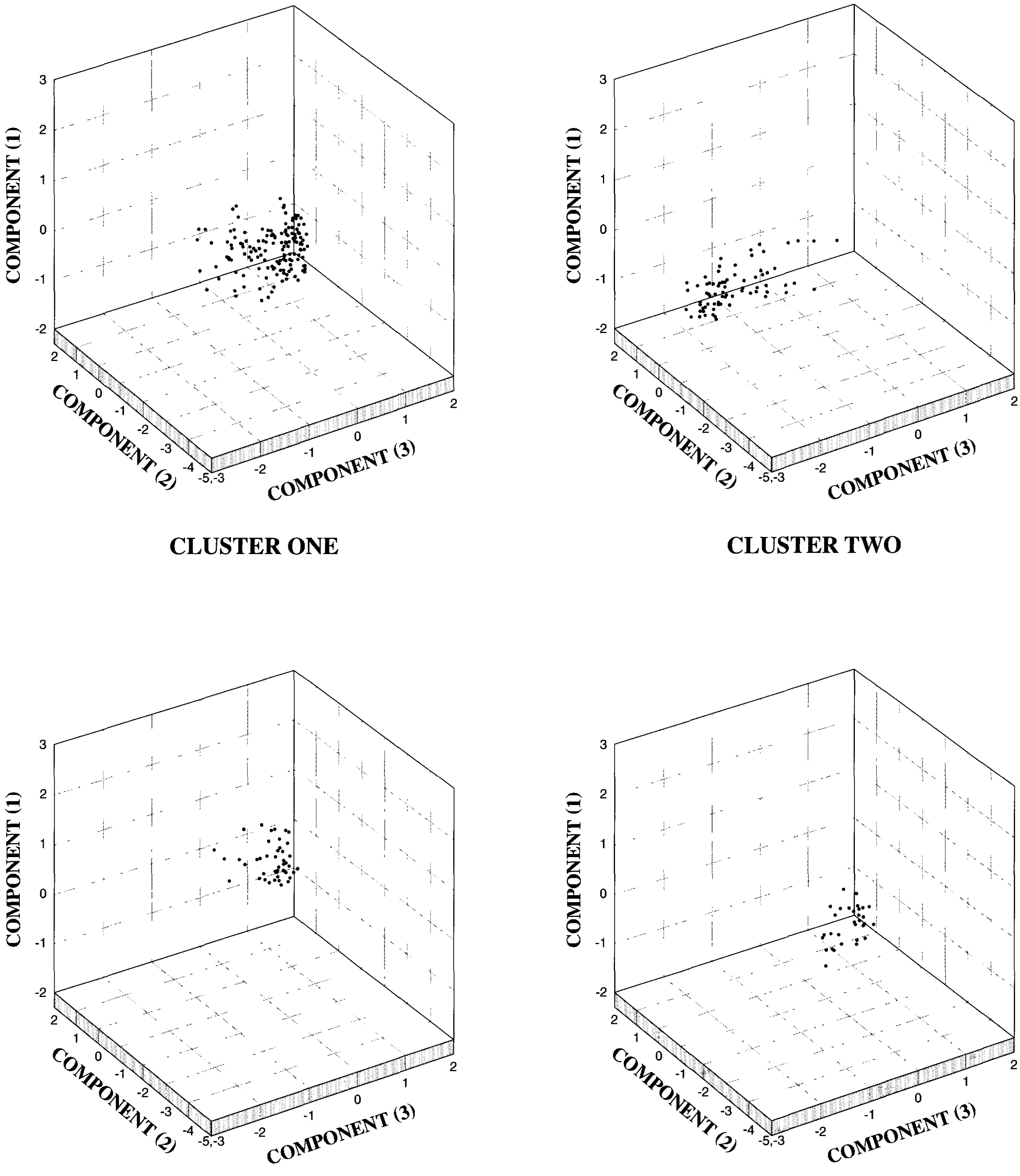

Figure 18. Relation between first three principal components, according to cluster, for first-order subbasins, central Idaho.

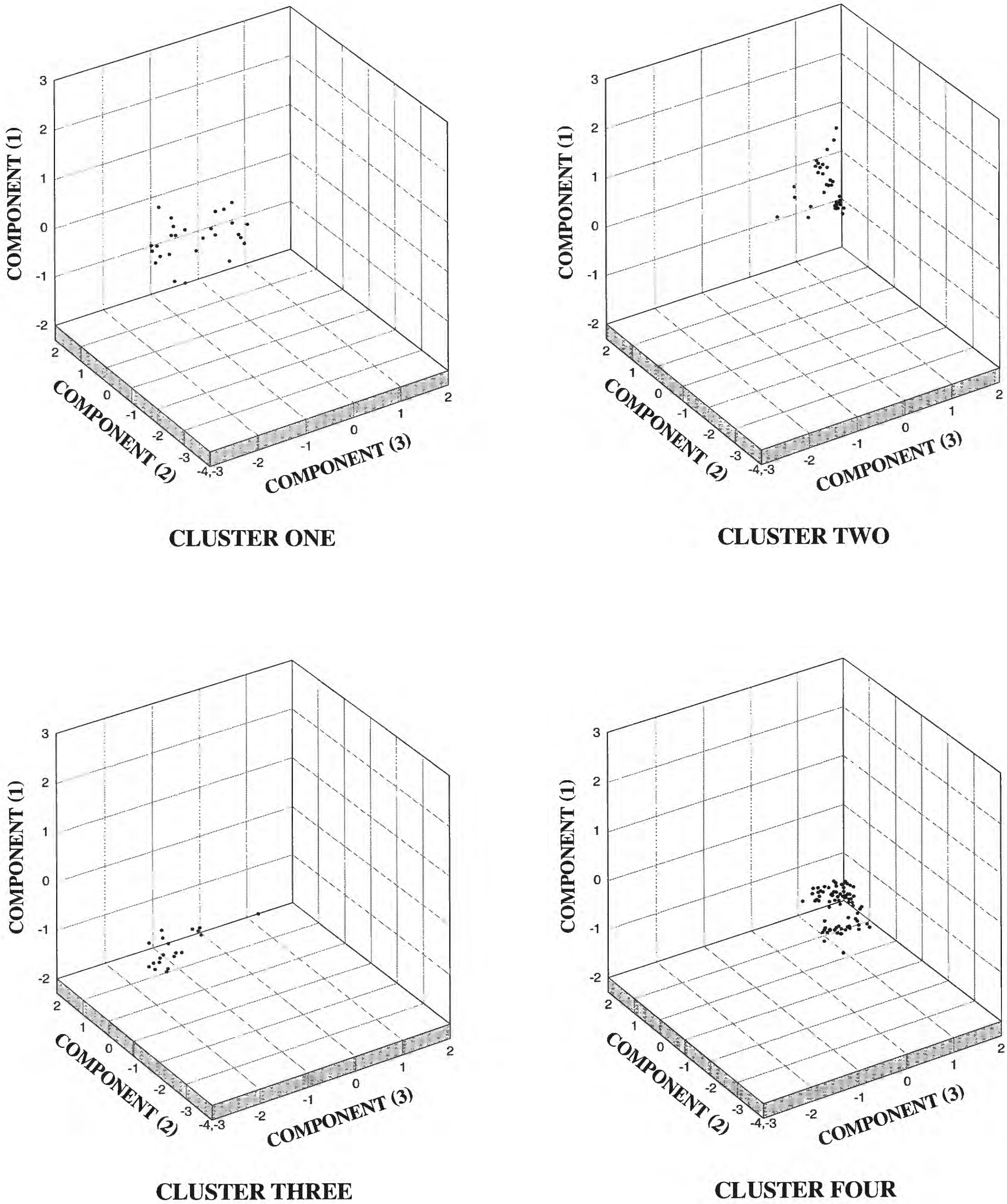

Figure 19. Relation between first three principal components, according to cluster, for second-order subbasins, central Idaho.

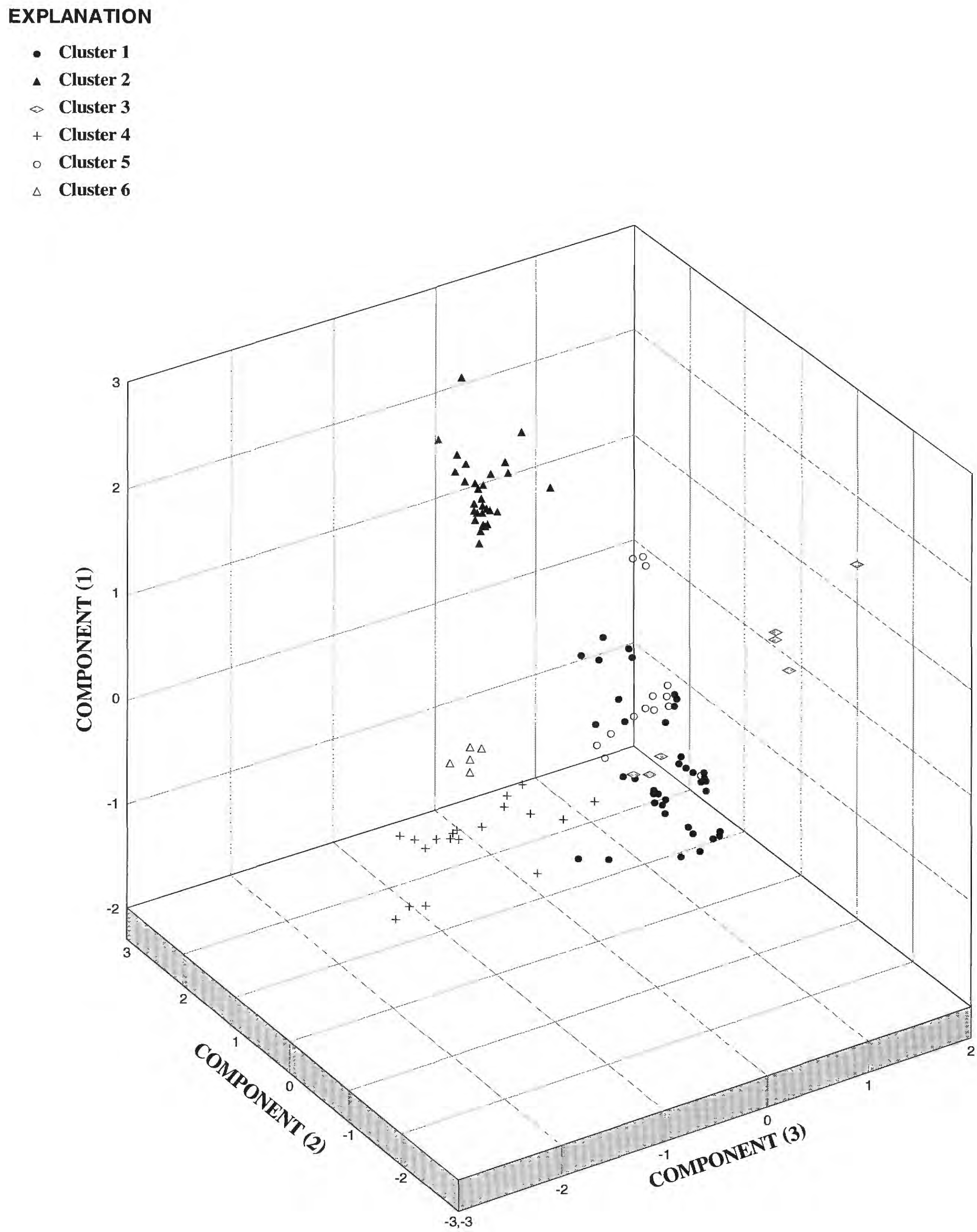

Figure 20. Relation between first three principal components, according to cluster, for third-order subbasins, central Idaho.

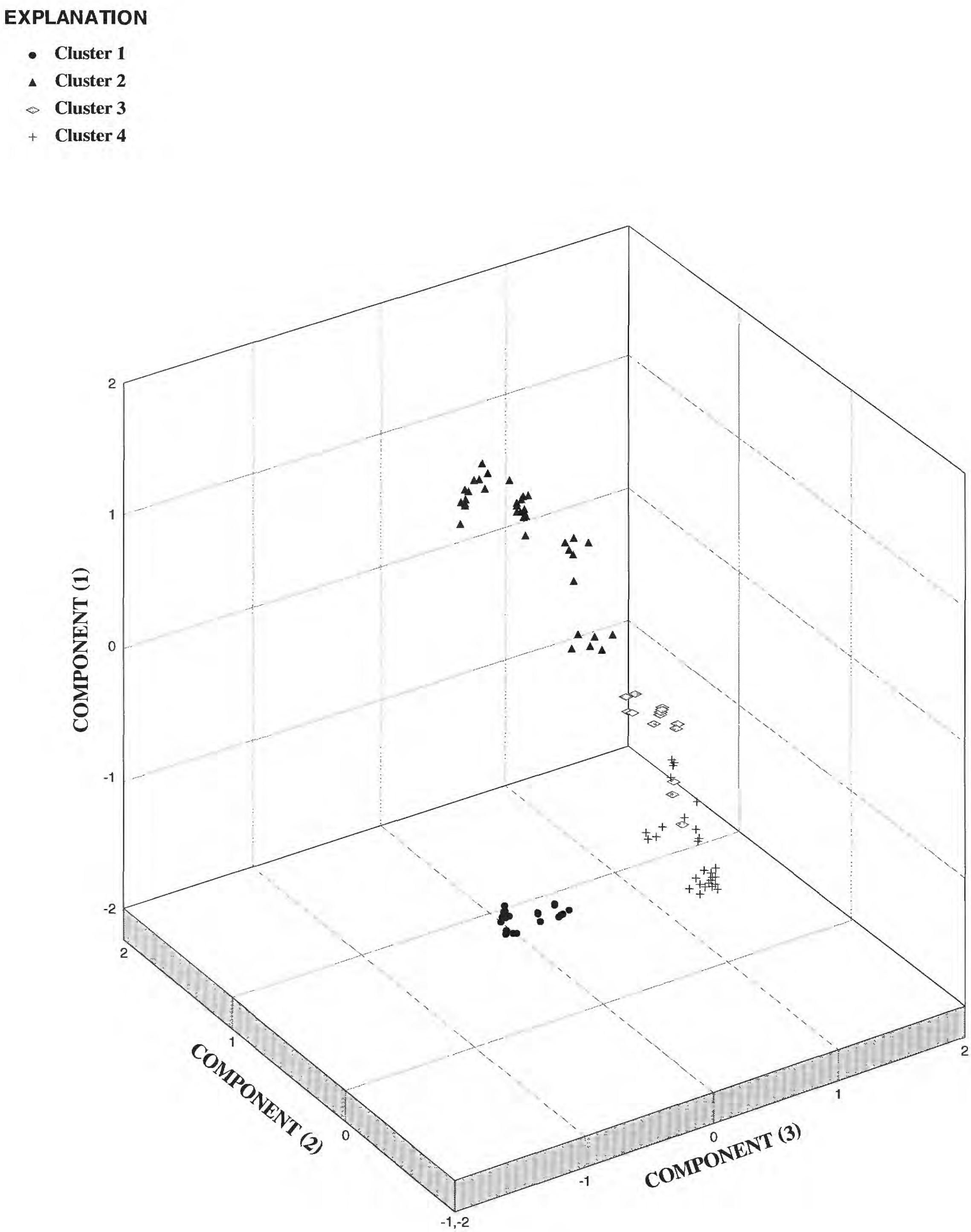

Figure 21. Relation between first three principal components, according to cluster, for fourth-order subbasins, central Idaho.

EXPLANATION

- ● Cluster 1
- ▲ Cluster 2

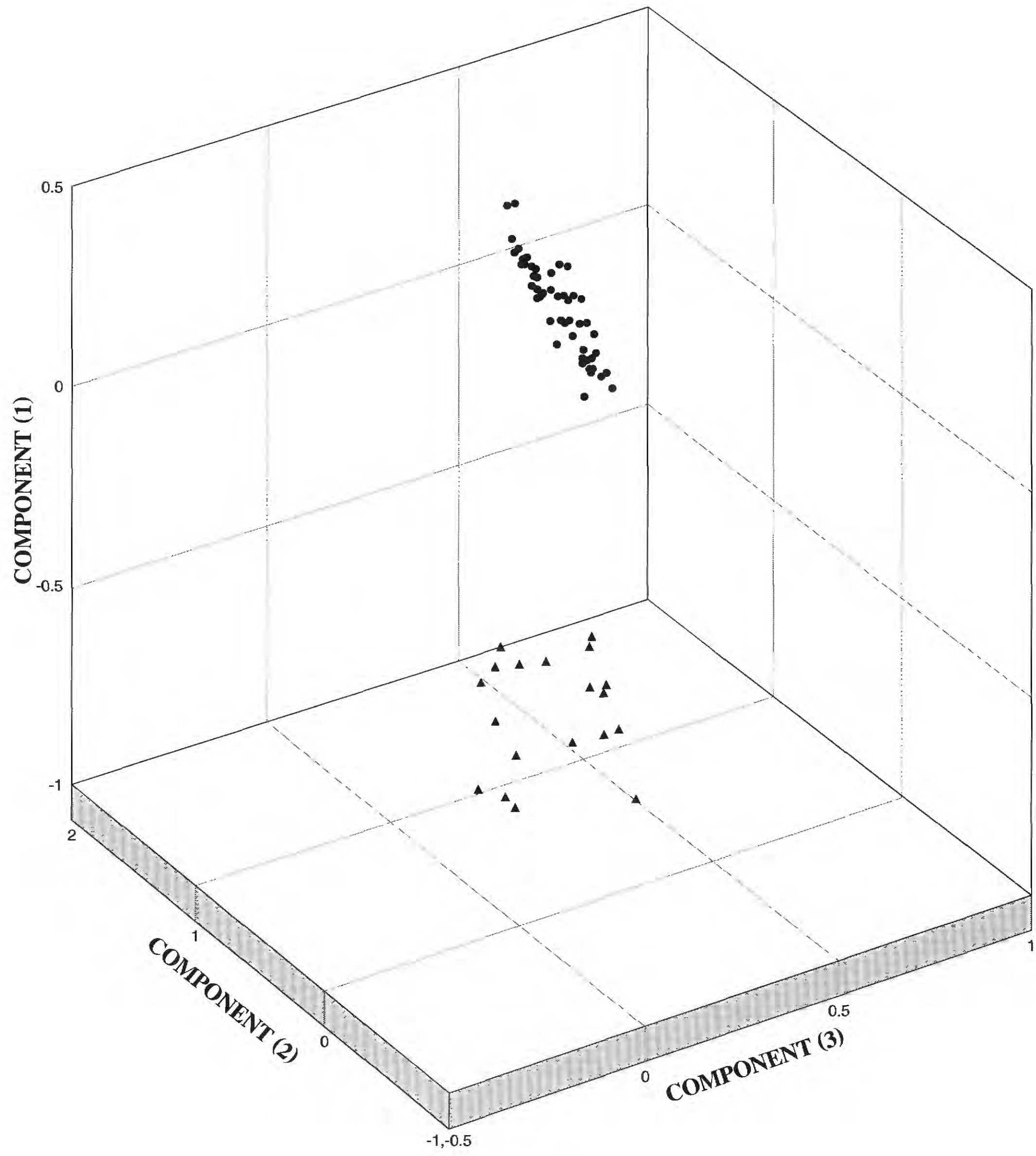

Figure 22. Relation between first three principal components, according to cluster, for fifth-order subbasins, central Idaho.

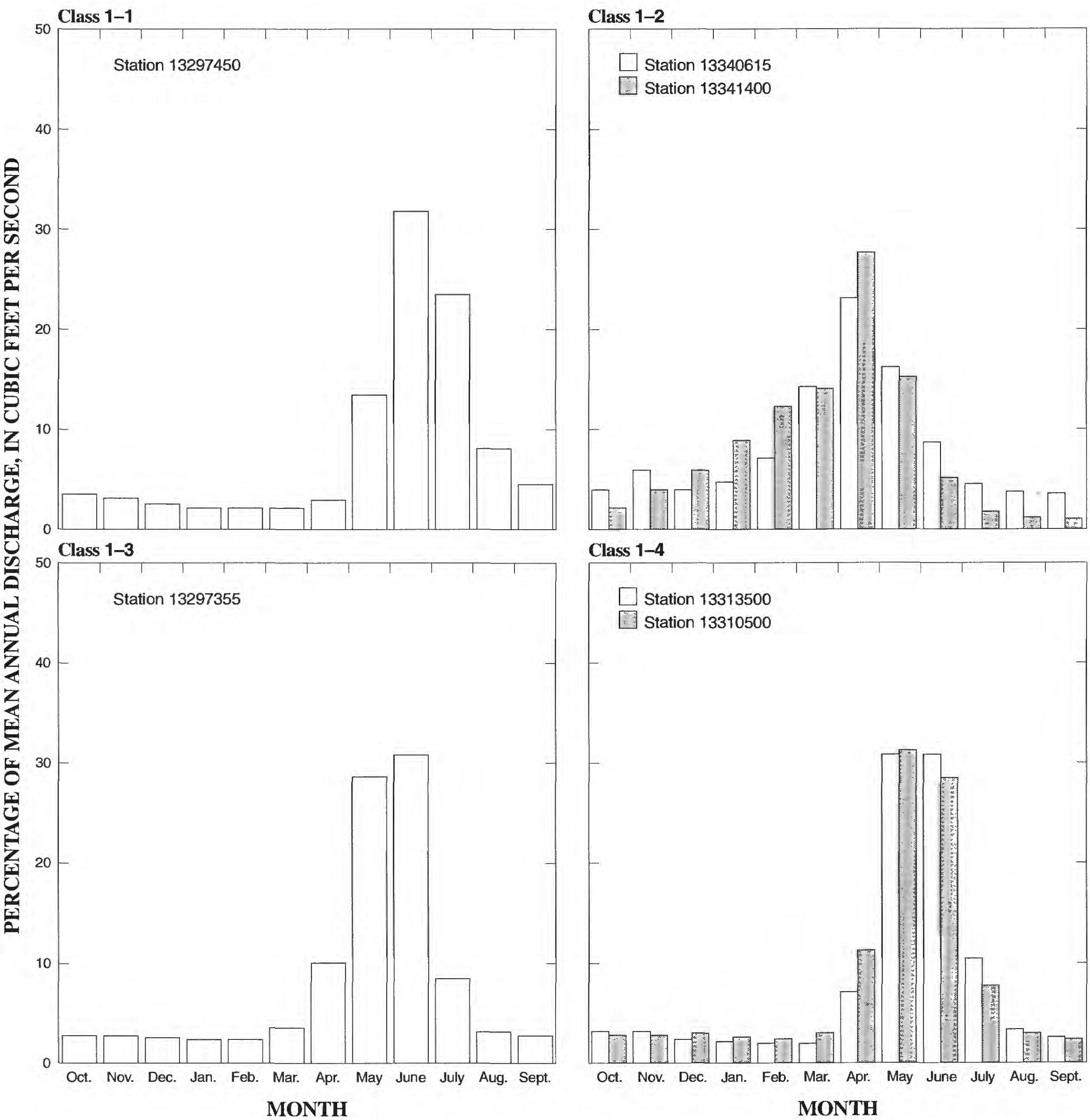

Figure 24. Normalized mean monthly discharges at streamflow-gaging stations within class 1, central Idaho.

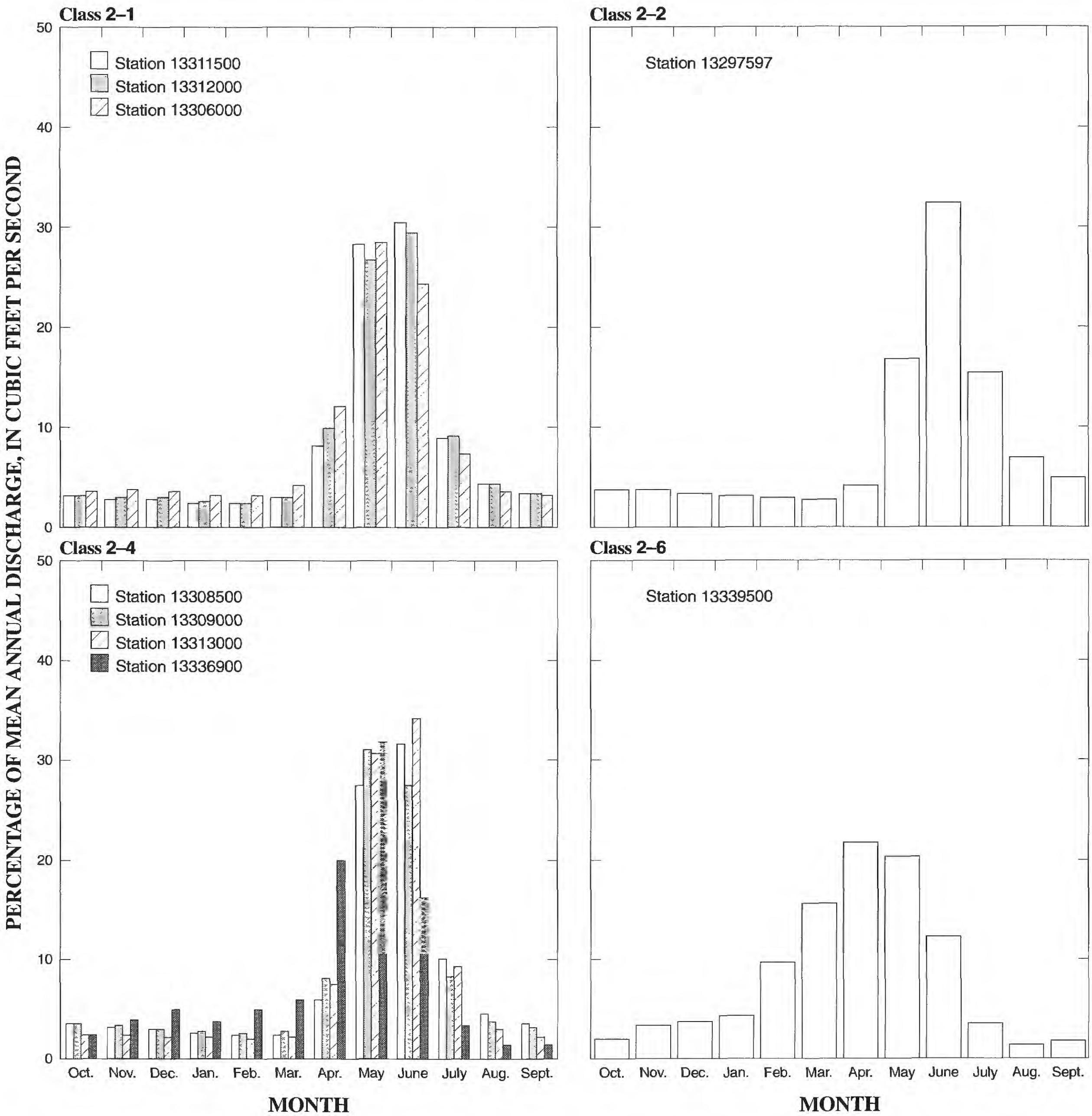

Figure 25. Normalized mean monthly discharges at streamflow-gaging stations within class 2, central Idaho.

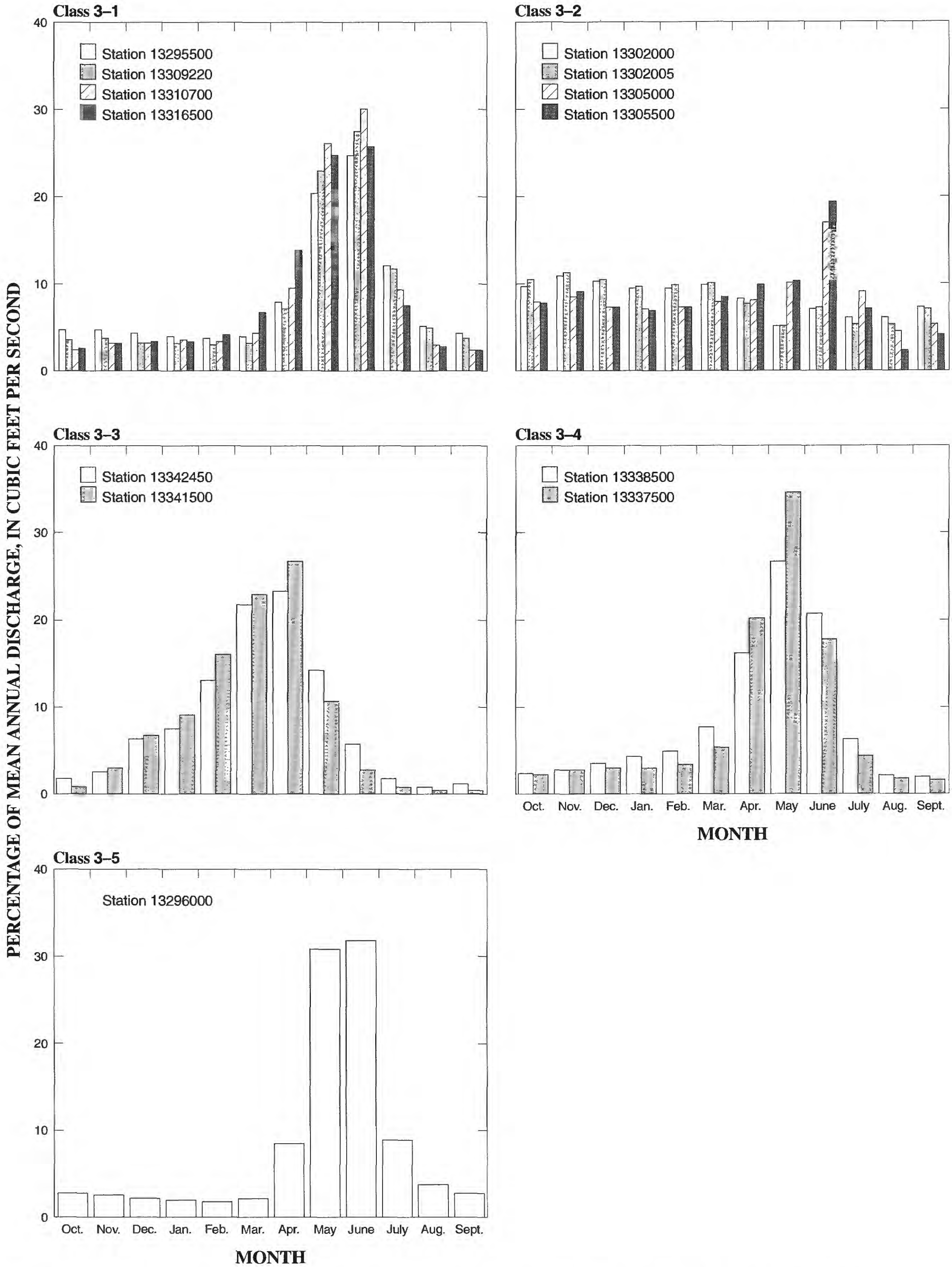

Figure 26. Normalized mean monthly discharges at streamflow-gaging stations within class 3, central Idaho.

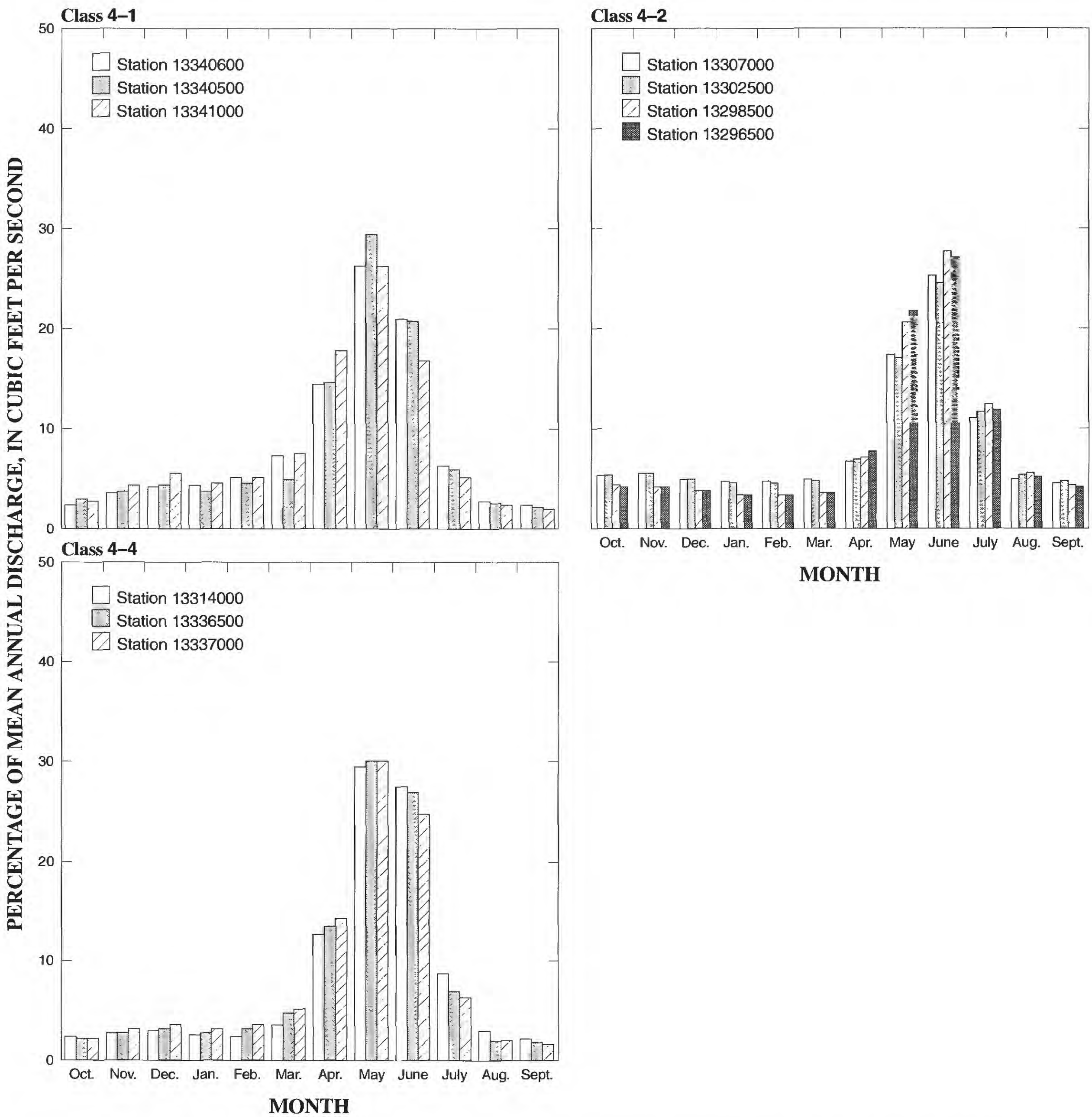

Figure 27. Normalized mean monthly discharges at streamflow-gaging stations within class 4, central Idaho.

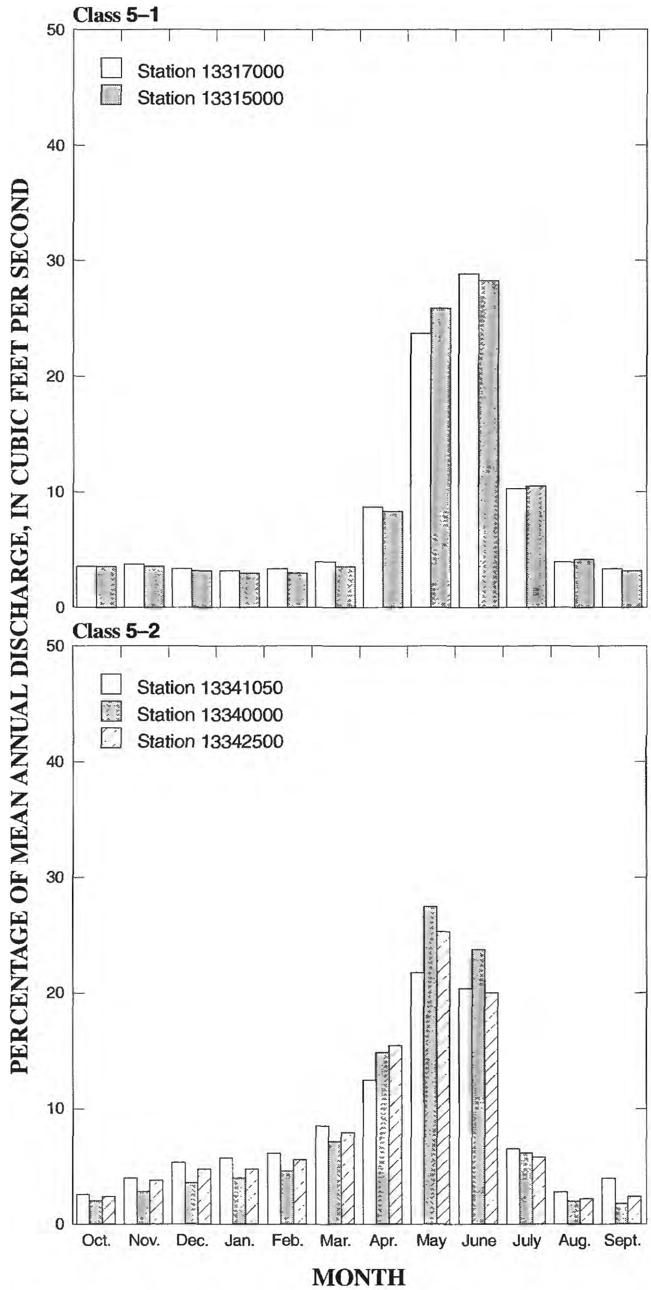

Figure 28. Normalized mean monthly discharges at streamflow-gaging stations within class 5, central Idaho.

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